MICHIGAN OHIO UNIVERSITY TRANSPORTATION CENTER

Alternate energy and system mobility to stimulate economic development.

MODELING METROPOLITAN DETROIT TRANSIT

Final Report

Report No: MIOH UTC TS14 2010 - Final

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DISCLAIMERS

Abstract

The seven-county Southeast Michigan region, that encompasses the Detroit Metropolitan Area, ranks fifth in population among top 25 regions in the nation. It also ranks among bottom five in the transit service provided, measured in miles or hours or per capita dollars of transit service. The primary transit agencies in the region essentially cater to ‘captive riders’. Cities with a stronger transit base in the nation have two things in common; their ability to draw “choice” riders, and their success in building some type of rail transit system, with capital funds generally provided by the federal government.

Over past three decades, a number of studies have examined the feasibility of rapid transit services in the Detroit region including speed link (rubber tired high speed buses), Light Rail Transit (LRT), Commuter Rail Transit (CRT) and High Speed Rail Transit (HRT). Among the many problems associated with building such a rapid transit system in the region, is the lack of a “quick response” tool for preliminary planning for light rail transit along an urban travel corridor.

The primary objective of this project is to develop a quick-response tool for sketch planning purposes that may be used by other cities to test the feasibility of building LRT systems along a predefined transit corridor (i.e., a corridor with existing transit service, in form of buses). The primary focus of this study is to maximize the use of available data without any new data collection effort. In the report, the authors present an LRT case study for Detroit, where a number of LRT planning studies are currently underway, each with specific objectives, followed by a set of guidelines that can be used by transit planners for sketch planning of LRT. The guidelines are designed to assist transit planners in the preliminary planning effort for a LRT system on an urban travel corridor with existing bus services.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The seven-county Southeast Michigan region, that encompasses the Detroit Metropolitan Area, ranks fifth in population among the top 25 regions in the nation. It also ranks among the bottom five in the transit service provided, measured in miles or hours or per capita dollars of transit service. The primary transit agencies in the region essentially cater to “captive riders.” Cities with a stronger transit base in the nation have two things in common; their ability to draw “choice” riders, and their success in building some type of rail transit system, with capital funds generally provided by the federal government.

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The research approach is based upon the development of a generic model, intended to predict the following outputs for a proposed light-rail transit system (LRT):

1. Ridership demand estimation (i.e., passenger demand per operating day)
2. Operating parameters (i.e., travel time, speed)
3. System fleet parameters (i.e., fleet size, minimum headway, service headway)
4. Cost estimates (i.e., capital cost, operating cost)

The generic model is also validated with a set of demonstration exercises for a LRT system along the most dominant travel corridor in the region using the available database. Under ideal circumstances, the methodology should be developed first, followed by the demonstration exercise. The proposed procedure is designed to ensure that all the procedural elements recognize the prevailing data constraints, and the available data is utilized to its maximum potential. Hence, the demonstration exercise is presented first, followed by the procedure, presented in the form of a set of guidelines.

Major Findings:

- LRT travel demand along Woodward Ave. for a 26-mile long corridor connecting the Detroit and Pontiac Central Business Districts (CBDs) in a north-westerly direction was established at 21,437 passengers per day.

- A total of 26 LRT stations have been proposed along Woodward Avenue. Using multiple regression analysis, station specific boarding and alighting estimates was generated. Based upon the station "loadings", the daily LRT demand for the Woodward Avenue corridor is revised at 21,522 passengers per day. Using an assumed 300 day duration for an operating year, the annual ridership for the system is estimated to be approximately 6.5 million passengers . The Maximum Loading Station (MLS) and corresponding Peak Hour Demand (PHD) were also established.

- The operating parameters for the proposed LRT system were investigated in this report.

- The proposed LRT system requirements were calculated along with: an analysis of operating parameters (e.g., LRTV travel speed, acceleration, deceleration etc.), Identification of a suitable LRTV manufacturer and model (Kinkisharyo), fleet size, headways, and commercial speed. Based upon a ten-minute peak and 20 minutes off-peak headway, the required fleet size was calculated as 15 LRTVs.

- Operating cost estimates for the proposed system were calculated using the Fully Allocated Cost (FAC) method. Based upon a review of the current literature, the Gwinnett Village CID model, developed by HDR Inc., was adopted for the proposed Woodward LRT system. The Gwinnett Village CID model was derived from parameters related to operating cost data compiled from nine peer LRT systems in the United States. The operating cost for the proposed LRT system is estimated at $550,000 per mile per year (2010 dollars)

- For sketch planning purpose, the capital cost for the proposed LRT system is estimated at $50 million per mile.

Guidelines:

These guidelines are designed to assist the transit planner in developing a sketch plan for a LRT system along an urban arterial that is currently, used as a major transit (primarily bus system) corridor. These guidelines are based on the authors experience in conducting the Detroit LRT case study presented in the main report.

There are essentially three Right of Way (R/W) categories (C, B, and A) in transit operation that are distinguished by the degree of separation from other traffic on the street. An exact definition of the three categories are given below from Vuchic[1].

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[1] Vuchic, V.R, "Urban Public Transportation: Systems and Technology", Prentice Hall, N.J., 1981

- *Category C* represents surface streets with *mixed traffic.* Transit may have preferential treatment, such as reserved lanes separated by lines or special signals, or travel mixed with other traffic, …….. .

- *Category B* includes R/W types that are *longitudinally physically separated* (by curbs, barriers, grade separation, etc.) from other traffic, but with grade crossings for vehicles and pedestrians, including regular street intersections. This R/W category is most frequently used for LRT systems…………. .

- *Category A* is a *fully controlled* R/W without grade crossings, or any legal access by other vehicles or persons. It is also referred to as "grade separated," "private," or "exclusive" R/W,…………………... . In exceptional cases the R/W may have widely spaced grade crossings with signal override and gate protection of the tracks, and yet be considered as category A, since such crossings have little effect on line performance."

Vuchic points out above that category B, often referred to as Partially controlled access, is most frequently used for LRT systems. The authors of this report recommend that category B should be used for LRT systems. A 14-step process to facilitate LRT sketch planning is presented below (Figure E-1).

Step 1: Identify the major travel corridors in the region (with current transit/Bus services), as possible candidates for an LRT system.

Step 2: Assemble the following data:

- Population, Employment and Land use data (design year forecasts) by TAZ's, along a specified band width (1/2 mile to 1 mile)
- Existing Transit Ridership data along the designated travel corridors
- Projected Transit Ridership for the design year along the designated travel corridors

Step 3: Based upon long term demographic and employment growth and current transit travel patterns, identify the most dominant travel corridor (usually along a major transit corridor), as the preferred LRT corridor. A preliminary ridership estimate for the corridor should be established at this point. A minimum of 15,000 daily ridership (4,500,000 annual ridership) is desired. Based upon the Detroit case study presented, the following two rules may be used in developing a preliminary ridership estimate:

- Transit ridership along an existing bus corridor is likely to increase by 25% to 35% when an LRT is introduced
- The split between LRT and bus ridership is likely to be within a range of 4.5:1 to 5.5:1

Step 4: Identify LRT station locations based upon the following principles:

- Station spacing should be between 0.5 miles to 1.5 miles, with 1 mile as the desired value
- Station spacing need not be the same for the entire corridor. Denser land uses requiring more frequent access make for shorter spacing. Higher mobility needs on the other hand, would result in longer spacing.
- Station locations should reflect the dual consequence of access and mobility (contradictory) requirements
- A number of existing bus stops may be aggregated into specific station locations.
- Major bus stop junctions, transfer points etc. make for ideal station locations.

Step 5: Derive ridership estimates (by boarding and alighting) for each station. Means to attain the goal include:

- An analysis of existing (and predicted) station ridership data, along part of the corridor if any, with socio-economic, employment, transportation as land use variables (example Segment 1 in the case study).
- Literature search in identifying models from similar LRT corridors.
- Development of Alighting and Boarding models using station ridership and socio-economic, land use and transportation data from similar LRT systems elsewhere.

Step 6: Finalize ridership estimate so that:

The sum of all Boardings equals the sum of all Alightings and together equals Total Ridership.

The total ridership thus obtained should be in close proximity with the preliminary ridership estimate established in Step 3. Adjustments may be necessary if there is a significant difference between the two estimates.

Step 7: Develop factors for Peak Direction Flow, Peak Period Flow and Peak Hourly Flow to identify design conditions. Use this information to identify the Maximum Loading Section (MLS) and the corresponding Peak hour Demand (Dp).

Step 8: Review current LRT technologies, as well as those under development to identify operating parameters for the proposed system. These should include, but are not limited to:

- Capital Cost, Operating Cost
- Size and capacity of vehicles/trains
- Max. attainable speed
- Acceleration, Deceleration capabilities
- Ride quality

Step 9: Based upon a review of the operating data, select a system to fit the proposed system.

Step 10: Use the relationships presented in the report in Chapter (5), equations (10) through (13) to establish the maximum peak hour headway, and the required fleet size. A necessary prerequisite to this step is the completion of T_d, T_s and T_l, and the resulting cycle time θ (being the sum total of T_d, T_s and T_l). A specific headway must be assumed to compute T_l, even though headway is the desired output of this exercise. An iterative process may be needed to "converge" these two headway estimates.

Step 11: Once the maximum peak hour headway is determined, a policy headway must be established from data on current state of practice. In the case study presented, the maximum peak hour headway was calculated as 20 minutes. However, a policy headway of 10 minutes was adopted (compatible with current state of practice). This step, may result in 'overdesign', but is considered necessary to sustain transit demand along the corridor where there is no precedence of LRT system. Fleet size must be adjusted to make it compatible with the policy headway adopted. Note: Policy Headway is less than or equal to Maximum Headway.

Step 12: Based upon the results of Step 11, the final system requirements should be established. This information serves as a critical input to the computation of operating cost.

Step 13: Conduct preliminary cost analysis for sketch planning purposes in two separate categories:

- Capital Cost
- Operating cost (annual)

For sketch planning purposes, capital cost can be estimated based on a unit cost per mile derived from the literature. For operating cost, the use of Fully Allocated Cost technique is suggested.

Step 14: Using the ridership data generated (Step 6) develop an estimate of fare-box revenue, and other sources of revenue. Use the operating cost (Step 13) to estimate the following:

- Fare box revenue (%)
- Other revenue (%)
- Subsidy (%)

Major
Milestones

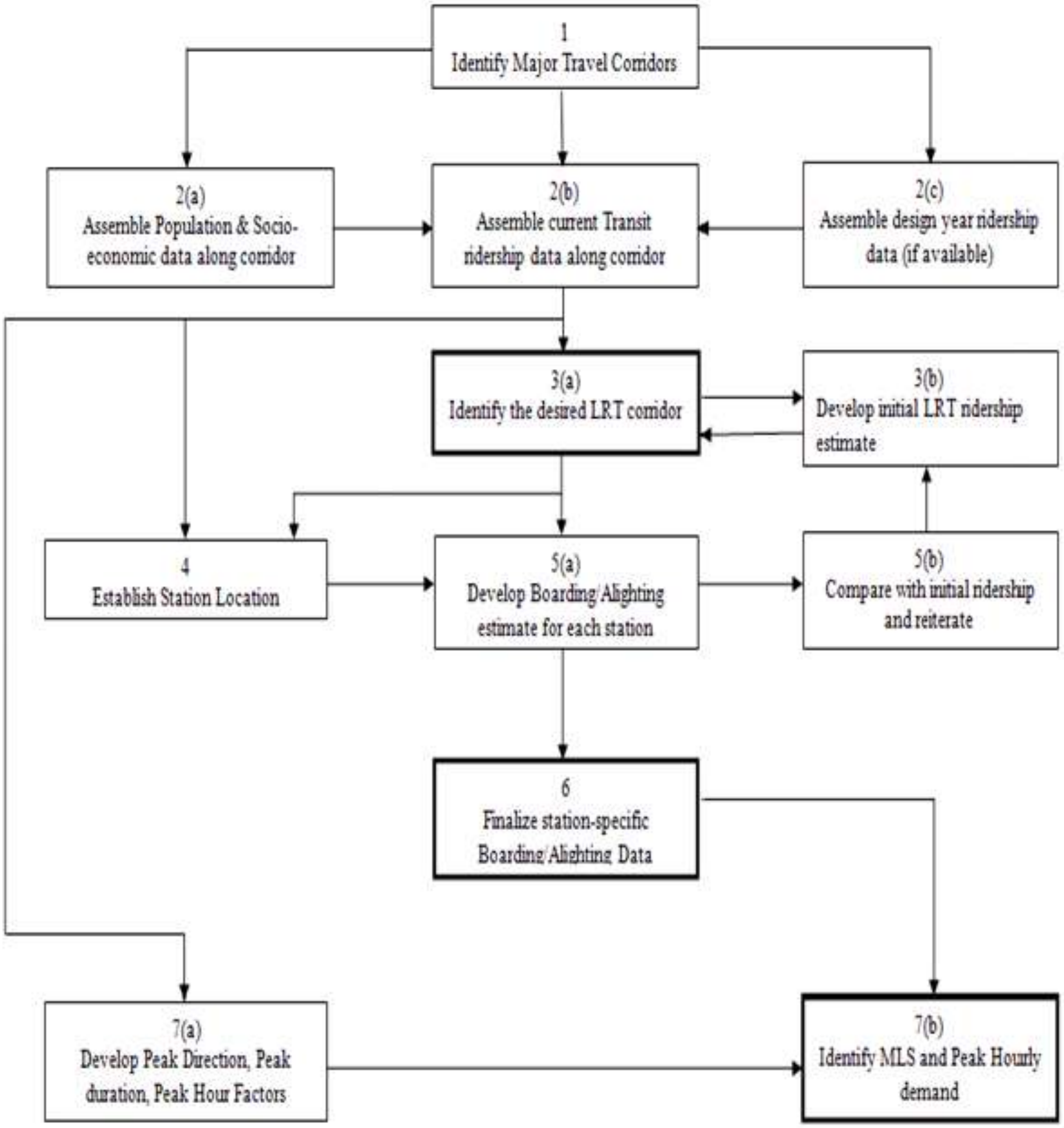

Figure E1. Guidelines for LRT Sketch Planning (Continued next page)

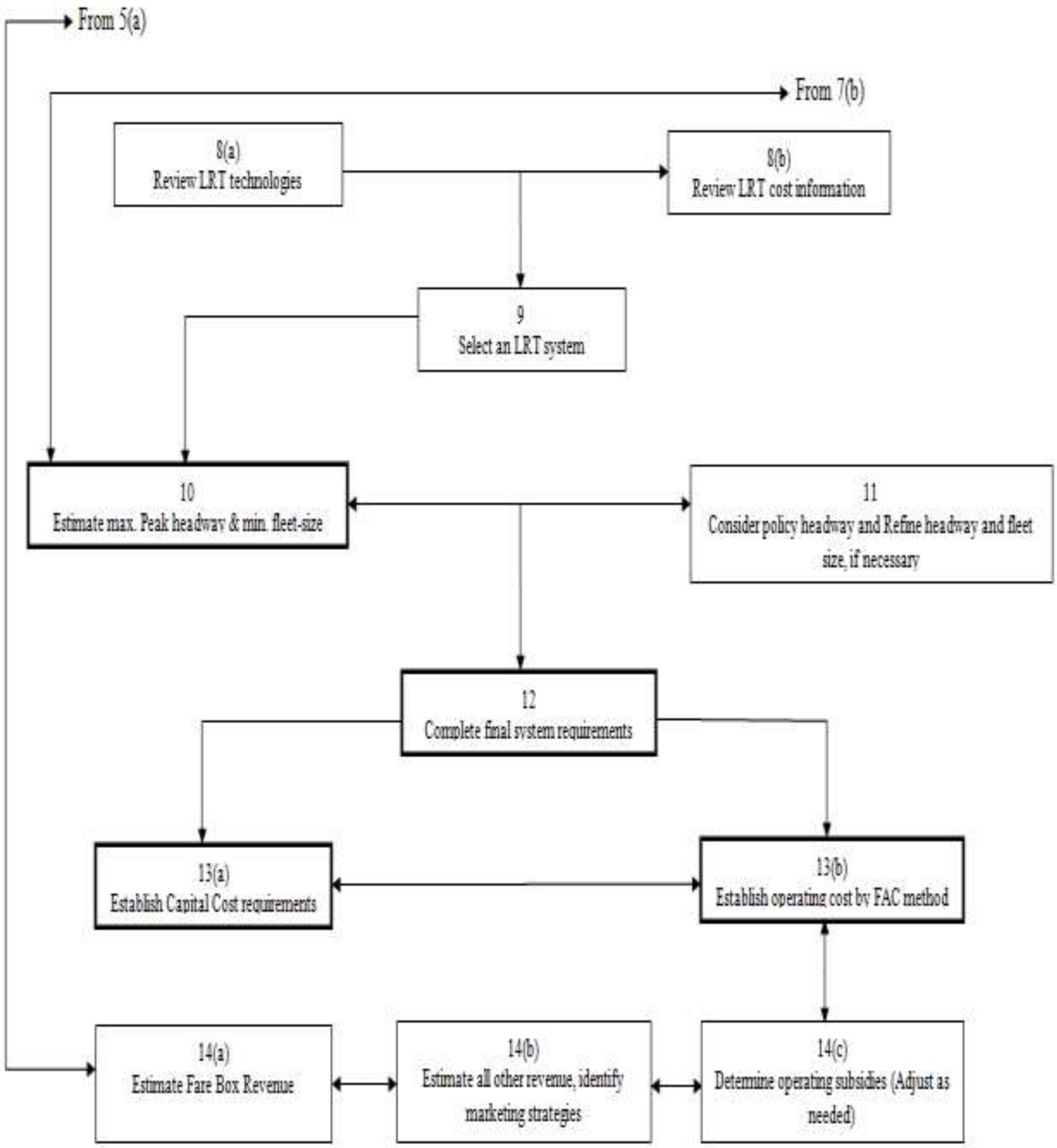

Figure E1. (Continued)

BACKGROUND

The seven-county Southeast Michigan region currently has an urbanized area population of approximately 4.0 million, with 1.9 million households that are expected to see a modest growth during the two decades. The region is also expected to add approximately 450,000 jobs over its current base during the same period[2]. Even though 192,000 households in the region do not have access to a private automobile, current use of transit in the region is very limited: only 2 percent of employed residents travel to work using public transit. By contrast, 94 percent employed residents in the Southeast Michigan Council of Governments (SEMCOG) region travel to work by private automobile, van, or light truck.

Transit in Southeast Michigan

The availability (or lack thereof) of transit service in the region is perhaps the root cause of a small transit mode share. Clearly, the current use of public transit in the SEMCOG region is characterized by a large number of “captive riders”. Captive riders are identified as members of the population who do not own, or have access to, a private automobile. This is in contrast to “choice riders”, members of the population who use transit modes by choice, despite having access to private automobiles. Other metropolitan regions in North America with similar population (e.g., Washington D.C., San Francisco, CA; Boston, MA; and Toronto, ON, Canada) have successfully created a transit base by attracting choice riders, thereby significantly reducing vehicle congestion levels, dependence on fossil fuel, and environmental pollution.

Very little emphasis, if any, has been placed on attracting choice riders by policymakers in the Southeast Michigan region. This is evident in the fact that, while the region ranks fifth in the country by population among the 25 major metropolitan areas, it ranks 23rd both in the number of miles and number of hours of transit services per capita provided [*1*]. The region also ranks 21st in the amount of local funds spent on transit services. As stated in a report compiled by SEMCOG, many regions in the country spend nearly three times as much per capita for transit services (Detroit: $59.00, Cleveland: $124.000, San Francisco: $255.00). Other factors limiting transit activities in the region are:

1. Lack of consensus between the city of Detroit and its surrounding suburban areas regarding the configuration (i.e., alignment, right-of-way (ROW)), governance, and funding for a transit system, and associated administrative structure.

2. General lack of support from the public at large, for a viable transit base.

This phenomenon is exemplified by a number of “missed opportunities” experienced in obtaining transit resources. For instance, the bulk of a $600 million commitment made by the Federal government in 1974 was lost because of a general lack of consensus on the programming and planning aspects for a transit system. Similarly the first regional transit agency in the Detroit metropolitan area, South-East Michigan Transportation Authority (SEMTA), was created in the early 1970’s without a dedicated local transit support base (unlike other metropolitan regions in the country), thereby limiting its ability to compete for federal grants.

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[2] These numbers are long-term predictions, and do not reflect the recent economic downturn in the region, and its impact on future population migration.

Lastly, no transit allocations were made out of increased gasoline tax revenues in the state of Michigan, resulting from a 1997 piece of legislation despite the fact that up to ten percent of the funds could have been spent for transit projects.

Transit services are currently provided by three major agencies in the area:

- Detroit Department of Transportation (DDOT): service within the Detroit city limits
- Suburban Mobility Authority for Regional Transportation (SMART): service for the Detroit metropolitan area, with limited service in the Detroit city limits
- Detroit Transportation Corporation (DTC) manages Detroit People Movers.

DDOT and SMART provide bus route service for over 100,000 transit miles per operating day, generating a daily ridership of over 170,000. A number of other transit services are available in the SEMCOG area for their respective local communities:

- Ann Arbor Transportation Authority (city of Ann Arbor)
- Blue Water Area Transportation Commission (city of Port Huron)
- Lake Erie Transit (city of Monroe and Monroe County)

Past and Current Studies

A brief summary of the recent activities is presented below to provide a basis for this report.

- In 1997, the Metropolitan Affairs Coalition and the Detroit Regional Chamber developed a three-tiered rapid transit system, comprising of both fixed and flexible local services [*2*].
- For many years, the SEMCOG has identified three major travel corridors: Woodward Avenue (connecting Detroit and Pontiac), Interstate 94/Michigan Avenue (connecting Detroit and Ann Arbor), Gratiot Avenue (connecting Detroit and Mt. Clemens) [*3*].
- Past transit studies have identified three travel corridors for viable rapid transit systems, with the first two having the highest potential. Most experts in transportation planning feel that a transit corridor developed along Woodward Avenue could attract riders from parallel corridors (e.g., Interstate 75, Michigan Highway 10 / John C. Lodge Freeway) over and above Woodward Avenue. Similarly, any transit system developed along I-94/Michigan Avenue could also draw riders from the east-west travel routes (e.g., I-96, Ford Road). The potential for transit development along the Gratiot Avenue corridor has never been fully investigated.
- The “Woodward Corridor Transit Alternative Study”, conducted in 2000 by the Detroit Transportation Corporation, recommended that both bus-rapid transit (BRT) and light-rail transit be further investigated [*4*].

- A 2001 SEMCOG study recommended rapid transit on 12 regional corridors in the region covering approximately 259 miles. Speed link services, (representing rubber-tired systems on dedicated lanes) were recommended along Woodward Ave, of the 12 corridors identified [*5*].

- A later study by the Michigan Department of Transportation (MDOT), investigated the potential for deploying signal pre-emption along the Woodward Avenue corridor. The study essentially found that signal pre-emption could be an effective tool for improving the flow of rapid buses over the signalized intersections along Woodward Avenue

- A recent SEMCOG study focused on exploring the possibility of transit development between the cities of Detroit and Ann Arbor, with connection to the Detroit Metropolitan Airport (DTW). A myriad of alternatives, ranging from BRT, LRT, and commuter rail (heavy rail) encompassing a number alignments, were evaluated.

- A recent study conducted by a consultant for SEMCOG and the city of Detroit explored the feasibility of building an LRT system from the Detroit central business district (CBD), to the northern city limits at Eight Mile Road The proposed system would follow the alignment of Woodward Avenue, with an approximate length of nine miles [*6*]. The capital cost of the proposed system, including tracks, train vehicles, and stations was estimated to be $373 million.

PROJECT SCOPE

The objective of this research is to develop a quick-response prediction model for sketch planning purposes that may be used by other cities to test the feasibility of building LRT systems along a predefined transit corridor (i.e., a corridor with existing transit service, in the form of buses). In the report, the authors present an LRT case study for Detroit, where a number of LRT planning studies are currently underway, each with specific objectives. The LRT case study is followed by a set of guidelines (Figure E-1). For the purpose of this study, the LRT route from the Detroit CBD (near West Jefferson Ave.) to the northern boundary of the city, was designated as Segment 1. The proposed expansion of the LRT route from Eight Mile Road, to E. Huron Street/Michigan Highway 59 (M-59) in the city of Pontiac, was designated as Segment 2.

A map showing Segments 1 and 2 along with cities is shown in Figure 1. The planned LRT system (Segments 1 and 2) will connect the cities of Ferndale, Pleasant Ridge, Royal Oak, Birmingham, Bloomfield Hills, Troy, and Pontiac with the central business district of the city of Detroit and will serve mobility needs of the region along one of its most-heavily travel corridors. For Segment 1, boarding and alighting data for each station were available by day of the week, period of the day (i.e., A.M., MID-DAY, P.M. OFF-PEAK), and direction of travel along Woodward Ave. Socioeconomic information such as population, employment, and household size were also available for the SEMCOG area, by predefined traffic analysis zones (TAZ).

The research approach is based upon the development of a generic model, intended to predict the following outputs for a proposed light-rail transit system (LRT):

1. Ridership demand estimation (i.e., passenger demand per operating day)
2. Operating parameters (i.e., travel time, speed)
3. System fleet parameters (i.e., fleet size, minimum headway, service headway)
4. Cost estimates (i.e., capital cost, operating cost)

The generic model is also validated with a set of demonstration exercises, using the available database from Segment 1 and Segment 2 of the Woodward Avenue corridor in the SEMCOG region. Under ideal circumstances, the methodology should be developed first, followed by the demonstration exercise. In reality, however, a viable methodology must be developed with due consideration given to data availability. Data constraints often require the methodology development and demonstration to proceed concurrently, with proper and frequent interface between the two phases. The authors used this concurrent procedure in this study to ensure that all the procedural elements recognize the prevailing data constraints, and the available data is utilized to its maximum potential. Hence, the demonstration exercise is presented first, followed by the procedure, presented in the form of a set of guidelines.

Other Background Information

SEMCOG databases serve as the baseline for ridership estimates, with the assumption that an LRT system would be constructed from the Detroit CBD, northward to the Detroit city limits at Eight Mile Rd (Segment 1). The remainder of the LRT route from Eight Mile Road to E. Huron Street/M-59 is designated as Segment 2 (Figure 1).

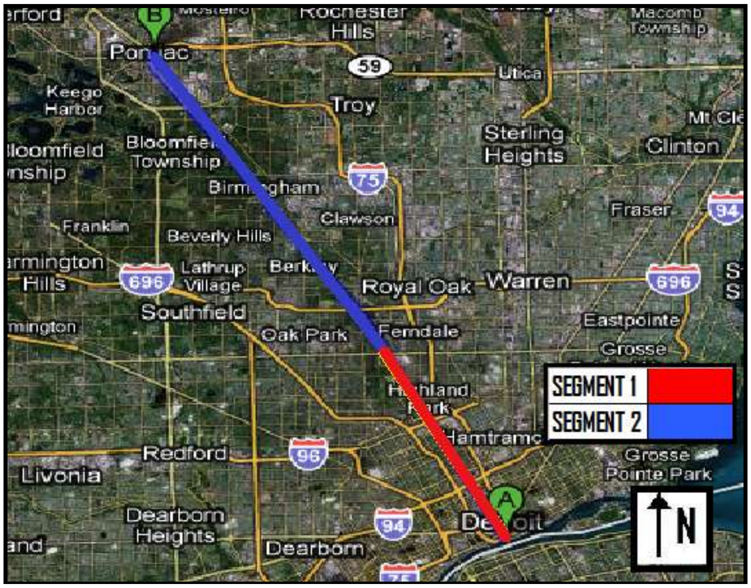


Figure 1. LRT Corridor Along Woodward Avenue (Segments 1 and 2)

Table 1 adapted from a SEMCOG report, contains transit ridership (both bus and LRT) data for a number of scenarios [1]. The original SEMCOG Table is included as Table A1 in Appendix A.

- The range of demand for the Woodward corridor, the subject of this demonstration exercise, is between 19,600 and 22,800 passengers per operating day. The following specific observations can be made relative to the Woodward corridor.
- For the year 2030, daily transit ridership (Bus & LRT) along the Woodward Ave. corridor ('2030 Woodward, Corridor Total') was estimated at 22,800 passengers per operating day, where 11,100 of that total would be contributed from Segment 1 of the LRT('LRTWoodward').
- DDOT bus route number 53 ('DD 53') along Woodward Ave was estimated to carry a total daily ridership of 8,300 passengers. However, this particular route is expected to be discontinued under the LRT scenarios.
- The remaining bus service, provided by SMART under the '2030 Woodward, LRT' scenario, is estimated to contribute a combined daily ridership of 11,700 passengers per operating day (SMART bus routes: SM 445, SM 450, SM 460, SM 465, SM 475, SM 495).
- Under the 'NO BUILD' scenario, the expected daily ridership along the Woodward corridor was estimated as 19,600 passengers per operating day. Thus, the net impact of the proposed LRT system (Segment 1) is an additional 3,200 passengers per operating day (net difference 22,800 of 19,600).

The information listed above is presented in a concise form in Figure 2, focusing primarily on the "2030 Woodward" component of Table 1.

Review of Related LRT Studies

A number of planning studies in the SEMCOG region are currently underway, with the intent of exploring the feasibility of constructing and operating an LRT system along Woodward Ave.:

SEMCOG Study: As a part of the 2035 regional plan for the Southeast Michigan region, SEMCOG's Regional Transit Coordinating Council has agreed upon three corridors for rapid transit, one of which is Woodward Ave. (Detroit CBD to M-59). The SEMCOG study has been conducted using a regional approach, where a combination of BRT, LRT, and arterial rapid transit (ART) would be implemented on each of the aforementioned corridors. ART is an approach to operate conventional buses along existing routes more efficiently, using one or more of the following: signal priority, limited stops between terminal points, and turn-outs at stops.

Table 1. SEMCOG Demand Summary (Woodward Ave. subset)

CORRIDOR	ROUTE NAME	EXISTING RIDERSHIP	2005 BASE	2030 BASE	2030 Woodward			
					NO-BUILD	TSM	BRT	LRT
Woodward	DD53	13,500	9,100	7,700	8,300	8,500		
	SM445	300	200	200	200	200	200	200
	SM450	4,800	3,700	3,800	3,800	3,900	3,900	3,800
	SM460	0	3,900	4,000	4,000	4,000	4,100	4,100
	SM465	300	300	300	300	300	200	200
	SM475	0	200	200	200	200	200	200
	SM495	2,300	2,900	2,800	2,800	2,800	3,100	3,200
	DD53T	0	0	0	0	100	0	0
	BRT Woodward	0	0	0	0	0	9,200	0
	LRT Woodward	0	0	0	0	0	0	11,100
	CORRIDOR TOTAL	**21,200**	**20,300**	**19,000**	**19,600**	**20,000**	**20,900**	**22,800**

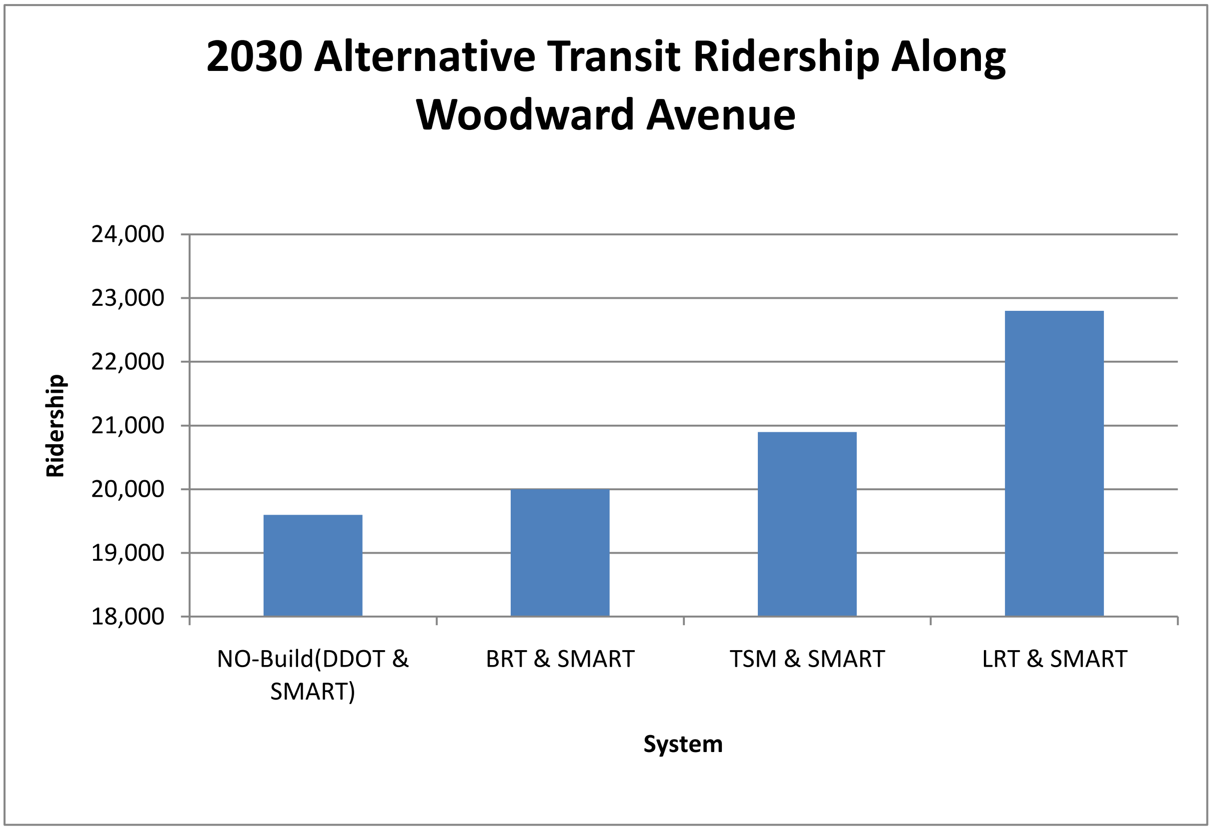


Figure 2. Daily Transit Ridership along Woodward Avenue in 2030 for Various Alternatives

The SEMCOG study plans for LRT to operate along the Woodward corridor from the Detroit CBD to an area just south of Eight Mile Road, near the Michigan State Fairgrounds (Table 1). Officials at SEMCOG have expressed the importance of such a system to have the ability to reach the suburban communities in metro Detroit, where the Eight Mile Rd station area could continue to be used as a regional bus transfer center. At the time of this writing, this regional plan has not yet been implemented in the SEMCOG region [*7,8*].

Detroit Transit Options for Growth Study (DTOGS): DTOGS was intended to investigate rapid-transit mobility options for the Detroit metropolitan area. The study followed guidelines established by the Federal Transit Administration (FTA), one of which was to conduct a "Transit Alternatives Analysis". Of the alternatives investigated (bus-rapid, LRT, and conventional bus transit), a plan calling for a Woodward Ave. LRT system prevailed. At the time of its completion, the study predicted that the proposed system (Table 1) would carry approximately 11,000 riders per day. The system, as proposed, is predicted to cost $371 million to construct (2007 estimate) [*9*].

M1-Rail Study: The M1-RAIL is a non-profit, public/private partnership of Detroit business and civic leaders that intend to develop light-rail transit in the city of Detroit to stimulate economic development. The proposed system is expected to operate along Woodward Ave, for approximately 3.4 miles from the Detroit riverfront (W. Jefferson Ave.) to West Grand Blvd. The M1-RAIL proposal differs from the previous studies, in that the planned stations are to be located less than 1/2-mile from one another. Given the smaller distances planned for spacing, the M1-RAIL partnership envisions the proposed system as an urban link rather than a commuter facility. To date, the organization has committed $125 million for the preliminary planning and pre-construction studies of the system [*11*].

The station locations proposed by various studies are presented in Table 2. Because the scope of the LRT system proposed in the M1-Rail study is somewhat different, the corresponding station locations also differ (Table 2).

Even though three studies were done to explore the feasibility of LRT along Woodward corridor, the SEMCOG study is the only one whose detailed modeling data were available to the project team, therefore it serves as benchmark for this study.

Table 2. Proposed Alignments for Woodward Ave. LRT System

SEMCOG	DTOGS	M1-Rail (Private Venture)
8 Mile Rd.	State Fairgrounds (Between 8 and 7 Mile Rd.)	New Center
7 Mile Rd.	7 Mile Rd.	AMTRAK
McNichols Rd.	McNichols Rd.	Wayne State University
Manchester St.	Manchester St.	Cultural Center
E Davison Serv. Dr.	Glendale St.	Detroit Medical Center NORTH
Woodland Heights	Calvert St.	Detroit Medical Center SOUTH
Arden Park	Hazelwood / Holbrook St.	Masonic Temple / Brush Park
Grand Blvd.	Grand Blvd.	Foxtown
Milwaukee	Piquette St.	Grand Circus Park
Warren Ave.	Warren Ave.	Campus Martius
MLK Blvd. / Mack Rd.	MLK Blvd. / Mack Rd.	Congress St.
Montcalm	Foxtown	
Grand River	Downtown*	
Congress	-	
Larned	-	
Jefferson Avenue	Jefferson Avenue	Jefferson Avenue

STUDY APPROACH

The intent of this modeling approach is to estimate the LRT ridership demand in Segment 2 of the project area (from Eight Mile Road to M-59, along Woodward Ave., as shown in Figure 1). The primary basis for this information is the bus ridership data for all routes along the Woodward Ave. corridor. The study plan consists of a number of steps as displayed in Figure 3. The steps are:

- Determine bus ridership for Segments 1 and 2 from SEMCOG data.
- Determine LRT ridership for Segment 1 from SEMCOG data.
- Determine the proportion of bus and LRT ridership for Segment 1. Also compute growth factor of an existing bus transit corridor, when LRT is added.
- Establish a relationship between LRT ridership by station and socioeconomic factors for Segment 1.
- Use developed relationship for Segment 1 to determine LRT ridership for Segment 2.
- Fine tune boarding and alighting data of Segment 2, so that total boarding equals total alighting.
- Compare the regression ridership estimate with the growth factor estimate and make adjustment if necessary.
- Determine peak loading station along peak direction.
- Determine headway during peak and off-peak hours and fleet requirements (# of trains).
- Refine headway (policy) and fleet requirements.
- Determine system capital as well as annual operational and maintenance cost.

Analysis of Segment 1 Data (Data source SEMCOG)

Passenger boarding and alighting for LRT and bus modes are derived from SEMCOG data as shown in Table 3. The database is broken down into four periods of an assumed eighteen –hour operating day:

- A.M. Peak (three-hour duration; from 6:00 to 9:00 A.M.)
- MID-DAY (six-hour duration; from 9:00 A.M. to 3:00 P.M.)
- P.M. Peak (three-hour duration; from 3:00 to 6:00 P.M.)
- OFF-PEAK (six-hour duration; from 6:00 P.M. to MIDNIGHT)
- **TOTAL** (eighteen-hour day; from 6:00 A.M. to MIDNIGHT)

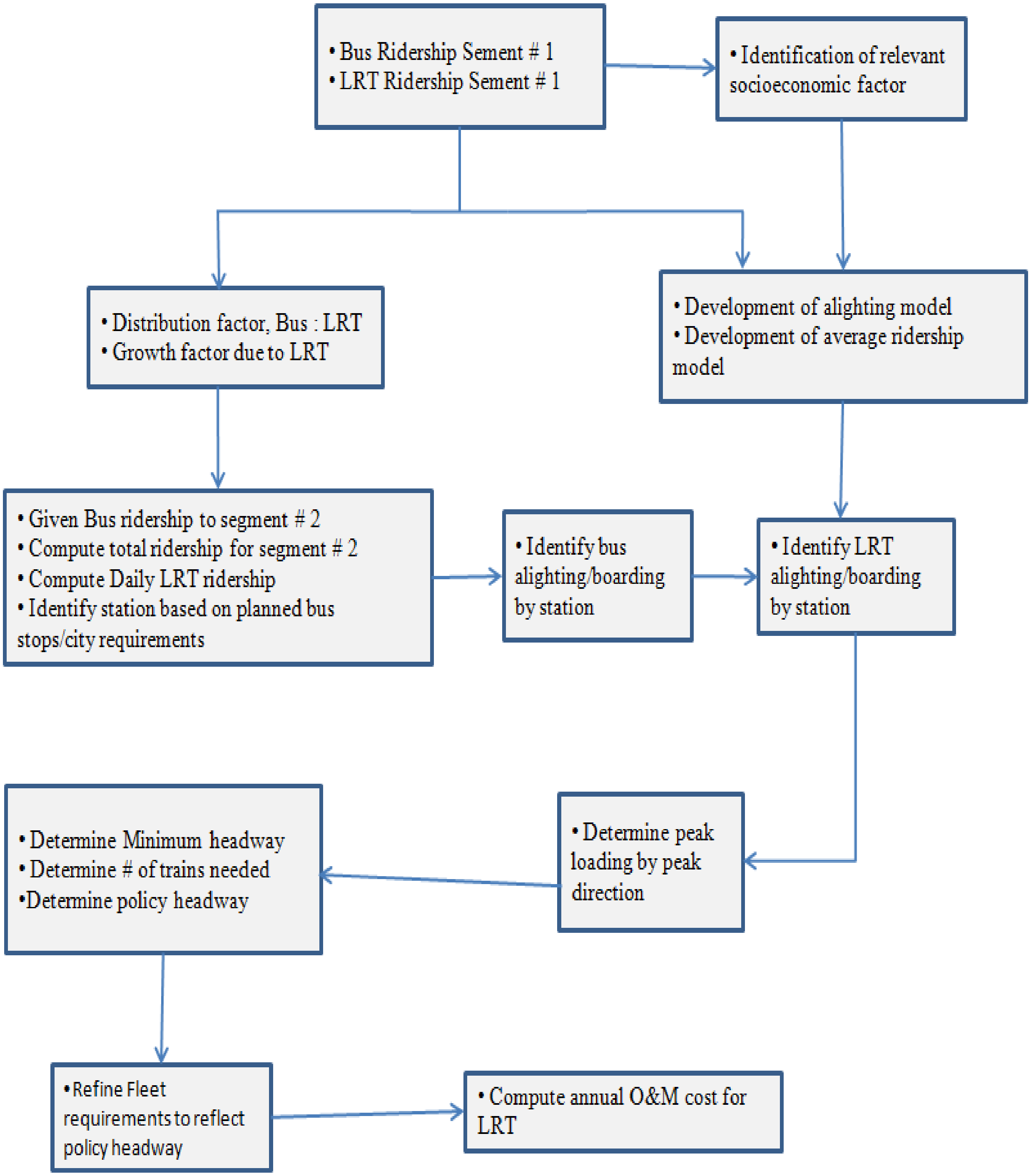


Figure 3. Flow Diagram Study Approach

Bus Ridership for Segment 1

Table 3 shows that for Segment 1, the total daily bus boarding and alighting are 2,624 and 1,532, respectively. For the LRT data in Table 3, there is a perfect match between boarding and alighting (both values round to 11,367 passengers per operating day).

Table 3. Summary of Bus and LRT Demand (2030 SEMCOG Model)

	BUS (Segment 1)		**BUS (Segment 2)**		**LRT (Segment 1)**		**Proportion of LRT Ridership Per Period**
Period	Board	Alight	Board	Alight	Board	Alight	
AM PK	442	232	887	1,160	2,103	2,103	0.19
MIDDAY	1,287	693	2,571	3,299	3,701	3,701	0.33
PM PK	613	439	1,713	1,970	3,100	3,100	0.27
OFF PK	282	168	834	972	2,463	2,463	0.22
TOTAL	**2,624**	**1,532**	**6,005**	**7,401**	**11,367**	**11,367**	**1.00**
AVERAGE	**2,078**		**6,703**		**11,367**		

Total Demand for Segment 1 (LRT & Bus) = 2,078 + 11,367 = 13,445 passengers per day

$$BusDemand\_Contribution = \frac{BusDemand}{Total\,Demand} = \frac{2{,}078}{13{,}445}x100 \approx 16\% \qquad (1)$$

$$LRT\,Demand\_Contribution = \frac{LRT\,Demand}{TotalDemand} = \frac{11{,}367}{13{,}445}x100 \approx 84\% \qquad (2)$$

Regarding ridership growth in segment 1 due to addition of LRT service is calculated as follows:

No-build LRT ridership for segment 1 (from Table 1) = 8,300+2,078 = 10,378

LRT build ridership for segment 1 (from Table 3) = 11,367+2,078 = 13,445

$$Growth\_from\_BuildLRT = \frac{13{,}445 - 10{,}378}{10{,}378}x100 = 30\%$$

Summary of Segment 1 Analysis:

- **Bus-LRT ratio = 5.25**
- **Total Transit ridership along an existing transit corridor will increase by 30% after introduction of LRT**

Identification of LRT ridership model for Segment 1

A total of 12 stations are planned along Segment 1. LRT boarding and alighting estimates for each station location on Segment 1 were developed by SEMCOG. A summary of the LRT ridership data by different periods in a day are presented in Table 3. LRT ridership demand data for segment 2 were not developed by SEMCOG. Hence, the project team attempted to develop a regression model relating LRT ridership by stations to socioeconomic factors for Segment 1. This regression model was used to estimate boarding and alighting demand for each LRT station along Segment 2.

The procedure employed involved an attempt to develop separate boarding and alighting demand estimates using a multi-variable regression model for Segment 1. The demand estimates were set as the dependent variable (boarding and alighting data shown for Segment 1 shown in Table 4), while a number of socioeconomic and transportation-related factors for the TAZ surrounding the proposed stations along the Woodward corridor were used as independent variables.

A series of regression models for boarding and alighting demand were tested with combinations of the aforementioned independent variables. As a part of this effort, the authors of the study analyzed three areas of influence surrounding each of the proposed LRT stations along Segment 1: 1/2, 1, and 2 mile radii. The influence areas were referred to as bandwidths for the purposes of this study. The models that were able to describe the most amount of variance in the relationship between the dependent and independent variables for Segment 1 were adopted as final model to predict the ridership demand for Segment 2.

According to the Manual of Uniform Control Devices (MUTCD), normally-paced pedestrian walking speed (*WalkSpeed*) is estimated to be equal to 4.0 feet per second [*12*]. Organizations such as the Maryland DOT, have suggested that new transit-oriented development (TOD) projects are planned within a 15-minute walk of a transit station, in any direction [*13*]. Using these values, the maximum walking distance ($Distance_{MAX}$) for transit riders can be calculated using the following relationship:

$$WalkSpeed = \frac{4\,ft}{\sec} * \frac{3{,}600\sec}{1hr} * \frac{1mi}{5280\,ft} = \frac{2.72mi}{hr}$$

$$Dis\tan ce_{MAX} = WalkSpeed * WalkTime \tag{3}$$

$$Dis\tan ce_{MAX} = \frac{2.72mi}{hr} * 0.25hr = 0.68mi$$

Thus, it was expected that a bandwidth size in proximity to this value would yield a reasonable prediction for transit ridership demand.

Regression Model for Alighting

Three single-variable regression models were developed to estimate alighting demand per station. Each model uses a different bandwidth (1/2, 1, and 2 mile radii surrounding the LRT station), as shown in Table 5. An examination of the R^2 and F values obtained for each model has indicated that the 1/2-mile bandwidth results in the best fit for the data.

This validated the assumption that the use of a ½-mile bandwidth around Woodward Ave. would yield a reasonable prediction.

Table 4. Segment 1 LRT Ridership Data

STATION NAME	SEMCOG		
	Board	Alight	Average
8 Mile Rd.	2,782	736	1,759
7 Mile Rd.	2,165	695	1,430
McNichols / 6 Mile Rd.	1,291	984	1,138
Manchester St.	477	453	465
Glendale St.	136	145	141
Calvert St.	410	197	303
Hazelwood / Holbrook St.	501	398	450
W. Grand Blvd.	378	974	676
Warren Ave.	1,029	2,141	1,585
MLK Blvd. / Mack Ave.	706	860	783
Foxtown	50	324	187
W. Jefferson	1,442	3,459	2,451
TOTALS	**11,367**	**11,366**	**11,367**

Table 5. Alighting Regression Model Summary

Number of stations (sample size), N = 12				
MODEL NO.	BANDWIDTH (mi)	EQUATION	R^2	F VALUE
1	0.5	ALIGHT = 474.548 + 29.274*[Total Empl./acre]	0.820	44.96
2	1	ALIGHT = 449.928 + 45.596*[Total Empl./acre]	0.770	33.52
3	2	ALIGHT = 243.788 + 121.896*[Total Empl./acre]	0.660	19.34

Referring again to Table 5, it was observed that both R^2 and F values decrease as the bandwidth is increased. The independent variable selected for the alighting model is total employment per acre. The model selected was the result of a number of iterations testing both single and multi-variable regression types, considering a range of land-use, demographic, and transportation-related variables of the TAZ's in proximity to the proposed LRT stations.

The models presented in Table 4 represent the best fit among all regression models developed (both single and multiple) for each of the three respective band widths.

Regression Model For Boarding

The project team was not able to develop a reliable boarding model with reasonable ANOVA values (i.e., t-test, F value, R^2, p value). Therefore an alternative approach was employed to estimate boarding data at each station considering following relationship:

- $AverageRidership = \frac{(Boarding + Alighting)}{2}$ (4)
- $(2 * AverageRidership) = (Boarding + Alighting)$
- $Boarding \cong (2 * AverageRidership) - Alighting$ (5)

A new regression analysis was employed relating the average ridership estimate (dependent variable) to the independent variables, namely employment density and intermodal connectivity (modal-conn). Three multiple regression models were then selected for each of the three bandwidths considered (Table 6). As in the previous section, the ½-mile bandwidth yielded the best performing model. The independent variables used for the model are as follows: total employment per acre and intermodal connectivity. The latter is a binary variable indicating whether or not a proposed transit station was within ½-mile of a facility promoting intermodal travel: bus stations (not stops), commuter train stations (i.e., AMTRAK), or other transit facilities (i.e., Detroit People Mover (DPM)). The list of stations that satisfy this condition are shown in Table 7.

Table 6. Boarding (Alternate Estimate) Model Summary

Number of stations (sample size), N = 12				
MODEL NO.	**BANDWIDTH (mi)**	**EQUATION**	**R^2**	**F VALUE**
1	0.5	AVERAGE Ridership = 579.177 + 14.297*[Total Empl./acre] + 330.033*[Modal_Conn]	0.480	4.154
2	1	AVERAGE Ridership = 585.850 + 21.523*[Total Empl./acre] + 301.686*[Modal_Conn]	0.420	3.426
3	2	AVERAGE Ridership = 520.952 + 47.444*[Total Empl./acre] + 366.00*[Modal_Conn]	0.330	2.182

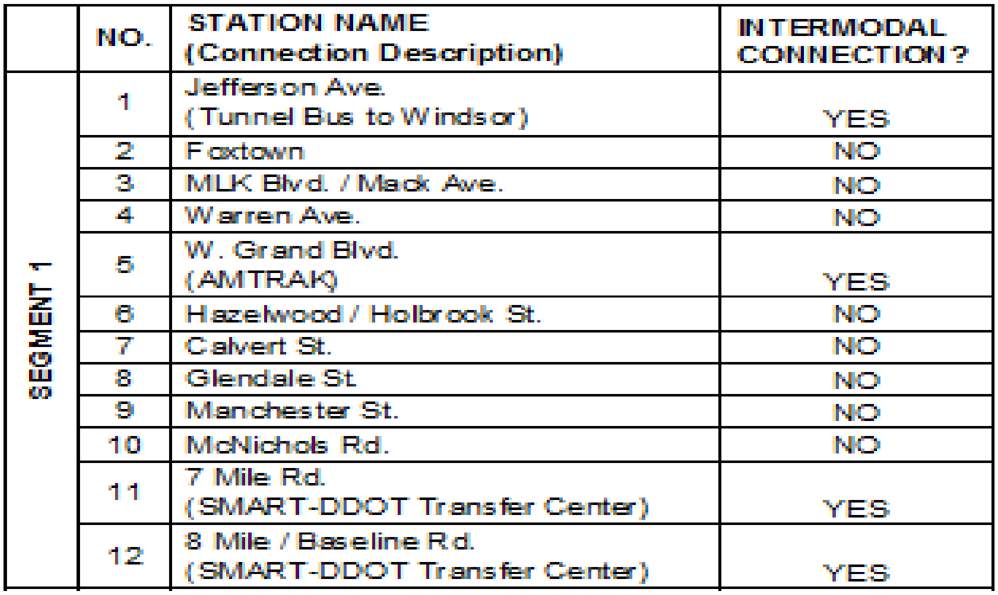
Based on the ANOVA values these two models were adopted for LRT ridership estimation for segment 2.

$$ALIGHT = 474.548 + 29.274[TotalEmpl./acre] \quad (6)$$

$$AVERAGE = 579.177 + 14.297[TotalEmpl./acre] + 330.033[Modal\_Conn] \quad (7)$$

Station specific boarding can be computed from equation (5), once the alighting and average are computed using equations (6) and (7) respectively.

Table 7. Proposed LRT Stations with Intermodal Connectivity



	NO.	STATION NAME (Connection Description)	INTERMODAL CONNECTION?
SEGMENT 1	1	Jefferson Ave. (Tunnel Bus to Windsor)	YES
	2	Foxtown	NO
	3	MLK Blvd. / Mack Ave.	NO
	4	Warren Ave.	NO
	5	W. Grand Blvd. (AMTRAK)	YES
	6	Hazelwood / Holbrook St.	NO
	7	Calvert St.	NO
	8	Glendale St	NO
	9	Manchester St.	NO
	10	McNichols Rd.	NO
	11	7 Mile Rd. (SMART-DDOT Transfer Center)	YES
	12	8 Mile / Baseline Rd. (SMART-DDOT Transfer Center)	YES

Demand Estimates for LRT Ridership Segment 1

LRT ridership demand estimates for Segment 1 as predicted by the equations 6 and 7 are presented in Table 8 along with SEMCOG data. Predicted boarding data were adjusted to make total alighting equals total boarding. .

Table 8. Segment 1 LRT Demand Comparison

STATION NAME	SEMCOG			Predicted LRT ridership		
	Board	Alight	Average	Board[3]	Alight[1]	Average[2]
8 Mile Rd.	2,782	736	1,759	1,341	572	957
7 Mile Rd.	2,165	695	1,430	1,343	506	925
McNichols / 6 Mile Rd.	1,291	984	1,138	683	501	592
Manchester St.	477	453	465	682	551	616
Glendale St.	136	145	141	681	574	628
Calvert St.	410	197	303	683	513	598
Hazelwood / Holbrook St.	501	398	450	682	553	617
W. Grand Blvd.	378	974	676	1,338	706	1,022
Warren Ave.	1,029	2,141	1,585	662	1,374	1,018
MLK Blvd. / Mack Ave.	706	860	783	673	916	795
Foxtown	50	324	187	1,330	1,055	1,192
W. Jefferson	1,442	3,459	2,451	1,269	3,545	2,407
TOTALS	**11,367**	**11,366**	**11,367**	**11,367**	**11,366**	**11,367**

[1] Based on equation (6). [2] based on Equation 7, [3] based on equation 5.

When the predicted boarding and alighting data are compared with the SEMCOG data, a reasonable correspondence has been observed between the two, and was expected. The authors of the study have concluded that such a phenomenon confirms the soundness of the two regression models used.

RIDERSHIP ANALYSIS: SEGMENT 2

The first task as a part of this effort is to identify LRT stations for Segment 2. Bus stops location information for Segment 2, along with boarding and alighting were collected from SEMCOG. LRT stations are selected by combining a number of bus stops and following these developed rules:

- An intersection of East-West and North-South bus route is a potential station location.
- Each city must have at least one LRT station.
- Spacing between the stations should be approximately one mile.
- Select a station where bus ridership demand is significant.

Considering the above rules, 15 LRT station are selected for segment 2 and presented in Table 9.

Table 9. Proposed LRT Stations with Intermodal Connectivity

	NO.	STATION NAME (Connection Description)	INTERMODAL CONNECTION?
SEGMENT 2	13	9 Mile Rd.	NO
	14	Washington / Allenhurst St. Near 10 Mile Rd.	NO
	15	Lincoln St.	NO
	16	11 Mile Rd. (Royal Oak Transit Center)	YES
	17	12 Mile Rd.	NO
	18	Coolidge Hwy.	NO
	19	Normandy St.	NO
	20	Lincoln St.	NO
	21	15 Mile / Maple Rd.	NO
	22	Oak Blvd.	NO
	23	Lone Pine Rd.	NO
	24	Long Lake Rd.	NO
	25	Square Lake Rd.	NO
	26	MLK / South Blvd.	NO
	27	E. Pike St. (AMTRAK)	YES
	28	E. Huron St. / M-59	NO

Total Bus Ridership for Segment 2

Table 3, presented before shows that for Segment 2, the total daily bus boarding and alighting are 6,005 and 7,401 respectively. Corresponding data for Segment 1 are 2,624 and 1,532, respectively. Total bus boarding for Segment 1 and Segment 2 (combined) are 8,629, while total alighting for Segment 1 and 2 (combined) is 8,933. Table 3 shows that the Segment 2 bus average ridership (average of boarding and alighting) can be estimated as 6,703 passengers per operating day. Alternatively, Segment 2 bus ridership can also be estimated indirectly as:

- Segment 2 bus ridership: ridership under "no-build" option, minus DD 53 ridership, minus Segment 1 bus ridership. Using the data presented in Tables 1 and 3:

  Segment 2 bus ridership = 19,600 – 8,300 – 2,078* = 9,222 passengers per operating day
  (*the value of 2,078 is the mean of boarding: 2,624 and alighting: 1,532)

- Alternative Segment 2 Bus Ridership Demand = 19,600 – 8,300 – 2,624 = 8,676
  (Substituting Boarding (2,624) for ridership (2,078))

Thus, the range of Segment 2 bus ridership was estimated to be between 6,703 and 9,222 passengers per operating day, or a mean value of 7,962 (close to 8,000). The value of 9,222 (higher of the two estimates) was used in developing ridership values, per station.

Projecting Segment 2 Transit Ridership Demand (Bus, LRT)

From segment 1 analysis, it is determined that growth factor due to LRT is 1.30. Also the split between LRT and bus ridership was estimated at 5.25:1. Using those factors, the projected total transit ridership for segment 2 and corresponding bus and LRT ridership are computed below:

Segment 2 transit ridership demand = 1.30 x 9,222 = 11,988

LRT: 84% of 11,988 = 10,070 passengers per day
Bus: 16% of 11,988 = 1,918 passengers per day

For the purpose of this research, a preliminary estimate of Segment 2 LRT ridership was established at 10,070 passengers per day. Preliminary estimate for corridor LRT ridership was established at 21, 437 per day (10,070+11,367). This estimate was further refined by considering socioeconomic factors and modal connectivity.

LRT Ridership by Station

The alighting and average ridership by station for segment 2 are computed using equations 6 and 7 and presented in Table 8. Once validated, the models were used to predict boarding and alighting demand for the proposed LRT stations along Segment 2. These estimates are listed in Table 10. The intermodal connectivity factors are presented earlier in Table 9 for segment 2. Because of the indirect procedure employed in the estimation of boarding data, the boarding prediction (12,198 passengers per day) is different from the alighting prediction (10,155 passengers per day). Hence, the boarding data required adjustment so that the boarding and alighting estimates are equal to one another. The total ridership estimate that was derived (10,155) is little higher than the estimate of 10,070.

Table 10. Predicted LRT Boarding and Alighting for Segment 2

STATION NAME (Intermodal Connectivity)	PREDICTED AVERAGE DEMAND[2]	2*(PREDICTED AVERAGE DEMAND)	PREDICTED ALIGHT[1]	PREDICTED BOARD [3]	ADJUSTED BOARD[4]
9 Mile Rd.	617	1,234	552	682	568
Washington / Allenhurst St. Near 10 Mile Rd.	609	1,218	535	682	568
Lincoln St.	689	1,379	700	679	565
11 Mile Rd. (Royal Oak Transit Center)	950	1,900	558	1,342	1,117
12 Mile Rd.	804	1,609	936	673	560
Coolidge Hwy.	642	1,284	604	680	567
Normandy St.	606	1,211	529	682	568
Lincoln St.	703	1,407	729	678	564
15 Mile / Maple Rd.	663	1,326	646	680	566
Oak Blvd.	596	1,193	510	683	569
Lone Pine Rd.	654	1,307	627	680	566
Long Lake Rd.	599	1,199	516	683	568
Square Lake Rd.	705	1,410	732	678	564
MLK / South Blvd.	771	1,543	868	675	561
E. Pike St. (AMTRAK)	945	1,891	549	1,342	1,117
E. Huron St. / M-59	622	1,243	561	682	567
Total	**11,175**	**22,354**	**10,152**	**12,201**	**10,155**

[1] based on equation 6,[2] based on equation 2,[3] based on 2*predicted average demand-predicted alight, [4]based on (10,152/12,201)*predicted board

CORRIDOR STUDY

Once boarding and alighting data for Segment 2 are computed, LRT ridership by station along Woodward corridor from downtown Detroit to M-59 is finalized by adopting SEMCOG data for segment 1 and predicted data for Segment 2. Total LRT boarding and alighting data is presented in Table 11. Once ridership data is computed, then peak loading by peaking direction, headway, fleet size and operating costs are calculated. These are presented in the following sections:

Peak Demand for Computing LRT System Requirements

The boarding and alighting data presented in Table 11 was used to compute demand (D_P) at the maximum loading section (MLS) for the proposed alignment (i.e., Segments 1 and 2).

The procedure consists of the following steps, executed in sequential order:

Step 1: Peak Directional Demand (PDD) was assumed to be equal to 60 percent of the daily demand (as opposed to an equal split of demand, or 50 percent of daily demand) to incorporate a factor of safety for system capacity requirements.

Step 2: The number of passengers on the system (i.e., on-line) between LRT station locations is calculated using Equations 8 and 9:

For Trip Origin Station: $$Pass\_Online_N = BOARD_N \qquad (8)$$

For remaining Stations Other than last one:

$$Pass\_Online_{N+1} = BOARD_N + BOARD_{N+1} - ALIGHT_{N+1} \qquad (9)$$

For Last Station: Pass_Online = 0

where:

Pass_Online: the number of passengers on-line

BOARD: the peak passenger boarding demand, based on the daily boarding calculated using the method discussed in *Projecting Segment 2 Transit Ridership Demand (Bus, LRT)*.

ALIGHT: the peak passenger alighting demand, based on the daily alighting calculated using the method discussed in *Total Bus Ridership for Segment 2*.

N: point along the LRT alignment corresponding to a station location

Equation 8 is used at the starting terminal point of the route. Equation 9 is used to compute the number of passengers on-line at each successive station location. It has been assumed that no alighting will occur at the starting terminal point, and that no boarding will occur at the ending terminal point of the LRT route.

Table 11. Woodward Corridor LRT boarding and alighting Data (Segments 1 & 2)

	NO.	STATION NAME (Intermodal Connectivity)	AVERAGE	ALIGHTING	BOARDING
SEGMENT 1	1	Jefferson Ave. (Tunnel Bus to Windsor)	2,451	3,459	1,442
	2	Foxtown	187	324	50
	3	MLK Blvd. / Mack Ave.	783	860	706
	4	Warren Ave.	1,585	2,141	1,029
	5	W. Grand Blvd. (AMTRAK)	676	974	378
	6	Hazelwood / Holbrook St.	450	398	501
	7	Calvert St.	304	197	410
	8	Glendale St.	141	145	136
	9	Manchester St.	465	453	477
	10	McNichols Rd.	1,138	984	1
	11	7 Mile Rd.(SMART-DDOT Transfer Center)	1,430	695	2,165
	12	8 Mile / Baseline Rd. (SMART-DDOT Transfer Center)	1,759	736	2,782
SEGMENT 2	13	9 Mile Rd.	617	552	568
	14	Washington / Allenhurst St. Near 10 Mile Rd.	609	535	568
	15	Lincoln St.	689	700	565
	16	11 Mile Rd.(Royal Oak Transit Center)	950	558	1,117
	17	12 Mile Rd.	804	936	560
	18	Coolidge Hwy.	642	604	567
	19	Normandy St.	606	529	568
	20	Lincoln St.	703	729	564
	21	15 Mile / Maple Rd.	663	646	566
	22	Oak Blvd.	596	510	569
	23	Lone Pine Rd.	654	627	566
	24	Long Lake Rd.	599	516	568
	25	Square Lake Rd.	705	732	564
	26	MLK / South Blvd.	771	868	561
	27	E. Pike St. (AMTRAK)	945	549	1,117
	28	E. Huron St. / M-59	622	561	567
CORRIDOR TOTALS			**22,542**	**21,518**	**21,522**

Step 3: The boarding and alighting daily ridership data (totaled over both directions of travel, northbound and southbound) were used as the baseline for computing the demand for the periods of an assumed 18-hour operating day. The proportions of ridership contributed by each period of the day were derived from the SEMCOG model for LRT Segment 1.

Step 4: In order to practice conservative estimation, the hourly distribution of the passenger demand during the four periods of the operating day was assumed to be non-uniform. The following additional assumptions have been made:

a. Distribution of LRT ridership during various peak and off-peak periods are presented in Table 12. Please note that they were presented before in Table 3.
b. Peak Hourly Demand (PHD) for the AM and PM Peak periods (each period having three-hour durations) equal to 0.40 times the Peak Period Demand (PPD) (as opposed to 0.33).
c. PHD for MID-DAY and OFF-PEAK periods (each period having six-hour durations) equal to 0.20 times the MID-DAY (or OFF-PEAK) demand (as opposed to 0.167).

d. From Table 12, the hourly peak occurs during the PM peak (27 percent of estimated total daily ridership), and is equal to 0.27 times (PHD of 40 percent). This value has been used as the design load to calculate the PHD (D_P), discussed in the next section.

Table 12. Ridership Distribution by Periods of LRT Operating Day

PERIOD	DURATION (hrs)	PROPORTION OF DAILY RIDERSHIP (%)
AM Peak	3	19
MID-DAY	6	33
PM Peak	3	27
OFF-PEAK	6	21
TOTALS	**18**	**100.00**

Columns 1 and 2 of Table 13 contain the PDD values resulting from this method, for the southbound direction of travel. The peak period demand (according to the percentages shown in Table 12) has been used to determine similar data for each station in Segments 1 and 2. These data are listed in columns 4, 6, 8, and 10 of Table 13. The hourly demand data (and the resulting values for passengers on-line) obtained for the four periods of the assumed operating day are listed in columns 5, 7, 9, and 11 of Table 13.

The Maximum Loading Section (MLS) was established for the Woodward corridor for the peak direction of travel. The peak direction demand D_p at the MLS was calculated as 363 passengers per hour, occurring during the PM peak hour period between stations 5 and 6: W. Grand Blvd. and Hazelwood/Holbrook Street, respectively (Table 13 and Figure 4). This demand value was used to estimate the system requirements (i.e., headway, travel time, fleet size). This value is also known as the design hourly volume (DHV). The procedure used in identifying the MLS, and in estimating the peak demand was adopted from Vuchic [*14*], and presented in Figure 5.

Table 13. Peak Direction LRT MLS Database

			1	2	3	4	5	6	7	8	9	10	11
		STATION NAME	**BOARD (60%)**	**ALIGHT (60%)**	**Pass On-Line**	**AM Peak**	**AM Peak Hourly**	**MID-DAY**	**MID-DAY Hourly**	**PM Peak**	**PM Peak Hourly**	**OFF-PEAK**	**OFF-PEAK Hourly**
SEGMENT 2	28	E. Huron St. / M-59	838		838	155	62	272	54	229	92	182	36
	27	E. Pike St.	670	329	1,179	218	87	383	77	322	129	256	51
	26	MLK / South Blvd.	337	521	995	184	74	323	65	272	109	216	43
	25	Square Lake Rd.	338	439	894	165	66	291	58	244	98	194	39
	24	Long Lake Rd.	341	310	925	171	68	301	60	253	101	201	40
	23	Lone Pine Rd.	340	376	889	164	66	289	58	243	97	193	39
	22	Oak Blvd.	341	306	924	171	68	300	60	252	101	201	40
	21	15 Mile / Maple Rd.	340	388	876	162	65	285	57	239	96	190	38
	20	Lincoln St.	338	437	777	144	57	253	51	212	85	169	34
	19	Normandy St.	341	317	800	148	59	260	52	219	87	174	35
	18	Coolidge Hwy.	340	362	778	144	58	253	51	212	85	169	34
	17	12 Mile Rd.	336	562	553	102	41	180	36	151	60	120	24
	16	11 Mile Rd.	670	335	888	164	66	289	58	242	97	193	39
	15	Lincoln St.	338	420	806	149	60	262	52	220	88	175	35
	14	Washington / Allenhurst St. (Near 10 Mile Rd.)	341	321	826	153	61	269	54	226	90	179	36
	13	9 Mile Rd.	341	331	836	155	62	272	54	228	91	181	36
SEGMENT 1	12	8 Mile / Baseline Rd.	1,669	442	2,063	382	153	671	134	563	225	448	90
	11	7 Mile Rd.	1,299	417	2,945	545	218	957	191	804	322	639	128
	10	McNichols Rd.	775	590	3,130	579	232	1,017	203	854	342	679	136
	9	Manchester St.	286	272	3,144	582	233	1,022	204	858	343	682	136
	8	Glendale St.	82	87	3,139	581	232	1,020	204	857	343	681	136
	7	Calvert St.	246	118	3,266	604	242	1,062	212	892	357	709	142
	6	Hazelwood / Holbrook St. *	301	239	3,328	616	246	1,082	216	909	363*	722	144
	5	W. Grand Blvd. *	227	584	2,971	550	220	965	193	811	324	645	129
	4	Warren Ave.	617	1,285	2,303	426	170	749	150	629	252	500	100
	3	MLK Blvd. / Mack Ave.	424	516	2,211	409	164	719	144	604	241	480	96
	2	Foxtown	30	194	2,047	379	151	665	133	559	223	444	89
	1	Jefferson Ave.		2,047	0	0	0	0	0	0	0	0	0
		TOTALS	**12,545**	**12,546**	**44,331**	**8,201**	**3,281**	**14,408**	**2,882**	**12,102**	**4,841**	**9,620**	**1,924**

****   The section between stations 6 and 5 represent the Maximum Loading Section with corresponding Peak Hourly Demand (D_p) of 363.***

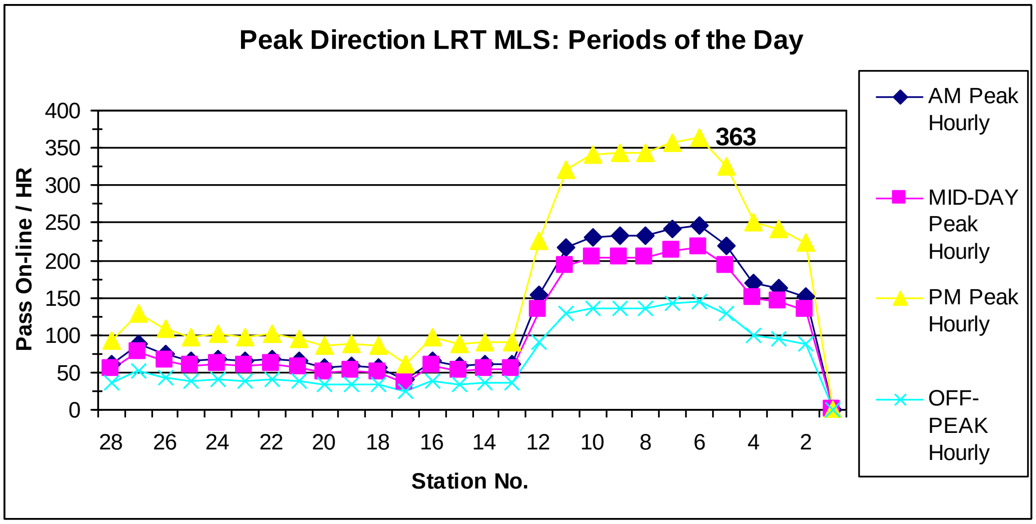


Figure 4. Peak Direction LRT MLS Database

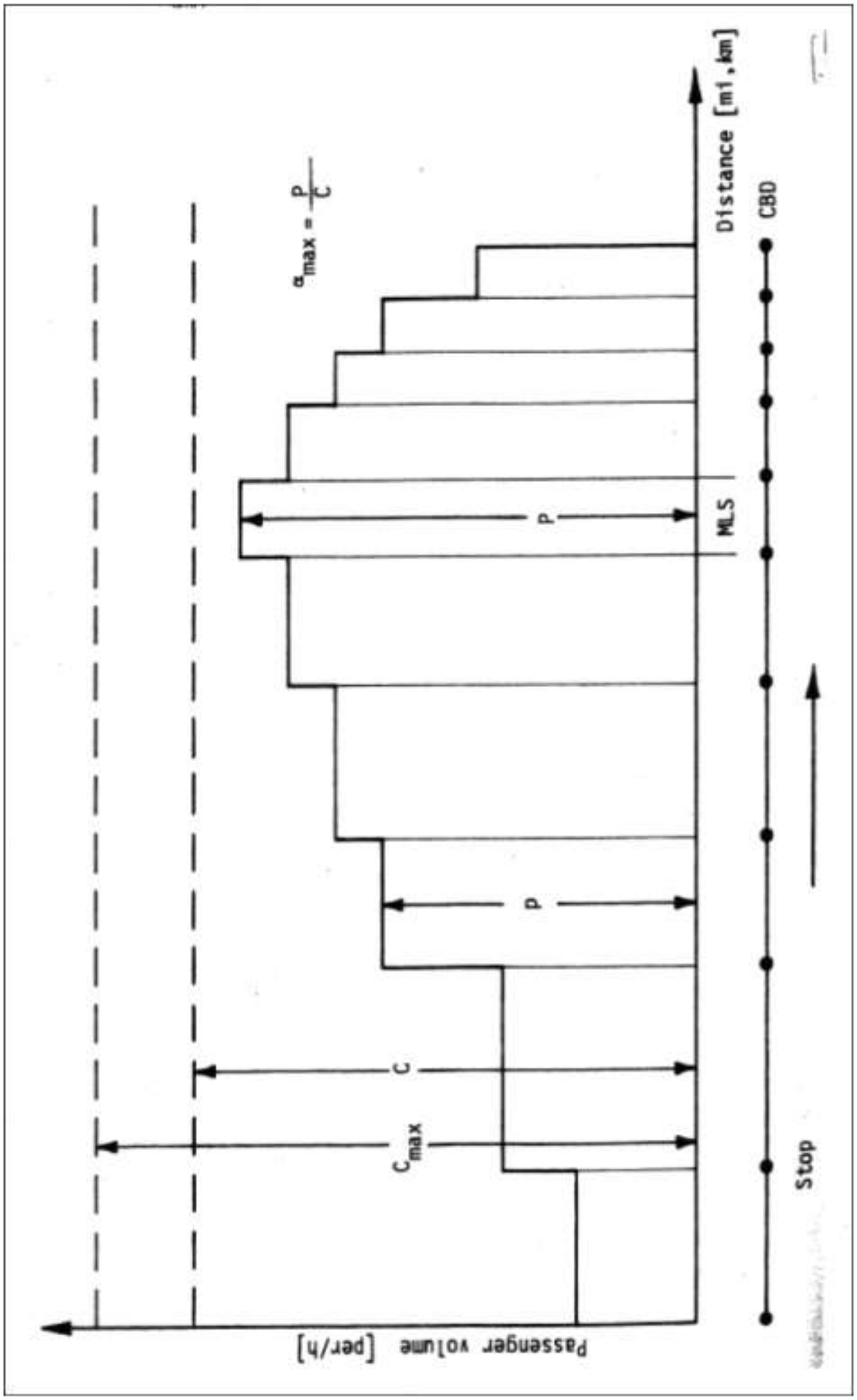


Figure 5. Graphical Representation of Terms Related to Maximum Loading Section Distribution (Source: Vuchic[14])

LRT SYSTEM REQUIREMENTS

Operating Parameters: Introduction

The system requirements for the proposed LRT system were calculated using the demand data, as reported in the previous section, along with information on station location (i.e., station spacing). The following equations were used [*15*]:

$$N_V \geq \frac{(D_P * C)}{(V_C * 60)} \qquad (10)$$

$$H = \frac{C}{N_V} = \frac{60 * V_C}{D_P} \qquad (11)$$

$$C = 2 * (T_D + T_S + T_C) \qquad (12)$$

where:

N_V: the number of LRT vehicles (LRTV) required; fleet size (number of LRTVs)
D_P: the hourly passenger demand at the MLS (passengers on-line, during the peak hour of the peak period)
C: the time required for an LRTV to travel from a starting terminal point A, to an ending terminal point B, and then reach point A again; cycle time (min)
T_D: the time required for an LRTV to travel between points A and B; driving time (min)
T_S: the total time required, between points A and B, for passenger boarding and alighting (min)
T_C: the downtime allotted after an LRTV has completed an A-to-B trip, usually planned to accommodate: breaks for vehicle operations, shift changes, or minor vehicle maintenance; layover time (min)
H: the duration of time between LRTV departures from point A; minimum service headway (LRTV per min headway)
V_C: LRTV capacity, including standing passengers (number of passengers)

Furthermore, the driving time, T_D, is calculated using the following equation:

$$T_D = \frac{(60 * D)}{V_{MAX}} + \left\{ n * \left(\frac{V_{MAX}}{2} \right) * \left(\frac{5{,}280}{3{,}600} \right) * \left[\frac{(a+b)}{60ab} \right] \right\} \qquad (13)$$

where:

D: the distance between the two terminal points of the LRT route (miles)
V_{MAX}: the maximum traveling velocity of an LRTV during normal operation (mph)
n: the number of stops between the two terminal points of the LRT route
a: the acceleration rate of an LRTV during normal operation (fps^2)
b: deceleration of an LRTV during normal operation (fps^2)

Equation 10 shows that for a given demand D_P and LRTV size V_C, the fleet size can be minimized by reducing the cycle time C. Furthermore, cycle time, being the total of driving time (T_D), boarding/alighting time (T_S), and layover time (T_C), can be minimized by reducing any of the three components or any combination thereof.

Operating Parameters: Assumptions

Equations 10-13 were used to determine the minimum requirements for the LRT system proposed for the metro Detroit region, considering the following assumptions [*16*, *17*, *18*]:

1. The project team is recommending Kinkisharyo LRTV manufactured by the Kinkishharyo Company Limited, of Osaka, Japan. Kinkisharyo has produced LRTVs for LRT systems in Dallas (Dallas Area Rapid Transit), Phoenix (METRO), Seattle (Sound Transit Central Link), and New Jersey (Hudson-Bergen). The selection LRTVs that are currently in production, rather than seeking customized specifications of another vehicle type, is expected to minimize capital costs related to the fleet size (Table 14, Figure6)

2. LRTVs operating along the Woodward corridor will be given traffic signal pre-emption through all intersections in the metropolitan Detroit area.

3. Boarding and alighting will only occur at the front and rear of the LRTVs, respectively, to facilitate efficient passenger flow.

Source: Dallas Area Rapid Transit (DART), Fact Sheet

Figure 6. Kinkisharyo LRTV [16]

As the result of the assumptions above, the following values have been selected as inputs for Equations 10-13:

D_P = 363 passengers on-line, during the peak hour of the peak period
D = 26 miles
N = 26 LRT stations
a = 3.2 fps^2
b = 4.4 fps^2

Table 14. Kinkisharyo LRTV Specifications [16,17,18]

PARAMETER	VALUE
Location	Osaka, Japan
Length (ft)	92.67
Height (ft)	12.5
Width (ft)	8.83
Weight (1,000 lbs)	107
Seating capacity (seated, plus standees)	150
Top speed (mph)	65
Design life (yrs)	30
Cost ($ million; 2008)	3.2
Maximum # of vehicles for multi-unit operation	4
(normal) Acceleration (fps^2)	3.2
(normal) Deceleration (fps^2)	4.4

With the assumption of exclusive boarding and alighting from separate doors and the average boarding and alighting time per passenger being the same, T_s can be calculated as follows:

$$T_S = n * \text{Av. \# of passengers boarding per stop} * \text{Av. Boarding time} \qquad (14)$$

-OR-

$$T_S = n * \text{Av. \# of passengers alighting per stop} * \text{Av. Alighting time} \qquad (15)$$

In order to use equation (14) or (15), the average # of passengers boarding or alighting needs to be estimated. Table 13 shows that the number of passengers boarding per day and the number of passenger alighting per day are the same, being 12, 545. Thus the use of equation (14) or (15) will result the same number. Hence equation (14) is used.

Average # of passengers boarding during peak hour = 12, 545*0.27*0.40= 1,355

Hence, the number of passengers boarding per hour per train = (# of passengers boarding/hr)/ (# of Trains/hr)

With an assumed headway of 10 minutes (peak- hour),

# of passengers boarding per hour per Train = 1355/6= 226

Assuming an even distribution of passengers boarding per stop,
# of passengers boarding/stop = 226/(# of Stops) = 226/26 = 8.7

Hence, using equation (14),

T_s = 26*8.7*2 = 452.4 seconds (Average time to board = 2 sec/passenger)
T_s is raised to 465 second, because of higher initial delays in the boarding process. Thus
T_s = 465 seconds = 7.75 minutes = 8 minutes

The maximum speed capacity of the Kinkisharyo LRTV has been listed at 65 mph, but it is not likely that such speeds will be attainable in a mixed-traffic ROW, where station spacing averages one mile. Thus, a lower value has been assumed for the top speed reached by the LRTV: 50 mph (note that this value is not the travel speed). The downtime provided at each terminal point along the route, T_C, has been estimated at ten minutes so that shift changes and operator breaks may occur:

V_{MAX} = 50 mph
T_C = 10 min

Operating Parameters: Resulting Values

Considering the variables and inputs discussed in *Operating Parameters: Assumptions*, the operating parameters for the proposed Woodward LRT system can be calculated. Using Equation 13, driving time is calculated and presented in Table 15. Please note that Cycle time can be calculated using Equation 12 as shown in Table 16.

Table 15. Driving Time, T_D

PARAMETER	VALUE
Distance (mi)	26.0
Max. velocity (mph)	50.0
Number of stops	26.0
Acceleration rate (fps^2)	3.5
Deceleration rate (fps^2)	4.4
Driving Time (min)	**39.8**

Table 16. Cycle Time, C

PARAMETER	VALUE
Driving Time (min)(T_d)	39.8
Board/Alight Time (min) (T_s)	8.0
Layover Time (min) (T_c)	10.0
Cycle Time (min)*	**116**

*$C=2(T_d+T_s+T_c)$ =115.6 minutes = 116 minutes (assumed)

The minimum fleet size is calculated using Equation 10 and presented in Table 17. It should be noted, however, that resulting value (15 trains) does not include additional LRTVs that may be required for system maintenance and special events (i.e., providing additional capacity in the event that ridership is significantly higher than that of the peak hour of a normal operating day).

Table 17. Minimum Fleet Size, N_V

PARAMETER	VALUE
MLS (pass/hr)	363.0
Cycle time (min)	116
Vehicle capacity (pass/vehicle)	150.0
Minimum fleet size (Train)	**4.67≈5(assumed)**

The final parameter of this process is the minimum service headway provided by the system, and is calculated using Equation 11 (Table 18). However, it should be noted that this value (23.2 seconds) has been calculated for planning purposes, and that a smaller value for headway is likely to be employed for the sake of convenience for those using the system: policy headway. The development and planning of establishing this value is discussed in the next Section.

Table 18. Minimum Service Headway, H

PARAMETER	VALUE
Minimum service headway (min)	**23.2**

The operating speed, $V_{O,}$ defined as the average speed of the transit vehicle including stopping time at LRT stations is calculated as:

$$V_O = \frac{60L}{(T_D + T_S)} \qquad (16)$$

where:

L: the distance between the two terminal points of the LRT route; takes the same value of D, used previously (miles)

The commercial speed, V_C, on the other hand, is the average speed of the transit vehicle for a complete round trip and is calculated as:

$$V_C = \frac{120L}{C} = \frac{120L}{2*(T_D + T_S + T_C)} = \frac{60L}{(T_D + T_S + T_C)} \qquad (17)$$

Using Equations 16 and 17:

$$V_O = \frac{60*(26mi)}{(39.8 + 8.0)} = 32.82mph \qquad (16)$$

$$V_C = \frac{60*(26mi)}{(39.8 + 8.0 + 10.0)} = 27mph \qquad (17)$$

In the transit industry, the commercial speed, V_C, is considered to be a more suitable measure of system performance when compared to operating speed, V_O. The logic for Equations 16 and 17 are schematically represented in Figure 7 [*14*].

Policy Headway

The equations presented in the previous section (*Operating Parameters: Resulting Values*) show that with a minimum headway of 23 minutes, and maximum LRTV capacity of 150 passengers, the passenger demand for the system can be met. However, it is customary to use policy headways for new transit operations. Policy headways are typically shorter than (i.e., more frequent service) the minimum headways. This practice is intended to build and sustain a long-term demand for transit services.

In order to obtain a suitable value for the policy headway for the Woodward LRT system, a list of similar LRT systems around the United States were reviewed by the research team. A summary of this data, derived from the National Transit database and other sources, is presented in Table 19.

A review of this information presented in Table 19 shows that:

1. The peak headways employed for each of the 14 transit systems range from 3 to 15 minutes.

2. For the LRT systems in the Minneapolis and Charlotte areas (average weekday demand of 26,500 and 19,700, respectively), peak headways range from seven to ten minutes. These areas are of interest since their average daily ridership values are comparable to the estimated value for the Woodward LRT system (Detroit area): approximately 22,000.

3. None of the peak headways are larger than 15 minutes. This does not compare favorably with the minimum headway value calculated for the Detroit area: 23 minutes.

4. The off-peak headways are generally twice as large as the peak headways.

Considering the items discussed above, the research team has recommended the following policy headways for the peak, and off-peak periods of the day: ten minutes and 20 minutes, respectively.

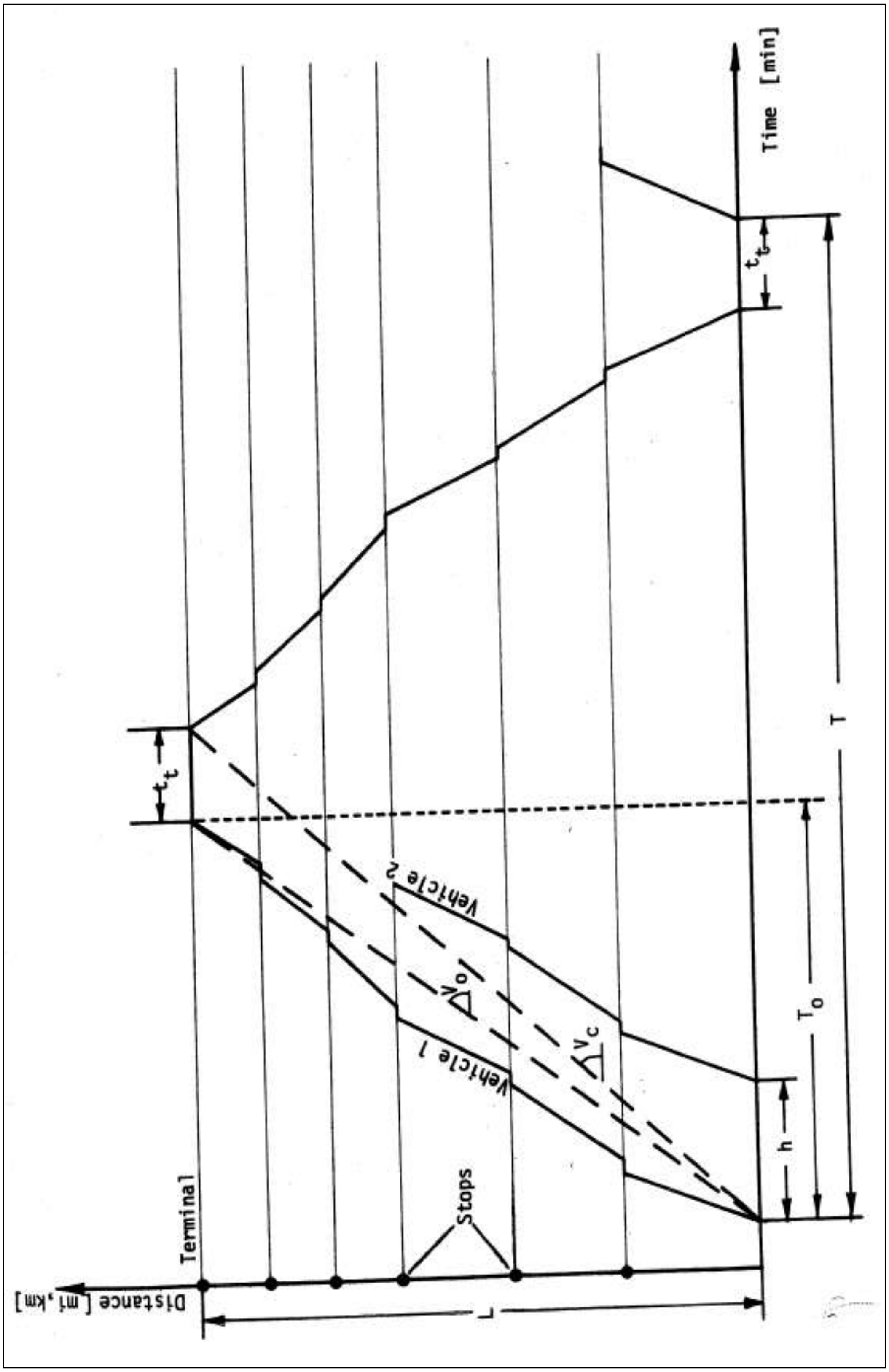


Figure 7. Graphical Representation of Terms Related to Vehicle Travel and Scheduling (Source: Vuchic [14])

Table 19. Comparison of LRT Systems in the United States[1]

SERVICE AREA	TRANSIT AUTHORITY	RIDERSHIP (pass)		HEADWAYS (min)	
		ANNUAL (x 1,000)	AVG. Daily (x 1,000)	PEAK	OFF-PEAK
Phoenix, AZ	Valley Metro Rail Inc.	10,020	33.4	10	20
Los Angeles, CA	Los Angeles County Metropolitan Transportation Authority (LACMTA)	40,740	135.8	4--6, 10	12—20
Sacramento, CA	Sacramento Regional Transit District	17,400	58	15	30
San Diego, CA	San Diego Trolley Inc.	28,800	96	15	30
San Jose, CA	Santa Clara Valley Transportation Authority	9,870	32.9	15	25—30
Denver, CO	Regional Transportation District (RTD)	20,640	68.8	5—10	15—30
Baltimore, MD	Maryland Transit Administration (MTA)	10,920	36.4	3—10	8—15
Minneapolis, MN	Metro Transit (MT)	7,950	26.5	7—10	15+
St. Louis, MO	Bi-State Development Agency (METRO)	15,720	52.4	15	20
Charlotte, NC	Charlotte Area Transit Authority (CATS)	5,910	19.7	7.5	15
Portland, OR	Tri-County Metropolitan Transportation District (TriMET)	31,050	103.5	4—9	15
Philadelphia, PA	Southeastern Pennsylvania Transit Authority	32,760	109.2	4—9	12—15
Dallas, TX	Dallas Area Rapid Transit (DART)	18,330	61.1	10	20+
Salt Lake City, UT	Utah Transit Authority (UTA)	12,960	43.2	15	15

[1] Source: National Transit Data Base [30]

Fleet Size

Previous calculations for the operating parameters of the proposed system (*Operating Parameters: Resulting Values*) revealed that the minimum fleet size is equal to 5 LRTVs (based on a minimum headway of 25 minutes). This topic required additional consideration because of the policy headway value that has been recommended above. Intuitively speaking, it is expected that when LRTVs are dispatched at a more frequent rate, additional vehicles will be required to meet the needs of the system. This relationship is derived from Equation 11:

$$H = \frac{C}{N_V} \qquad (11)$$

So that, $$N_V = \frac{C}{H} = \frac{116 \min}{\left(\frac{1 LRTV}{10 \min}\right)} = 11.6 = 12 trains\,(assumed\,)$$

Using the other part of Equation 11:

$$H = \frac{60 * V_C}{D_P} \qquad (11)$$

$$D_P = \frac{60 * 150}{H} = \frac{60 * 150}{12} = 900 \; passengers \;\; / \, hr$$

The version of Equation 11 above, results in a value for system capacity equal to 900 passengers per hour (during the peak hour of the peak period), compared to the estimated demand (Dp) of 363 passengers per hour at the MLS (during the peak hour of the peak period).

Finally, the final fleet size ($N_{V,\ FINAL}$) for the proposed system would be most efficient when a contingency factor of 30 percent of the policy fleet size ($N_{V,\ POLICY}$) was added (Equation 18). The intent for the contingency is to accommodate the following scenarios for the system: vehicle repair, scheduled maintenance, emergency repairs, and special events (i.e., sports event, parade, etc.).

$$N_{V,FINAL} = N_{V,POLICY} \; *1.30 \qquad (18)$$

$$N_{V,FINAL} = 12 * 1.30 = 15.6 \cong 16 \, LRTV\,'s$$

COST ESTIMATION

The cost elements associated with the delivery of transit services can be broadly classified under two categories: fixed costs and variable costs. Fixed costs are those that hold constant over a large range of service, and do not vary with modest changes in transit level of service. Examples include, but are not limited to, the following: all facility-related capital costs, administrative labor costs, and material costs other than those required to support revenue services. Variable costs, on the other hand, are directly related to the level of transit service provided and include driver wages, vehicle operating costs, etc. The bulk of the fixed cost variables include what is often referred to as the capital expense, which is typically derived from a capital budget, separate from operating revenue and expenses. Variable costs, on the other hand, are generally associated with the operating and maintenance expenses.

The prevailing practice in the transit industry is to include only operating and maintenance expenses, ignoring capital expenses, in computing cost estimates. The prevailing practice is to omit the annualized portion of the capital cost for any proposed transit system into the FAC. However, it can be included in the model by simply allocating the capital cost elements into the appropriate cost variables into the FAC, if necessary. While capital costs represent a large fraction of the total system costs, funds for capital improvements are typically derived from inter-governmental loans, Federal and state subsidies, etc.

Two conflicting factors further confound the relationship between capital and operating costs [*20, 21*]:

- Capital costs associated with fixed facilities (i.e., land, structures, equipment, etc.) are not affected by incremental changes in transit services levels.
- Modest changes in transit service levels may require some changes in the allocation of certain capital resources (e.g., number of transit vehicles on-line).

A review of the current literature has revealed the existence of two methods for estimating transit services: partially-allocated cost (PAC) and fully-allocated cost (FAC).

Partially-Allocated Cost Models

A partially-allocated cost (PAC) model incorporates a limited number of items for the operating expenses in the estimation process. The most common and simple example is based upon the use of one service variable, typically the number of vehicle-hours (V_H) or vehicle-miles (V_M). The estimated cost can be calculated using Equations 19 and 20:

$$EstimatedCost = U_{VH} * VH \qquad (19)$$

$$EstimatedCost = U_{VM} * VM \qquad (20)$$

where the unit costs have been empirically-derived from data sources:

U_{VH}: unit cost per vehicle-hour traveled
U_{VM}: unit cost per vehicle-miles traveled
VH: number of vehicle-hours of travel
VM: number of vehicle-miles of travel

The advantage of the PAC method is in its relatively simplistic data requirement. The disadvantage, however, lies in the quality of the results obtained, which could be considered to be a crude estimate at best. The choice of the variable for the PAC model (i.e., *VH* versus *VM*) often depends upon the availability of data, and the type of expense (hour-related or mile-related) that comprises the dominant expenditure for the case analyzed. Sometimes, the breadth of the PAC is expanded by including two pertinent variables, as follows:

$$EstimatedCost = (U_{WAGES} * VH) + (U_{POWER} * VM) \qquad (21)$$

where:

U_{WAGES}: the unit cost for wages associated with vehicle-hours traveled
U_{POWER}: the unit cost of power used per vehicle-mile traveled

Results obtained from PAC models are not precise, but they provide a preliminary estimate of costs, that may be appropriate for planning purposes.

Fully-Allocated Cost Models

A fully-allocated model (FAC) is an expanded version of its predecessor, the PAC, and has been designed to allocate the cost among a larger number of variables. The variables used for the model are those that conceivably affect transit operation. A typical example of FAC model is shown in Equation 22:

$$EstimatedC\ ost = (U_{VH} * VH) + (U_{VM} * VM) + (U_{PV} * PV) \qquad (22)$$

where:

PV: the number of transit vehicles required for operation during the peak hour
U_{PV}: the unit cost per peak vehicle

It should be noted that in multi-variable cost models (as opposed to single-variable models), the unit costs must be calculated to include the expenses for those inputs associated with each service characteristic, avoiding duplication. Table 20 is a typical representative of how cost items are allocated in a typical FAC model [*22*]. The following FAC has been derived for the Los Angeles County Metropolitan Transportation Authority (LACMTA)

$$AnnualCost = \left[(U_{VH} * VH) + (U_{VM} * VM) + (U_{PV} * PV) + (U_{TP} * TP)\right] * F_1 \qquad (23)$$

where:

U_{TP}: the unit cost per passenger
*T*P: the total number of passengers traveling on the system, per year
F: a multiplication factor used to incorporate a number of alternate costs related to operations (e.g., administration, contingency, changes in consumer price index, etc.)

Table 20. Recommended Expense Assignment for Three-Variable Cost Model

	ASSIGNMENT VARIABLE		
EXPENSE OBJECT CLASS	VEHICLE-HOURS	VEHICLE-MILES	VEHICLE
Transportation Expense			
Driver Wages & Salaries	X		
Driver Fringe Benefits	X		
Fuel & Oil		X	
Tires & Tubes		X	
Vehicle Insurance			X
Vehicle Lease			X
Purchased Transportation	X		
Other	X		
Maintenance Expense			
Mechanic Wages & Salary		X	
Mechanic Fringe Benefits		X	
Materials & Supplies		X	
Contracted Maintenance		X	
Facility Rental			X
Utilities			X
Contracted Services			X
Other			X
Call Taking & Dispatching Expense			
Dispatcher Wages & Salary			X
Dispatcher Fringe Benefits			X
Telephone Expenses			X
Computer Expenses			X
Rent			X
Other			X
Administrative Expense			
Administrative Salaries			X
Administrative Fringe Benefits			X
Materials & Supplies			X
Non-Vehicle Insurance			X
Professional Services			X
Travel			X
Office Rental			X
Utilities			X
Equipment Rental/Service			X
Other			X

Source: Improving Transit Performance Using Information based Strategies [22]

Fully-Allocated Cost and Capital Cost

As mentioned previously, FAC's, originally introduced in the cost analysis framework, did not include capital costs. The process of obtaining capital funds for building transit systems has historically been quite different from that of operating expenses. On the other hand, it has been argued that independent of the source of funding, transit cost models should include capital costs because they are real costs. Furthermore, their incorporation into such cost models will help future cost-containment efforts by transit officials and policymakers.

The capital costs for transit systems include, but are not limited to, the following: vehicles, real estate, structures, and operating equipment (i.e., signals, signage, etc.). For rail transit, additional costs may be incurred in the acquisition of ROW, rail tracks, switching/signal equipment, service stations, and rail yards. The following FAC model has been proposed for estimating the costs related to rail transit systems:

$$FAC = \left[(U_{RH} * VH) + (U_{VM} * VM) + (U_{PV} * PV) + (U_{RM} * RM)\right] * F_1 \qquad (24)$$

where:

U_{RM}: the directional route-miles of travel

LRT Cost Models

While in the past, most FAC models have been developed for various types of bus systems, there are some rail transit cost models that have been discussed in the current literature. The majority of these models only account for operation and maintenance (O&M) costs.

LRT Operations and Maintenance Cost: METRORail, Red Line

Harris County is the most populous county in the state of Texas, where the city of Houston serves as the county seat. The Metropolitan Transit Authority of Harris County, Texas (METRO) serves the Houston metropolitan area with the following transportation services: light-rail, high-occupancy vehicle lanes (HOV), commuter rail, standard bus, and transit centers. METRO Solutions is a regional transit plan for Harris County, intended to alleviate travel congestion by improving the transportation infrastructure for all modes [*23*].

The 7.5-mile METRO Red Line is an LRT system operated within shared ROW in the Houston area. The Red Line began normal operation in January of 2004 serving 16 stations, traveling between two major terminal stations: University of Houston-Downtown Campus and Reliant Park (home of the Houston Texans, a National Football League team). The following five-factor operations and maintenance (O & M) cost model was developed for METRO. The model was developed for the year 2007 (originally developed for the year 2004, then inflated to reflect current costs for the year 2007) [*24*] (Table 21).

Using the approach depicted in Table 21, the estimated range of O & M costs for a one-car METRO Red Line rail transit system was estimated as: $6.9 to 10.5 million per year.

Table 21. LRT Build Alternative Operation and Maintenance Cost Factors (2007)

O & M COST FACTORS	LRT, ONE-CAR TRAINS ($)
Cost per Revenue Train-Hour	57.46
Cost per Revenue Car-Mile	6.17
Cost per Peak Vehicle	19,699
Cost per Station	118,332
Cost per Guideway-Mile	315,968

Source: METRO Cost Allocation Model [24]

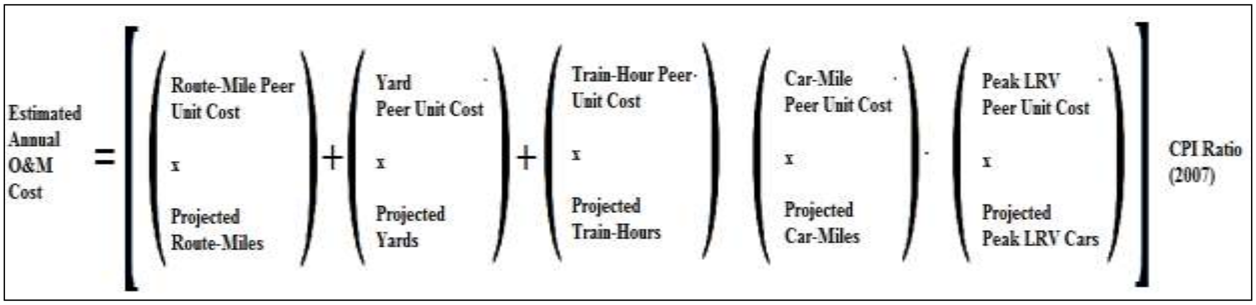
LRT Operations and Maintenance Cost: Metropolitan Atlanta

The city of Atlanta is the 33rd largest in the United States, with an estimated population of 537,958. While the city proper does not compare with the larger cities (e.g., Los Angeles, Chicago, New York City), the metropolitan Atlanta area has experienced significant growth during the last decade. The Atlanta-Sandy Springs-Marietta metropolitan statistical area (MSA) is the 9th largest in the United States, with an estimated population of 5.5 million [*25*].

The Atlanta city proper is served by the Metropolitan Atlanta Rapid Transit Authority (MARTA), which operates heavy-rail and standard bus services throughout the region. However, no heavy-rail service is provided to the suburban counties surrounding the city of Atlanta. The lack of a regional heavy-rail transit network, combined with a booming population that is heavily reliant on private automobiles, places Atlanta among MSAs having the worst commute times in the United States [*26*].

Said commute times are likely to be longer in the suburban and exurban areas of the Atlanta MSA, where transit service is nearly non-existent. For instance, Gwinnett Village, a group of communities located in southwest Gwinnett County (approximately 20 miles northwest of the Atlanta CBD) has expressed a desire to investigate the feasibility of an LRT system for the area. Gwinnett Village is a typical decentralized suburban/exurban population center, consisting of a significant amount of low-density development: 100,000 residents, 60,000 employees, and 5,000 businesses [*27*].

An O & M cost model was developed for the Gwinnett County Community Improvement District (CID) because LRT had not been constructed there previously (similar to the current situation in Detroit, and its suburbs). The model was developed from available system data from nine comparable LRT systems, considered to be peer systems by the model developers: Baltimore (MD), Dallas (TX), Denver (CO), Houston (TX), Minneapolis (MN), Portland (OR), Sacramento (CA), Salt Lake City (UT), St. Louis (MO). Table 22 lists the O & M costs associated with each of the nine aforementioned peer systems[2], where total costs range from $15.0 to 79.8 million (Houston and Dallas, respectively). The unit costs per directional mile, calculated from the National Transit Database, range from $0.565 to $0.913 million (St. Louis and Minneapolis respectively) [*28, 29, 30*]. It was observed that the unit costs are inversely related to the length of the transit system. The FAC O & M model proposed for the Gwinnett Village CID is listed in Figure 7.



$$\text{Estimated Annual O\&M Cost} = \left[\begin{pmatrix} \text{Route-Mile Peer Unit Cost} \\ \text{x} \\ \text{Projected Route-Miles} \end{pmatrix} + \begin{pmatrix} \text{Yard Peer Unit Cost} \\ \text{x} \\ \text{Projected Yards} \end{pmatrix} + \begin{pmatrix} \text{Train-Hour Peer Unit Cost} \\ \text{x} \\ \text{Projected Train-Hours} \end{pmatrix} \begin{pmatrix} \text{Car-Mile Peer Unit Cost} \\ \text{x} \\ \text{Projected Car-Miles} \end{pmatrix} \cdot \begin{pmatrix} \text{Peak LRV Peer Unit Cost} \\ \text{x} \\ \text{Projected Peak LRV Cars} \end{pmatrix} \right] \text{CPI Ratio (2007)}$$

Source: I-85 Corridor LRT Feasibility Study, Phase I, Final Report (HDR Engineering Inc.) [28]

Figure 8. Gwinnett Village O & M Cost Model

where:

Route-Miles: the total number of directional route miles.
Yards: the total number of LRTV maintenance and storage facilities.
Annual Revenue Train-Hours: the total number of hours of revenue service operated by all trains in one year.
Annual Revenue Car-Miles: the total number of miles of revenue service operated by all trains in one year.
Peak LRV Cars: The maximum number of passengers vehicles scheduled in service, at the same time.

Table 22. Peer LRT System Productivity (Year 2007)

	Baltimore (MTA)	Dallas (DART)	Denver (RTD)	Houston (METRO)	Minneapolis (METRO)	Portland (TriMET)	Sacramento (RT)	Salt Lake City (UTA)	St. Louis (METRO)	TOTALS
2007 Units of Service Supplied										
Peak Passenger Cars in Operation	18	85	91	13	27	81	56	46	56	**473**
Train Revenue-Hours	77,449	123,819	201,478	57,660	66,946	261,675	81,641	88,858	134,505	**1,094,031**
Car Revenue-Miles	2,797,732	5,224,548	8,721,165	877,433	1,903,780	6,564,411	4,127,718	2,818,235	6,193,455	**39,228,477**
Directional Route-Miles	58	88	70	15	24	95	74	37	91	**552**
No. of Yards	2	1	1	1	1	1	1	1	2	**11**
Annual Passenger Trips	6,740,923	17,892,532	18,655,496	11,708,960	9,101,036	36,123,810	14,489,691	16,272,468	21,783,634	**152,768,550**
2007 Costs										
Vehicle Operations ($)	20,248,485	28,270,203	18,825,913	6,120,990	6,333,921	25,958,428	18,468,196	8,602,748	19,556,566	**152,385,450**
Vehicle Maintenance ($)	6,791,757	16,623,466	8,825,675	3,212,386	2,877,329	15,091,287	9,906,179	7,361,881	6,887,441	**77,577,401**
Non-Vehicle Maintenance ($)	10,260,675	14,816,022	5,485,171	4,666,814	3,666,297	16,215,291	6,286,302	7,380,353	13,205,449	**81,982,374**
General Administration ($)	2,448,606	20,106,218	7,363,673	1,049,633	9,049,291	16,391,168	12,763,378	2,845,932	11,747,815	**83,765,714**
TOTAL COSTS	**39,749,523**	**79,815,909**	**40,500,432**	**15,049,823**	**21,926,838**	**73,656,174**	**47,424,055**	**26,190,914**	**51,397,271**	**395,710,939**
Productivity Factors (2007)										
Cost per Revenue Train-Hour ($)	513.23	644.62	201.02	261.01	327.53	281.48	580.89	294.75	382.12	
Cost per Revenue Train-Mile ($)	14.21	15.28	4.64	17.15	11.52	11.22	11.49	9.29	8.3	
Cost per Passenger-Trip ($)	5.9	4.46	2.17	1.29	2.41	2.04	3.27	1.61	2.36	
Cost per Directional Route-Mile ($ million)	0.686	0.901	0.578	1	0.913	0.775	0.64	0.708	0.565	

Source: I-85 Corridor LRT Feasibility Study, Phase I, Final Report (HDR Engineering Inc) [28]

The O & M cost data for the peer systems (in 2007 costs), when fully-allocated among the five variables, result in different unit cost values as listed in Table 23. Furthermore, the grand average for the nine systems, results in the following unit costs: yard ($4,157,759), route-miles ($101,888), train-hours ($120.89), car-miles ($3.36), cars ($131,048). These values are listed in the last row of Table 23.

The unit costs, when applied to six LRT alternatives (i.e., track alignments) for the Gwinnett Village CID, result in a set of total annual costs ranging from $25.05 (Alternative 5) to 25.63 million (Preferred 1). The costs have been listed in Table 24. It should be noted that the unit costs outlined above only represent the O & M costs, and that no capital costs were included.

Table 23. Peer Systems Service Provided, Unit Costs

SERVICE AREA	YARDS		ROUTE-MILES		TRAIN-HOURS		CAR-MILES		CARS	
(TRANSIT AUTHORITY)	UNITS	UNIT COST ($)	UNITS	UNIT COST ($)	UNITS	UNIT COST ($)	UNITS	UNIT COST ($)	UNITS	UNIT COST ($)
Baltimore, MD (MTA)	2	2,397,299	58	111,503	77,449	219.98	2,797,732	3.19	18	143,005
Dallas, TX (DART)	1	8,418,502	88	90,698	123,819	161.31	5,224,548	4.60	85	228,837
Denver, CO (RTD)	1	2,285,620	70	47,892	201,478	71.98	8,721,265	1.49	91	81,217
Houston, TX (METRO)	1	4,491,122	15	190,267	57,660	92.56	877,433	4.65	13	43,708
Minneapolis, MN (METRO)	1	2,224,172	24	103,512	66,946	75.89	1,903,780	5.30	27	74,575
Portland, OR (TriMet)	1	8,044,587	95	103,574	261,675	87.77	6,564,411	2.44	81	207,101
Sacramento, CA (RT)	1	3,098,640	74	52,767	81,641	181.55	4,127,718	4.11	56	154,647
Salt Lake City, UT (UTA)	1	3,637,705	37	118,699	88,858	71.05	2,818,235	2.53	46	101,514
St. Louis, MO (METRO)	2	2,822,185	91	98,077	134,505	125.93	6,193,455	1.90	56	144,831
AVERAGE UNIT COST ($)		**4,157,759**		**101,888**		**120.89**		**3.36**		**131,048**

**Source: I-85 Corridor LRT Feasibility Study, Phase I, Final Report
(HDR Engineering Inc.) [28]**

Table 24. Estimated Operating and Maintenance Costs by Alternative

ALTERNATIVE	YARDS	ROUTE-MILES	TRAIN-HOURS	CAR-MILES	CARS	TOTAL ANNUAL O & M COST (2009)	UNIT COST PER DIRECTIONAL MILE
Peer Unit Costs ($)	**4,157,759**	**101,888**	**120.89**	**3.36**	**131,048**		
Preferred 1	1	27.7	46,160	2,382,100	24	**25,629,365**	0.925
O & M Cost by Variable ($)	4,157,759	2,818,210	5,580,295	7,994,360	3,145,164		
Alternative 1	1	27.5	46,160	2,366,600	24	**25,553,266**	0.929
O & M Cost by Variable ($)	4,157,759	2,799,871	5,580,295	7,942,342	3,145,164		
Alternative 2	1	27.2	46,160	2,339,100	24	**25,418,180**	0.935
O & M Cost by Variable ($)	4,157,759	2,767,267	5,580,295	7,850,052	3,145,164		
Alternative 3	1	26.8	46,160	2,309,800	24	**25,274,356**	0.943
O & M Cost by Variable ($)	4,157,759	2,732,625	5,580,295	7,751,721	3,145,164		
Alternative 4	1	26.9	46,160	2,320,100	24	**25,324,968**	0.941
O & M Cost by Variable ($)	4,157,759	2,744,851	5,580,295	7,786,287	3,145,164		
Alternative 5	1	26.3	46,160	2,263,300	24	**25,046,059**	0.952
O & M Cost by Variable ($)	4,157,759	2,677,606	5,580,295	7,595,666	3,145,164		
AVERAGE							**0.938**

**Source: I-85 Corridor LRT Feasibility Study, Phase I, Final Report
(HDR Engineering Inc.) [28]**

where:

$$Directiona\ lRoute - Miles \cong 2 * RouteLengt\ h(one - way) \qquad (25)$$

LRT Operations and Maintenance Cost: Metropolitan Detroit

The FAC O & M model developed for the Gwinnett Village CID study, was used to estimate the costs associated with the proposed Woodward Ave. LRT system in metropolitan Detroit:

$$\begin{aligned} AnnualCost\ (O\ \&\ M) &= [4{,}157{,}759 * (\#Yards)] + [101{,}888 * (Directiona\ lRoute - Miles)] \\ &+ [120.89 * (Annual\ Revenue\ Train - Hours)] + [3.36 * (Annual\ RevenueCar - Miles)] \qquad (26) \\ &+ [131{,}048 * (PeakLRTCar\ s)] \end{aligned}$$

Members of the research team found that the following items, related to the Gwinnett Village CID study, were conducive to Gwinnett Village CID model's application to the Woodward LRT system:

1. The directional length values ranged from 15 to 91 miles, compared to 52 miles for the Detroit area.

2. The peak number of train cars ranged from 13 to 91, compared to 22 equivalent cars for the Detroit area (the concept of equivalent train cars will be discussed in the next section).

3. The number of annual passenger trips ranged from 6.7 to 36.1 million, compared to 6.5 million for the Detroit area.

In order to estimate the variables required for Equation 26, and to assure that the values derived are reasonable, a review of LRT operating data for a number of transit systems was conducted. The transit system data was derived from the Federal Transit Administration’s National Transit Database, and has been listed in Table 23 [*30*]. It should be noted that the system length values reflect the track network in one direction, and is approximately half of the directional length used in the previous tables (‘Route-Miles’ fields in Tables 23 and 24).

Number of Yards

Table 24 lists the number of yards provided in each of the nine peer systems. It has been observed that this value ranges between one and two yards, thus it has been assumed that the proposed Woodward Ave. LRT system will utilize one yard. It should be noted that the inclusion of each additional yard increases the estimated annual O & M cost by $4.5 million, according to the Gwinnett Village FAC model selected.

Number of Directional Route-Miles

This value has been calculated as two times the one-way system route length:

$$Directiona\ lRoute - Miles \cong 2 * RouteLengt\ h(one - way) \qquad (25)$$

$$Directiona\ lRoute - Miles \cong 2 * 26 = 52$$

Entering the system route length into Equation 25 results in a total directional route-mile value of 52 miles.

Number of Annual Revenue Train-Hours

- Each train (LRTV) completing a cycle will complete 116 minutes or 1.93 hours of travel time, where 116 minutes is the cycle time as calculated in Equation 12 and Table 16.

- At a peak headway of ten minutes, for each peak hour, six cycles will have been completed.

- During the six hours of peak periods (i.e., AM and PM peak periods, each with a three-hour duration), a total of 36 cycles will have been completed (6 cycles, times 6 hours equals 36 total cycles).

- During the 12 hours of off-peak periods (i.e., MID-DAY and OFF-PEAK periods, each with a six-hour duration), at a 20 minute headway, a total of 36 cycles will have been completed.

- Over an 18-hour operating day there will be 72 cycles (36 cycles, times two equals 72 cycles), or 72 times 1.93 train-hours.

- Assuming an operating year with a duration of 300 operating days, the total number of revenue vehicle-hours is calculated to be 41,688 train-hours per year (72 times 1.93 times 300).

Number of Annual Revenue Vehicle-Miles

- Each vehicle will complete 52 directional miles of travel per cycle.

- Following the process presented above, the number of vehicle-miles per year is calculated as 1,123,200 (72 times 52 times 300).

- For cost estimation purposes, each Kinkisharyo model LRTV with a maximum capacity of 150 passengers, has been assumed to be equivalent to two vehicles to be conservative.

- Thus, the total vehicle-miles per year is estimated to be 2,246,400, rounded to 2,250,000 (2 times 1,123,200).

Number of Peak LRT Vehicles

- In the previous section, the number of LRTV unit vehicles, required to provide 10 minute peak headways, was calculated as 11. After applying a 30 percent spare factor, however, this value increases to 15 vehicles.

- Using two combined unit LRTVs, the number of peak LRTVs is estimated as 30 (2 times 15 vehicles).

Thus, the annual O & M cost for the proposed system is estimated as (Equation 26):

$$AnnualCost\ (O\ \&\ M) = [4{,}157{,}759 * 1] + [101{,}888 * 52] + [120.89 * 41{,}688] + [3.36 * 2{,}250{,}000] + [131{,}048 * 30] \qquad (26)$$

$$AnnualCost\ (O\ \&\ M) = \$25{,}987{,}037\ /\ year$$

When adjusted for a 3% inflation above figure translate to $28,403,383/year or $546,228/mile/year in 2010

LRT Capital Cost

The capital cost of any rail system is likely to vary widely depending primarily on the cost of right away, the type, extent and quality of stations and the type of technology used in the vehicles and infrastructures. Table 25 shows cost of LRT construction per mile in 2010 after considering 3 percent inflation factor for various cities across US. It is observed that the equivalent cost per mile is around $50 million[3].

Table 25. Cost of LRT Construction by Various Cities [31]

CITY	TYPE OF CONS.	LENGTH (MILES)	YEAR OF CONS.	COST/MILE (MILLIONS)	ADJUSTMENT FACTOR (3% PER YEAR)	COST/MILE IN YEAR 2010 (MILLIONS)
Portland	Street	6	2004	63	1.194	75.225
San Diego	Street	4	1998	30	1.426	42.777
San Francisco	Street	2	1998	37	1.426	52.753
San Jose	Street	6	2004	54	1.194	64.479
Denver	Street	6	1994	21	1.605	33.699
Denver	Street	9	2000	22	1.344	29.566
San Jose	Street	8	1999	42	1.384	58.138
San Jose	Street	6	1988	25	1.916	47.903

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[3] =∑((Cost/mile in year 2010 in million)*Length of mile)/∑(Length of miles)

SUMMARY

In the previous six sections of this report the research team has documented the (Detroit area) Woodward LRT case study, starting with a brief discussion of the background of transit in the region, and ending with a detailed operating cost analysis. A set of conclusions in the form of guidelines for sketch planning an LRT system (along a travel corridor in a metropolitan area), were developed and have been included in the executive summary. The sketch plan represents a synthesis of the case study that has been presented. The specific set of summaries for the case study are as follows:

- The scope of the study has been presented in the *Project Scope* of this report, along with a discussion of current planning efforts in the study area and travel demand estimates along the major corridors. Woodward Ave. has clearly been established as the major travel corridor (excluding Interstate freeways) in the study area.

- LRT travel demand along Woodward Ave. for a 26-mile corridor connecting the Detroit and Pontiac CBD's in a north-westerly direction has been established in *Ridership Analysis: Segment 2*. Total daily LRT demand, for Segments 1 & 2 combined, has been estimated at 21,437 passengers per day.

- A total of 26 LRT stations have been proposed along Woodward Ave. Using multiple regression analysis, boarding and alighting estimates for each proposed station have been generated. Based upon the station "loadings,” the daily LRT demand for the Woodward Ave. corridor is revised at 21,522 passengers per day. Using an assumed 300 day duration for an operating year, the annual ridership for the system is estimated to be 6.5 million passengers (*Corridor Study*). The MLS and corresponding PHD have also been established in this section.

- The operating parameters for the proposed LRT system have been investigated in section: *Corridor Study* of this report.

- The proposed LRT system requirements have been calculated in *LRT System Requirements*, along with: an analysis of operating parameters (e.g., LRTV travel speed, acceleration, deceleration, etc.), identification of a suitable LRTV manufacturer and model (Kinkisharyo), fleet size, headways, and commercial speed. Based upon a ten-minute peak headway, the required fleet size was calculated as 15 LRTVs.

- Operating cost estimates for the proposed system have been calculated in *Cost Estimation*, using the FAC cost method. Based upon a review of the current literature, the Gwinnett Village CID model, developed by HDR Inc., has been adopted for the proposed Woodward LRT system. The Gwinnett Village CID model is derived from parameters related to operating cost data compiled from nine peer LRT systems that have been constructed in the United States.

- For sketch planning purpose, the capital cost for the proposed LRT system is estimated at $50 million per mile.

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APPENDICES

Table 1A. SEMCOG & URS Database: Detroit Options for Growth Study (DTOGS)

					2030 Gratiot				2030 Michigan				2030 Woodward			
CORRIDOR	**ROUTE NAME**	**EXISTING RIDERSHIP**	**2005 BASE**	**2030 BASE**	**NO-BUILD**	**TSM**	**BRT**	**LRT**	**NO-BUILD**	**TSM**	**BRT**	**LRT**	**NO-BUILD**	**TSM**	**BRT**	**LRT**
GRATIOT	DD34	6,900	7,700	6,500	6,700	6,300										
	DD76	600	200	100												
	SM510	2,900	3,900	4,000	4,000	4,000	4,000	3,900								
	SM530	200	100	100	100	100	100	100								
	SM560	5,700	4,900	4,800	4,900	4,900	5,500	5,600								
	SM580	100	400	200	200	200	200	200								
	DD34T	0	0	0	0	100	0	0								
	BRT Gratiot	0	0	0	0	0	8,200	0								
	LRT Gratiot	0	0	0	0	0	0	9,900								
	CORRIDOR TOTAL	**16,400**	**17,200**	**15,700**	**15,900**	**15,600**	**18,000**	**19,700**								
MICHIGAN	DD37	1,400	1,600	1,800					2,400	700						
	SM200	2,700	3,100	3,300					3,200	3,200	3,300	3,300				
	DD37T	0	0	0					0	1,800	0	0				
	BRT Michigan	0	0	0					0	0	5,200	0				
	LRT Michigan	0	0	0					0	0	0	6,400				
	CORRIDOR TOTAL	**4,100**	**4,700**	**5,100**					**5,600**	**5,700**	**8,500**	**9,700**				
WOODWARD	DD53	13,500	9,100	7,700									8,300	8,500		
	SM445	300	200	200									200	200	200	200
	SM450	4,800	3,700	3,800									3,800	3,900	3,900	3,800
	SM460	0	3,900	4,000									4,000	4,000	4,100	4,100
	SM465	300	300	300									300	300	200	200
	SM475	0	200	200									200	200	200	200
	SM495	2,300	2,900	2,800									2,800	2,800	3,100	3,200
	DD53T	0	0	0									0	100	0	0
	BRT Woodward	0	0	0									0	0	9,200	0
	LRT Woodward	0	0	0									0	0	0	**11,100**
	CORRIDOR TOTAL	**21,200**	**20,300**	**19,000**									**19,600**	**20,000**	**20,900**	**22,800**
TOTAL OF THREE CORRIDORS		**41,700**	**42,200**	**39,800**	**40,000**	**39,700**	**42,100**	**43,800**	**40,300**	**40,400**	**43,200**	**44,400**	**40,400**	**40,800**	**41,700**	**43,600**

Table 2A. Transit Ridership along Wood ward Under Various Options

OPTIONS	**SEGMENT 1**		**SEGMENT 2**		**TOTAL**
	Bus	**LRT**	**Bus**	**LRT**	
No Build	8,300	X	11,300	X	19,600
LRT(Seg. 1) Bus (Seg. 2)	2,078	11,367	9,222	X	22,667
LRT (Seg. 1 & 2) (preliminary Estimate)	2,078	11,367	1,918	10,070	25,433
LRT (Seg. 1 & 2) Final Estimate)	2,078	11,367	1,918	10,155	25,518