Intelligent Transportation Systems: Automated Highways, Autonomous Vehicles, aTaxis & Personal Rapid Transit

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Intelligent Transportation Systems

- Coined by Fed DoT in early ‘90s to include:
    - Intelligent Traffic Control Systems and Value Pricing Systems (EZ Pass mid 80s)
    - Turn-by-Turn GPS Route Guidance Systems (‘97 CoPilot Live)
  - ATS (Automated Transit Systems)
    - Automated People Movers and Personal Rapid Transit (Ficter ‘64, W. Alden ‘71, WWU ‘75)
  - AHS (Automated Highway Systems) (1939 World’s Fair, RCA-Sarnoff late 50s*, R.Fenton ‘72 OSU)
    - Autonomous vehicles
Intelligence (aka Automation) in the current Automobile

- Self-parking systems [video] (1st version Toyota ’03; US ’06) MB Park Assist
- Lane Departure Warning Systems
  - Continental LWDS; Bendix AutoVue LDWS; Ford Driver Alert; Bosch Lane Departure and Lane Keeping Support; Continental Driver Assistance Systems
- Frontal Impact Warning Systems [video]
- MBML350 Safety Features *; Mercedes Benz; MB Lane Keeping Assistance; MB Active Lane Keeping Assist YouTube*
- MB Attention Assist YouTube;

Attention Assist:
How the Mercedes driver assistance system detects tiredness

Lane-departure warning system: steering wheel vibrations warn the driver if he or she is veering out of the lane.

The steering wheel vibrates if the driver leaves the lane unintentionally.

Detection of personal driving style
Detection of driving conditions—such as time of day and duration of drive
Detection of driver’s use of the controls
Detection of a change in drivers
Detection of steering behaviour
Detection of lane changes based on control signals, steering wheel movements and lateral acceleration
Detection of traffic situation, for example based on longitudinal and lateral acceleration

Mercedes-Benz TecDay – Blind Spot Assist

Mercedes-Benz TecDay – Blind Spot Assist

CS 402
What’s Next:
Lateral & Longitudinal Vehicle Control

Exclusivity of Guideway

- Dedicated
- Mixed

Duration of Automation

- intermittent
- Always

- Automated Transit
- PRT, APM & AHS
- Autonomous Vehicles & aTaxis

DriverAssist
Conceptually, the Vehicle Control Problem is basically:

• “Simple”
  – Feasible region is a flat plane with boundaries and the environment is somewhat well structured.

• “Challenge”
  – to properly identify and tag the boundaries and the objects in some neighborhood of the vehicle

• Longitudinal and Lateral control problems:
  – Have velocity vector be **Tangent** to a centerline between feasible lateral boundaries and don’t hit anything
Focus on Intelligent Vehicle Control Systems for Automated Transit Systems (Personal Rapid Transit)

- extensive research on control and management systems for large fleets of vehicles in a large interconnected dedicated network of guideways and stations
- area-wide network design for large-scale implementations
  - state-wide PRT
  - for Automated Highways (Personal hands-off & Feet-off vehicles operating on conventional roadways)
  - participation in DARAP Autonomous Vehicle Challenges
    - focus on stereo vision-based systems for sensing local environments
      - dynamic depth mapping, object identification and tracking, road edge identification.
    - robust control in the presence of substantial uncertainty and noise
- Evolution to autonomous Taxis concept of Area-wide Public Transit
Starting in the late 60s...

Some thought that: “The automation & computer technology that took us to the moon could now revolutionize mass transit and save our cities from the onslaught of the automobile”

Donn Fichter “Individualized Automatic Transit and the City” 1964

Westinghouse Skybus Late 60’s-

CS 402

PRT

APM
Now exist in essentially every Major Airport and a few Major Activity Centers.
Starting in the early 70's, U of Minnesota became the center of PRT research focused on delivering auto-like ubiquitous mobility throughout urban areas.

- **Since Demand very diffuse** (Spatially and Temporally):
  - Many stations served by Many small vehicles
    - (rather than a few large vehicles).

- **Many stations**
  - Each off-line with interconnected mainlines
    - To minimize intermediate stops and transfers

- **Many small vehicles**
  - Require more sophisticated control systems,
    - both longitudinal and lateral.
PRT
Personal Raid Transit

Some early test-track success...
DFW AirTrans PRT
Was built and operational for many years
– About 40 years ago: Exec. Director of APTA* said to me:

“Alain: PRT is the transportation system of the future...

And Always will be!!!”

Well after 40 years....

...are we finally approaching the promised land???

*American Public Transit Association
Remains a critical mobility system today & planning an expansion
And Today...

- Masdar & Heathrow are operational
So Let’s Consider Going...

From: the Paved State
Back to: the Garden State

Mobility without Personal Automobiles for New Jersey
So...

• Premise:
  – NJ in 2012 is very different from NJ in 1912

• A look at what might be NJ’s Mobility in 2112 (or before)
Looking Back

• let’s look at the automobile:

  Daimler, 1888

• In the beginning, it takes a while
Central Ave. Caldwell NJ c. 1912
Bloomfield Ave. & Academy Rd. c. 1912 Before it was paved
Muddy Main St. (Rt. 38) Locke, NY. c. 1907
Finally:

Automobile Congestion - present
Starting to Look Forward

Daimler, 1888

Morgantown, 1973
So...
What might it take for PRT to provide essentially ubiquitous mobility for New Jersey?

• For the past 6+ years this issue has been addressed by my Transportation Systems Analysis Class

• Address the question: Where to locate and interconnect PRT stations such that ~90% of the trip ends in New Jersey are within a 5 minute walk.

• After assembling a database of the precise location of trip end, students layout and analyze a statewide network.
Personal Rapid Transit (PRT) for New Jersey

<table>
<thead>
<tr>
<th>County</th>
<th>Stations</th>
<th>Miles</th>
<th>County</th>
<th>Stations</th>
<th>Miles</th>
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<tr>
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<td>191</td>
<td>526</td>
<td>Middlesex</td>
<td>444</td>
<td>679</td>
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<td>Bergen</td>
<td>1,117</td>
<td>878</td>
<td>Monmouth</td>
<td>335</td>
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<td>577</td>
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<td>405</td>
<td>483</td>
<td>Warren</td>
<td>484</td>
<td>437</td>
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<td>Mercer</td>
<td>413</td>
<td>403</td>
<td><strong>Total</strong></td>
<td>11,295</td>
<td>12,261</td>
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## Bottom Line

<table>
<thead>
<tr>
<th>Element</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>PRT Trips per day (90%)</td>
<td>26.51M</td>
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<tr>
<td>Peak hour trips (15%)</td>
<td>3.98M</td>
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<tr>
<td>Fleet size</td>
<td>530K</td>
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<tr>
<td>Fleet Cost $B</td>
<td>$53B @ $100K/vehicle</td>
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<td>Stations</td>
<td>11,295</td>
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<tr>
<td>Station Cost</td>
<td>$28B @ $2M/Station</td>
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<td>Guideway</td>
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<tr>
<td>Guideway Cost</td>
<td>$61B @ $5M/mile</td>
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<td>Total Capital Cost</td>
<td>$143B</td>
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</table>
What the APTA guy was telling me was...

- Final Region-wide system would be really great, but...
- Any great final system MUST evolve from some great initial system and be great at every step of the way, otherwise...
- It will always be “a system of the future”.
- The *dedicated grade-separated guideway infrastructure* requirement of PRT may simply be too onerous and risky for it to ever serve a significant share of the urban mobility market.
While there are substantial challenges for PRT...

– All other forms of Transit are today **hopelessly uncompetitive** in serving anything but a few infinitesimally small niche markets.

Current State of Public Transport...

• Not Good!:
  – Serves about 2% of all motorized trips
  – Passenger Miles (2007)*:
    • $2.640 \times 10^{12}$ Passenger Car;
    • $1.927 \times 10^{12}$ SUV/Light Truck;
    • $0.052 \times 10^{12}$ All Transit;
    • $0.006 \times 10^{12}$ Amtrak
  – Does a little better in “peak hour” and NYC
    • 5% commuter trips
    • NYC Met area contributes about half of all transit trips
  – Financially it’s a “train wreck”

Transit’s Fundamental Problem...

- **Transit is non-competitive to serve most travel demand**
  - Travel Demand (desire to go from A to B in a time window $\Delta T$)
    - A & B are walk accessible areas, typically:
      - Very large number of very geographically diffused \{A,B\} pairs
    - $\Delta T$ is diffused throughout the day with only modest concentration in morning and afternoon peak hours

- **The Automobile at “all” times Serves...**
  - Essentially all \{A,B\} pairs demand-responsively within a reasonable $\Delta T$

- **Transit at “few” times during the day Serves...**
  - a modest number of A & B on scheduled fixed routes
  - But very few \{A,B\} pairs within a reasonable $\Delta T$

- **Transit’s need for an expensive driver enables it to only offer infrequent scheduled fixed route service between few \{A,B\} pairs**
  - But... Transit can become demand-responsive serving many \{A,B\} if the **Driver** (aka **Intelligence**) is made **cheap** (aka **artificial**)
  - If it is really **Intelligent** then it can utilize the existing roadway infrastructure.
Intelligent Transportation Systems

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    - Autonomous vehicles
Evolution of AHS Concept

- GM Futurama @ 1939 World’s Fair
- Zworykin & Flory @ RCA-Sarnoff in Princeton, Late 50s*
- Robert E Fenton @ OSU, Early 70s*
Evolution of AHS Concept

- AHS Studies by FHWA in late 70’s and mid 90’s
The DARPA Grand Challenges

Defense Advanced Research Projects Agency

- **DARPA Grand Challenge**
  Created in response to a Congressional and DoD mandate: a field test intended to accelerate research and development in autonomous ground vehicles that will help save American lives on the battlefield. The Grand Challenge brings together individuals and organizations from industry, the R&D community, government, the armed services, academia, students, backyard inventors, and automotive enthusiasts in the pursuit of a technological challenge.

- **The First Grand Challenge: Across the Mojave, March 2004**
  Across the Mojave from Barstow, California to Primm, Nevada: $1 million prize. From the qualifying round at the California Speedway, 15 finalists emerged to attempt the Grand Challenge. The prize went unclaimed as no vehicles were able to complete more than 7.4 miles.

- **The 2005 Grand Challenge**
  Multi-step qualification process: Site Visits, NQE – Semifinals, GC final event 132 miles through the Nevada desert. Course supplied as list of GPS waypoints. October 8, 2005 in the desert near Primm, NV. Prize $2 million.

- **The 2007 Urban Challenge**
  Nov. 2007; 60 miles in an urban environment. Lane keeping, passing, stop-signs, K-turns “driving down Nassau Street”. Range of Prizes
Prospect Eleven & 2005 Competition
the making of a monster
2005 Grand Challenge
Objective

• Enrich the academic experience of the students

Constraints

• Very little budget

Guiding Principles

• Simplicity
Homemade

“Unlike the fancy “drive by wire” system employed by Stanford and VW, Princeton’s students built a homemade set of gears to drive their pickup. I could see from the electronics textbook they were using that they were learning as they went.”

http://www.pcmag.com/slideshow_viewer/0,1205,l=&s=1489&a=161569&po=2,00.asp
Fall 2004
Fall 2005
It wasn’t so easy...
Pimp My Ride

(a video presentation)
Our Journey to the 2005 Grand Challenge

Video Submission
March, 2005

195 entries

118 teams

Site Visit
May, 2005

40 semi-finalists

2nd Site Visit
August, 2005

9 alternate semi-finalists

3 additional semi-finalists

Semifinals
September, 2005

Final Event
October 3, 2005

Complete 9.5 miles Autonomously

Return to Mojave Run: 2005 course BB; 2004 course

10th Seed of 23 finalists

3 weeks later

Video NQE 5th Run

Video Launch

Video After 8 miles

Video Summary Movie

Video Fixing one line

Video Flat road

Video Launching
Link to GPS Tracks
Achievements in the 2005
Participation in the 2007 DARPA URBAN CHALLENGE
2007

- Semifinalist in the 2007 DARPA Urban Challenge
- Stereo and Monocular cameras, along with RADAR
- Homebrewed State Estimation system
Perception
Monocular VISION
Lane Detection
StereoVISION
Obstacle DETECTION
Obstacle DETECTION
Precision GPS

MEMS IMU
Sensor FUSION
Cognition
Global and Local Navigation
Actuation
Home-brewed ELECTRONICS
Mechanical ACTUATORS
Substrate
Quad-core PROCESSING
Today..

• Continuing to work on Prospect 12
• Vision remains our focus for depth mapping, object recognition and tracking
• Objective is to pass NJ Driver’s Test.
Evolved Since the DARPA Challenges..

- **“Bus 2.0”** GPS-based (Steering/Lateral-control) Driver Assistance System in Twin Cities
  - Provides lateral-control assistance to buses operating on narrow freeway shoulders

- **Autonomous Buses at La Rochelle** (CyberCars/Cybus/INRIA) http://www.youtube.com/watch?v=72-PISFwP5Y
  - Simple virtual non-exclusive roadway
    - Virtual vehicle-based longitudinal (collision avoidance) and lateral (lane keeping) systems
Evolved Since the DARPA Challenges..

From the Stanford team...

Google Team: ~50 People ~ $15M/yr (chump change)
Addressing the fact that...

We really don’t want to drive...
Addressing the fact that...

We aren’t that good...

>90% crashes involve human error

Google’s:

Estimated Safety Benefits

- Analysis based on NHTSA
- For Highway relevant scenarios
  - 71% fewer crashes
  - 65% fewer injuries
  - 81% fewer fatalities

More on Google: Levandowski Presentation
Google is demonstrating that...

The way to really get STARTED is to concentrate the intelligence in the Vehicle

and be Robust to the infrastructure

Prove the concept in “one” vehicle, then replicate
Beginning to see a response by the vehicle manufacturers...

2013MB ML-Class Active Lane Keeping and JamAssist is coming (video)

The 1st Showroom Taste of Hands-off, Feet-off

Next may be: Daimler’s “6D” vision:
Initial Demonstration
Transit-based Driver Assistance

• “Bus 2.0” GPS-based (Steering/Lateral-control) Driver Assistance System in Twin Cities
  – Provides lateral-control assistance to buses operating on narrow freeway shoulders
  – Based on high precision GPS
Opportunity for a Substantive Extension of Transit-based Driver Assistance

• Specific: “495-viaduct” Counter-flow Exclusive Bus Lane (XBL) [URL]
  – Currently:
    • Fleet of 3,000 buses use the XBL leading to the Lincoln Tunnel & 42nd Street PA Bus Terminal.
    • Unassisted practical capacity: 700 busses/hr (5.1 sec headway)
  – By adding Intelligent Cruise Control with Lane Assist to 3,000 buses...
    • e.g. Daimler Benz Distronic Plus with Traffic Jam Assist
  – Could achieve sustained 3.0 second headways
    • Increases practical throughput by 50%
    • from 700 -> 1,000 buses/hr; 35,000 -> 50,000 pax/hr
    • Increased passenger capacity comparable to what would have been provided by $10B ARC rail tunnel.
Initial Demonstration of Autonomous Transit

- **Autonomous Buses at La Rochelle**
  (CyberCars/Cybus/INRIA) [Video](http://www.youtube.com/watch?v=72-PlSFwP5Y)
  - Simple virtual non-exclusive roadway
    - Virtual vehicle-based longitudinal (collision avoidance) and lateral (lane keeping) systems
Far-term Opportunities for Driverless Transit

• Recall: NJ-wide PRT network
• Objective: to effectively serve essentially all NJ travel demand (all $3 \times 10^6$ daily non-walk trips)
  • Place “every” demand point within “5 minute walk” of a station; all stations interconnected; maintain existing NJ Transit Rail and express bus operations
• Typically:
  – ~10,000 stations (> $25B)
  – ~10,000 miles of guideway (> $100B)
  – ~750,000 PRT vehicles (> $75B)
  – Optimistic cost: ~$200B
Far-term Opportunities for Driverless Transit

- Biggest Issues
  - How to get started
  - How to evolve
  - Cost & complexity of guideway

- What if ????
  - autonomousTaxi (aTaxi) served passengers from curb-side aTaxi stands
  - Offered on-demand service between aTaxiStands using existing streets

- Ability to get started
  - With a few aTaxis from a few aTaxiStands

- and evolve to
  - ~10,000 aTaxi stands
  - ~750,000 aTaxis
  - Offering
    - peak hours: stand2stand shared aTaxi service
    - else: stand2stand shared services and door2door premium service
State-wide autonomous Taxi (aTaxi)

- Ability to serve essentially all NJ travel demand in
  - sharedRide mode during peak demand
  - premium door2door mode available during off peak hours
- Shared ridership allows
  - Av. peak hour vehicle occupancies to ~ 3 persons/vehicle in peak directions
  - Essentially all congestion disappears with appropriate implications on the environment
  - Required fleet-size under 1M aTaxis
    - (3.71 registered automobiles in NJ (2009))
Thank You