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AN ASSESSMENT OF AUTONOMOUS TRACTOR-TRAILER USAGE FOR FULL TRUCK LOAD SHIPMENTS

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ABSTRACT

The purpose of this thesis is to explain the future outlook of autonomous vehicles through the lens of driverless tractor-trailers and their impact on transportation. Research was conducted through interviews with leaders in robotics and information systems management. The strengths, weaknesses, opportunities, and threats of autonomous vehicle usage were analyzed.

Through this research it was determined that autonomous vehicles have the ability to revolutionize ground transportation by making shipments more efficient, affordable, and safe. Companies should considering purchasing autonomous tractor-trailers in the future, but only after the trucks have been on the market for a few years. By waiting a few years, companies will be able to capitalize on reduced costs, better safety, and established regulations on this new technology.

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Chapter 1

Introduction

Within any supply chain, transportation is the largest variable cost and, therefore, it is one of the most important decisions a supply chain executive must make. Tractor-trailers are the most commonly used transportation mode for intermodal shipments. Something revolutionary is on the horizon: autonomous vehicles. According to Nevada's new transportation law, an autonomous vehicle is defined as "a motor vehicle that uses artificial intelligence, sensors and global positioning system coordinates to drive itself without the active intervention of a human operator" (Rich, 2012). The technology is currently being developed that eliminates the need for a driver. Tractor-trailers, trains, planes, and more are moving towards fully autonomous technology. For the purpose of this thesis, the focus will center on autonomous vehicles and the feasibility of autonomous tractor-trailers.

Soon these autonomous vehicles will be introduced to the mass market; making the right decisions on whether or not to use these new types of technology becomes vital. Through driverless technologies, companies will be able to save time, money, and lives while getting product into its customer's hands more efficiently than ever before.

Through this thesis, the current state of the commercial trucking market will be explained. The shortage of drivers, restrictions on hours, and common crash causes will be discussed to demonstrate a need for new technology within the commercial trucking industry. This thesis will focus on full truckload shipments and highway driving.

After a background on the state of the commercial trucking industry, the development of autonomous vehicles in both academic and commercial settings will be discussed. Within the academic side, the 2007 DARPA Urban Challenge ignited the interest in driverless vehicles at universities across the nation. Carnegie Mellon University in conjunction with General Motors took first place. Dr. John M. Dolan of the Robotics department at Carnegie Mellon University serves as a great reference for this thesis. The commercial side will focus on high tech companies like Google and car companies like Delphi and Mercedes Benz. Mercedes Benz promises a fully autonomous tractor-trailer on Europe's roads by 2025 (Davies, 2014). Both technology and car companies are working quickly to put autonomous vehicles in the hands of consumers.

The feasibility of autonomous tractor-trailers from a technology perspective will be examined followed by an explanation of the barriers to entry for adding autonomous vehicles to the roads worldwide. Legal implications of driverless vehicles must be examined as well. Lastly a final recommendation for this new autonomous technology will be given.

Chapter 2

The Current State of the U.S. Trucking Market

The current state of the U.S. trucking market is less than healthy. There are a variety of reasons for this including: truck driver shortages, tight restrictions on hours driven, and bad publicity from crashes involving tractor trailers. This chapter will examine the current state of the trucking market as an illustration as to why the introduction of autonomous tractor trailers would revive the trucking industry.

A shortage of truck drivers has been an issue in the United States since the recession. At that time, this shortage was not as big of an issue because the recession limited the demand for tractor-trailer shipments. As the economy has improved, the need for tractor-trailers and drivers has returned and increased. As demand returned for trucks, the shortage of truck drivers became very evident. The number of truck drivers after the recession was less than the number of truck drivers before the recession (Cassidy, 2014).

There are many causes of the truck driver shortage including an aging population, the stigma of being a truck driver, and strict regulations. The population is aging and older truck drivers are retiring (Hingham, 2012). Many experienced drivers are reaching the end of their careers. Today, the number of current commercial drivers is less than the total number of open commercial driver positions. Older drivers are continuing to retire which continues to grow the driver deficit (Wee, 2014). As these drivers retire, more spots become available for new drivers. Here lies a problem: the younger generation is less interested in becoming drivers.

The current generation considers truck driving a less desirable career path. Deloitte's Manufacturing Institute ran a study to understand the industry preferences of 18-24 year olds for the beginning of their careers. Below, in Table 1, are the top industry preferences as determined by Deloitte's Manufacturing Institute (Wee, 2014):

Rank	Industry
1	Technology
2	Energy
3	Health care
4	Communications
5	Manufacturing
6	Financial Services
7	Retail

Table 1: Industry Preferences of 18-24 Year Olds

Studies done by trucking and transportation groups such as the American Trucking Association and Federal Motor Carrier Safety Administration show that truck driving is an unattractive career choice for young people (Higham, 2012). How can companies sell commercial driver positions to young job applicants? The answer may be as simple as increased pay or shorter hours, but the company may not be able to afford either. Here lies the difficulty in reducing the shortage in commercial drivers.

Thirdly, government restrictions on drivers is limiting the amount of qualified applicants. For safety reasons, commercial drivers must meet certain body mass index (BMI) requirements and pass exams and drug screens. The current system evaluates candidates based on BMI, their ratio of height and weight, and their neck size but does not take physical fitness or body composition into the picture. This means that larger candidates are getting passed up simply because their BMI is considered overweight even though their weight may or may not interfere with their ability to drive a tractor trailer.

Current Hourly Regulations

Think of how much more could get done if there were more hours in the day. This is exactly how the commercial trucking industry is currently operating. To maintain the safety of the truck driver and other occupants of the road, limitations on how long drivers may operate are in place. Table 2 below outlines the current regulations for commercial drivers' hours of service (FMCSA, 2014).

Hours of Service Rules
11-Hour Driving Limit May drive a maximum of 11 hours after 10 consecutive hours off duty.
14-Hour Limit May not drive beyond the 14th consecutive hour after coming on duty, following 10 consecutive hours off duty. Off-duty time does not extend the 14-hour period.
Rest Breaks May drive only if 8 hours or less have passed since end of driver's last off-duty or sleeper berth period of at least 30 minutes. Does not apply to drivers using either of the short-haul exceptions in 395.1(e). [49 CFR 397.5 mandatory "in attendance" time may be included in break if no other duties performed]
60/70-Hour Limit May not drive after 60/70 hours on duty in 7/8 consecutive days. A driver may restart a 7/8 consecutive day period after taking 34 or more consecutive hours off duty.
Sleeper Berth Provision Drivers using the sleeper berth provision must take at least 8 consecutive hours in the sleeper berth, plus a separate 2 consecutive hours either in the sleeper berth, off duty, or any combination of the two.

Table 2: Current Regulations on Hours Driven for Commercial Drivers

Drivers are physically limited to how long they can safely drive before their attention fades or the risk of falling asleep escalates. These time limits improve the safety of drivers, cars on the road, and pedestrians. From a safety perspective these restrictions are necessary. From a supply chain perspective, these limitations create bottlenecks on transportation speed. Trucks take longer to arrive at destinations or multiple truck drivers are needed to get the job done.

Crash Data

A big fear in trucking is the risk of crashes. Crashes are bad news for companies for multiple reasons: physical injuries and deaths, damage to vehicles, lawsuits, and bad publicity for the company. The repercussions of a crash last long after wounds heal and damage is repaired. For companies, the bad press that comes with a crash can cause irreparable damage to a company's reputation with its consumers. The June 7, 2014 Wal-Mart truck accident in Cranbury, NJ illustrates just that. A Wal-Mart truck crashed into the back of celebrity Tracy Morgan's limousine. The investigation identified that the driver had driven 13 hours and 32 minutes at the time of the accident. The driver was 20 miles from his destination with 27 minutes of time left before his hours ran out (Epstein, 2014).

As seen in the Wal-Mart accident, the actions of one driver can affect an entire company's image in the public's eye. The crash also demonstrated that hourly restrictions do not ensure safety or high driver alertness.

The U.S. Department of Transportation's National Highway Traffic Safety Administration published Traffic Safety Facts of Large Trucks using 2012 data. The report identified the number of crashes involving large trucks and different configurations of the data to illustrate causes, a break down by the state level, etc.

According to the study, the majority of fatalities and injuries in crashes involving large trucks are the occupants of other vehicles involved in the crash (US DoT & NHTSA, 2014).See Table 3 below.

People Killed or Injured in Crashes Involving Large Trucks, 2011–2012

	2011		2012	
People Killed	**Number**	**Percentage of Total**	**Number**	**Percentage of Total**
Occupants of Large Trucks	640	17%	697	18%
— *Single-Vehicle Crashes*	*408*	*11%*	*424*	*11%*
— *Multiple-Vehicle Crashes*	*232*	*6%*	*273*	*7%*
Occupants of Other Vehicles in Crashes Involving Large Trucks	2,713	72%	2,843	73%
Nonoccupants (Pedestrians, Pedalcyclists, etc.)	428	11%	381	10%
Total	**3,781**	**100%**	**3,921**	**100%**
People Injured	**Number**	**Percentage of Total**	**Number**	**Percentage of Total**
Occupants of Large Trucks	23,000	26%	25,000	24%
— *Single-Vehicle Crashes*	*7,000*	*8%*	*9,000*	*9%*
— *Multiple-Vehicle Crashes*	*15,000*	*17%*	*17,000*	*16%*
Occupants of Other Vehicles in Crashes Involving Large Trucks	64,000	72%	76,000	73%
Nonoccupants (Pedestrians, Pedalcyclists, etc.)	2,000	2%	3,000	3%
Total	**88,000**	**100%**	**104,000**	**100%**

Note: Injury totals may not equal the sum of components due to independent rounding.

Table 3: Fatalities and Injuries in Crashes Involving Large Trucks

Causes of Accidents

According to the 2007 Large Truck Crash Causation Study conducted by the Federal Motor Carrier Safety Administration, the below are the ten most common causes of truck crashes (Craft, 2009):

1. Brake problems
2. Traffic flow interruption (congestion, previous crash)
3. Prescription drug use
4. Traveling too fast for conditions
5. Unfamiliarity with roadway
6. Roadway problems

7. Required to stop before crash (traffic control device, crosswalk)
8. Over-the-counter drug use
9. Inadequate surveillance
10. Fatigue

These crash causes involve a mixture of human error, road issues, and truck problems. The majority of these problems can be reduced or completely removed if autonomous capabilities are added to large trucks.

Chapter 3

Autonomous Vehicles

The technology is here. Between big companies like Google and Delphi, and top Universities like Carnegie Mellon and Stanford, driverless cars are currently being tested on national and international roads. These companies and universities are still perfecting the technology, but autonomous vehicles are becoming a close reality. Predictions on when fully autonomous vehicles differs by expert. According to Tesla's Elon Musk, he predicts autonomous cars will dominate the roads by 2035 and that there is a high probability human drivers will be banned (Poeter, 2015).

How Autonomous Vehicles Work

Every car manufacturer is different when it comes to their autonomous vehicle's design but there are a few common types of technology used. The three most notable types of technology used include LiDAR, GPS, and a computer system to make thought-through decisions on what to do on the road. In a video by the Telegraph UK, the video explains the different types of technology that enable cars to drive themselves (Armstrong, 2015).

Radar sensors monitor the position of the car by releasing signals to understand vehicles near by. Video cameras scan for traffic lights, road signs, other vehicles, and pedestrians. LiDAR sensors detect the edges of the road and other line markings. LiDAR sensors work by bouncing pulses of light off of its surroundings. Ultrasonic sensors in wheels can detect edges of the road. The central computer system then analyzes all of the collected data to control the steering, acceleration, and breaking. Some of the predicted benefits to autonomous vehicles are reductions in accidents, emissions, and congestion (Armstrong 2015).

Educational Development of Autonomous Vehicles

DARPA Urban Challenge

Once seen as science fiction, driverless cars are becoming a reality. DARPA's 2007 Urban Challenge jumpstarted the development of fully autonomous vehicles. As the DARPA Urban Challenge website explains:

> [T]his event required teams to build an autonomous vehicle capable of driving in traffic, performing complex maneuvers such as merging, passing, parking and negotiating intersections. This event was truly groundbreaking as the first time autonomous vehicles have interacted with both manned and unmanned vehicle traffic in an urban environment (DARPA, 2008).

Many teams applied and 35 received invitations to the National Qualification Event. After various rounds and tests including intersections, traffic lights, and road obstacles, the final teams were announced. Eleven teams were invited to the Final Event on November 3, 2007. At this Final Event, the cars were put through the ultimate test of a planned course and a mission. The requirements of the mission were released just five minutes before the start of the final round. To make the challenge more realistic, thirty manned cars were added to the course to resemble typical driving conditions.

The top finishers were Tartan Racing in first place and Stanford Racing in second. Carnegie Mellon partnered with General Motors to form the Tartan Racing Team. To get a better understanding of the current technology and future feasibility of autonomous tractor-trailers, an interview was conducted with Carnegie Mellon University's Professor John M. Dolan. Professor Dolan is a Mechanical Engineering professor with a strong focus on autonomous vehicles and technologies to improve interactions between humans and technology. He worked with students and academics on the Tartan Racing team and watched his team place first.

Tartan Racing's win got the attention of some big names in transportation. Most recently, Carnegie Mellon University and Uber have teamed up to work on autonomous vehicles projects. Speculations predict a "driverless cars on demand" project.

Commercial Development of Autonomous Vehicles

From the commercial side, both car companies and high tech companies are working towards fully autonomous vehicles. Chris Taylor for Mashable noted that, "The number of miles now driven by all car companies involved in this driverless race now exceeds 1 million" (Taylor, 2015). These cars are operating on U.S. and European roads and are proving that the technology is becoming closer and closer to being in everyone's garages. Some of the biggest names in the autonomous vehicle development are Google, Delphi, and Mercedes Benz. Mercedes Benz is actively working toward bringing autonomous tractor-trailers to the market by 2025.

Autonomous Cars

Google

Google is a unique company. Originally a search platform, Google has transformed itself into a high tech company with products and initiatives in a wide array of markets. Most relevant to this thesis is Google's increased interest in robotics. Google's division, called Google X, has hired robotics experts from top institutions to work around the globe, including Chris Urmson from Carnegie Mellon University. Urmson is the Self-Driving Car Director at Google. With all of these robotics experts on Google's staff, Google has developed fully autonomous cars. In total, Google's autonomous vehicle fleet has driven over 700,000 miles (Davies, 2015).

Google's street mapping, which was initially used for Google Maps, is facilitating the navigation of autonomous vehicles through the streets. Google has launched a variety of autonomous vehicles including outfitted Toyota Priuses and more. In December of 2014, Google unveiled its first fully autonomous car that was designed by Google. In the four months since announcing the car, Google has put the car through various rounds of testing, proving that there are still many nuances of driving to be understood, but the car is doing very well. The car has a very futuristic look and no steering wheel. Figure 1 below shows Google's latest self-driving car.

Figure 1: Google's Latest Self-Driving Car

In a recent TED conference with Google director Chris Urmson, he mentioned that Google is striving to have fully driverless cars available by 2020 (Mlot, 2015). Urmson was recruited to Google after his success at Carnegie Mellon University though his work on the

DARPA military challenge in 2005, and winning the DARPA Urban Challenge with team Tartan Racing in 2007.

Urmson explains that Google will most likely work with an automotive company to manufacture their autonomous cars instead of working alone. Google's strengths are the technology, but not the physical manufacturing of cars. As Urmson put it, "We think the right answer is to work with an automotive company. It turns out they're really good at what they do" (Atiyeh, 2015).

Delphi

The biggest new name in autonomous vehicles is Delphi. On May 22, 2015, an upgraded Audi SQ5 with autonomous technology began a newsworthy road trip at the Golden Gate Bridge. The trip started in San Francisco and ended in Manhattan, New York. The car was outfitted with a variety of technology additions to drive on its own: "radar, high-end microprocessors, and software to let the car make human-like decisions such as exiting and entering highway traffic, navigating city streets or parking" (Isidore, 2015).

After nine days, 15 states, and 34,000 miles, the Delphi Autonomous Audi SQ5 arrived in downtown Manhattan. The car drove itself 99 percent of the time, with a driver only stepping in when taking the car off of the highway and onto city streets (Davies, 2015).

This drive was a huge step for all companies working on autonomous vehicles because it demonstrated to the public that the technology works and is safe. Improving the public perception of driverless cars is a big step in the right direction.

Figure 2 below is Delphi's Audi SQ5 at the beginning of its journey to Manhattan.

Figure 2: Delphi's Audi SQ5

Autonomous Tractor Trailers

Mercedes Benz

Mercedes Benz has announced plans and videos for the "Future Truck." The Future Truck is a concept and design that promises to revolutionize supply chains across the globe. Mercedes Benz plans to debut the Future Truck in 2025, a rendition of the Future Truck is shown in Figure 3. Concept videos display that the truck driver will drive the truck onto the highway, then once 50 mph is reached, the autopilot engages. The tractor-trailer will drive itself and will notify the driver should he or she have to step in. The videos illustrate a radically new image of what a truck driver looks like and can also be seen in Figure 4 (Davies, 2014).

Figure 3: The Future Truck Exterior

Figure 4: The Future Truck Interior with Driver

The driver is a clean-cut man that looks like he works in a corporate office. As soon as the tractor-trailer switches to autopilot, the driver is free to work on his tablet computer or other mobile device (YourCar, 2014). This brings up the question of what does a future truck driver look like? Can autonomous tractor-trailers serve as a mobile office? Will we see accountants "driving" trucks?

Testing Autonomous Vehicles

M City

Currently driverless vehicles are being tested on roads across the world and share the road with other drivers. On June 20, 2015, the University of Michigan is opening M City, a 23-acre mock city where autonomous car manufacturers will be able to test their vehicles. The $6.5 million miniature mock city includes 40 building facades and driving obstacles of every sort (Businessweek, 2015).

M City will be an important step in bringing autonomous vehicles to customers by allowing manufacturers to run different simulations and improve vehicles' handling.

Chapter 4

Interviews

Interviews were conducted with Carnegie Mellon's Principal System Scientist John Dolan and Penn State's Clinical Professor John Jordan to better understand the current state of autonomous vehicle technology and the scalability of the technology to tractor-trailers. Interviews with both of these robotics experts, Dolan from an engineering perspective and Jordan from a business perspective, give insight into when this technology will become available, costs, risks, opportunities, barriers to entry, and best practices.

Dr. John Dolan

Professor John M. Dolan is a Principal Systems Scientist at the Robotics Institute at Carnegie Mellon University. Dolan participated in the 2007 DARPA Urban Challenge with team Tartan Racing. His latest projects focus on autonomous cars and the communication between technologies. In the context of driverless vehicles, he focuses on developing the technology for "vehicle-to-vehicle" (V2V) communication. In other words, the technology will allow vehicles to transmit data to one another to improve the driving capabilities of all vehicles involved.

Dr. John Jordan

Dr. John Jordan is a clinical professor in Penn State University's Department of Supply Chain and Information Systems Management. He has had experience both in industry and education. Most recently Jordan published *Information, Technology, and Innovation* with John Wiley. He has also published books on global business model innovation, and on human-centric information fusion (Jordan, 2012).

Interview Analysis

Through interviews focusing on autonomous vehicles and applying this technology to driverless tractor-trailers, several distinct themes surfaced. These themes include: establishing a timeline, the feasibility autonomous tractor-trailers, costs, hacker threats, insurance, legal issues, public acceptance, and technology still needed.

Both Dolan and Jordan agree that in the near future, driverless cars and tractor-trailers will be on roads across the globe. Both also agree that though the technology is coming fast, the days of cars without steering wheels or breaks is far away. For the near future, all autonomous vehicles will require a driver to be in the car just in case something goes wrong and the driver needs to take over the vehicle. The remaining analysis assumes that a human needs to be present in these vehicles; however, during the majority of the time on the road, the "driver" can work on other activities with hands off the steering wheel and eyes off the road.

Timeline

Currently various car makers are working on driverless vehicles. As mentioned previously companies like Google have 700,000+ miles of road time already. Dolan estimates that by 2020, there will be 95 percent autonomous capabilities in vehicles. The technology has mastered highway-style driving but still has difficulty in urban environments. On the highway, cars do not need to look out for pedestrians, bikers, and for the most part, stop lights. Highways are well mapped and fairly simple. Urban and rural driving, on the other hand, need a much different set of skills with more complex sensing and decision making. Autonomous cars' strong ability to drive on highways makes the technology perfect for tractor-trailers, where the majority of driving is done on large stretches of highway.

Jordan's insight aligns with Dolan's. Jordan believes that autonomous tractor-trailers will come to market before consumer-owned autonomous cars. Big names like Wal-Mart and Schneider Trucking could be some of the first big customers for these tractor-trailers. He cites the nature of highway driving as the reason tractor-trailers will be introduced to the market before cars. He predicts tractor-trailers will be on the market for big corporations between 2020 and 2025, a slightly later date than Dolan predicted. This number is based on Mercedes Benz's Future Car launch date of 2025. Within the car area, Jordan predicts a "cars on demand" type services similar to Uber will be the first popular way to transport passengers autonomously.

Feasibility of Autonomous Tractor-Trailers

Dolan and Jordan believe that driverless technology is scalable to tractor-trailers. To account for the larger mass and size of the tractor-trailer, more sensors will need to be added to better sense the tractor trailer's surroundings and account for blind spots. With the current state of autonomous sensors and computers, the tractor trailer could successfully drive on highways. Where the tractor-trailer would struggle is on urban roads and the nuances of truck driving. These nuances include parking, driving up to customer docks, etc. To accommodate for the difficulty the tractor-trailer would have on these specific tasks, Dolan recommends the driver step in to manually drive the truck. The driver would be in charge of all activities except highway driving, meaning that the driver would get the truck on the highway and off, and leave the rest of the driving to the tractor-trailer, sensors, and computers.

Costs

Dolan predicts that on the consumer side, high-end car companies will be the first to introduce autonomous cars to market. High end cars like Mercedes Benz and BMW already offer semi-autonomous technologies in their vehicles such as automatic parallel parking and lane centering. Also, customers in the high-end car market are more willing and able to spend more on a car. Dolan predicts that autonomous cars will be priced at 20 percent higher than current car costs due to the high cost of LiDAR sensors and other accompanying technology. After several years the technology will become more affordable due to economies of scale and Moore's Law.

Jordan also mentioned that with time, the technology will become more affordable through economies of scale and innovation. Initially the costs of autonomous tractor trailers will be more expensive, but over time these vehicles will save money on variable costs such as fuel and repairs. Human drivers have a tendency to over-accelerate then brake, wasting fuel and wearing down break pads. The computer system will drive the vehicle at the optimal speed, reducing fuel usage and need for repairs. Another large opportunity for cost savings is labor. If the driver is no longer "driving" the tractor-trailer but is instead simply in the driver's seat as a precautionary measure, the hourly rate for drivers can be reduced.

As Jordan notes, companies have a tendency to invest in infrastructure rather than people as demonstrated with the addition of robots into factories world wide. It is easier to quantify cost savings when automation takes place.

Hackers

A notable risk with autonomous vehicles is the vehicle's susceptibility to hackers. Since these vehicles are steered by a combination of computers and sensors, hackers will have the ability to hack into these devices. Dolan compares the protection against hacker to the protection against diseases. As a new disease develops, a vaccine is created. When the disease mutates and begins to infect people again, the vaccine is altered. This is how he anticipates car companies will handle hackers. Once it happens, the security will be improved, and so on.

There is a heightened risk from hackers because of the vehicle-to-vehicle communication. Vehicles talking to one another is great for sharing information and learning from other vehicles, but it also means increased susceptibility to hackers.

Jordan agrees that hackers are a big threat when it comes to autonomous vehicles. He predicts that before these vehicles come to market the technology must be designed to be impervious to hackers. Vehicles that drive themselves open up a wide array of new concerns and questions. Will this technology be used for good or evil? When will there be the first self-driving car bomb? How will police be able to control or stop these vehicles? There are still many questions that need to be answered before this technology is available to consumers and businesses world wide.

Insurance

Both Jordan and Dolan predict insurance responsibility will transfer from the vehicle's owner to the vehicle's manufacturer. If the control of the vehicle is transferred from the driver to the vehicle, now the vehicle manufacture should hold the liability. For example, if Schneider Trucking owned a Mercedes Benz autonomous tractor-trailer, Mercedes Benz would hold the insurance for the vehicle. The only case in which the car manufacturer should not hold the insurance is if the autonomous components were purchased from another company. In that case, the manufacturer of the autonomous components should hold the insurance, not the vehicle manufacturer.

To ensure the vehicle is safe on the roads, Jordan recommends installing an inspection system similar to that of airplanes. For example, if Wal-Mart were shipping product from Newark to Chicago in an autonomous tractor-trailer, a system of checks would need to be completed before the tractor can leave Newark. The systems then move the liability into the hands of the users if the inspections are not done properly. The inspections would check that both the hardware and software of the vehicle are working.

Legal Issues

From a legal perspective, analysis needs to be done for autonomous vehicles to become a common sight on roads. Currently only four states have laws allowing driverless cars on the roads: California, Nevada, Florida, and Michigan. In all of these states, a driver and co-driver must be present in the vehicle and that vehicle must have a steering wheel and brake in case of an emergency. Before autonomous vehicles hit the market, a standardized law needs to be enacted to define what is and is not allowed in terms of driverless vehicles.

Public Acceptance

Public perception is another barrier to entry for autonomous vehicles. The public is warming up to the idea of driverless vehicles and has become more accepting over time, however there are still many skeptics. It will only take one crash involving an autonomous vehicle for the public to question the safety of these new vehicles. For that reason, manufacturers are not rushing to putting these vehicles on the road, but instead are being careful to work out as many issues with the technology as possible

Crashes are an enormous risk for autonomous vehicles for two reasons: endangering lives and bad reputations for the new technology. A gradual introduction could help ease the public into this new type of technology in their lives.

Technology Needed

Within the umbrella of technological barriers to entry there are two main types: technology within the vehicle and infrastructure. As mentioned previously, the technology within the autonomous vehicles is still being perfected and improved to better handle urban driving. Before those capabilities are fully developed, there will not be a 100 percent fully-autonomous vehicle. From the infrastructure side, many decisions need to be made. Who will pay for “smart” transmitters to be added to road signs, red lights, and roads? Is that the responsibility of local governments, car companies, both?

Also, will drivers be willing to share the road or will driverless vehicles have a specific lane? If so, money will need to be invested to add these lanes to roads across the nation.

Chapter 5

SWOT Analysis

To better assess whether using autonomous tractor-trailers is a beneficial for companies, a SWOT analysis was created. The analysis displays the strengths, weaknesses, opportunities, and threats associated with using autonomous tractor-trailers in the supply chain. Table 4 below outlines the SWOT analysis:

Strengths	**Weaknesses**
• Reduction is emissions • Less repairs caused by human error • Less restrictions on hours driven • Reduced need for drivers • Less variable costs • Faster deliveries	• More expensive capital costs • New driver training • Public perception • New infrastructure needed • Not fully autonomous (yet) • Maintenance/inspection of autonomous components
Opportunities	**Threats**
• More hours to drive • Mobile office • Increased interest in truck driving • More efficient supply chains • Less crashes, better publicity • Saving money in long term • Augmented Reality	• Crashes in any amount • Unions • Liability disputes • Hackers and Security • Government restrictions

Table 4: A SWOT Analysis of Autonomous Tractor-Trailer Usage

Strengths

There are many strengths to using autonomous tractor-trailers for long-haul shipments. Some of these strengths are cost savings and improving the efficiency of deliveries. By driving more effectively, the tractor-trailers will use less fuel than a human driver would use. Also the tractor-trailer will drive more effectively, meaning less wear and tear on the breaks and engine. Since the driver does not need to be fully alert while driving, restrictions can be lifted or improved for the number of hours driven. By reducing hour restrictions, deliveries can get to customers faster than ever before because the driver does not need to take breaks or rest days. Ultimately, decisions on transportation focus on two variables: price and customer service. The faster product can get to the customer while also maintaining cost savings means a happier company and customer.

Weaknesses

Some of the weaknesses associated with employing autonomous tractor-trailers in the supply chain include higher fixed costs and the need for new training and infrastructure. These new autonomous vehicles will cost more because of the combination of sensors, radar, LiDAR, and computer components not originally found in a tractor-trailer. Dolan predicts that these vehicles will initially cost about 20 percent more than current tractor-trailer prices but may decrease over time towards a 10 percent premium (Dolan, 2015). Besides the price of the vehicle, new training will need to be developed and taught to drivers of these new vehicles. The changing responsibilities could lead to an influx of tractor-trailer driver applicants, requiring companies to train drivers that have never driven a tractor-trailer before.

To make road signage and stoplights easier to read for autonomous vehicles, sensors and other infrastructure will need to be installed. This will alert the vehicle what color the stop light is and how to respond. The problem is who is responsible for purchasing and installing sensors like these on roads across the county and globe.

Another big weakness with autonomous vehicles is convincing the public that autonomous vehicles are not dangerous and that they can actually improve the lives around us. Science fiction and the media have a tendency to put impressions of technology in our minds without the product being real. Now car and truck manufacturers must find ways to convince the public that this technology should not be feared.

Lastly, the technology is not 100 percent autonomous yet so there is still work and development that need to be done to make autonomous vehicles fully automated. For now, cars and tractor-trailers will still need help with urban driving and some of the nuances of driving these vehicles, but as time progresses, the technology will improve and become more dependable.

Opportunities

There are many opportunities associated with using autonomous tractor-trailers for shipments. Since this is a new and continuously developing market it is hard to predict all of the opportunities that will come from incorporating autonomous vehicles into supply chains. Some predicted opportunities are faster, more efficient supply chains. There will be a higher labor market for tractor-trailer "drivers" because of the reduction in actual driving. This reduction in physically paying attention to the road opens up possibilities of creating a mobile office within the tractor-trailer. In theory, a sales employee could work from the tractor-trailer making calls to clients and working on his or her tablet or computer while the tractor is driving itself down the highway. The mobile office concept could lead to cost savings in drivers because an employee from the office could take over the vehicle, thus reducing the number of total employees.

Assuming the technology proves to be safe and successful, the use of autonomous tractor-trailers will improve the public's perception of the companies using them. The companies will be seen as protecting lives by investing in safer transportation.

These vehicles can incorporate other forms of technology to improve the driving experience even more. For example, augmented reality devices can be added to the windshield of vehicles and translate road signs into the drivers native language in real time (Jordan, 2015). Augmented reality could also be used to point out notable landmarks and sites while the vehicle is driving down the road.

Threats

A single crash with an autonomous vehicle could completely derail the progress this technology has made in the eyes of the public. Even if these vehicles cause half as few crashes as manned vehicles on the road, the public will still be more comfortable will manned vehicles because at least there is a human at the wheel to try and avoid the accident.

Cyber security and the risk of hackers is a major threat to autonomous vehicles. The threat is high because these vehicles work off of a network and also will communicate with one another in the future. High levels of cyber security will need to be installed to protect against hackers. Imagine how bad it could be if a hacker programmed a specific vehicle to drive off of a cliff. That would be the end of autonomous vehicles. Legally, there are still many questions on how this technology can be used and who is at fault if something does go wrong.

Chapter 6

Final Recommendations

In approximately the next ten years, autonomous vehicles will be on the market. It is important for supply chain executives to make the right choice in deciding whether or not to purchase autonomous tractor-trailers for their ground transportation fleets. Transportation managers should be thinking about these questions now in preparation for a completely new transportation market in the near future. Below are the recommendations developed through the research, interviews, and SWOT analysis outlined in this thesis.

The recommendation is that these vehicles will be a priceless addition to the trucking fleets across the world, but the questions are who, when, why and how?

Who

Larger companies, like Wal-Mart and Schneider Trucking are great candidates for adding autonomous tractor-trailers to their fleets. Strong candidates are companies that frequently send large, full truckload shipments over long distances. Large companies have the resources and high volume and number of shipments to best capitalize on the investment in autonomous tractor-trailers.

As time passes and the cost of driverless tractor-trailers moves closer to the cost of standard tractor-trailers, smaller companies will be able to enter the market. The cost savings will be easiest to see in companies that have frequent long haul shipments.

When

With adding new technology of any sort to the highway, there are high risks. Between problems with the vehicles, rubber necking, and more, the launch of a new vehicle can be risky. With this case, the launch of autonomous vehicles is even riskier because the technology is so new, and the driver relinquishes control.

For these risks and reasons, big companies should wait at least two years after autonomous tractor trailers launch before buying these vehicles and adding them to their fleets. By waiting, companies can avoid any deficiencies that still need to be worked out. Also, no company wants its name associated with the first autonomous tractor-trailer crash.

Why

As explained throughout this thesis, there are many benefits to using autonomous tractor-trailers for full truckload shipments including: more efficient deliveries, reduced fuel cost, reduced emissions, less probability of an accident, and savings in driver salary. By using these autonomous tractor-trailers in supply chains, companies can reap all of these benefits and then some.

How

As regulations stand now, a driver will still need to be in the vehicle at all times just in case something happens. The technology is currently very good at highway driving, but the nuances of driving, like parking a vehicle and urban driving, are still better in the hands of a human driver. Assuming this stays the same, a truck driver of an autonomous vehicle will be expected to drive the truck from the origin to the highway, then set the truck to autopilot. After this point, the vehicle will drive itself and the driver will be able to work on whatever he or she pleases. This free time leads to two different opportunities: a mobile office or reduced pay. Paying the driver to do other work for the company is one option. The other option is paying the driver less and giving the driver reigns to do whatever he or she pleases. Both options are very beneficial to the company.

With the first option, the company can put any employee in the vehicle, paying the employee extra to also drive the vehicle. For example, a truck driver currently makes around $50,000 a year and an entry level sales person at the same company might make a similar $50,000 annually. If the sales employee now drives the tractor-trailer, he or she can work remotely from the vehicle. The employer can increase the salesperson’s pay substantially while still achieving cost savings for the company by eliminating the driver.

For the second option, the company can pay the driver a reduced rate for the hours that he or she is not actively driving the tractor-trailer. The driver can then do as he or she pleases: sleep, watch movies on a tablet, or do some other type of work. This type of option would be beneficial to creative careers like writers. In theory, a book author can write anywhere. He or she can work on the book while the tractor-trailer is in autopilot and still generate revenue while he or she works on the book.

Driverless tractor-trailers will completely change the demographic of truck drivers as the role changes to more free time or to a mobile corporate job.

Conclusion

In summary, autonomous tractor-trailers will revolutionize ground transportation by lifting regulations on hours, reducing emissions, reducing accidents, improving the trucking labor market, and creating cost savings for companies. After a certain point, all companies will be incorporating this technology into their supply chains, but large, logistics-centric companies will be first to adopt autonomous tractor-trailers.

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