The Future of Automated Self Driving Automobiles

John F. Meagher, CIH
Northrop Grumman/IT Intelligence Group (TASC)
Arlington, VA

AIHCE 2007
Philadelphia, PA
Overview of Five Megatrends Leading to Robotic Individual Transportation in our Future

- **Social**- we need to, safety, aging, youth, behavior of population on the road, quality of life.
- **Technological**- we can do it, convergence of new capabilities with competitive innovation.
- **Economics**- we can make money doing it, new markets and big direct and spin-off revenue opportunities, death and injury loss reduced.
- **Environmental**- we impact environment less, energy savings, traffic congestion, human factors.
- **Political**- challenges may drive this form of solution-military spin-off, looming insurance crisis avoidance, individual acceptance.
Social Drivers

- The Bimodal Age Curve of Youthful and Aging Drivers Intersect in 2010-2015.
- Human Attention Span Challenge/Diversions Grow.
- Language Integration/Immigrant Drivers.
- Driver Behavior Modification Plateaus and is Limited.
- Disparity of the Number of Heavy Vehicles versus Light.
In the U.S., an average of 2,100 workers died from motor vehicle crashes each year between 2000 and 2004.

Since the early 1990s, annual totals have remained static, with increases in the number of fatalities on public roadways offsetting decreases in the number of fatalities off public roadways.
Motor vehicle crashes account for over 35% of all workplace fatalities in the U.S. [Bureau of Labor Statistics 2006].

In the nations of the European Union (EU), road traffic and transport accidents at work account for higher proportions of fatalities, 41% in 1999 [European Commission 2002].

Crash experience for Australia is similar, nearly half of all workplace fatalities between 1989 and 1992 associated with either driving for work or commuting to work.
Number and rate of fatal occupational injuries by industry sector\(^1\), 2005

<table>
<thead>
<tr>
<th>Industry Sector</th>
<th>Number of Fatalities</th>
<th>Fatality rate (per 100,000 employed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>1,196</td>
<td>11.0</td>
</tr>
<tr>
<td>Transportation and warehousing</td>
<td>881</td>
<td>17.6</td>
</tr>
<tr>
<td>Agriculture, forestry, fishing, and hunting</td>
<td>714</td>
<td>32.5</td>
</tr>
<tr>
<td>Government</td>
<td>514</td>
<td>4.8</td>
</tr>
<tr>
<td>Professional and business services</td>
<td>481</td>
<td>2.9</td>
</tr>
<tr>
<td>Retail trade</td>
<td>397</td>
<td>2.2</td>
</tr>
<tr>
<td>Manufacturing</td>
<td>393</td>
<td>2.2</td>
</tr>
<tr>
<td>Leisure and hospitality</td>
<td>210</td>
<td>1.8</td>
</tr>
<tr>
<td>Other services (excl. public admin.)</td>
<td>208</td>
<td>3.0</td>
</tr>
<tr>
<td>Wholesale trade</td>
<td>204</td>
<td>4.4</td>
</tr>
<tr>
<td>Mining</td>
<td>159</td>
<td>25.6</td>
</tr>
<tr>
<td>Educational and health services</td>
<td>149</td>
<td>0.8</td>
</tr>
<tr>
<td>Financial activities</td>
<td>98</td>
<td>1.0</td>
</tr>
<tr>
<td>Information</td>
<td>67</td>
<td>2.1</td>
</tr>
<tr>
<td>Utilities</td>
<td>30</td>
<td>3.6</td>
</tr>
</tbody>
</table>

Total fatalities = 5,702
All worker fatality rate = 4.0

\(^1\) Individual industry sectors exclude data for employees of governmental agencies, which are provided separately.
Rate = (Fatal work injuries/Employment) x 100,000. Employment data based on the 2005 Current Population Survey (CPS) and Department of Defense (DOD) figures.
The four most frequent work-related fatal events, 1992-2005

Number of fatalities

1,600
1,400
1,200
1,000
800
600
400

557 565 590 547 582 579 520 585 571 553 505 531 559 564
560 618 665 651 691 716 714 705 651 677 643 609 632 604
1,074 1,080 1,036 927 860 714 721 734 810 719 696 698 822 767
1,158 1,242 1,343 1,346 1,346 1,393 1,442 1,496 1,365 1,409 1,373 1,353 1,398 1,428

- Highway incidents
- Homicides
- Falls
- Struck by object

NOTE: Data from 2001 exclude fatalities resulting from the September 11 terrorist attacks.
Trend of Little or No Improvement for Occupational Transportation Deaths

- Fatal highway incidents remained the most frequent type of fatal workplace event, accounting for one in every four fatalities nationally in 2005.
- Fatal highway incidents rose by 2 percent in 2005, accounting for 1,428 worker deaths.
- Non-highway incidents (such as those that might occur on a farm or industrial premises) stayed about the same.
- The number of workers who were killed after being struck by vehicles or mobile equipment rose from 378 in 2004 to 390 in 2005.

Automobile/Transportation Safety Statistics-Greater Society

- Nearly 6,420,000 auto accidents in the United States in 2005.
- 2.9 million people were injured
- 42,636 people killed.
- About 115 people die every day in vehicle crashes in the United States -- one death every 13 minutes.
Trend of Little or No Improvement for Greater Societal Transportation Deaths and Injury

- In 2003 there were 6,328,000 car accidents in the US. There were 2.9 million injuries and 42,643 people were killed in auto accidents.

In 2002, there were an estimated 6,316,000 car accidents in the US. There were about 2.9 million injuries and 42,815 people were killed in auto accidents.

In 2000, there were an estimated 6,356,000 car accidents in the US in 2000. There were about 3.2 million injuries and 41,821 people were killed in auto accidents.

More than 3 million people get injured due to car accidents, with more than 2 million of these injuries being permanent.

1,800,000 sustain nonfatal injuries from auto accidents; but 150,000 of these auto injury victims suffer permanent impairments.

Difference in definition of impairment

Range: 8% to 66% suffer permanent injury or impairment

Michael Parenti_Hidden Truth; www.lawcore.com
Heavy vs. Light Vehicle Collisions

- Statistics show more deaths occur in small cars versus large vehicles, including passenger cars, light trucks and SUVs overall.
- Research shows that vehicle deaths go up, safety diminishes, as weight goes up above 4,000 lbs.
- Heavy vehicle collisions with smaller lighter vehicles result in more deaths to occupants of smaller vehicles.
- New increased risk environment for drivers unintended consequence.
No Surprise to IH and Safety Professionals

- Human error to root cause of most transportation accidents on or off the job.
- More than 25% of all car drivers were involved in car accidents in a five year period.
- In more than half of all car accident fatalities, the deceased were found not to be wearing their seat belts at the time of the crash. Even with seat belts being mandatory, a vast majority of people choose to disregard this safety precaution and end up losing their lives because of it.
Self Driving Automobiles
Social Benefits/Consequences

- Drive Time Becomes Personal Time.
- Dramatic Reduction in Loss of Life and Injury Due to Vehicles.
- Individual Freedom via Auto Transportation Enhanced for All Age Groups and Disadvantaged.
- Mass Transit Less Used.
- Freedom to Do What You Want Behind the Wheel (Redefining the American Driving Experience.)
Technological Drivers

- Moore’s Law Still Holding (Double Computing Power/24 months).
- Shift to “Smart Cars” Versus “Smart Highways.”
  - On-Board Sensor/Radar Technology Improving and Miniaturizing.
  - AI for Driving, “faster, effective and more reliable” than human response to driving the key technical challenge.
- Consortiums of the Right Stakeholders Asking the Right Questions for Needed Major, Rapid Technological Breakthroughs (Defense, Automakers, Computers Firms and Regional Highway Administrations)
  - In 1997 there were 26 programs surrounding intelligent highways.
  - NASA Spin-Off from Mars Rover.
  - California’s Partners in Advanced Transportation (PATH) consortium (Richmond, Calif.)
  - National Automated Highway System Consortium (Troy, Mich.)
  - Advanced Transit Association (urban intercity).
Future of the car

In order to limit deaths, there has been a push for self-driving automobiles

- Efforts funded by the NHTSA
- NavLab group at Carnegie Mellon University.
- A current invention is Electronic Stability Program (ESP) by Bosch that is claimed to reduce deaths by about 30% and is recommended by many lawmakers and carmakers to be a standard feature in all cars sold in the EU.
- ESP recognizes dangerous situations and corrects the drivers input for a short moment to stabilize the car.
Electronic Stability Program (ESP®)

- Brake Assist
- ABS
- TCS
- ESP®

**Brake Assist**: Reduces Braking Distance

**ABS**: Braking and Steering

**TCS**: Acceleration without wheel slip

**ESP®**: Counteracts skidding
DARPA Grand Challenge

- 2004 DARPA GC 1
- 134 miles rugged terrain
- Obstacles
- Pilot-less automotive transport; true autonomy goal
- 1 million dollar prize
- Not single car made it past 7 miles
DARPA Grand Challenge

- 2005 DARPA GC 2
- Same goals, new course, 134 miles
- 5 vehicles completed course, 4 within time limits
- Times were close, ranged from about 6 hours, 54 minutes to 7 hours and a half for 4 race finishers.
- Sebastian Thrun and Stanford team won 2 million competition.
  - Adaptive vision software for long range and short range selection of terrain for “Stanley”
- Other race completers used gimble mounted laser rangefinders and other approaches.
- Amazing technical progress in one year on shoestring budgets for many competitors.
Technological Examples
How to Do We Transition?

- Mixed traffic streams of a mimic freeway interchange simulated on-ramp section with autopilot-equipped vehicles and normal manual vehicles.
- General rules for traffic control were proposed for more efficient traffic flow during the transition stage.

Technological Benefits/Consequences

- Automotive Competition Drives Innovation.
- Adaptability of Sensing and Response Technology for Cars to Other Domestic Uses.
- Asimov’s Laws of Robots- Never Harm a Human, Save Yourself Next and Sacrifice Yourself to Save a Human- Must Be Embedded in All Operations for Robotic Autos. If Not, Technological Failure that would lead to Social, Political and Economic Consequences.
Economic Drivers

- Cost to U.S. Economy, Now and in Future, from Lost Productivity in Traffic and Loss of Life/Limb.
- Market Opportunities from Robotic Cars, US and Abroad.
- Road and Infrastructure Costs.
- Defense Needs.
Estimated Cost from Auto Accidents Now

- The financial cost of automobile crashes is estimated at more than 230 Billion dollars annually.

Report Focus

- The scenarios concentrate on the development and application of IMT in three industries that represent different levels of maturity in the adoption of IMT: automotive manufacturing, aerospace manufacturing, and capital project construction.
- 12 major industries and consulting firms in these industry sectors participated in questionnaires, workshops to explore future of IMT in U.S. and world.
- Qualitative and quantitative conclusions drawn from data.
Economic ROI for IMT

- “For our future scenarios, we find that the social rate of return on investments in IMT (a key measure of economic impact) is quite high (72% - 77% per year over 20 years).
- “This suggests that we may be under investing in Intelligent Machine Technology (IMT) development.”
- “IMT has been and will continue to be a key ingredient in the advancement of the manufacturing sector in the years ahead. Arguably, if our investments in this area are not adequate going forward, the high-tech manufacturing sector that “exports” vital technological benefits to other segments of the economy will feel the impact in terms of reduced productivity and competitiveness at home and abroad.”
In 2004, North America was the second largest market for robots, behind Japan and ahead of Germany.

Table 1.1 – Operational Stock of Multipurpose Industrial Robots at Year-End
(Number of Units)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>31,600</td>
<td>34,090</td>
<td>36,710</td>
<td>39,410</td>
<td>43,454</td>
<td>49,130</td>
<td>56,945</td>
<td>60,965</td>
</tr>
<tr>
<td>World Total</td>
<td>381,857</td>
<td>454,465</td>
<td>506,475</td>
<td>537,705</td>
<td>557,516</td>
<td>577,220</td>
<td>605,000</td>
<td>644,200</td>
</tr>
<tr>
<td>North America</td>
<td>66,395</td>
<td>70,466</td>
<td>79,959</td>
<td>89,880</td>
<td>97,257</td>
<td>103,515</td>
<td>112,390</td>
<td>121,937</td>
</tr>
<tr>
<td>World Total</td>
<td>684,059</td>
<td>703,149</td>
<td>723,272</td>
<td>750,729</td>
<td>756,498</td>
<td>770,105</td>
<td>800,473</td>
<td>847,764</td>
</tr>
</tbody>
</table>

Implication for Industrial Hygiene:

- Fewer workers in manufacturing sector, traditional IH reduced in manufacturing sector
- Improved health and safety via exposure source reduction
- Engineering elimination of hazards
- Shift: Greater man and intelligent machine interface IH factors now and in future
Economic Benefits/Consequences

- Auto Industry Re-Transformation
  - Robotic Research and Design-US, National Security Implications.
  - Manufacturing and Assembly-US and Abroad.
  - Increase in Tourism.
- Time= Economic Productivity.
- Cottage Industries for Interior Design and Useful Products for “Extended Living Space” Car Lifestyle.
- Traffic Control, Auto Repair, Insurance Industry and Other Industries Embedded to Human Drivers Negatively Effected.
Environmental Drivers

- Fuel and Energy Use Optimization.
- Road Construction Reduction and Greenspace Conservation.
  - Continual Need to Impact Environment Less from Urban Transportation Footprint
- After fuel cells or electric autos based on green energy what do we do next?
  - Answer: remove inefficiency in consumption and use from human drivers and make better use of current road infrastructure to handle increased vehicles.
Environmental Benefits/Consequences

- Less Pollution From Idle or Inefficient Traffic.
- Robotic Optimum Efficient Vehicle Use Translates into Energy Saving Per Unit (mi/km) Driven
- *Effortless and Pilotless Driving Promotes a Techno-Nomadic Lifestyle and Actually Increases Fuel/Energy Consumption Dramatically.*
Political Drivers

- Traffic Court Operations and Expenditures.
- Road Building and Public Transit.
- Quality of Life Votes.
- “Freedom to Drive” Movement vs. “Robotic Safe Driving for All”
  - Insurance Crisis- Aging Drivers and Younger Ones, Health Care and Liability, Property Damage.
- Public Sector/Private Sector Partnerships Needed for Development Increasing.
Political
Benefits/Consequences

- Reduced State and Municipal Cost Related to Human Automobile Operations (e.g. Training, Licensing, Traffic Violations Control, Traffic Lights and Human Error Highway Infrastructure to Emergency Medicine.)
- Jobs, Jobs, Jobs (New Consumption Patterns.)
- More Time for Citizens to Do Human Activities of Choice.
  - Desirable in an Upcoming Age of Projected Morbidity/Mortality via Genetics
- Insurability or Not (New Regulations.)
- National and International Standards.
- Resistance from Groups Negatively Affected by Change to Robotic Auto’s.
- Resistance from Citizens to Human Piloting.
- Phased Integration of Robotic and Human Drivers.
IMT NIST Report
Automotive Future Scenarios

**CONSERVATIVE**

**2015**

1. **Computer-Aided Humans**
   - Enterprise integration software common
   - Standardized data exchange throughout enterprise and supply chain
   - Virtual models used for most product testing
   - Single-task computer controlled and robotic tools
   - Single $1000 PC performs $10^{11}$ operations per second
   - Demand high in all focal industries, especially alternative fuel vehicles and unmanned aerial vehicles

**2025**

3. **Human-Machine Partnership**
   - Fully integrated enterprise (IT and tools)
   - Semi-intelligent, learning systems
   - Predictive, adaptive, multitasking robots and machine tools
   - Sensor integration with enterprise systems
   - Self-monitoring tools
   - Single $1000$ PC performs $10^{13}$ operations per second
   - Demand higher in all focal industries
   - 10 extra years over scenario 2 increases IMT penetration and product demand

**OPTIMISTIC**

**2015**

2. **Human-Machine Integration**
   - Fully integrated enterprise (IT and tools)
   - Semi-intelligent, learning systems
   - Predictive, adaptive, multitasking robots and machine tools
   - Sensor integration with enterprise systems
   - Self-monitoring tools
   - Single $1000$ PC performs $10^{13}$ operations per second
   - Demand high in all focal industries
   - Rapid advance in IMT gives early adopters competitive advantages

**2025**

4. **Machine Oversight**
   - IMT outperforms humans in logical tasks
   - IMT enterprise systems interact directly with supply chain and market
   - Lights out factories, construction sites
   - Real-time and predictive process optimization
   - Autonomous robots widespread
   - Ubiquitous sensing and computing
   - Self-repairing systems and robots
   - Single $1000$ PC performs $10^{15}$ operations per second
   - Demand highest in all focal industries

*NB: Scenarios 2 and 3 share IM technology, but differ in rate of penetration and final market demand for products.*
Penetration into:
- Enterprise Information Technology
- Design & Test Engineering
- Business Support & Analysis
- Production or Construction Operations
- Material Handling
- Logistics
- Supply Chain Management
# Machine Oversight

## Automotive Industry

- World population growth and rising affluence continues to grow demand for alternative fuel automobiles and trucks
- ~300 million licensed drivers in US
- Intelligent-system-designed advanced materials (e.g., composites, alloys, aerogels, concretes, ceramics, and nanomaterials), tools, and production techniques provide across-the-board opportunities for major product and process changes
- Auto-piloted cars are safer and more efficient than human driven cars on road or off and available as a standard option
- Army logistics convoys are fully automated
- Army indirect fire, direct fire, and scouting vehicles fully automated

## Mainstream Intelligent Machine Technologies

- Agile lights-out facilities, running 24 hours per day, and allowing mass customization (i.e., individually tailored vehicles with pricing reflective of economies of scale)
- Supercomputer overseer information system models real world and predicts all factory intelligent machine behaviors in advance, giving them the benefit of its integrated insights and overcoming potential production issues in virtual space
- Modeling and simulation of materials and processes enable cars and trucks to be manufactured with sufficient predictability that the first product, and every subsequent product, meets specifications
- Networked intelligent machines are self-diagnosing, self-reconfiguring, and able to re-task themselves to optimize their workflow

## Cutting-Edge Intelligent Machine Technologies

- Maintenance and repair of intelligent machines managed and conducted by robots
- Time from design to production of automobiles and trucks is reduced to 3 months
- Time from customer design order to loading on hauler is less than 24 hours
- The factory itself manages supply chain communications and configures production to match its requirements forecasts and past experience
“The automotive industry has the highest penetration of IMT systems and devices today in 2006. The most advanced large-scale manufacturers use them in almost all functions. Japan’s leadership in both robotics and automobile manufacturing, combined with its emphasis on automation over immigration, will play an important role in maintaining the push for automotive automation. This global competitive pressure and increasing demand for automobiles as world population continues to rise, will ensure continued early adoption of IMT technologies by this industry “
Three Possible Futures for Robotic Automobiles

- Full Service “All the Way” Robotic Autos-
  - Mode of Transportation of Choice for U.S.
  - Freedom and Safety Key.
  - Human Remote Control Taxi’s for Aged, Youth and Disadvantaged. Virtual Reality Professional Drivers on Call 24 Hours.
  - *Driving Yourself is Like Riding A Horse Now, Fun to Do on Occasion but Impractical for Everyday.*
Three Possible Futures for Robotic Automobiles

- Hybrid - Part Robotic Automobile/ Part Human Driving.
  - Automated Autos for High Risk, High Speed areas (long highway driving, 40 mph or higher.)
  - Tedious and Monotonous Tasks (e.g. parking.)
  - Human Drivers used for Short Trips (25-35 mph or slower.)
  - On Board Computing Assistance with Voice Activation/Buttons - Dials Removed as an Unneeded Distraction in Many Functions (e.g. directions, maps, radio, CD.)
Three Possible Futures for Robotic Automobiles

- Never Arrives-Human Driving is Essential and Protected
  Right, We Work to Improve Human Behavior Behind the
  Wheel and Robotic Driving Techno Challenges Never
  Mastered to Acceptability by US Public.
  - Testing and Training in Virtual Reality for Youth (Games
    at Early Age) and Seniors Becomes the Norm.
  - Vision and other enhancement drugs for elderly to
    improve performance.
  - Continued Improvement of Safety Features and Injury
    Free/Crash Proof Automobile.
  - Insurance Industry Expands and Absorbs the Cost for
    Elder and Youthful Drivers.
  - Telecommuting and Telework Grows Dramatically in All
    Scenarios.
We Will Soon Know Where We Are Headed

- Emergent Future Path Apparent By 2010.
- Decision makers in Science and Other Arenas Can Influence Policy Now.
- Pick the Future that is Best.
Acknowledgements

- TASC/NG IT; David Leech, Jim Burke, Matthew Russell, Christopher Waychoff, John T. Scott (consultant)
- Washington Academy of Sciences
- Lawrence S. Hecker, President
  Automotive Maintenance and Repair Association (2003)NERAC