Columbia River CROSSING

Road Map Item #: 5.13

Product Name: **RAIL FLEET MANAGEMENT PLAN (RFMP)**

PMP Appendix: APPENDIX I

Submittal Date: May 1, 2013

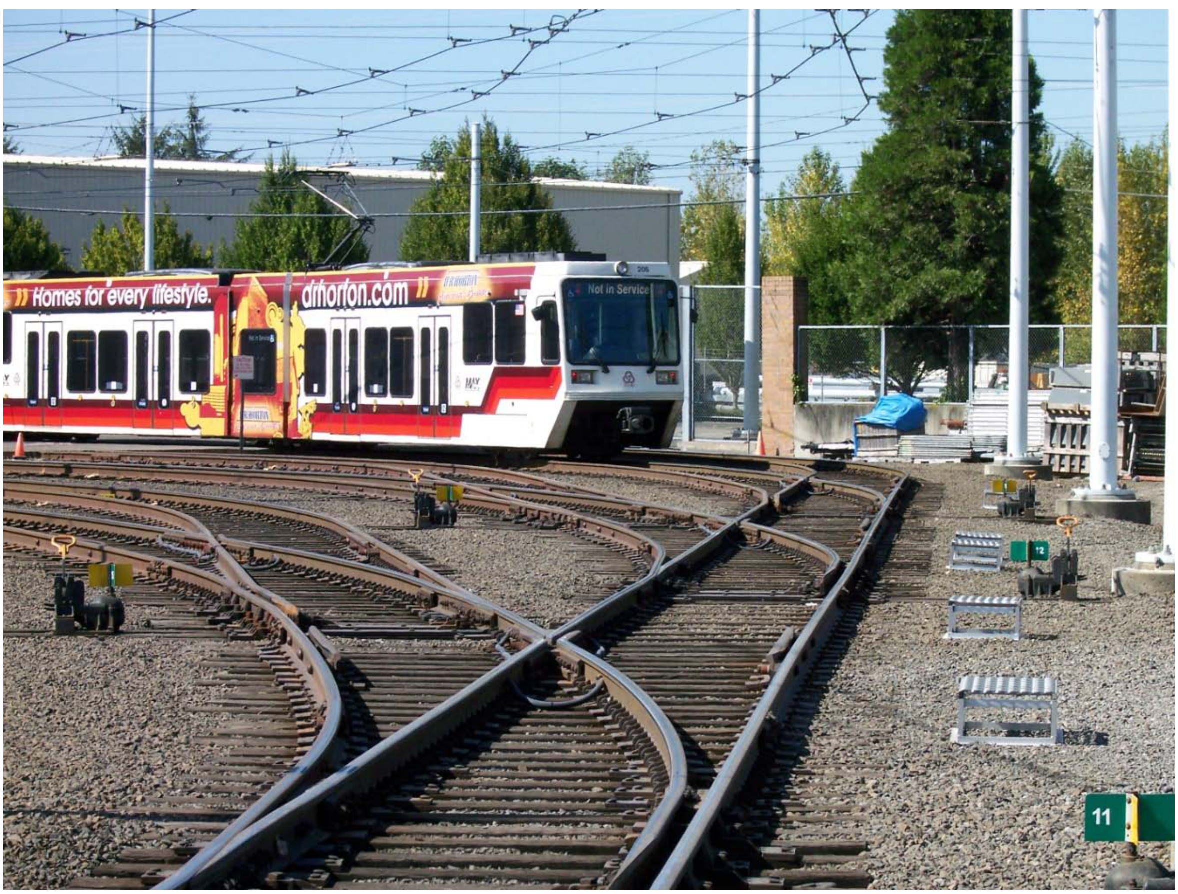
ABSTRACT: This deliverable documents characteristics of the TriMet light rail fleet and maintenance facilities as well as the process of forecasting TriMet's future fleet requirements. Also, the report projects the fleet's spare ratio in the overall context of an operations and maintenance program that meets or exceeds rail transit industry best practices.

Tri-County Metropolitan Transportation District of Oregon

Light Rail Transit Fleet Management Plan

2013 - 2030

April 30, 2013
Revision 16 Draft



Revision History

Revision Number	Date	Approval	Comments
0	10/30/97	JG	Light Rail Fleet Analysis
1	4/1/98	JG	Original RFMP
2	6/1/99	JG	
3	10/15/99	JG	IMAX project
4	7/15/01	JG	
5	6/2/02	JG	
6	6/15/02	JG	Addendum
7	8/15/03	JG	
8	8/16/04	JG	
9	4/15/05	JG	
10	4/10/06	JG	I-205/Portland Mall Project
11	3/15/07	JG	Type 4 LRV details
12	7/30/08	JG	Milwaukie PE application revision
13	8/29/08	JG	CRC PE application revision
14	1/4/10	JG	Revision to address Milwaukie and CRC FEIS and PMOC comments
15	1/17/11	JG	Revision to address Milwaukie recalibration and PMOC comments
15 Final	6/21/11	JG	Additions for Preventive Maintenance Force Account Plan
16 Draft	4/30/13	JG	Update for CRC FFGA application

Cover photo: Track fan north of Ruby Main where connection to new west yard will be.

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1) Introduction

This plan documents characteristics of the light rail fleet and maintenance facilities as well as the process of forecasting TriMet's future fleet requirements. Also, the report projects the fleet's spare ratio in the overall context of an operations and maintenance program that meets or exceeds rail transit industry best practices. Tri-Met has and will continue to update this document periodically to reflect emerging trends in such key areas as ridership, service policies, and system expansion.

This plan update also includes TriMet's two light rail system extensions; the Portland-Milwaukie Light Rail (PMLR) Project currently under construction, and the Columbia River Crossing (CRC) Project that is a joint highway and transit project extending into Vancouver, Washington.

- **Milwaukie.** The Milwaukie extension will run from the south terminus of the Green and Yellow Lines on the Portland Mall 7.3 miles to a Park Ave. terminus south of Milwaukie. The line, designated as the Orange Line and scheduled to open in the Fall of 2015 to Park Ave. will require 14 LRVs initially and 18 LRVs in 2030, including spares, for 8.6-minute peak hour and 15-minute mid-day headways.

- **Columbia River Crossing (CRC).** The CRC extension is planned to run 2.8 miles from the north terminus of the Yellow Line at Expo Center to a terminus near Clark College in Vancouver, Washington. The extended Yellow Line, proposed to open in the Fall of 2019, initially requires 10 LRVs, including spares, to provide 7.5-minute peak hour and 15-minute mid-day headways. The planning horizon peak load forecast indicates that 19 LRVs, including spares, will be required to provide Yellow Line service in 2030 with 6-minute peak hour, 7.5-minute peak 2-hour and 15-minute mid-day headways.

Currently, TriMet has a fleet of 127 light rail vehicles (LRVs) for its MAX (Metropolitan Area Express) light rail system and 18 LRVs on order for the Milwaukie (Orange Line) extension. The fleet consists of 101 low floor cars and 26 high floor cars. A vehicle chronology follows:

- In 1986, a 26-vehicle fleet began serving passengers on a 15-mile line between Portland and Gresham.
- During 1997 and 1998, an additional 46 vehicles entered service in conjunction with an 18-mile system expansion to the West. These were North America's first low floor light rail vehicles.
- Prior to 1998 there were too few vehicles to keep pace with growing ridership. In response to these ridership trends and in consideration of the rare opportunity to purchase a small number of cars, TriMet's Board exercised an option (in the Westside vehicle contract) to purchase 6 additional vehicles put in service in 2000 and 2001.
- In 2000, 17 vehicles were ordered for the Interstate MAX, Yellow Line, opening.

- In 2002, 10 option vehicles were ordered for system ridership growth, 7 of those for Interstate MAX through 2020 as stated in the North Corridor FEIS.
- In 2006, 21 vehicles were ordered for the I-205/Portland Mall, Green Line extension. An option for 1 more vehicle was exercised in 2008.
- In 2012, 18 vehicles were ordered for the Portland to Milwaukie, Orange Line extension.

The light rail operating and maintenance program reflects industry best practices. Maintenance is conducted at two modern facilities, one, Ruby Junction, 13 miles east of Portland and the other, Elmonica, 10 miles to the west of Portland. Rather than conduct major vehicle overhauls at mid-life or periodically, TriMet follows the practice of progressive overhauls by subsystem as indicated by failure rate analysis for each subsystem.

This plan differs from the previous, June 2011, Revision 15 Final Plan in the following ways:

1. The Milwaukie extension is now under construction and scheduled to open in 2015, so it will be in operation when the proposed CRC extension is planned to open in 2019.

2. Some acronym definitions were added in Section 2.

3. All Figures and Tables that carry over into this revision were updated with current data.

4. In Section 5 the individual tables for the PMLR project were removed and a new MAX system table, Table 5.8, was added.

2) Definition of Terms and Acronyms

AWB - Average Weekday Boardings

Capacity … achievable – The portion of design capacity that reflects uneven loading of cars in a train and uneven passenger arrivals at stations upstream of the peak load point during the peak hour. For MAX this is 80% of design capacity or an average of 133 passengers per vehicle (266 per 2-car train) during the peak hour with standees at a density of 2.7 per square meter. This capacity is equivalent to a load factor of 2.1. This is TriMet's adopted loading standard for the peak hour.

Capacity … design (AW2) – The total number of seated and standing people a vehicle is designed to accommodate with some comfort as opposed to no comfort (crush load). Design capacity equals 166 passengers per vehicle (332 per 2-car train) with standees at a density of 4 per square meter. This capacity is equivalent to a load factor of 2.6.

Capacity … crush (AW3) – The total number of seated and standing people a vehicle is designed to accommodate with no comfort (crush load). As so defined crush capacity would equal 217 passengers per vehicle (434 per 2-car train) with standees at a density of 6 per square meter. This capacity would be equivalent to a load factor of 3.4. Historical manual counts have never recorded a 2-car train passenger load above 370 passengers even when holding a train until it was full after a special event.

Capacity … structural design (AW4) – The maximum passenger capacity of a vehicle used for calculating maximum loaded vehicle weight for structural analysis, with standees at 8 per square meter. This capacity would be equivalent to a load factor of 4.2.

CIP – Capital Improvement Program

CRC – Columbia River Crossing Project

Cycle time – The round trip travel time (run time in both directions) plus the layover times at both ends of the transit line.

Daybase train – A train that provides service most of the day and is in service generally between 16 and 20 hours per day.

Dwell time – The time a train spends stopped in the station waiting for passengers to board and a clear signal to proceed.

FFGA – Full Funding Grant Agreement

Forecast – Future passenger demand based on a mathematical model.

FTA – Federal Transit Administration

Gap train – A train with an assigned operator that waits at a designated location to fill a gap between scheduled trains that are off schedule creating an unacceptable gap in service.

Headway – The time interval between the passing of the front ends of trains moving along the same track in the same direction, usually expressed in minutes.

Life cycle – The length of time that it is economic to operate a vehicle. For light rail vehicles this is usually between 25 and 36 years.

Loading Standard - The maximum acceptable passenger load set by TriMet policy. TriMet's loading standard for an individual train equals 166 passengers per vehicle (332 per 2-car train) with standees at a density of 4 per square meter. This standard is equivalent to a load factor of 2.6. To achieve this standard for individual trains the standard for the peak hour is set lower to an average of 266 passengers per 2-car train.

Load factor – The number of sitting and standing passengers divided by the number of seats in a transit vehicle. A full-seated load has a load factor of 1. Load factor comparisons between different vehicles or transit systems are not valid because the ratio of areas for sitting and standing varies from vehicle to vehicle. The density of standees is a valid comparison of vehicle crowding.

LRV – Light Rail Vehicle

MAX – Metropolitan Area Express is the name of TriMet's light rail system

MDBF – Mean Distance Between Failures

OCC - Operations Command Center consists of Rail Central Control, Bus Dispatch, administrative staff and the equipment to support their activities

OSR – Operating Spare Ratio that equals the total active fleet minus the PVR divided by the PVR, (fleet-PVR)/PVR. The OSR is usually shown as a percentage.

Overhaul – The disassembly, inspection, repair or replacement and reassembly of all vehicle systems. Mid-life overhauls usually occur half way through the vehicle's life cycle.

PMLR – Portland -Milwaukie Light Rail Project, Orange MAX Line

PVR - Peak Vehicle Requirement is the number of vehicles needed to meet the expected passenger demand at the peak load points during the peak hour in the peak direction during a typical weekday and provide at least daybase headways elsewhere in the MAX system.

Passenger demand – The number of passengers and the time of day they desire to travel.

Peak tripper – A train that runs only during the peak periods to supplement the daybase trains when peak passenger demand is such that daybase trains alone cannot carry the loads. Trippers generally run from two to five hours at a time.

Progressive overhaul – The disassembly, inspection, repair or replacement and reassembly of only those vehicle systems that analysis of failure rates indicate is economically desirable.

Spare vehicle – Vehicles in the active fleet that are not needed during the peak periods for service and are therefore available for maintenance. If not scheduled for maintenance a spare can be used to replace a vehicle that fails in service.

Spare ratio – The number of spare vehicles divided by the PVR.

TC – Transit Center or passenger transfer station

Runtime – The one-way travel time from one end of a transit line to the other end.

3) The Existing System

a) TriMet Overview

The Tri-County Metropolitan Transportation District of Oregon, TriMet, was established by the State Legislature in 1969 to provide mass transit service to the more populous parts of Multnomah, Washington, and Clackamas counties (the Portland metropolitan area). The governing body of TriMet is a seven member board of directors, who are unpaid citizen volunteers appointed to four year terms by the governor and confirmed by the Oregon Senate.

The TriMet district covers about 530 square miles containing approximately 1.5 million people. TriMet's services as of September 2012 consist of:

- 104 peak light rail vehicles operating on 4 routes with 52 miles of right-of-way and 75 stations,
- 4 peak commuter rail vehicles operating on one 14.7-mile route with 5 stations.
- 498 peak buses operating on 79 routes with over 8,000 stops and over 1,000 shelters,
- 18 bus / train interchange transit centers and 57 park and ride lots providing about 10,000 parking spaces.

The light rail system is referred to as MAX, for Metropolitan Area Express. The 33-mile long, east to west, Blue Line was opened in stages during 1986, 1997 and 1998. The 5.6-mile Airport Extension Project, the Red Line, opened for revenue service in September of 2001. The 5.8-mile Interstate Ave. Extension Project, the Yellow Line, opened for revenue service in May of 2004. The 6.7-mile I-205/Portland Mall Extension Project, the Green Line, opened for revenue service in September of 2009. Figure 3.1 is a map of the system from September 2012 on. Each line runs between the following terminals:

- Blue – Government Center and Cleveland Ave.
- Red – Portland International Airport (PDX) and Beaverton Transit Center (BTC)
- Yellow – Expo Center and South Terminal just south of Portland State University (PSU)
- Green – Clackamas Town Center (CTC) and South Terminal / PSU

Current headways by line are as follows:

Blue – 15 minute daybase and 7 minute peak hour
Red – 15 minute daybase and peak hour
Yellow – 15 minute daybase and peak hour
Green – 15 minute daybase and peak hour

Blue Line headways include some Red Line trains that become Blue Line trains by running west to Hillsboro Government Center in the PM peak.

Combined or trunk headways along shared track are as follows:

Rose Quarter to Gateway - 5 minute daybase and 3 minute peak hour
Downtown east/west to BTC - 7.5 minute daybase and 5 minute peak hour
Downtown north/south – 7.5 minute daybase and peak hour

Responsibility for the rail fleet is generally split between the Operations Division and the Capital Projects Division. Responsibility for design, procurement, and testing predominately rests with systems engineers within the Capital Projects Division. Operation and maintenance of the fleet is the responsibility of the Operations Division.

b) Light Rail Vehicles (LRV's)

The fleet consists of vehicles produced by two manufacturers: Bombardier and Siemens, referred to as Type 1 and Type 2, 3, 4 and 5, respectively. At the end of 2005 the fleet included 26 Type 1 LRVs, 52 Type 2 LRVs and 27 Type 3 LRVs. The I-205 / Portland Mall MAX project contract for 22 Type 4 vehicles resulted in these cars being available for service in 2009. The Portland to Milwaukie Light Rail (PMLR) project has a contract for 18 Type 5 LRVs that will be available for service in 2015, see Table 3.1.

Table 3.1 Fleet Size Chronology

Ordered	Available	Increase	Fleet Size	Notes
1982	1986	26	26	Original Eastside Purchase, cars 101-126 all active
1993	1997	8	34	Piggy-back Eastside order with Westside contract, cars 201-208, all active
1993	1997	2	36	Favorable price allowed an increased order, cars 209 & 210, both active
1993	1998	29	65	Original Westside Order, cars 211-239, all active
1995	1998	7	72	Expansion to accommodate Hillsboro Extension, cars 240-246, all active
1997	2000	6	78	Option allowed increased order to meet system growth, cars 247-252, all active
2000	2003-4	17	95	Interstate (North) MAX Line Order, cars 301-317, delivery 2003
2002	2004-5	10	105	Option allowed increased order to meet 2020 fleet size of 24 for Interstate, cars 318-327, delivery 2004-5
2006	2009	22	127	I-205/Portland Mall MAX Line Order, cars 401-422, delivery 2008-9
2012	2014-15	18	145	Portland to Milwaukie MAX Line Order, cars 521-538

With the introduction of the Type 2, 3, 4 and 5, low floor vehicles, all two-car consists must include at least one Type 2 or 3 vehicle or two Type 4 or 5 vehicles to insure accessibility for mobility devices. Type 1 vehicles have steps and cannot operate alone as the train would not be accessible to passengers requiring the use of mobility devices. Also, the system is designed to operate with trains of no more than two cars. (A two car train is roughly the length of one city block, thus when stopped at a platform cross-traffic can proceed unimpeded.)

Type 1 – Bombardier

The Bombardier vehicles were placed into service in September 1986. BN of Belgium designed the cars. Bombardier, the principal shareholder of BN, assembled TriMet's vehicles in Barre, Vermont. The cars are electrically propelled (DC drive) to a maximum design speed of 55 miles per hour, are constructed of corten steel, and have bi-directional operating capability. The cars seat 76 with a design capacity of 166 passengers with standees at 4 per square meter.

Type 2 and Type 3 – Siemens Duewag SD 660

The Siemens' vehicles entered service at various times between August 1997 and September 1998. Siemens Duewag of Germany designed the cars, with final assembly in Sacramento, California. They are designed with operator cabs at both ends to allow bi-directional operation. There is seating for 64 people and a design capacity of 166 passengers with standees at 4 per square meter. The 92-foot long cars are air-conditioned.

These are the first low floor light rail vehicles placed into service in North America. The cars are constructed of high tensile steel and designed for a top speed of 55 miles per hour with electric propulsion (AC drive). The cars are double articulated and can be operated in train sets of up to four, but are limited to two due to the length of MAX stations. These cars can be used in any combination of Type 1, Type 2 or Type 3 vehicles. Along with passenger/operator-activated bridgeplates on the center four doors, the low floor design allows full wheelchair access. The low floor section encompasses 70% of the vehicle, which is supported by a non-powered truck in the center articulation section.

Type 3's are the same as Type 2's with the following additions:

- Automatic passenger counters, APC's, for collecting better passenger load data for scheduling purposes
- Thermoking instead of Sutrak HVAC equipment.

Type 4 and 5 – Siemens S70

Type 4 and 5 vehicles are not backward compatible with the previous fleet in terms of the ability to train-line electrically with Type 1, 2 and 3 vehicles. Therefore, they are not able to run coupled together as trains with the existing Type 1, 2 or 3 vehicles in revenue service, see Figure 3.2 for all 2-car train consist configurations. Type 4 and 5 vehicles are mechanically compatible so that they may tow or be towed by a previous fleet vehicle. Type 4 and 5 vehicles are single-ended (have a control cab only at one end) which means they will be run as two-car trains, since the ends of the existing and planned lines do not have loops. Single-ended cars were selected because they have 5% greater passenger capacity. All vehicles will be capable of operating anywhere in the MAX system, so that the single-ended vehicles can be used where passenger loads and train congestion are greatest.

A schematic of the individual car types and lengths is shown in Figure 3.3.

c) Maintenance Facilities

TriMet's Rail Operations Department has two operations and maintenance facilities. Ruby Junction is located two miles west of the eastern terminus in Gresham and Elmonica located in Beaverton seven miles east of the western terminus in Hillsboro. The two facilities operate as a unit with most specialized functions, such as central train control and heavy maintenance work, occurring at Ruby Junction.

Ruby Junction

This facility, opened in 1985, houses TriMet's light rail vehicle maintenance department. During 1995, remodeling prepared the facility to service the new low floor vehicles as well as house a new system-wide communication and control center, based on a fiber optic network (SONET) and supervisory control and data acquisition (SCADA) technology. For the Interstate MAX extension, Yellow Line, that opened in 2004 new storage tracks were added and a new building, Ruby South was built to house Maintenance of Way (MOW) and a new LRV body shop and paint booth. In 2015 the Operations Command Center (OCC) consisting of rail central control, bus dispatch and some rail operations staff will be relocating to TriMet's Center Street facility. A back up OCC of reduced size will remain at Ruby Junction.

The 17-acre facility (see Figure 3.4) includes the following:

- Storage track for 67 vehicles, 20 additional spaces are under construction on 5.6 acres for 2015
- Ruby Main, a 112,000 square foot three story shop, operations and administrative building with 13 maintenance bays excluding the wash bay and the 2nd bay on the wheel truing track, a truck shop and two sets of in floor jacks
- Ruby West, a 9,500 square foot non-revenue vehicle (support vehicles) servicing shop and storage area
- Ruby South a satellite building with a 21,000 square foot footprint, containing paint and body bays, one flat track bay for interior car work, a metal fabrication area, some body parts storage, a Maintenance-of–Way (MOW) shop and offices, restrooms, lockers and a lunch room to accommodate 60 workers over 3 shifts.
- 161 employee and visitor parking spaces, 42 additional spaces are under construction for 2015
- A 6,700 square foot MOW shop and covered/open MOW storage

Elmonica

This facility was constructed in conjunction with the Westside project. To allow for testing and storage of new vehicles, the construction contract for this facility was one of the first completed, opening in 1996. The design was based on existing facilities in Europe, where low floor cars are commonly used.

The 18-acre facility (see Figure 3.5) includes the following:

- Storage track for 53 vehicles
- A 70,000 square foot two story shop and operations building and 1,500 square foot storage building for LRV cleaning supplies
- A 6,000 square foot parts storage building (mostly MOW spare parts)
- 9 maintenance bays excluding the wash bay and the 2nd bay on the wheel truing track (six with access to the LRV roofs)
- A seven and a half ton overhead crane
- 97 parking spaces

Storage Yard Size vs. Fleet Size

Since 1986 Tri-\Met has had a surplus of storage yard spaces to accommodate fleet size increases due to ridership growth. The I-205 / Portland Mall South Corridor MAX Green Line extension only added 5 spaces reducing the surplus to minus seven in 2009, see Table 3.2. The 2009 surplus of -7, although not ideal, is workable since 7 or more LRVs will be in some of the 26 available repair bays, not including wash bays.

Table 3.2

Storage Yard Size vs. Fleet Size

		2004	2007	2009	2015
Yard storage spaces	Ruby Junction	48	67	67	67
	Elmonica	42	42	48	53
Yellow/Orange Line additions:	at Ruby Junction	19			20
	at Elmonica		6		
Green Line additions	at Elmonica			5	
Total storage		**109**	**115**	**120**	**140**
	Existing LRV Fleet	78	105	105	127
	Yellow/Orange Line fleet additions	24			18
	Green Line fleet additions			22	
	System Growth fleet additions	3			
Total fleet		**105**	**105**	**127**	**145**
Surplus		4	10	-7	-5

d) Service Design, Ridership and Fleet Size

In September of 2009 the MAX system evolved from a 3-route to a 4-route system. The four routes are identified by colors: the Green Line for the south corridor service to Clackamas Town Center, the Yellow Line for the north corridor service to Expo Center, the Red Line for Airport to Beaverton service via Downtown Portland and the Blue Line for Gresham to Hillsboro service via Downtown Portland. All four lines share the same right-of-way and tracks between Rose Quarter and the west end of the Steel Bridge, as shown in Figure 3.6 which is a time scaled diagram of the track plan and the MAX routes that use it. The north, east, south and west peak load points are also shown in Figure 3.6.

The MAX light rail system's service design is based on the use of daybase trains to provide the base service, 15-minute headways throughout the system. These 15-minute policy headways are provided for most of the service day until about 10:30 PM when there is a transition to 30-minute headways. As a supplement to the daybase trains, peak tripper trains are added during peak periods where peak passenger demand is such that daybase trains alone cannot carry the loads. Trains are mostly 2-car consists, but can be single cars if passenger demand permits. The downtown block length, tunnel station platform lengths and the station design criteria limit train length to a maximum of two cars.

Peak passenger demands are caused primarily by work trips and are greatest inbound, to downtown Portland, in the AM peak and outbound in the PM peak. As a result the Blue and Red lines have two peak load points, one east of downtown at Lloyd Center and one west of downtown at Goose Hollow. The Yellow Line's peak load point is north of Rose Quarter while the Green Line's peak load point is east of Lloyd Center. These are the points where most trains have their heaviest passenger loads and are used to apply TriMet's loading standards, detailed in Section 5.b, to estimate future peak vehicle requirements (PVR) and to monitor crowding that may require schedule or service adjustment.

The existing peak vehicle requirements (PVR) are shown in Table 3.3. Since April of 2004, TriMet has been receiving accurate passenger counts through the automatic passenger counters built into the newer light rail cars. TriMet continually monitors crowding on MAX and makes adjustments within our ability to shift capacity to alleviate it. A typical two-car (four section) MAX train can seat 128 people and carry 332, including standing passengers. When average daily peak passenger loads on a two-car train reach 266 passengers at the peak load point TriMet either adjusts that train's schedule or adjusts its leader's schedule or both. If schedule adjustments do not solve the problem another train may be added. TriMet makes these changes to accommodate and foster further ridership growth.

The light rail system's average weekday boardings (AWB) have been about 1,000 passengers per LRV since MAX opened in 1986, see the comparison of AWB vs. LRVs in Figure 3.7.

4) System and Service Expansion

a) Orange Line under construction opens 2015; PMLR Project

This is the second phase of the South Corridor Project; the first phase was the Green Line. The Orange Line extends light rail south from Downtown Portland to south of downtown Milwaukie at Park Ave., see Figure 4.1. The extension will operate as a through route with the North Corridor's Yellow Line, Interstate Ave. MAX. Revenue service on the Milwaukie extension is scheduled to begin in 2015, initially with 14 Type 5 LRVs (12 in service and 2 spares) to provide 10-minute peak hour and 15-minute mid-day policy headways. A fleet of 18 LRVs (14 in service and 4 spares) have been ordered to accommodate the estimated 2030 passenger demand of about 27,000 weekday boardings on this extension.

b) Columbia River Crossing (CRC) Planned Opening 2019

The Columbia River Crossing (CRC) project will extend the Yellow Line north from the Exposition Center station in Portland to a terminus near Clark College in Vancouver, Washington, see Figure 4.1. Revenue service on the CRC extension is planned to begin in 2019, initially with 10 LRVs (8 in service and 2 spares) to provide 7.5-minute peak hour and 15-minute mid-day headways. It was estimated that a fleet of 19 Type 5 LRVs (16 in service and 3 spares), will be needed to accommodate an average of about 19,000 weekday boardings on this extension in 2030. The large increase in trains is caused by the fact that trains added to the extension must also travel the length of the existing Yellow Line to shorten headways to 7.5 minutes for a full 2 hours in the peak periods to provide the needed passenger capacity, see Section 5 for calculations.

Type 5 vehicles will be compatible with Type 4 vehicles but not electrically compatible with Type 1, 2 and 3 vehicles. Therefore, they will not be able to run coupled together as trains with Type 1, 2 or 3 vehicles in revenue service. Type 5 vehicles will be single-ended like the Type 4 vehicles.

c) Green Line Service Improvements

Twenty-two LRVs were purchased for the Green Line within the FFGA. The 2025 passenger demand forecast indicated that 30 LRVs will be needed in the planning horizon year of 2025. This means TriMet needs to acquire 8 more LRVs prior to about 2025. TriMet will monitor actual ridership growth to determine when these 8 LRVs need to be acquired.

d) Operations and Maintenance Facility Expansion

Facility expansion for LRV storage and maintenance will be done at Ruby Junction for both projects. The expansion will occur in two phases: Phase 1 for the Milwaukie project is under construction in 2013 and 2014 while Phase 2 is planned to be built in 2015 and 2016 with CRC project funding.

Operation and Maintenance Facility additions for the Milwaukie fleet at Ruby Junction (Phase 1) on about 5.7 acres of land acquired with Milwaukie project funds include:

- LRV Storage
  - Construct the first phase of Ruby's west storage yard to a capacity of 20 spaces on 5 tracks (4 LRVs on each track).

- Maintenance Bays
  - Relocate the wash bay to make room for added maintenance bays.
  - Add 2 pit & platform bays on the west side of the main shop.

- Rail Control Improvements
  - Build a new Operations Command Center (OCC) on a more central TriMet site, Center St., to accommodate control room expansion, redundant equipment for reliability in emergencies and an overview display of greater height for acceptable readability.
  - Retain space for a scaled down back-up OCC at Ruby Junction.

- Parking and Parts Storage
  - Add about 42 parking spaces for the increase in workers.
  - Prepare outdoor storage area site for equipment that can be stored outside.
  - Retain one of the acquired existing buildings for indoor covered parts storage.

- Unit Repair Area
  - Expand the unit repair area on the 1st floor of the main shop through the relocation of administrative functions and parts storage to other floors or buildings.

Operation and Maintenance Facility additions for the CRC fleet at Ruby Junction (Phase 2) on about 4.8 acres of land acquired with CRC project funds will include:

- LRV Storage; 22 new spaces
  - Complete Ruby's west storage yard for a total capacity of 42 spaces on 7 tracks (6 LRVs on each track)

- Maintenance Bays; Complete the shop expansion by
  - Adding 3 pit & platform bays.
  - Adding 1 bay for a second wheel truing machine.
  - Adding 1 flat bay with jacks for truck work.

- Ruby Main Building Improvements
  - Finish the back up Operations Command Center (OCC) at Ruby.
  - Update locker and lunch rooms for additional operators and maintenance personnel.

- Parking and outdoor storage
  - Add about 52 parking spaces for the increase in workers.
  - Finish outdoor storage area for equipment that can be stored outside.

- Unit Repair Area
  - Retain an acquired existing shop building for MOW shop use.
  - Retain and adapt other acquired buildings for reuse.

A more detailed description and drawings of these improvements are contained in the "Operating and Maintenance Facilities Basis of Design Report for Entering Final Design" dated October 2010.

5) Demand for Revenue Vehicles

This Section is consistent with FTA guidance including the 1999 Hiram J. Walker Memo that outlined eight steps to calculate the demand for revenue vehicles. Those step numbers are shown in this section and in Section 8, Vehicle Demand and Supply Balance, to provide easy reference to the FTA guidance.

a) Passenger Demand Forecasts (Step 1)

Peak Passenger Loads. The Blue and Red Lines have two peak load points: Lloyd Center east of downtown and Goose Hollow (SE18th & Jefferson) west of downtown. The Green Line also passes Lloyd Center and serves that peak load point. The Yellow Line's peak load point is just north of Rose Quarter before it shares the right-of–way with the Blue, Red and Green Lines over the Steel Bridge and into downtown. The Milwaukie extension will have a new peak load point south of Tacoma while CRC is an extension of the Yellow Line and will share its peak load point, north of Rose Quarter.

2012 to 2030 actual, forecasted and interpolated PM peak direction passenger loads are shown in Table 5.1. Volumes were forecast for 2015 (Milwaukie model runs), 2018 (CRC FEIS model runs) and 2030 (CRC model runs in 2012) using the regional EMME2 travel demand model. CRC is now planned to open in 2019 so those load volumes are linear interpolations between 2018 and 2030. The Red, Green and Blue lines volumes are linear interpolations between actual 2012 counts and the 2030 forecast from the last CRC model run. This is also true for the Yellow line volumes between 2012 and 2018 using the 2030 baseline forecast.

PM peak passenger loads are used for fleet size forecasting because they are higher than AM peak passenger loads.

Table 5.1

PM Peak Direction Passenger Loads past the peak load points

	Milwaukie Orange Line **south** of Holgate		CRC Yellow Line **north** of Rose Quarter		Blue, Red and Green Lines **east** of Lloyd Center		Blue and Red Lines **west** of Goose Hollow	
	1-hour	2-hour	1-hour	2-hour	1-hour	2-hour	1-hour	2-hour
2012	0	0	**631**	**1,157**	**2,610**	**4,656**	**2,314**	**3,936**
2013	0	0	639	1,166	2,756	4,872	2,384	4,044
2014	0	0	647	1,175	2,902	5,088	2,454	4,152
2015	**1,239**	**2,354**	655	1,184	3,048	5,304	2,524	4,260
2016	1,266	2,374	663	1,193	3,194	5,520	2,594	4,368
2017	1,293	2,394	671	1,202	3,340	5,736	2,664	4,476
2018	1,320	2,414	679	1,211	3,486	5,952	2,734	4,584
2019	1,347	2,434	1,864	3,021	3,632	6,168	2,804	4,692
2020	1,374	2,454	1,926	3,118	3,778	6,384	2,874	4,800
2021	1,401	2,474	1,987	3,216	3,924	6,600	2,944	4,908
2022	1,428	2,494	2,049	3,313	4,070	6,816	3,014	5,016
2023	1,455	2,515	2,110	3,411	4,216	7,032	3,084	5,124
2024	1,482	2,534	2,172	3,508	4,362	7,248	3,154	5,232
2025	1,509	2,554	2,233	3,605	4,508	7,464	3,224	5,340
2026	1,536	2,574	2,295	3,703	4,654	7,680	3,294	5,448
2027	1,563	2,594	2,356	3,800	4,800	7,896	3,364	5,556
2028	1,590	2,614	2,418	3,898	4,946	8,112	3,434	5,664
2029	1,617	2,634	2,479	3,995	5,092	8,328	3,504	5,772
2030	**1,640**	**2,660**	**2,540**	**4,092**	**5,233**	**8,539**	**3,574**	**5,872**

Bold load amounts are from counts (in 2012) or forecasts (for 2015 and 2030). Other load amounts are from linear interpolations.

b) MAX Service Standards for Train Loading (Step 2)

In 1989, The TriMet Board of Directors adopted Service Standards for the design, evaluation and adjustment of transit service. The Service Standards do not apply to individual train trips but to average vehicle loads during each time period. This Service Standards document established the operating policies for headways as well as passenger loads. Headway is the time interval between train arrivals at stations. The minimum policy headways for light rail are:

- 10 minutes in the peak (7-9AM & 4-6PM)
- 15 minutes in the daybase (6-7AM & 9-4PM)
- 15 minutes in the evening (6-9:30PM)
- 30 minutes at night (9:30 PM -12 midnight)

The peak policy headway does not apply to the Red Line that averages 15-minute headways nearly the entire service day, seven days a week. This near uniform headway is a result of the line’s more even demand levels due to a lower percentage of commuters and the bi-directional nature of travel patterns on the line during peak periods.

Due to the recent downturn in the economy and the resulting budget pressures the Green Line and Yellow Line are operating on 15-minute peak headways with 2-car trains, however the loading standards described below are being met.

The first eighteen years of operating experience taught TriMet that, in Portland, rider’s crowding threshold is an average of 266 people per 2-car train during the peak hour in the peak direction. While some trains do carry the standard maximum passenger load of 332 or more riders, the average during the peak hour is 266, see Figure 5.1. This average is comparable to achievable capacity as defined in TCRP Report 13, “Rail Transit Capacity”.

TriMet’s loading standard is based on seated passengers plus standees at a peak hour average of 2.7 standees per square meter of standing floor area. This 2.7 average for the peak hour is very close to the 3.3 value suggested on page 5-27 and 28 of the TCRP Report 100 for the peak 15 minutes allowing for the peak hour factor, see Appendix A of this report. Using load factors would result in a different standard for each LRV type.

Type 4 and 5 LRVs have a slightly higher capacity than the Type 1, 2 and 3 LRVs, see table 5.2. However, since Type 4 and 5 LRVs make up only 27% of the fleet as of 2015 and due to increases in the demand from passengers who bring bicycles with them TriMet has elected to continue using the peak hour loading standard of 266 passengers per 2-car train.

Table 5.2

LRV Capacity

LRV Type	Design Capacity				Achievable Capacity	
	Seats per car	Standees per car	1-car train	2-car train	1-car Train	2-car Train
1	76	90	166	332	133	266
2 & 3	64	102	166	332	133	266
4 & 5	68	104	172	344	138	275

c) Run and Cycle Times by Line (Step 3)

Cycle time is the round trip travel time for a train and its operator on a particular line that accounts for travel time variations during peak and non-peak periods of the day. Cycle time includes the run times from one end of the line and back as well as schedule recovery and operator break time. Schedule recovery time is 10 percent of run time and operator break time is five minutes per hour. There is also a labor contract requirement for meal breaks that results in one additional daybase train on some lines. The run and cycle times for the MAX lines and the resulting daybase train requirements are shown in Table 5.3. TriMet's use of peak tripper trains results in a lower PVR than full cycle trains require, because a tripper train can serve the peak load point's passenger trips without making a full cycle. For CRC in 2030 the difference for through routed Yellow/Orange trains is 30 full cycle trains versus 23 trains (12 daybase trains plus 11 peak direction trippers). That is a 14-car reduction in the PVR for 2-car trains.

Table 5.3

MAX Run and Cycle Times

	2013 to 2030				2030	
MAX Line and Alignment	One-way Run Time	Round Trip Cycle Time	Daybase Headway in minutes	Number of Daybase Trains	Peak Hour & Direction Headway in minutes	Number of Peak Trains if Full Cycle
Blue Gov. Ctr. To Clev. Ave.	96	230	15	16	6	39
Red PDX to BTC	58	150	15	10	15	10
Green CTC to PSU	46	120	15	8	10	12
Yellow/Orange Expo Center To Park Ave.	58	150	15	10	Runs only until 2019	Runs only until 2019
Yellow/Orange Clark Col. To Park Ave.	67	180	15	12	6-north 8.6-south	30

d) Application of Loading Standards (Step 4)

Applying the 266 passenger 2-car train loading standard to the load data from Table 5.1 gives the minimum required number of trains that are needed in the peak direction past the peak load points. The minimum number of required trains in the peak hour is shown in Table 5.4. The minimum number of required trains in the peak two hours is shown in Table 5.5. Since many peak tripper trains do not make full cycles the 2-hour load must be examined to insure a smooth transition from the peak hour to the off-peak period.

The maximum headway can then be calculated by dividing the time period in minutes by the minimum number of trains required. Therefore, for CRC an average headway of 7.5 minutes is required in 2019 and 6 minutes in 2030 during the peak hour. During the 2-hour peak period an average headway of 10 minutes is required in 2019 and 7.5 minutes in 2030.

Table 5.4

Minimum Number of 2-car Trains required past the peak load points in the peak hour

Year	Milwaukie Orange Line **south** of Holgate		CRC Yellow Line **north** of Rose Quarter		Blue, Red and Green Lines **east** of Lloyd Center		Blue and Red Lines **west** of Goose Hollow	
	1-hour load	Trains Required	1-hour load	Trains Required	1-hour load	Trains Required	1-hour load	Trains Required
2012	0	0	**631**	3	**2,610**	10	**2,314**	9
2013	0	0	639	3	2,756	11	2,384	9
2014	0	0	647	3	2,902	11	2,454	10
2015	**1,239**	5	655	3	3,048	12	2,524	10
2016	1,266	5	663	3	3,194	13	2,594	10
2017	1,293	5	671	3	3,340	13	2,664	11
2018	1,320	5	679	3	3,486	14	2,734	11
2019	1,347	6	1,864	8	3,632	14	2,804	11
2020	1,374	6	1,926	8	3,778	15	2,874	11
2021	1,401	6	1,987	8	3,924	15	2,944	12
2022	1,428	6	2,049	8	4,070	16	3,014	12
2023	1,455	6	2,110	8	4,216	16	3,084	12
2024	1,482	6	2,172	9	4,362	17	3,154	12
2025	1,509	6	2,233	9	4,508	17	3,224	13
2026	1,536	6	2,295	9	4,654	18	3,294	13
2027	1,563	6	2,356	9	4,800	19	3,364	13
2028	1,590	6	2,418	10	4,946	19	3,434	13
2029	1,617	7	2,479	10	5,092	20	3,504	14
2030	**1,640**	**7**	**2,540**	**10**	**5,233**	**20**	**3,574**	**14**

Note: See Section 3.d for an explanation of why 2-car trains are assumed.

Table 5.5

Minimum Number of 2-car Trains required past the peak load points in the peak 2-hours

Year	Milwaukie Orange Line **south** of Holgate		CRC Yellow Line **north** of Rose Quarter		Blue, Red and Green Lines **east** of Lloyd Center		Blue and Red Lines **west** of Goose Hollow	
	2-hour load	Trains Required	2-hour load	Trains Required	2-hour load	Trains Required	2-hour load	Trains Required
2012	0	0	**1,157**	5	**4,656**	18	**3,936**	15
2013	0	0	1,166	5	4,872	19	4,044	16
2014	0	0	1,175	5	5,088	20	4,152	16
2015	**2,354**	9	1,184	5	5,304	20	4,260	17
2016	2,374	9	1,193	5	5,520	21	4,368	17
2017	2,394	9	1,202	5	5,736	22	4,476	17
2018	2,414	10	1,211	5	5,952	23	4,584	18
2019	2,434	10	3,021	12	6,168	24	4,692	18
2020	2,454	10	3,118	12	6,384	24	4,800	19
2021	2,474	10	3,216	13	6,600	25	4,908	19
2022	2,494	10	3,313	13	6,816	26	5,016	19
2023	2,515	10	3,411	13	7,032	27	5,124	20
2024	2,534	10	3,508	14	7,248	28	5,232	20
2025	2,554	10	3,605	14	7,464	29	5,340	21
2026	2,574	10	3,703	14	7,680	29	5,448	21
2027	2,594	10	3,800	15	7,896	30	5,556	21
2028	2,614	10	3,898	15	8,112	31	5,664	22
2029	2,634	10	3,995	16	8,328	32	5,772	22
2030	**2,660**	**10**	**4,092**	**16**	**8,539**	**33**	**5,872**	**23**

Note: See Section 3.d for an explanation of why 2-car trains are assumed.

The calculations for number of peak tripper trains needed during the peak hour and transition periods to the daybase for each line are described in the next subsection. The marginal difference from the Baseline operation of the Yellow/Orange Line to operation of the CRC extension is also shown in the next subsection.

e) Peak Vehicle Requirements (Step 5)

Calculation of 2030 CRC PVR

The calculation of the PVRs for CRC in the planning horizon year of 2030 are shown in Table 5.6. The description of the PVR calculation that follows refers to the table, which has the rows, numbered for reference.

The table begins with travel times, step 3 in the FTA Guidance; used to determine the daybase cycle time, line 6. The number of daybase trains, line 9, are then calculated based on these cycle times and the daybase headways, line 8. TriMet's longest average daybase headway allowed by policy is 15 minutes. Daybase trains provide frequent service to all passengers whether they are peak direction or reverse direction commuters or are traveling on the extremities of the system. Only some of the daybase trains pass the peak load points in the peak direction during the peak hour, line 10.

Next the peak hour, peak direction demand is considered, FTA step 4. Line 13 the forecast passenger load for 2030, FTA step 1, comes from Metro's demand model. Line 14 divides the forecast by 266, the load standard for a 2-car train, FTA step 2. Line 15, the proposed number of trains, rounds up to a whole train or provides for the longest peak hour peak direction headway of 10 minutes allowed by policy. The number of peak hour trippers, line 18, is the proposed number of trains, line 15, minus the number of daybase trains passing the peak load point in the peak direction during the peak hour, line 10.

Next the peak period outside the peak hour is considered, lines 19-25. If peak period demand is great enough outside the peak hour trains may be added to smooth the transition between the daybase and the peak hour headways.

Next total peak trains, line 27, are calculated by adding up daybase trains, line 9, and peak trippers in the peak hour, line 18 and outside the peak hour, line 25. Then the PVR, line 28 and FTA step 5, is calculated by multiplying by 2 cars per train and accounting for any single car trains. Finally the Total Fleet with Spares, line 29, is calculated using TriMet's spare ratio target of 15 to 18 percent.

FTA step 6, TriMet does not currently use or plan to use gap trains.

The far right-hand column, CRC Marginal, shows the difference between the baseline and the build alternative car requirements for a through-routed Yellow/Orange Line. The total car requirement is 19 LRVs for CRC in 2030.

2019 CRC PVR

The calculation of the PVR for the planned opening year, 2019, of the CRC project is shown in Table 5.7. This table is calculated in the same manner as the 2030 table was except that 2019 peak passenger loads are used as input. These loads were interpolated from the 2018 and 2030 demand model forecasts as shown earlier in Table 5.1.

Existing Line PVRs in 2030

The calculation results of the PVRs for the existing Lines are shown in Table 5.8 for 2030. For the MAX Lines that share common peak load points (East – Blue, Red & Green and West – Blue & Red) the proposed number of trains is based on the requirements shown in Tables 5.4 and 5.5. The demand model forecast underestimates the share of load that the Red Line will carry as evidenced by higher current Red Line loads shown in Table 3.3.

f) Gap or Ready Reserve Train Usage (Step 6)

After the introduction of Type 2 vehicles in October of 1997, TriMet did operate gap trains, when available, to mitigate the impact of more frequent mechanical failures which resulted in cars from the new fleet being taken out of service. As the Type 2 vehicles became more reliable the need for gap trains ended.

6) Supply of Revenue Vehicles

a) Financial Constraints

TriMet carefully studies the capital and operating (financial) implications of expanding the fleet. This is done in the context of the Agency's overall financial planning process. Every year TriMet updates its five-year capital and operating financial forecasts. While financially sound, agency resources are scarce. The purchase of vehicles requires either federal funding assistance, the issue of TriMet long-term debt, or both. Equally important, operating costs are forecast so that local, continuing-revenue, sources will adequately meet any new continuing-expenditures. Funding for the fleet expansion for service in 2019 in this plan will come from the CRC Project. Funding for fleet expansions after 2019 will come from either the next Light Rail Project or bonding, see Section 8 for an estimate of when these fleet expansions will be needed.

b) Vehicle Purchasing Constraints

Like most light rail systems in the United States, TriMet vehicle specifications are unique to Portland. Thus, there are several "logistical" constraints to purchasing vehicles. First, purchase orders require a long (several years) lead-time to allow adequate time for the manufacture and transport of thousands of precision components, as well as the fabrication, assembly, and testing of the vehicles. Second, due to the long lead times, purchase orders of fewer than ten vehicles are uneconomical. For these reasons it is not possible to quickly purchase a few vehicles in response to an unexpected surge in ridership. On the contrary, large orders are placed years in advance for any project or extension. This inability to purchase a few vehicles at a time leads to interim spare ratios that are often higher than the transit agency desires.

c) Fleet Life Cycle

TriMet's anticipated replacement cycle for LRVs is 41 years for Type 1 LRVs and 36 years for all other LRV Types. The 26 Type 1 vehicles are due for replacement in 2027 prior to 2030; see Section 8, Vehicle Demand and Supply Balance, and the vehicle replacement schedule in Appendix B from TriMet's Capital Improvement Plan (CIP) for further details of timing. Type 1 LRVs are subject to a sale and leaseback arrangement that has penalties for early retirement. Type 1 vehicles are currently undergoing a full body rebuild after 18 to 27 years of service, this is the only body rebuild planned before retirement. To help maintain reliability these cars may be assigned to trains with shorter runs to reduce annual mileage. TriMet intends to maintain these vehicles via progressive overhauls until their retirement to assure a high level of in-service reliability and a reasonable resale value. If the possibility of resale looks doubtful during the last few years prior to retirement, then the deferral of some maintenance prior to sale for scrap will be considered.

7) Maintenance and Reliability

a) Maintenance Program Elements

TriMet's overall LRV maintenance program consists of seven distinct, but mutually supportive maintenance work programs: preventive maintenance, running repairs, component rebuild, progressive overhaul, scheduled maintenance, modifications (product improvements), and equipment engineering analysis and training. These seven work programs required about 127,000 labor hours per year for the 127-car fleet, or just less than 1,000 labor hours per year per vehicle.

<u>Preventive Maintenance (40% of total labor hours)</u>

Preventive Maintenance (PM) inspections, including correction of defects found, are performed on a consistent schedule based on mileage. PM inspections are scheduled at intervals of 4,500, 9,000, 13,500, 27,000, 40,500, and 81,000 miles, each mileage grouping accrues mileage independently from the other and is scheduled based on the mileage accrued since the completion of the last PM, each mileage interval is based on the specific needs of that system's components. Any periodic, scheduled inspection and maintenance tasks with intervals greater than 81,000 miles are performed under the Progressive Overhaul program.

The PM program content and intervals are based on manufacturer recommendations, refined through continuous analysis by equipment engineering staff, maintenance supervisors and technicians. Physical inspections of components and systematic data tracking of failures and repairs are continually analyzed to maximize both effectiveness and efficiency of the PM program. See Appendix C of this report for a description of PM Inspections and their respective mileage intervals by LRV type. Items with a 0 for the mileage interval are no longer covered by technicians during PMs instead they are performed as running repairs when reported by operators or cleaners.

TriMet's goal is to complete at least 80 percent of PM inspections on time.

TriMet Preventive Maintenance Force Account Plan. TriMet's rail and facilities maintenance program includes work performed by TriMet's labor force and by contractors. By far the great majority of preventive maintenance is performed by TriMet's own labor forces as negotiated by the Working and Wage Agreement between Amalgamated Transit Union Division 757 and TriMet. Under the labor agreement work that is contracted out must meet criteria specified in the labor agreement. Contracted maintenance must also be pre-approved by the ATU. The justification for using force account work for preventive maintenance is the TriMet ATU labor agreement. Budgets for this work are shown in Appendix D of this report.

Running Repairs (25% of total labor hours)

Running Repairs diagnose and correct defects on vehicles identified during revenue service and reported to LRV Maintenance by Transportation personnel. Vandalism and accident repairs are also classified under the Running Repairs program.

Component Rebuild (5% of total labor hours)

The component (or unit) rebuild program refers to repairable equipment removed and replaced on the vehicle. Such equipment components or subsystems are rotated through the component rebuild section of LRV Maintenance in appropriate cycles so as to maintain availability of rebuilt or repaired components to meet running repair requirements for removal and replacement of such components. This allows much faster return of defective vehicles to service. Component rebuild production and quality is under dedicated supervision, and is also supported by equipment engineering analysis and product improvement modifications at the component/subsystem level.

Progressive Overhaul (16% of total labor hours)

TriMet's LRV maintenance program seeks to keep current with the entire scope of vehicle maintenance requirements, and therefore seeks to avoid requirements for mid-life remanufacturing for its LRVs. Accordingly, long-cycle tasks (beyond the 81,000 PM program cycle) are also scheduled based on continuing fleet condition assessment and design of overhaul campaigns. Each overhaul campaign bundles multiple overhaul tasks which are now due, for simultaneous performance on each vehicle cycled through the campaign, for efficient overhaul program production. This progressive overhaul approach was recognized by USDOT in a 1995 report as best-practice in the rail transit industry, preferable to mid-life vehicle remanufacturing in terms of keeping the fleet continuously in service at a higher spare ratio and in minimizing fleet life-cycle total cost.

Scheduled Maintenance (14% of total labor hours)

Other scheduled maintenance tasks that are outside of preventive maintenance or progressive overhaul and are scheduled from time of completion, from measured wear limit or by seasonal requirements are captured under scheduled maintenance. Maintenance tasks such as wheel truing, car floor height adjustment and brake disc truing are examples of scheduled maintenance.

Modifications (product improvements are 1% of total labor hours)

Modifications are product improvements made to (1) increase vehicle reliability by decreasing failure and wear rates, (2) increase maintainability by easing or decreasing maintenance tasks, and (3) increase customer service by improving vehicle amenities or comfort.

Vehicle reliability and maintainability modifications are an ever-present element of the LRV maintenance program, and arise out of continuous analysis by equipment engineering staff, maintenance supervisors and technicians. Introduction of a new-type vehicle fleet to operate in train consists with existing vehicle types can also require considerable modifications to existing vehicle types, as was required for TriMet's Type 1 LRVs when the Type 2 LRVs were introduced. The new curved platforms on the Portland Transit Mall resulted in the addition of side view CCTV on the entire LRV fleet. Customer service modifications have include retrofitting air conditioning to the Type 1 LRVs, retrofitting CCTV surveillance to Type 1 and 2 LRVs, and modifying interior stanchions of Type 2 LRVs to increase bicycle boarding accommodations.

<u>Equipment Engineering Analysis and Training (less than 1% of total labor hours)</u>

Equipment engineering analysis and training functions are provided through a 4-member staff unit working in a team effort with maintenance supervisors and technicians, continuously analyzing failure data among component subsystems, refining maintenance techniques (e.g., procedures and training, including PM program effectiveness), and developing product improvement modifications.

The equipment engineering staff is dual-function, by also serving as LRV maintenance trainers. Training program elements include (1) initial training of apprentices from Tri-Met's maintenance helper classification to become LRV maintenance technicians (30-month program of classroom and on-the-job training), (2) technician recurrent training, and (3) training of technicians and apprentices on modifications, new or revised maintenance procedures, and new types of LRVs or maintenance equipment.

b) Train Failure Definitions and Actions

Train failures can require the use of spare vehicles to maintain scheduled service. The term relevant failure has been used to define which failures are used to calculate the mean distance between failures (MDBF).

Relevant failures used in TriMet’s traditional calculation of the mean distance between failures (MDBF) include any independent failure of an item which results in any of the following:

1. A four-minute or longer delay of revenue service.
2. Failure to enter revenue service at the scheduled time.
3. Need to remove a vehicle from revenue service.
4. Failure of the ventilation system.
5. Door and bridgeplate system failure that requires two or more doors or bridgeplates per car to be cutout.

Relevant failures varied between 7,500 miles and 25,000 miles between 2000 and 2004. Problems with the software’s tracking of delays between 2004 and 2008 resulted in erratic data of little use for measuring trends in vehicle reliability.

In the year 2000, a new measure of vehicle reliability was developed, for more precision in measuring reliability, determining trends and meeting TriMet's goal of continuous improvement in LRV reliability. This service related failures measure is based on the number of times any symptom code is used to log in a repair on the pending worklist, see Appendix E of this report for examples. There was much improvement in this measure of MDBF since 2001, from below 2,000 miles to above 4,000 miles. The MDBF for the past 12 years is shown in Figure 7.1. When new LRVs enter the fleet they tend to bring down the MDBF for some period of time as can be seen from the 3rd quarter of 2009 on.

8) Vehicle Demand and Supply Balance

a) Spare Vehicle Requirements (Step 7)

There are three purposes for vehicle spares:

- to allow for routinely scheduled, preventative maintenance work to be performed during day and swing shifts in service bays that would otherwise be vacant
- to replace vehicles that fail in peak revenue service
- to allow for progressive overhaul and vehicle modification campaigns that take more than 1 or 2 shifts per car to complete.

Prior to Green Line opening in September 2009 TriMet operated with an 18 percent spare ratio, 16 spare cars compared with 87 cars in PM peak service. Two Type 1 cars at a time were out of the active fleet of 103 undergoing mid-life body rebuilds. Since TriMet's fleet is fairly small a certain number of spares are not dedicated to a given category of work on a regular basis. With only 16 spares an entire car cannot be devoted to the smaller categories of work on a continuous basis. However on average: 5.6 cars were undergoing Preventive Maintenance, 3.36 cars were undergoing Running Repairs, 0.64 of a car was undergoing Component Rebuild, 3.52 cars were undergoing Progressive Overhaul, 2.08 cars were undergoing Scheduled Maintenance, 0.8 of a car was undergoing Modifications, and 0.16 of a car was involved in Equipment Engineering Analysis & Training.

Since Green Line opening in September 2009 TriMet has operated with a spare ratio of 20 or 21 percent. Two Type 1 cars at a time remain out of the active fleet of 127 undergoing mid-life body rebuilds. The Type 1 mid-life body rebuilds will be completed by the end of 2014 or early in 2015.

TriMet's long term goal is to operate with a spare ratio between 15 and 18 percent. This range allows TriMet to meet its service objectives in a cost effective manner. However, because small LRV orders are not economical and service increases for passenger load growth on existing lines are limited to an additional train every few years many LRVs must be acquired before they are required. This situation results in a spare ratio that fluctuates over time, higher just after LRV acquisitions and gradually declining as more LRVs are put in service.

b) Fleet Demand and Spare Ratio (Step 8)

The fleet size, at any given time, is governed by:

- The Peak Vehicle Requirement (PVR) required to serve the current passenger demands based on data from automatic passenger counters
- The Peak Vehicle Requirement (PVR) required to serve future passenger demands based on transportation demand modeling with assumptions on future population and employment growth
- Financial constraints

- Vehicle procurement constraints including minimum economical size of order and delivery schedule
- The spare ratio target of 15 to 18 percent for the planning horizon year

The anticipated fleet size requirements for MAX between 2013 and 2030 with both the Milwaukie extension and the CRC extension are summarized in Table 8.1. Based on the passenger demand model forecast for 2030 the fleet will total 175 cars. This includes new LRV deliveries available for peak service and spares in the following years:

- 2015 – 18 for Milwaukie
- 2019 – 19 for CRC
- 2025 – 11 for system growth (includes the 8 Green Line cars not delivered for 2009)
- 2027 – 26 replacement LRVs for Type 1 retirements

The operating spare ratio (OSR) is the number of spares (active fleet - the PVR) divided by the PVR. The spare ratio forecast which varies from 17 to 24 percent is shown in Table 8.1. A 17 percent spare ratio would be fairly close to the lowest spare ratios in the rail transit industry. Achieving spare ratios below 15 percent would force uneconomical and inflexible operating and maintenance practices such as:

- concentrating the vast majority of maintenance during off-peak periods leaving maintenance bays idle several hours twice daily
- forcing more swing and graveyard shift work at higher wages and lower productivity while increasing the need for more maintenance bays.

The future service increases shown in Table 8.1 are estimates of when service would be added based on passenger demand models that are updated often. Actual service implementation will be based on updated model forecasts and the evaluation of automatic passenger counter data from existing MAX service.

Table 8.1

LRV Demand Supply Balance

Year	PVR increase on Extensions		PVR increase on existing lines		PVR	LRV delivery	Active Fleet	Spares	OSR
	South	North	East	West					
2009		1	14	1 shuttle	103	22	125	22	21%
2010					103		125	22	21%
2011		Mall shuttle discontinued -1, west side peak tripper added +2			104		125	21	20%
2012					104		125	21	20%
2013					104		125	21	20%
2014			2		106		125	19	18%
2015	12			2	120	18	145	25	21%
2016					120		145	25	21%
2017			2		122		145	23	19%
2018					122		145	23	19%
2019	2	8			132	19	164	32	24%
2020					132		164	32	24%
2021		2	2		136		164	28	21%
2022				2	138		164	26	19%
2023					138		164	26	19%
2024		2			140		164	24	17%
2025			2		142	11	175	33	23%
2026		2			144		175	31	22%
2027					144	26*	175	31	22%
2028					144		175	31	22%
2029		2	2		148		175	27	18%
2030					148		175	27	18%

Two Type 1 LRVs, on a rotating basis, are out of the active fleet for body rebuilds until 2015. The entire 2009-2014 fleet totals 127 LRVs.

***** In 2027 the 26 Type 1 LRVs are due for replacement.

Appendices

- A. TCRP Report 100 “TCQSM” 2nd Edition 2003 – Chapter 5 Rail Transit Capacity
- B. Capital Improvement Program (CIP) Replacement Table
- C. PM Inspections by LRV Type
- D. Preventive Maintenance Force Account Plan Budgets
- E. Service Related Failures MDBF Oct. Nov. & Dec. 2012

Appendix A

TCRP Report 100

Transit Capacity and Quality of Service Manual

2^{nd} Edition

Part 5 Rail Transit Capacity

Chapter 4 Passenger Loading Levels

Pages 5-25 to 5-29

APPENDIX B

Capital Improvement Program (CIP) Replacement Table

APPENDIX C

PM Inspections by LRV Type

APPENDIX D

Preventive Maintenance Force Account Plan Budgets

APPENDIX E

Service Related Failures MDBF Oct. Nov. & Dec. 2012