Road Manager and Off-Road Manager Views on Automated Transport: Off-Road Activities in the U.S.

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Why is the off-road Perspective Important?  
Problem: How Do You “Finish” The Drive…

- Efforts at Automated Driving have focused on:
  - Paved roads
  - Pavement markings / traffic control devices

- To finish the drive in many places you need:
  - Ability to navigate roads that are not paved or mapped (63% of world wide roads paved, 65% in the US)
  - Environments with lots of vegetation and no stripes/signs
When AVs arrive at their destination…

- On average approximately 63% of the roadways in the world are paved:

<table>
<thead>
<tr>
<th>Selected Countries</th>
<th>Total Kilometers</th>
<th>Paved Kms</th>
<th>Unpaved Kms</th>
<th>Percent Paved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brazil</td>
<td>1,580,964</td>
<td>212,798</td>
<td>1,368,166</td>
<td>13.5%</td>
</tr>
<tr>
<td>Canada</td>
<td>1,042,300</td>
<td>415,600</td>
<td>626,700</td>
<td>39.9%</td>
</tr>
<tr>
<td>China</td>
<td>4,106,387</td>
<td>3,453,890</td>
<td>652,497</td>
<td>84.1%</td>
</tr>
<tr>
<td>Indonesia</td>
<td>496,607</td>
<td>283,102</td>
<td>213,505</td>
<td>57.0%</td>
</tr>
<tr>
<td>Japan</td>
<td>1,217,128</td>
<td>988,536</td>
<td>228,592</td>
<td>81.2%</td>
</tr>
<tr>
<td>Mexico</td>
<td>377,660</td>
<td>137,544</td>
<td>240,116</td>
<td>36.4%</td>
</tr>
<tr>
<td>Russia</td>
<td>1,283,387</td>
<td>927,721</td>
<td>355,666</td>
<td>72.3%</td>
</tr>
<tr>
<td>United States</td>
<td>6,586,610</td>
<td>4,304,715</td>
<td>2,281,895</td>
<td>65.4%</td>
</tr>
</tbody>
</table>

Worldwide Total: 46,771,989 29,364,673 17,407,316 62.8%

- What will happen when an AV needs to leave a highly structured road environment and deliver the riders to the “door”?
  - In the US this will happen very frequently
  - Many large estates / ranches with “last mile” entrances 100m to 1500m
Rural Roads

- Very difficult to pre-drive and map
- Major objects change each season
- Road surface varies widely based on season and maintenance practices

<table>
<thead>
<tr>
<th>Select States (kilometers)</th>
<th>Total</th>
<th>Paved</th>
<th>Unpaved</th>
<th>% Unpaved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texas</td>
<td>512,656</td>
<td>357,499</td>
<td>155,157</td>
<td>30%</td>
</tr>
<tr>
<td>California</td>
<td>273,822</td>
<td>160,797</td>
<td>113,026</td>
<td>41%</td>
</tr>
<tr>
<td>Michigan</td>
<td>195,426</td>
<td>99,667</td>
<td>95,759</td>
<td>49%</td>
</tr>
<tr>
<td>Nebraska</td>
<td>154,802</td>
<td>82,499</td>
<td>72,303</td>
<td>47%</td>
</tr>
<tr>
<td>Alaska</td>
<td>25,088</td>
<td>4,857</td>
<td>20,231</td>
<td>81%</td>
</tr>
<tr>
<td>Total US:</td>
<td>6,584,739</td>
<td>4,214,233</td>
<td>2,370,506</td>
<td>36%</td>
</tr>
</tbody>
</table>
Unusual Road conditions

- Negative Obstacles
- Water with unknown consequences
- Short term construction detours that utilize alternative road materials and limited to no lane markings (use barrels / cones)
State of the Practice: Agricultural

• Constrained environment:
  – Limited perception requirements
  – Limited obstacles
  – Easy location
State of the Practice: Mining

• Constrained environment:
  – Fixed route
  – Very dirty conditions
  – 24x7 operations

Source: Komatsu
State of the Practice (military)
(mules and support tools)

- Squad Mission Support System (SSMS)
  - Active sensor technology
  - Carry loads over difficult terrain

Source: Lockheed Martin
State of the Practice (military)

(small bots)

- Many variants developed
- Some variants deployed
- Challenges:
  - Maintenance issues
  - Proprietary nature of devices

Source: iRobot
State of the Practice (military): AMAS
Introduced “A-Kit” (autonomy) and “B-Kit (by wire)"
State of the Practice (military): SUMET EO-Only Perception
(Introduced “passive sensors”)

Material Classification

Cost Map and Path Planners
State of the Practice (military): Marine Corps SUMET Program

Office of Naval Research – Code 30
Ground Vehicle Autonomy Program:
Small Unit Mobility Enhancement Technology (SUMET)

SUMET v2.0 Experimentation

SwRI – San Antonio, TX
29 November 2012
State of the Practice (military):
Army: DSAT (Dismounted Soldier Autonomy Tools)
ATEC Tested and Deployed System
State of the Practice (military): DSAT Capability Video
Testing

• Commercial:
  – Ad hoc by development organizations at this point
  – No government requirements to “test”

  – Purpose: ATEC testing was a requirement for obtaining a safety confirmation for use by soldiers
  – Process
  – Government provided requirements
  – Tested each formal release (subset of program’s requirements)
  – Tests executed on Army bases with terrain similar to target environment
  – Lesson learned:
    • Little history in testing certifying computerized systems to be “soldier safe”
    • Delays / misinterpretations due to test staff not being familiar with automated driving systems
    • Preliminary testing at contractor’s site with similar terrain
State of the Practice (military): Lockheed Martin K-MAX

- Marine Corps program
- Capable of delivering a full 6,000 lb of cargo at sea level and more than 4,000 lb at an altitude of 15,000 feet.
- First mission in Afghanistan on December 17, 2011.
- Deployment ended 2014

Source: Lockheed Martin
State of the Practice (military): Current Programs

RTK (Robotics Technology Kernel)
Provides: platform, non-proprietary AV

AGR (Autonomous Ground Supply)
Manned Leader, automated follower(s)
State of the Practice (military): Current Programs - continued

Wingman:
- Platoon / convoy
- Cooperative behaviors

Tracked Vehicle Autonomy
(program in the initial stages)
Lessons we have learned in Off-Road Driving

• Perception:
  – No pre-defined markings
  – Dust / heavy moisture complicate recognition
  – Negative obstacles
  – Winding roads limit FOV which is complicated with poor/no lane markings
    • Will AVs need to go slower than humans who can better use the environment to “sense” the direction of curve

• Positioning:
  – GPS may be worse than in “urban canyons” (e.g. heavy tree cover)
  – Pre-recording routes provided limited effectiveness in off-road:
    • Vegetation constantly changes
    • Continual road surface changes
    • Parked vehicles / objects can move
  – Edge detection becomes critical in a non-structured environment

• Route Planning:
  – Alternative routes are less “obvious” (usually unchartered territory)
Questions / Comments?

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