Intelligent Transportation Systems Institute

Intelligent Vehicles Laboratory
Develop, test and evaluate innovative, human centered technologies that improve the operations, safety, mobility, and productivity of vehicles.

Minnesota Traffic Observatory
Develop, test and evaluate innovative transportation management and operational strategies, and traveler information technologies.

HumanFIRST Program
Investigate human strengths and weaknesses to gain an understanding of the role of the individual in complex technological transportation systems.

Google Driverless Car

What’s more forward thinking...?

Driverless Cars

Car-less Drivers

Efficient Public Transport

Walt Handelsman, October 15, 2010
Driverless vs Driver assist
Video: KARE-11 News (Sept. 7, 1997)

Snowplows & Airport Rescue and Firefighting (ARFF)
 Vehicles Deployed
- Now: 3 in Minnesota, 4 in Alaska
- 2011-2: 3 more in Alaska, 3 in California
“Avalanche Road”
Broadcast March, 2010
Speed Channel

Recorded 3 day storm that occurred in October 2009
Video is accessible over the net at:
http://www.slashcontrol.com/free-tv-shows/dangerous-drives/3933939089-avalanche-road

Our DGPS-based HUD is shown in a 2 minute segment at about 20 minutes into the 45 min video.

BRT Advantages for “Guided” Buses

- Reduced right-of-way required; track or lane width is only slightly larger than vehicle width.
- Passenger transfers are avoided or reduced compared to rail bound systems, since buses can leave track or lane to drive remaining route.
  - Full flexibility of buses is maintained.
  - Travel time becomes shorter with fewer transfers.
- Increased safety, as driver error during steering maneuvers is reduced or eliminated. Blind zones minimized.
- Possibility of:
  - Platoon formation; can carry large passenger volume with small headway between moving vehicles, or maintain controlled intervals as needed
  - Precision docking; facilitates level boarding
Where Driver Assist Technology (Lanekeeping and Merging) Applies

- Limited right-of-way due to environmental conditions (e.g. lakes, wetlands), valuable property, existing structures
- Squeezing busway into and around existing neighborhoods
- Existing highway shoulders or medians
- Tunnels, bridges
- Historical areas
- Former rail lines, canals
- Re-allocation of traffic on existing road from \( n \) lanes to \( n +1 \) lanes

Bus Only Shoulders (BOS): Advantages

- Close to 300 miles of “bus only shoulders” in over 70 locations, 15-20 miles added each year
- Buses operate on shoulders when normal progress slowed by congestion
- Significant time savings realized when shoulders utilized
- Bus customers very receptive to concept - they perceive time savings 2 x greater than actual
- Earlier work was part of partnership between Metro Transit, Mn/DOT (Team Transit) and U of MN
  - Conversion of shoulders to Bus Only Shoulders
  - Regulations regarding use of shoulders is in place.
  - FHWA (Minnesota Division) approved new use of shoulder
  - For more info, see http://www.dot.state.mn.us/metro/teamtransit/
Economic Benefits: Capital Cost Comparison

- LRT projects vary in cost from $15 million to $100 million per mile, with the average cost per mile approximately $46 million.

- Cheapest BRT option - $2.5 million to $2.9 million per mile, mixed flow with general traffic, excluding any cost associated with acquiring the right of way.

- BOS operation in the Twin Cities range from as little as $1,500 per mile to $200,000 per mile (2007 dollars: avg $150,000 per mile).
Bus Only Shoulders: Challenges

- 9 foot (2.7m) wide bus operating on 10 foot (3.1m) wide shoulder
  - 9.5 ft (2.9m) across rear view mirrors
  - 8.5 ft (2.6m) across dual rear wheels
  - Only 6 inches (8 cm) on either side of the mirrors to spare
  - Not much room to maneuver
  - Tunnel effect under bridges
- Transition from lane to shoulder much less severe than transition from shoulder to soft ground
- Greatest time savings when weather is poor
  - Traffic congestion increases with bad weather
  - Drivers have difficulty seeing shoulder/median interface
  - Consequences when bus leaves shoulder
- “Jealous” motorists partially block shoulder
- Drivers get stressed out when operating in narrow lanes; use of shoulder is voluntary; some refuse

Minnesota BRT: Driver Assist Program

- Technologies used in Driver Lanekeeping Assist System:
  - High accuracy differential GPS system ($\sigma < 10$ cm)
  - Virtual Reference Station from Trimble and digital cell phone access provide metro-wide correction signals to bus.
  - Radar and/or LIDAR sensors used for obstacle detection, merge assist, sensing in blind zones
  - High accuracy “digital map” facilitates guidance and obstacle detection.
  - “Human-in-the-loop” driver interfaces including head up display (HUD), vibratory seat, haptic feedback through steering wheel, virtual mirror
  - New augmented GPS and non-GPS approaches to provide redundant lane guidance
Urban Partnership Agreement: Minnesota’s Congestion Mitigation Initiative

Heading N on I-35W at MN13 on opening day - 9/30/09

See http://www.dot.state.mn.us/upa/
Dual Frequency Differential GPS

- Dual-frequency GPS receivers have ability to internally resolve ionospheric delay.
- Differential signal corrects for:
  - GPS satellite clock error
  - Ephemeris data error
  - Tropospheric delay

Virtual Reference Station (VRS)

VRS server
- Collects raw GPS data from GPS base stations over Internet (GPSNet)
- Processes raw GPS data and generates correctional signals (RTKNet)

Wireless channel (requires only 10 Kbits/sec) to/from vehicles with/without authentication for subscription

Vehicles
- GPS receiver that can handle CMR, CMR+, or RTCM formatted correctional signals
Hi-Accuracy DGPS Correction
Signal Coverage in Minnesota
July, 2010
From
http://mncors.dot.state.mn.us/

VRS Network

- All 260 miles of I-94 corridor in MN covered
- Minnesota first one to start
- 12 states with operational VRS (8 managed by the state or DOT)
- 5 states & 5 EU countries with Trimble “VRS Now” subscription service
- Many states have plans to set up similar networks
- Green & Taupe: Operational
- Brownish green: Proposed; Orange: Pending (to be shared with Iowa)

VRS: Trimble RTKNet Systems (Sept 08)
MVTA Bus 2.0

IBEO Lux LIDAR
25 Hz,
Tracks 64 targets
4 laser planes

Bus “cockpit” – Driver Interface
How do drivers best receive relevant information?

Head Up Display for vision enhancement & fwd collision avoidance

Graphical display for fwd & side collision avoidance

Torque feedback for lane departure prevention

Tactile seat for lane departure prevention (directional “buzzing” of seat cushion)
An Augmented Conformal Head Up Display

- By referencing the vehicle AND the driver’s eye position within an accurate digital map, one can accurately recreate the field of view from the driver’s eye perspective.

- System allows all lane boundaries and obstacles to be drawn and projected in real time on a virtual screen 30 ft. in front of vehicle (to reduce eye fatigue)

Video of HUD (Approaching intersection)
Video through HUD on Minnesota Hwy 101 (Radar OFF)
Day time view to show accuracy of projected lane markings

Additional Modality: Haptic Feedback

- Under current operations, drivers like to use the curb to determine the extent of the drivable surface
- When curb is not there, can use DGPS, geospatial database, and steering actuator to provide “virtual curb.”
- Steering wheel is actuated to feel like a curb (albeit a soft one) when one is not there. Can create a detent or torque valley to identify the center of lane.
- Seat with vibration actuators indicates “out of shoulder lane.”
Video:  
Haptic Feedback Assist for Lane Keeping

Sequence Showing Bus Operating in Narrow Lane with Adjacent Truck
High-Accuracy DGPS: Accommodating “Outages”

- Achievable DGPS position accuracy: 4 - 8 cm at 95% level of confidence
- Limitation with suburban / urban highway applications:
  - DGPS isn’t sufficiently robust on roads with bridges, overpasses, etc.
  - Must accommodate various DGPS “outages”
  - Lose “fix” solution every time one drives under bridge
  - If initial heading angle error = 1 deg when DGPS position “fix” solution is lost, then 8 sec loss after last accurate position acquired @60mph => 12ft lateral error

Limitation addressed:
Developed a unique non-inertial 2D velocity sensor-based DGPS augmentation system.

- Performance requirement:
  - No more than 0.75ft lateral error after 16 sec outage at 30mph (based on bus wheel track of 8.5 ft (2.6m) traveling in minimum 10 ft (3m) wide lane)
- 16 sec loss of DGPS “fix” @30mph (48kph) => 0.75 ft (23cm) max. lat. error over 704 ft (214m) of travel
- Maximum tolerable initial heading angle error before loss of “fix” ≈ 0.06 to 0.07 deg
Route for 10-bus Bus Only Shoulder Service

- Vehicle-based DGPS augmentation used
- Vehicle-Infrastructure cooperative augmentation used

Bus Driving Simulator (driver training)

Expected Benefits

◆ Driver Benefit
  ❖ Lane and Merge Assist
    • Feedback through Head Up Display, Vibrating Seat, Active Steering Wheel
  ❖ Collision Avoidance
    • Forward and side sensors
    • Integrated Display
  ❖ Touch Panel Control
    • Driver can choose/modify feedback

◆ Passenger Benefit
  ❖ Better Schedule Adherence
  ❖ Utilization of road shoulders to bypass congestion

NYC Transit's M15 Select Bus Service BRT
New non-GPS Approach
Provides Redundant Lane Guidance:
Enhanced Vehicle Positioning System (VPS)

◆ New method of obtaining decimeter level
  (~ width of lane stripe) vehicle lateral position
◆ Main components of position sensing system. Sensor
  fusion of:
  ❖ Basic VPS
  ❖ Odometry
  ❖ LIDAR curb detection
  ❖ Map database

Basic VPS Concept:
RFID Reader on Vehicle Reads
Position from Passive Tag

1. Reader passes by tag
2. Reader interrogates tag
3. Data transferred from tag to reader
Curb Detection

Towards bus  
Index 1
LiDAR data points, $S_1 \rightarrow S_N$

Away from bus  
Index N

Curb model

Curb model overlaid onto data point, $S_1$

Curb model overlaid onto data point, $S_B$

Curb model overlaid onto data point, $S_C$

LIDAR-based curb following

IBEO Lux
Also used for collision avoidance, and pedestrian detection (future)
Nine city blocks between Chicago Avenue and Hennepin Avenue were instrumented.

RFID tags were placed on metal light poles before each intersection (~ 100 meter spacing).
Video: Enhanced VPS Used in Downtown Area

High Accuracy Vehicle Location Technology Supports Many Transit Applications

- Lane Assistance (primary application)
- Ability to modify route as needed (based on digital map)
- Merge Assistance (benefits both buses and motoring public)
- Pedestrian and other object detection and avoidance
- Elimination of blind zones
- Integration with Transit Signal Priority using wireless communications
- Platooning of buses
- Precision docking
- Improve traffic flow in adjacent lanes
Level of service: Density and Speeds

- Density DROPS as speed increases.
- Higher speeds, more space between vehicles.

### TABLE 3-1
Level of service criteria for a basic freeway segment

<table>
<thead>
<tr>
<th>Level of Service</th>
<th>Density (passenger car equivalents)</th>
<th>Traffic Flow Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>≤ 11</td>
<td>Free flows operation, vehicles are almost completely unimpeded in their ability to maneuver within the traffic stream.</td>
</tr>
<tr>
<td>B</td>
<td>11 - ≤ 25</td>
<td>Reasonably free flow, vehicles maneuver within the traffic stream is only slightly restricted.</td>
</tr>
<tr>
<td>C</td>
<td>&gt; 25 - ≤ 35</td>
<td>Freedom to maneuver within the traffic stream is noticeably restricted.</td>
</tr>
<tr>
<td>D</td>
<td>&gt; 35 - ≤ 50</td>
<td>Freedom to maneuver within the traffic stream is more noticeably limited, and the driver experiences reduced physical and psychological comfort level.</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 50 - ≤ 65</td>
<td>Vehicles are closely spaced, leaving little room to maneuver within the traffic stream at speeds that still exceed 60 mph.</td>
</tr>
<tr>
<td>F</td>
<td>&gt; 65</td>
<td>Breakdowns in vehicular flow.</td>
</tr>
</tbody>
</table>

Source: Highway Capacity Manual (HCM), 2000

<table>
<thead>
<tr>
<th>Speed Ranges, MPH</th>
<th>Flow, vehicles/hour/lane</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>LOS A</td>
<td>60</td>
</tr>
<tr>
<td>LOS B</td>
<td>57</td>
</tr>
<tr>
<td>LOS C</td>
<td>54</td>
</tr>
<tr>
<td>LOS D</td>
<td>46</td>
</tr>
<tr>
<td>LOS E</td>
<td>30</td>
</tr>
<tr>
<td>LOS F</td>
<td>0</td>
</tr>
</tbody>
</table>

Density, Speed, and Flow: All Levels of Service (Indianapolis data)
Goal

- To reduce congestion, we want to MAXIMIZE Flow.

- To MAXIMIZE Flow, we want to “control/encourage/manage” the traffic so that it sits at the boundary between LOS F and LOS E (the inflection point).


Consider the following:

- Say the congested highway speed is 18 MPH. That’s about 75 vehicles per lane per mile.
- If you want to move to 30 MPH, you want to have ~65 vehicles per lane mile.
- If most cars are SOV, you need to move 10 people per lane mile on to a bus (moving from 75 to 65).
- If you have 4 lanes of traffic, that translates into a 45’ Gillig bus (40 passengers) running at 1 mile (distance) headways, or 2 minute time headways (at 30 MPH).

Note flatness of curve. Sensitivity is very high here. Taking out a small number of vehicles can affect a LARGE change in LOS.
Transit Signal Priority (TSP)
Background

- Bus signal priority has been implemented in many cities (e.g. Seattle, Portland, LA, Chicago)
- Most TSP strategies use sensors to detect buses at a fixed or preset distance (e.g. based on emergency response vehicle requests).

Wireless Bus Signal Priority: Minnesota Approach

- Include bus location, speed and schedule status
- Bus transmits conditional priority request to signal, based on its **readiness**, not **presence**
Wireless Bus Signal Priority: Minnesota Approach (cont’d)

- Adaptive bus signal priority strategy using existing GPS/AVL system and wireless communication
- Provide conditional signal priority based on bus adherence to schedule, speed, location (near-side vs far-side stops) and estimated dwell time at bus stop
- Transmit priority request wirelessly from bus to intersection signal controller
- Developed wireless communication prototype using commercial off-the-shelf (COTS) products
- Developed prototype system and will validate enhanced TSP algorithms previously tested in simulation on 4 buses along corridor with 26 signalized intersections using wireless TSP.

Wireless Connectivity (TSP and other)

Dilbert ©Scott Andrews, April 24, 2010
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