Bus Signal Priority Based on GPS and Wireless Communications

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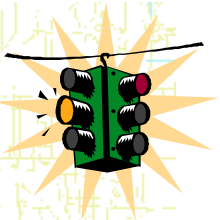

ITS Advanced Transportation Technologies Seminar Series, September 25, 2007

Outlines

- Background
- Phase I - Simulation Study
- Phase II – Prototype system development

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What is Transit Signal Priority (TSP)?

" Transit signal priority systems use sensors to detect approaching transit vehicles and modify signal timings to improve transit performance. "

"A tool to help make transit service more reliable, faster, and more cost effective. It has little impact on general traffic and is an inexpensive way to make transit more competitive with the automobile."

- ITS America TSP planning and implementation handbook

Priority vs. Preemption

- Signal priority modifies normal signal operation process to accommodate transit vehicles
- Preemption interrupts the normal signal operation process for special events (railroad crossing, emergency vehicles)

Transit Signal Priority
Detection Technologies

Inductive loop-based detection

- Advantage:
  - Compatible with commonly used loop detectors
  - Relatively reliable
  - Does not require line-of-sight or visibility
- Disadvantage:
  - Require in-pavement loop detectors
  - Prone to failure due to pavement flexing
- Example:
  - IDC LoopComm
- Implementation:
  - LA, Chicago

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Transit Signal Priority
Detection Technologies

Light-based (Infrared) detection

- Advantage:
  - Widely used in U.S. for EVP,
  - Well tested for many years
- Disadvantage:
  - Require Line-of-sight clearance between emitter and detector
- Example:
  - 3M Opticom, Optronix/Tomar Strobecom, Novax Bus Plus
- Implementation:
  - Oakland, Tacoma, Portland, Vancouver

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Transit Signal Priority
Detection Technologies

Sound-based detection

- Advantage:
  - Emergency vehicle does not need additional equipment
  - Facilitate inter-jurisdictional emergency response
  - Does not require line-of-sight or visibility
- Disadvantage:
  - Not practical for transit signal priority (need additional audible siren)
  - False activation from building/car alarms
- Example:
  - Sonic Sonem 2000, EPS II

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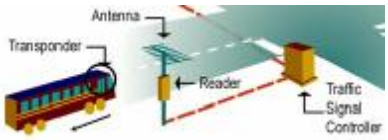
Transit Signal Priority
Detection Technologies

Radio-based detection

- Advantage:
  - Does not depend on line-of-sight or visibility
- Disadvantage:
  - Require RD tag installation at upstream curbside
  - None directional vehicle information (with no RF tag installation)
- Example:
  - TOTE (RF Tag), Econolite (EMTRAC)
- Implementation:
  - King County Seattle



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Transit Signal Priority
Detection Technologies

Satellite (GPS)-based detection

- Advantage:
  - Does not depend on line-of-sight or visibility
  - Can easily notify controller when vehicle has cleared
- Disadvantage:
  - Slow AVL polling rate
  - Low/no GPS reception in urban canyon
- Example:
  - 3M GPS Opticom
- Implementation:
  - City of Edinburg, TX?

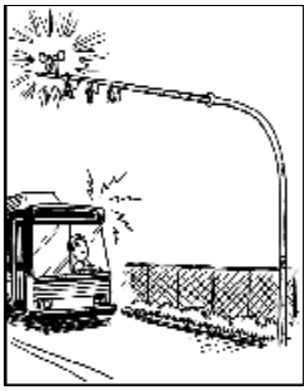
TSP Experiences in US

An Overview of Transit Signal Priority, ITSA

Location	# of lines	TSP strategy	Benefit/Impact
Portland	3	Early/green	Bus travel time savings of 7 to 14.3% per trip
Lane Transit District Highway		Conditional	Peak 3.4% reduction in travel time variability
Portland	4	Early/green	2.8% average time reduction
Tri-Met Bus		Conditional	[illegible]
Seattle Rapid Ride	30	Early/green	2.8% reduction in travel time
		Conditional	[illegible] 40% reduction in travel speed
			[illegible] 847,000 passengers benefit from reduction
Chicago			7 to 25% reduction in travel time depending on time of day, route and corridor
Cleveland	[illegible]	Early/green	[illegible]
		Conditional	[illegible] Passenger load/occupancy level increased since TSP was implemented
			[illegible] 8.3 percentage point average increase in [illegible] passengers +2.4 to +37 %
Los Angeles	31	Early/green	Introduced as part of Metro Rapid BRT
Metro Bus		Conditional Adjustment phase	[illegible] 33.39% reduction in bus delay and signalized intersections
			[illegible] TSP delivery range of benefit: 1 to 4 of 5
Pierce County,	42	Early/green	Introduced as part of Metro Rapid BRT
Pierce Transit		Conditional Coordinator	[illegible] 33.39% reduction in bus delay and signalized intersections
[illegible]		[illegible]	[illegible] TSP delivery range of benefit: 1 to 4 of 5

Transit Signal Priority (TSP)
Background

- Bus signal priority has been implemented in several US cities (Seattle, Portland, LA, Chicago, St. Cloud, etc.)*
- Metro Transit performed tests on Lake Street using 3M Opticom technology (problem w/ nearside bus stops & trigger timing)
- Metro Transit contracted SEH Inc. to conduct TSP conceptual design along Northwest (Bottineau) corridor
- Most TSP deployments use sensors to detect buses at a fixed or preset distance.



* An Overview of Transit Signal Priority, ITS America 2002

Adaptive Bus Signal Priority
Objectives

- Provide efficient and reliable bus transit service to traveling public.
- Reduce transit operation cost.
- Use already installed GPS/AVL on bus & a wireless communication based adaptive signal priority system with minimum impact on other traffic.
- Conduct traffic modeling and simulation to analyze and evaluate the possible impact.

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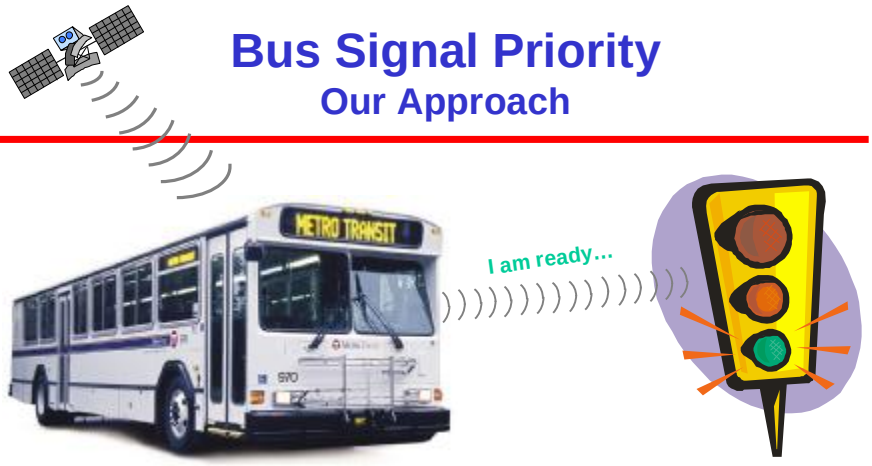
Bus Signal Priority
Our Approach



- Bus transmits signal priority request to traffic controller based on its **readiness** not **presence.**

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Bus Signal Priority
Our Approach (continue)

- Adaptive bus signal priority strategy using GPS/AVL and wireless communication technology.
- Provide conditional signal priority based on bus's schedule adherence, speed, location and estimated dwell time at bus stop.
- Transmit priority request wirelessly from bus to intersection signal controller.
- Evaluate benefits and impacts of signal priority from simulation model.

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Key Features of Our Approach

- Non-proprietary wireless communication (802.11x protocol)
- Use existing GPS/AVL system on bus
- Incorporate passenger count and bus lateness to provide conditional priority
- Consider bus stop dwell time for signal priority request when it is ready (Intersection arrival time forecast)
- Include controller phasing and timing status in priority request, forecast and decision making

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Study Site – Franklin Ave. Minneapolis

Dupont Ave.

3 miles, 22 signalized intersections

27th Ave

To I-94 & I-394

I-35W

I-94

Hiawatha LRT

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Simulation Model Development

- Intersection Capacity Analysis (Synchro)
- Data Collection
  - Signal timing plan (from Minneapolis)
  - Volume and turning movements (Use Jamar)
  - Travel time (Vehicle probe)
  - Bus dwell time & delay (20%) at intersection
  - Bus stop location (GIS from Metro Transit)
- Use AIMSUN Micro-Simulator

Simulation Model Development (con't)

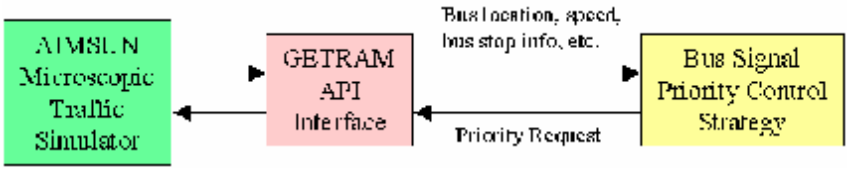
- Capacity Analysis

Franklin Avenue - Intersection LOS			
Intersection	AM Peak	Off Peak	PM Peak
Hennepin	F	C	F
Lyndale	D	C	C
Nicollet	E	B	F
Chicago	C	D	F
11th	B	D	E
Cedar	C	B	D
Minnehaha	B	B	B

Franklin Avenue - Intersection Delay (sec)			
Intersection	AM Peak	Off Peak	PM Peak
Hennepin	183.4	27.6	148.0
Lyndale	47.2	39.0	39.4
Nicollet	86.8	25.0	676.2
Chicago	33.8	49.5	202.5
11th	23.1	51.8	84.3
Cedar	25.9	19.1	64.3
Minnehaha	14.3	11.3	16.9

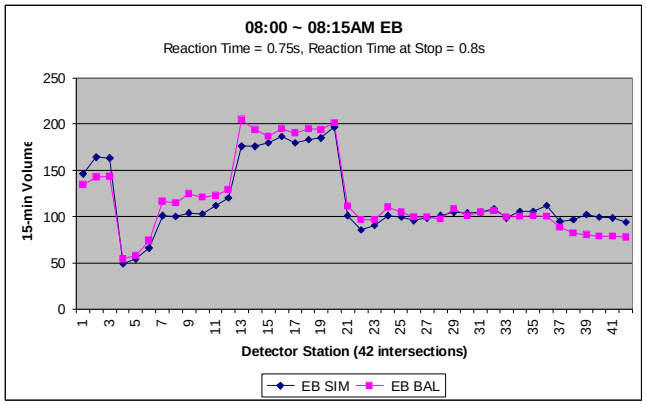
Simulation Model Development (con't)

- Network Modeling



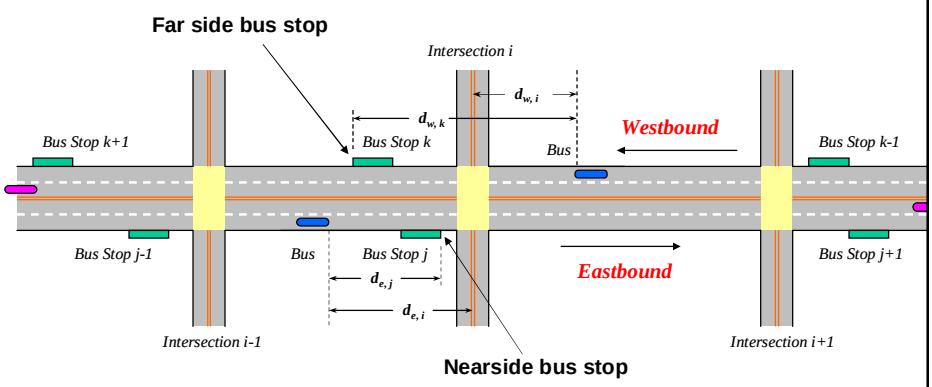
Simulation Model Development (con't)

- Network Model Calibration



Franklin Avenue Eastbound

Signal Priority Strategy



Signal Priority Request

- Nearside Bus Stop

Average bus travel time to stop j:

$$T_{aj} = \frac{d_{e,j}}{1.467 \times v_b} + T_{br} + T_{delay}$$

v_b : is bus speed, in MPH.

$d_{e,j}$: is the distance from the current bus location to bus stop *j*, in feet.

T_{br} : is bus braking/stopping time.

T_{delay} : is the traffic delay on bus route.

Signal Priority Request

- Far side Bus Stop

Average bus travel time to intersection i:

$$T_{ai} = \frac{d_{w,i}}{1.467 \times v_b} + T_{delay}$$

v_b : is bus speed, in MPH.

$d_{w,i}$: is the distance from the current bus location to intersection *i*, in feet.

T_{delay} : is the traffic delay on bus route.

Bus Dwell Time Calculation

- Dwell Time Forecast at Bus Stop

$$T_{dj}^{B} = l_j(t) \times [t_k(j) - t_{k-1}(j)] \times T_{boarding}$$

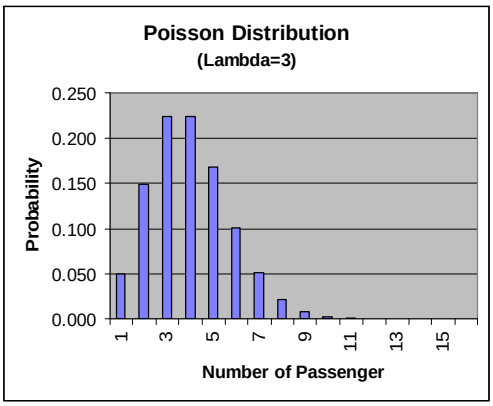
T_{dj}^{B} is the bus dwell time for boarding at stop j,

$\lambda_j(t)$ is the passenger arrival rate to stop j,

$t_k(j)$ is the arrival time of bus k at stop j,

$t_{k-1}(j)$ is the arrival time of bus k-1 at stop j,

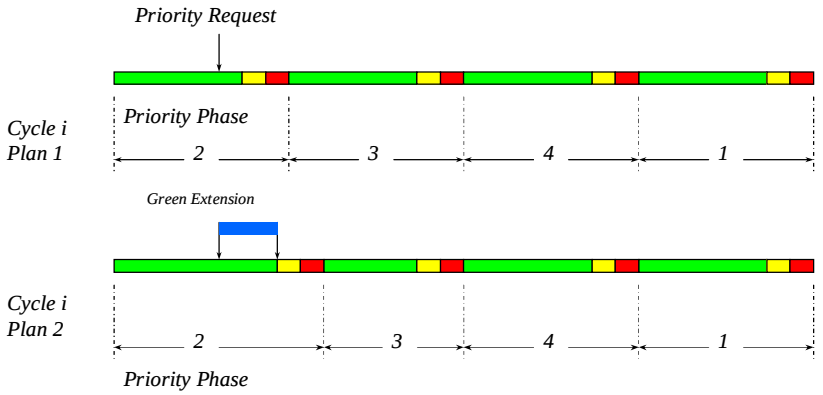
$T_{boarding}$ is the average boarding time per passenger.



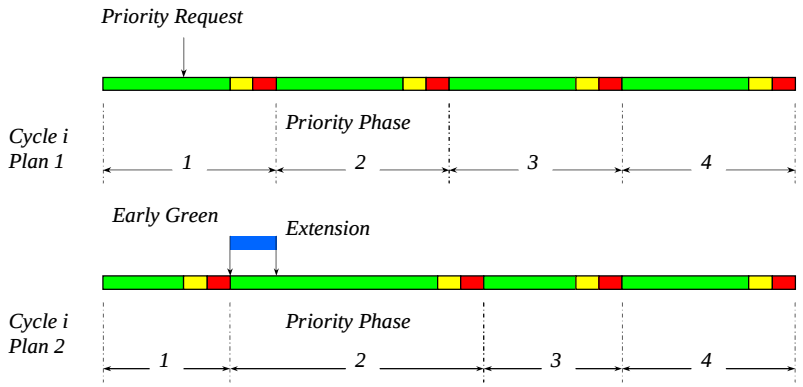
Signal Priority Acknowledgement

- Request Time, TF (Time factor)
  - First come first serve
- Bus Schedule Adherence, LF (Lateness Factor)
  - LF=0 if bus is ahead of schedule
- Number of Passenger, PF (Passenger Factor)

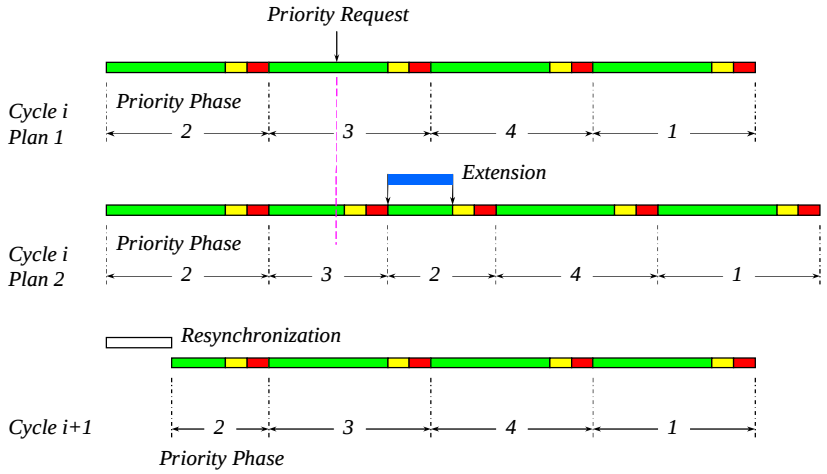
Signal Priority Treatment: Green Extension



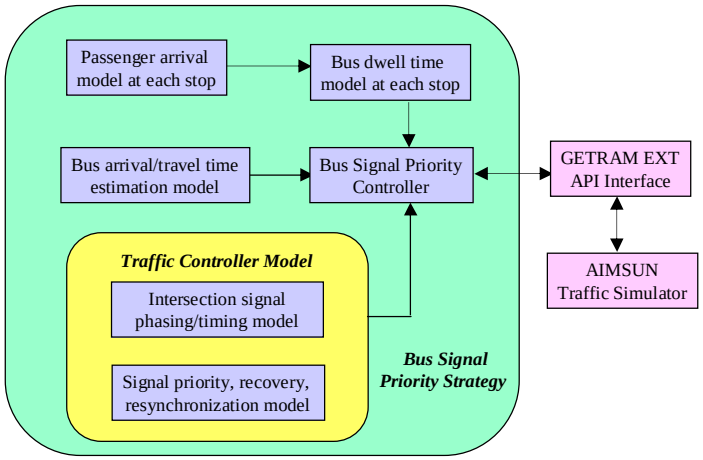
Signal Priority Treatment: Red Truncation



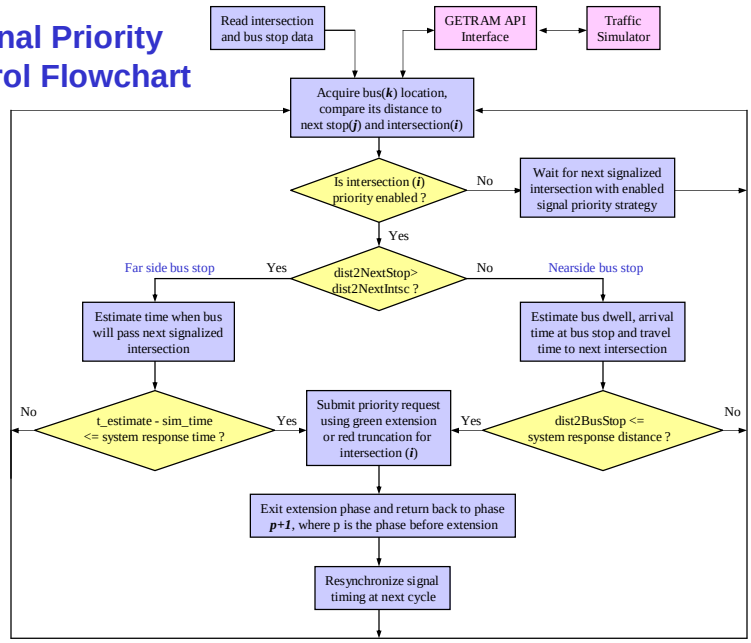
Signal Priority Treatment: Phase Insertion



Signal Priority Strategy Modeling



Signal Priority Control Flowchart



Bus Signal Priority

Phase I Simulation Study Results

- Bus travel time reduction
  - AM-Peak: 12-15%
  - PM-Peak: 4-11%
- Bus delay time reduction
  - AM-Peak: 16-20%
  - PM-Peak: 5-14%

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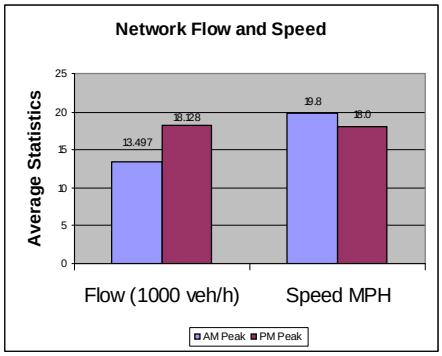
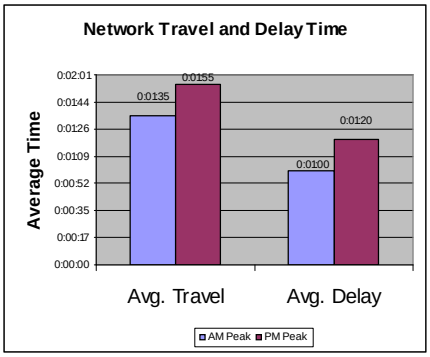
Overall Network Measures





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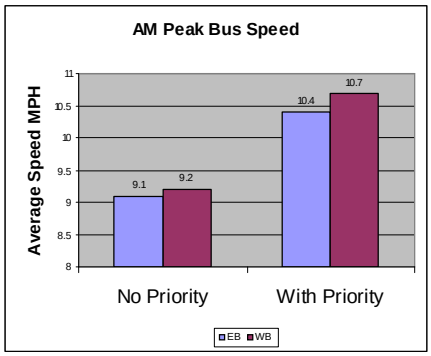
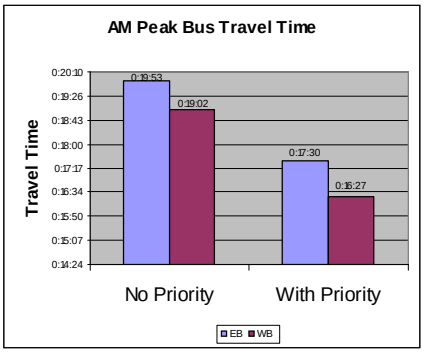
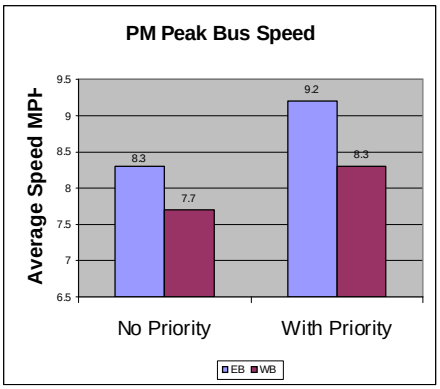
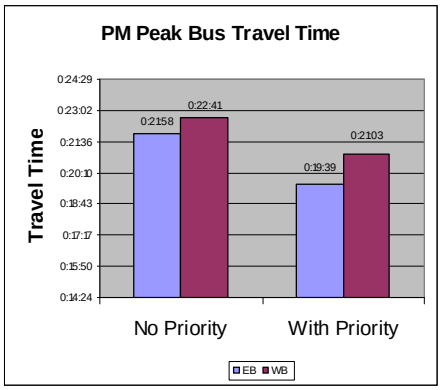
Bus Travel Time and Speed (AM Peak)





Bus Travel Time and Speed (PM Peak)





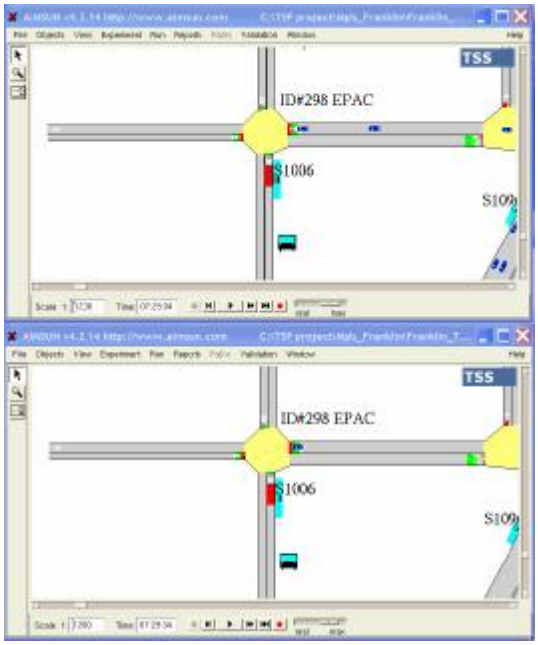
MOE Analysis of Major Intersections

- Hennepin – No significant change
- Lyndale – 10% decrease in delay & stops
- Nicollet – about 30%increase in travel time and 47% increase in delay
- Chicago – about 5% decease in travel time & delay time
- Cedar - about 24% increase in travel time and 30% increase in delay

Video Clip

Without Priority

With Priority



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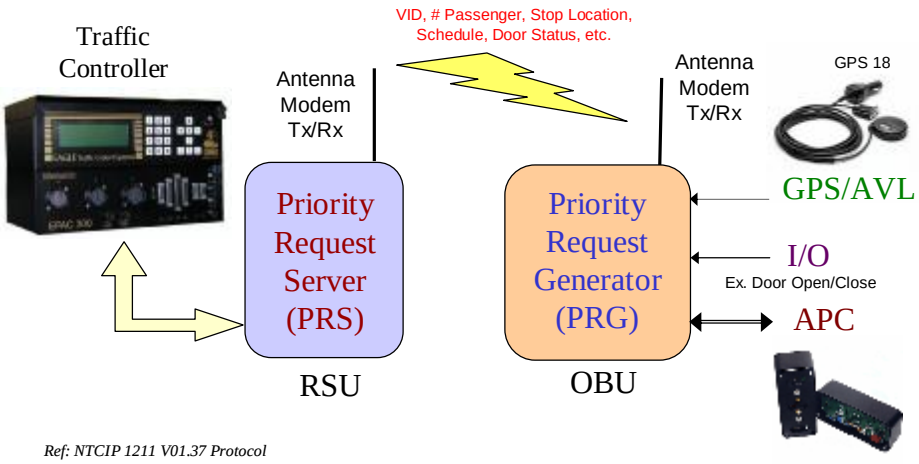
Phase II Study Overview

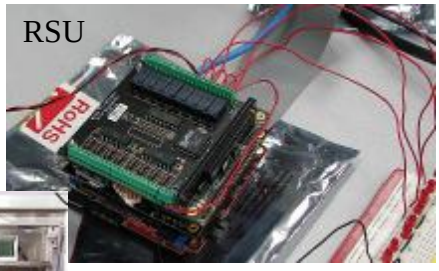
- Develop wireless communication prototype using commercial off-the-shelf (COTS) product
- Implement & validate GPS/AVL and wireless communication based signal priority strategy
- Field testing and validation

Phase II Prototype Systems



Ref: NTCIP 1211 V01.37 Protocol

Signal Priority System Hardware



Controller Cabinet

GPS Receiver

NEMA Controller

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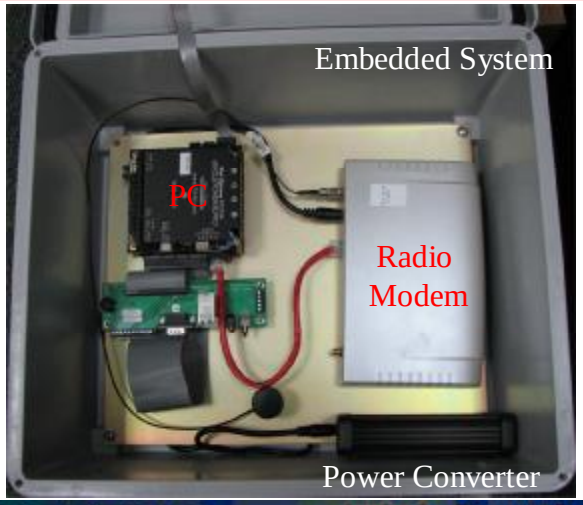
Signal Priority Embedded System



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Wireless Communications

- Minneapolis Wi-Fi Network

- 5.9 GHz WAVE Radio

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Minneapolis Wi-Fi

Wireless Minneapolis
USI Wireless

Implementation Start
November, 2006

30-40 nodes/sq mile

Phase One
Anticipated Completion.....June, 2007

Phase Two
Anticipated Completion.....September, 2007

Phase Three
Anticipated Completion.....October, 2007

Phase Four
Anticipated Completion.....October, 2007

Phase Five
Anticipated Completion.....November, 2007

Phase Six
Anticipated Completion.....December, 2007

http://www.usiwireless.com/service/minneapolis/schedule.htm

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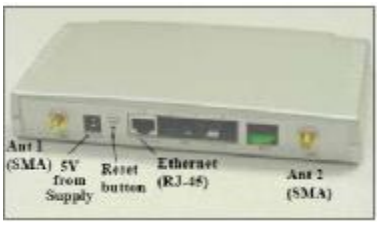
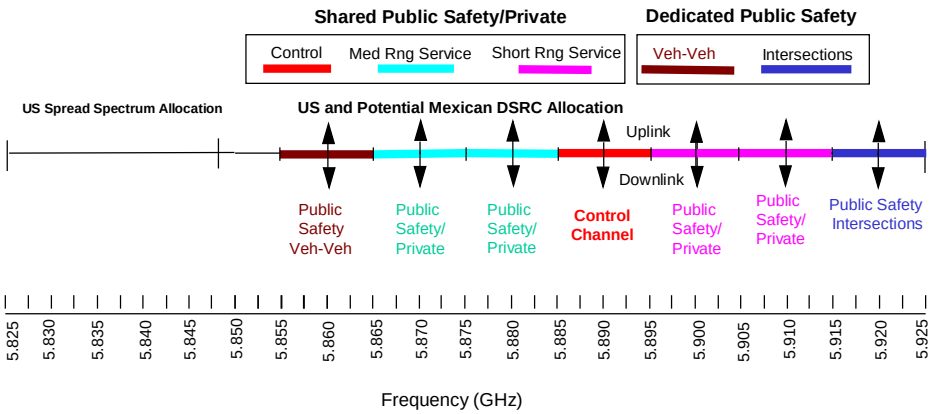
5.9 GHz Radio

Denso WAVE (Wireless Access in Vehicular Environment) Radio Module Prototype

- Bandwidth: 75 MHz (5.850 ~ 5.925 GHz)
- 5.89 GHz (IEEE 178, control channel)
- Channels: 10 MHz per channel (20 MHz optional)



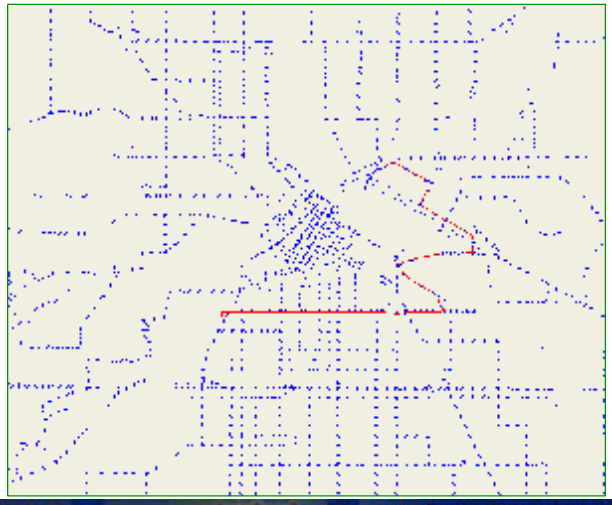
5.9 GHz DSRC Band Plan



IEEE DSRC Standard, http://www.ieee802.org

Bus Stop & Intersection Geo-Database

Bus route #2
Travel Pattern #1



Test Plan and Data Collection

- Equip a passenger vehicle for initial testing
- Wireless communication reliability and latency data collection and analysis
- Signal priority algorithm verification and validation
- Final testing and validation (one bus + one intersection)

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Acknowledgement

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- Priya Iyer, EE student.
- Ted Morris & Pi-Ming Cheng at ITS Institute.
- Tony Juettner at Brown Traffic Products, Inc.

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Thank You Very Much!

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