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HOW RIDE SHARING AND AUTONOMOUS VEHICLES IMPACT CUSTOMER USAGE AND RELIABILITY

James Wasiloff
Science and Technology Growth
BAE Systems
Sterling Heights, MI

ABSTRACT

The concept of Autonomous Vehicles ultimately generating an "order of magnitude" potential increase in the duty or usage cycle of a vehicle needs to be addressed in terms of impact on the reliability domain. Voice of the customer data indicates current passenger vehicle usage cycles are typically very low, 5% or less. Meaning, out of a 24 hour day, perhaps the average vehicle is actually driven only 70 minutes or less. Therefore, approximately 95% of the day, the vehicles lay dormant in an unused state. Within the context of future fully mature Autonomous Vehicle environment involving structured car sharing, the daily vehicle usage rate could grow to 95% or more.

INTRODUCTION

The biggest challenge we envision from the paradigm shift associated with contemporary ride sharing scenarios and the introduction of autonomous vehicle technology is the emergence of a radically new, highly accelerated "24/7" customer usage profile. This discovery of an "order of magnitude" potential increase in the duty or usage cycle of an autonomous vehicle is definitely worth exploring. Voice of the customer data indicates current passenger vehicle usage cycles are typically very low, five percent or less. In the current scenario, twentyfour hour day, perhaps the average vehicle is actually driven only seventy minutes or less. Therefore, approximately ninety five percent of the day, the vehicles lay dormant in an unused state. Within the context of the fully mature Autonomous Vehicle environment involving future structured car sharing, the daily vehicle usage rate could correspondingly grow to ninety five percent or more.

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LEVELS OF AUTONOMY DEFINED

Society of Automotive Engineers (SAE) and the National Highway Traffic Safety Administration (NHTSA) define five levels of AVs (SAE, 2016; NHTSA, 2016a, p. 9) as follows:

Level 0 – No automation: the driver must be in complete control of the vehicle at all times.

Level 1 – Driver assistance: the vehicle can assist the driver or take control of either the vehicle's speed, through cruise control, or its lane position, through lane guidance. The driver must monitor the vehicle and road at all times and must be ready to take control at any moment, with hands on the steering wheel and feet on or near the pedals.

Level 2 – Occasional self-driving: the vehicle can take control of both the vehicle's peed and lane position in some situations, for example on limited-access freeways. The driver may disengage, with hands off the steering wheel and feet away from the pedals, but must monitor the vehicle and road at all times and be ready to take control at any moment.

Level 3 – Limited self-driving: the vehicle is in full control in some situations, monitors the road and traffic, and will inform the driver when he or she must take control. When the vehicle is in control the driver need not monitor the vehicle, road, or traffic but must be ready to take control when required.

Level 4 – Total self-driving under certain conditions: the vehicle is in full control for the entire trip in these conditions, such as urban ride-sharing. The vehicle can operate without a driver in these conditions; the driver's only role is to provide the ultimate destination.

Level 5 – Total self-driving under all conditions: the vehicle can operate fully without a human driver or occupants.

AUTONOMOUS VEHICLE FUNDAMENTALS AND EMERGING NEW CHALLENGES

The introduction of autonomous vehicles and car sharing will lead to the emergence of a radically new customer usage profiles. When one envisions a potential twenty fold increase in vehicle usage and aging, the impact on vehicle system life measured on a time scale may be significant. For example, will engines, transmissions or alternative propulsion systems need to be replaced more frequently, perhaps every six to twelve months? Will new, longer life materials and advanced technologies be needed to extend vehicle life to new ultra high mileage targets? Are all contemporary vehicle, system and subsystem reliability targets, models and analysis methodologies suddenly invalid or insufficient? Will overall vehicle counts drop resulting in a global reduction in automotive production? Will new business opportunities and innovations emerge such as periodic, full vehicle re-build, re-fit service (ie., "Pit Stop" engine replacement)? In order to quantify the future impact on reliability targets and useful life targets, these questions and paradigms need to be studied thoroughly.

DEFINING CUSTOMER PERCEPTION OF AUTONOMOUS VEHICLES

"Voice of the Customer" data obtained via surveys through the Autonomous Vehicle Community of Practice has yielded some very profound observations. The survey data portrays user acceptance as a function of age where the youngest responders and oldest responders view autonomy in a very positive perspective. In Figure x, we see a "bathtub" characterization that bears resemblance to the well known reliability bathtub curve depiction of failure rates as a function of time.

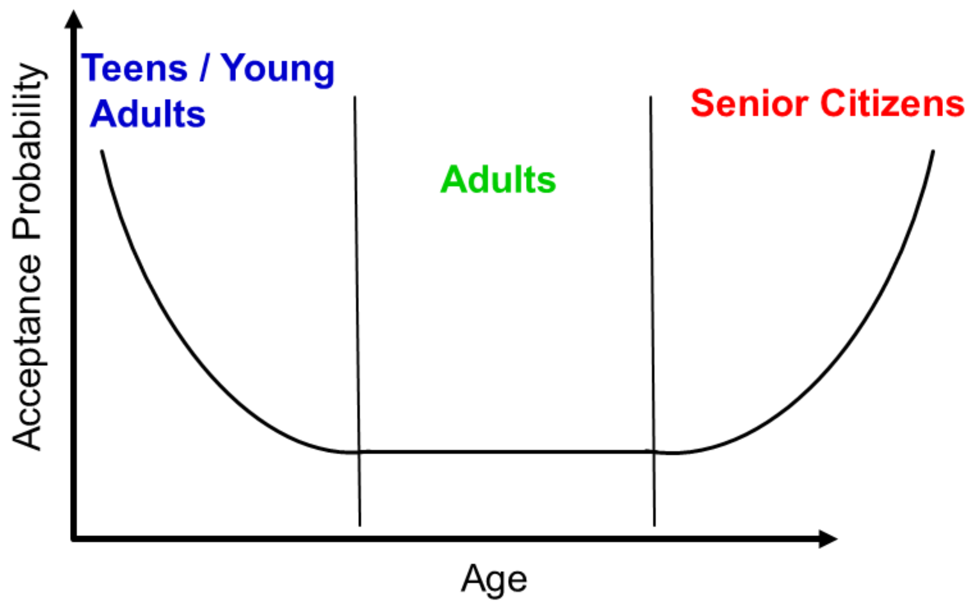

Figure 1: Test of Hypothesis: AV Acceptance Can be Characterized with a Bathtub Curve

This infographic indicates a strong correlation of the Autonomous Vehicle acceptance probability with age where the very young and old appear to embrace the concept.

Teens and Young Adults are characterized as "Advocates / Early Adopters" and typically cite numerous attractive alternatives to driving and are open to the concept of "commanding" a vehicle versus driving

Mid-life Adults are defined as Skeptics / Resistors" based on the existence of many driving paradigms and history. We observed inertia and resistance to change with a general focus on risks / negatives.

Senior Citizens are identified as "Advocates / Early Adopters" with a positive view of extended mobility
And the general improvement in quality of life in the advancing years.

Common "Voice of the Customer" Themes / Discussion Topics include Driver licensing, non-licensed driver access and the minimum age to command an Autonomous Vehicle. Environmental impact is perceived as positive when considering the reduced collision threat may lead to lighter structures and improved fuel efficiency with a potential overall reduction in automotive fleet fuel consumption. Consumers of all ages expressed concerns about Cyber

Security especially when considering the "connected" Autonomous Vehicle design concept. Challenges include the need for ultra-high reliability / risk reduction, negotiating road hazards / inclement weather. It is interesting to note that Google has filed a variety of patents to address specific inclement weather and road hazard cases. Also, many automakers are now testing Autonomous Vehicles in challenging environment such as inclement Michigan winter weather. Users are interested in exploring new and innovative in-cabin activities envisioned to replace the act of driving a vehicle. The concept of "commanding" versus driving a vehicle generates concerns in many customers. Urban impact is envisioned to include a reduction in parking lots and parking structures and hospital emergency room utilization. Obviously, the current traditional Public transit model with be impacted to a large degree.

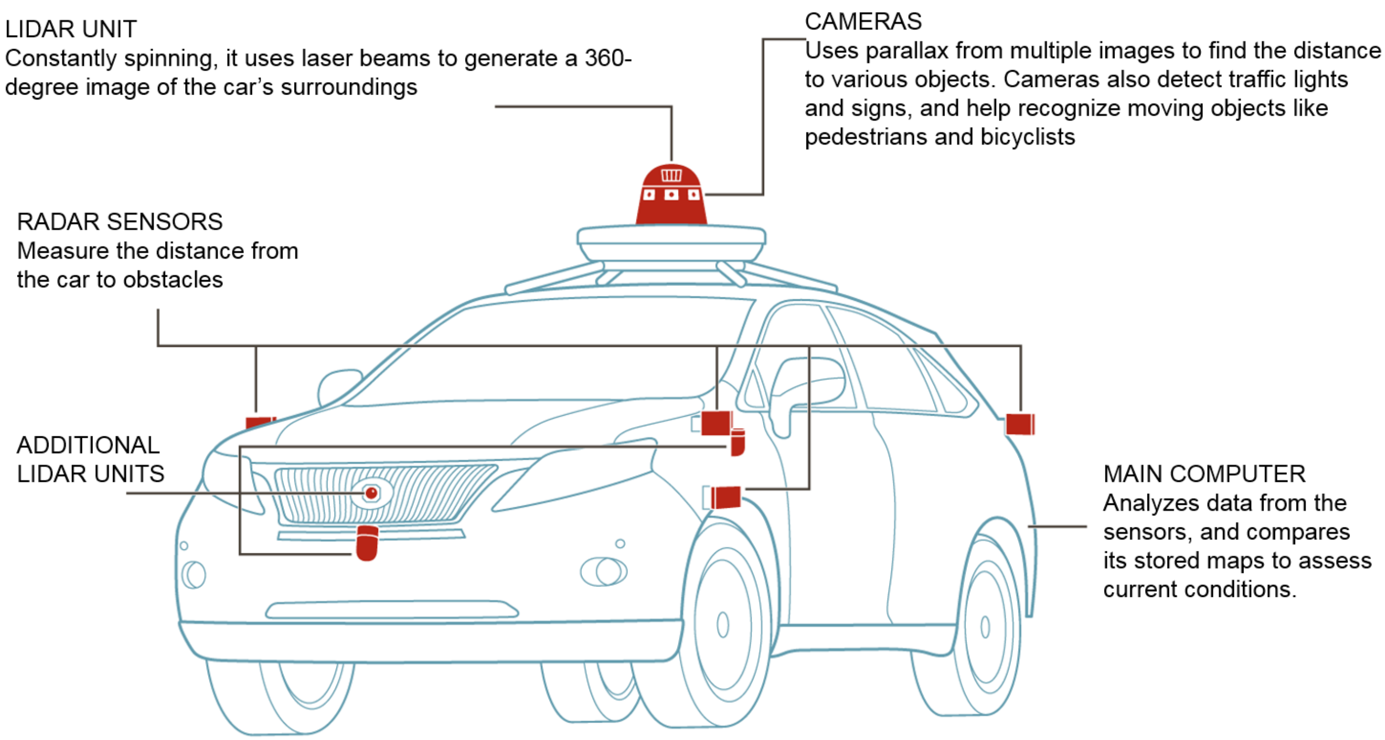

Figure 2: How an Autonomous Vehicle Drives Itself

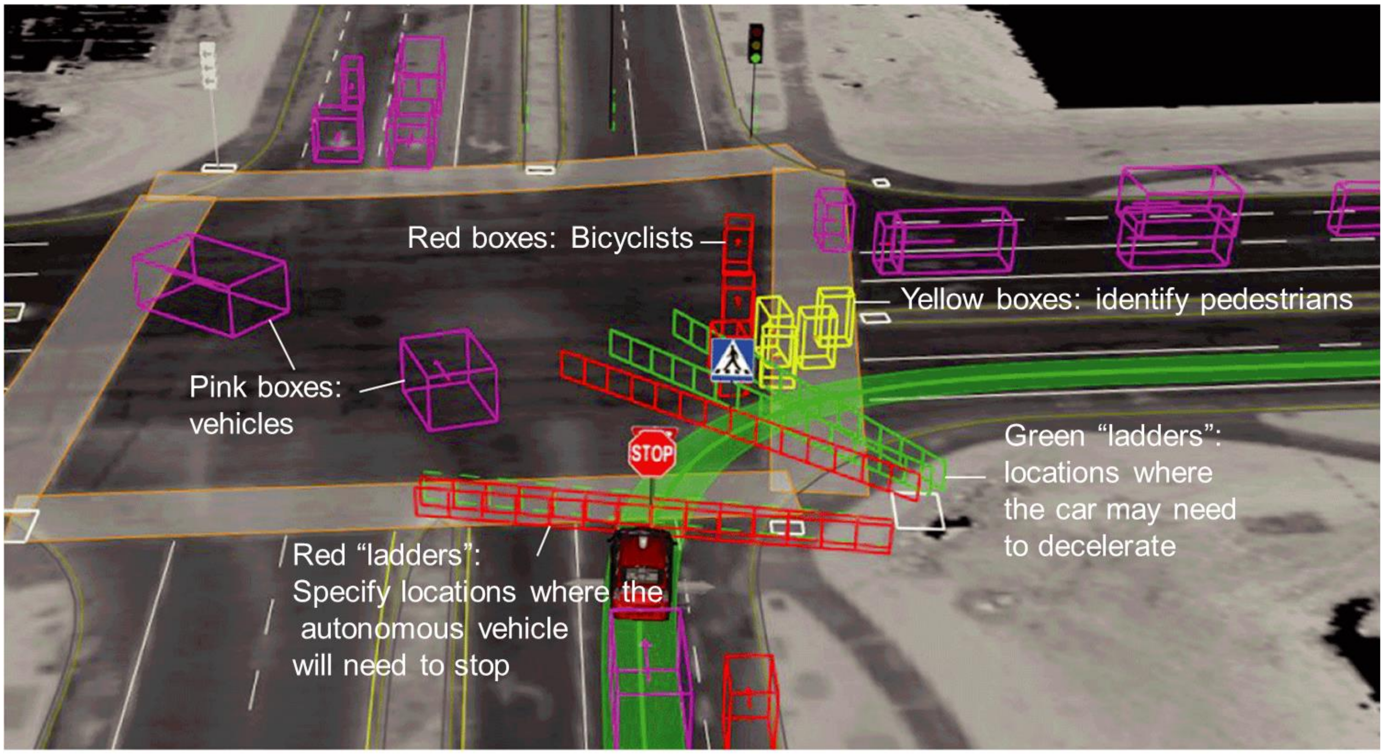

Figure 3: Detection and Categorization of Typical Objects

The array of various critical autonomous vehicle sensors such as forward facing cameras, forward radar, LIDAR, ultrasonics and GPS gather data on nearby objects, For example, their physical size, position and velocity are calculated. It categorizes the objects as bicyclists, pedestrians or other vehicles and objects. Some conclusions are based on how they are likely to behave.

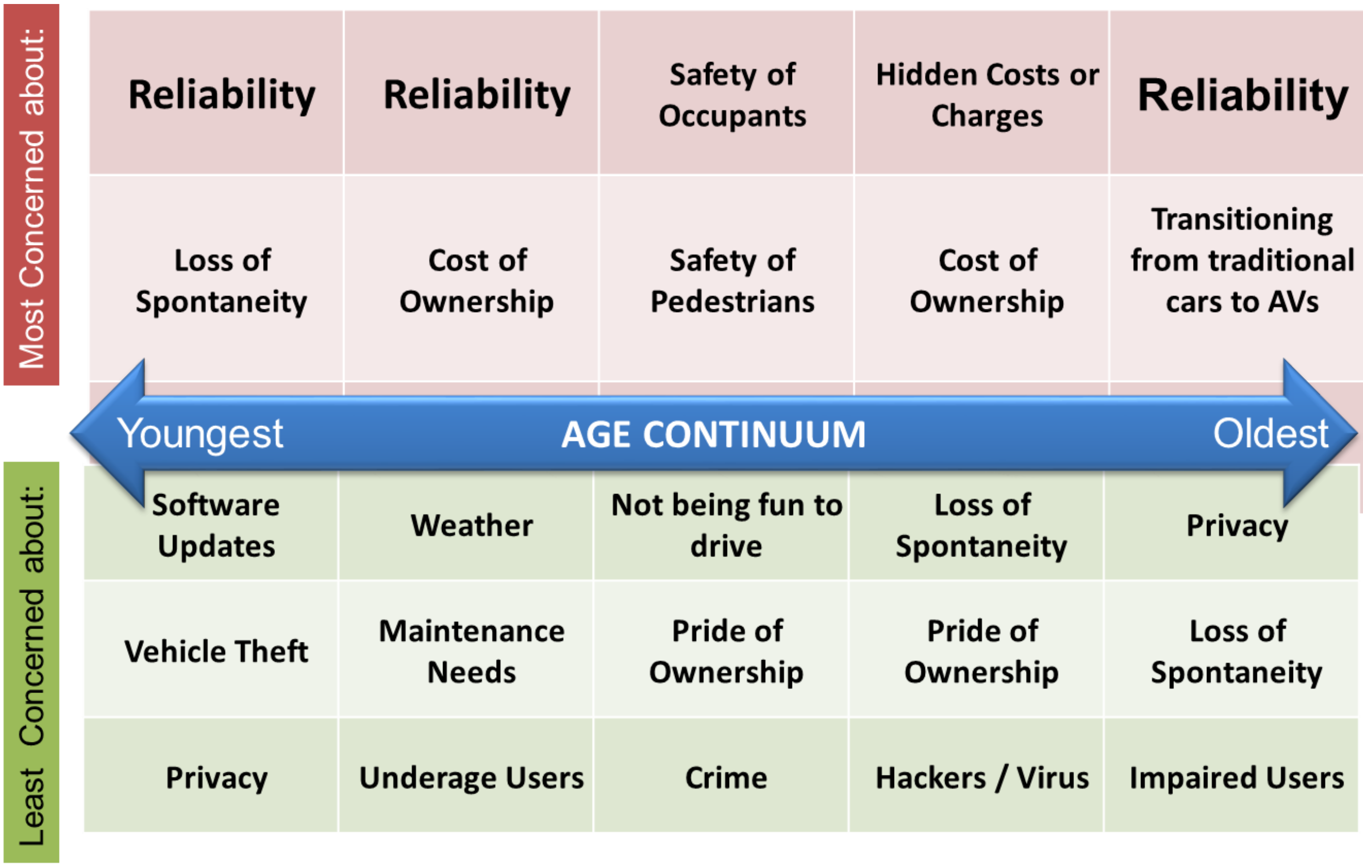

Figure 4: What Future AV Users are Concerned About

Several intriguing themes emerge from Voice of the Customer data analytics. First, cost is critical. Second, uncertainty about AV performance lies behind many of the discouraging responses. This will be overcome only after AVs demonstrate that they perform reliably and safely, preferably allowing potential purchasers
to get first-hand experience with them. Finally, many drivers would prefer a vehicle that can be operated either autonomously or by a human driver. Manufacturers understand this desire (Schultz, 2016).

AVs offer substantial benefits to manufacturers. They will be a new product, a disruptive technology that eventually could make traditionally driven cars almost obsolete, in the same way that smart phones have almost completely replaced older cell phones. Manufacturers can be expected to promote AV sales vigorously as soon as they have a safe and reliable product to offer. On the other hand, vehicles are expensive and last many years: the average age of cars on the road in 2015 was 11.5 years (Culver, 2015). Many drivers may prefer to keep their present vehicle for several more years rather than invest in a new and costly AV or participate in a shared mobility concept. The need for highly reliable and safe operation are paramount. All vehicle systems, sub-systems and components need to be designed to survive in an automotive environment and be fully tested to demonstrate that they achieve their reliability targets and goals. System reliability must also be demonstrated by actually exposing the autonomous vehicle to the stresses it will encounter in the conditions of the real world. In the case of specific autonomous systems, the stresses include not only environmental stresses like shock, vibe, temperature and humidity, but also situational stresses unique to the autonomous domain. Noah Lassar of Google / Waymo suggests "Autonomous Vehicles must not only be efficient, fast, comfortable—and in this industry, smarter than humans— they must also be reliable." To conceptualize the challenge, the basic tools and methodologies in reliability are compared and contrasted. Obviously, the introduction of redundant systems improve reliability as shown in the simple math reliability calculation of a basic "series system" (no redundancies) as opposed to a parallel system (redundancies in critical sensors).

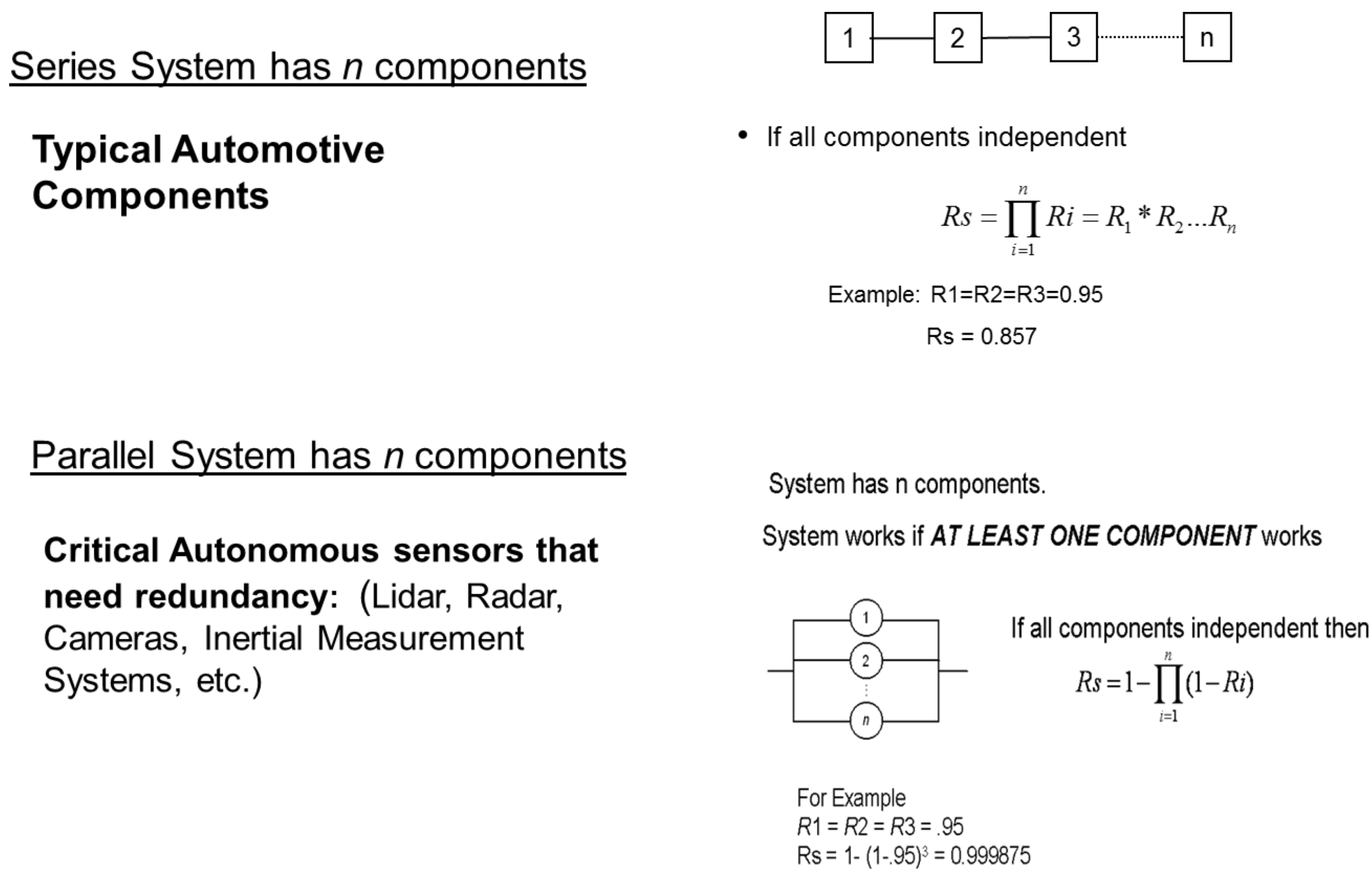

Figure 5: Reliability Models Applied to Autonomous Vehicle Technology

RELIABILITY CHALLENGES ASSOCIATED WITH AUTONOMOUS VEHICLES

New challenges from the paradigm shift associated with contemporary ride sharing scenarios and the introduction of autonomous vehicle technology may include a radically new, highly accelerated "24/7" customer usage profile with " associated "Order of magnitude" potential increases in the duty or usage cycle of an autonomous vehicle. For example in the current State, customer data indicates current vehicle usage cycles are typically very low, perhaps 5% or less. In other words, out of a 24 hour day, the average vehicle is actually driven only 60 minutes or less. Therefore approximately 95% of the day, the vehicles lay dormant, unused. In the future State (NHTSA Level IV Autonomy Achieved), within the context of the fully mature Autonomous Vehicle environment involving structured car sharing, the daily usage rate could grow conceivably to 95% or more.

The Current State in 2016 in a mixed, primarily urban duty cycle, with 30 MPH mean speed and a 5% customer usage profile, approximately 12960 miles per year would be driven. This translates to 38,680 over a typical three year usage span. The future, fully autonomous domain: in a mixed, primarily urban duty cycle with 30 MPH mean speed would result in a mileage accumulation of 738,720 miles over s typical three year usage span.

In addition, unique reliability requirements specific to autonomous vehicle systems and subsystems may emerge. For example, autonomous sensors need to verify position and alignment over life to ensure reliability and robustness. Lidar, Radar, Cameras, and Inertial Measurement Systems must validate alignment over life. Sensor alignment may be validated relative to a fixed reference on the vehicle or to other sensors and Inertial Measurement System alignment may be validated relative to the alignment of another inertial measurement system.

In terms of Taguchi defined “Noise Factors”, “outer” (customer conditions including environment, interfacing components), “inner” (age, wear) and “between” (manufacturing variation, tolerances) would have to be optimized to achieve a robust state.

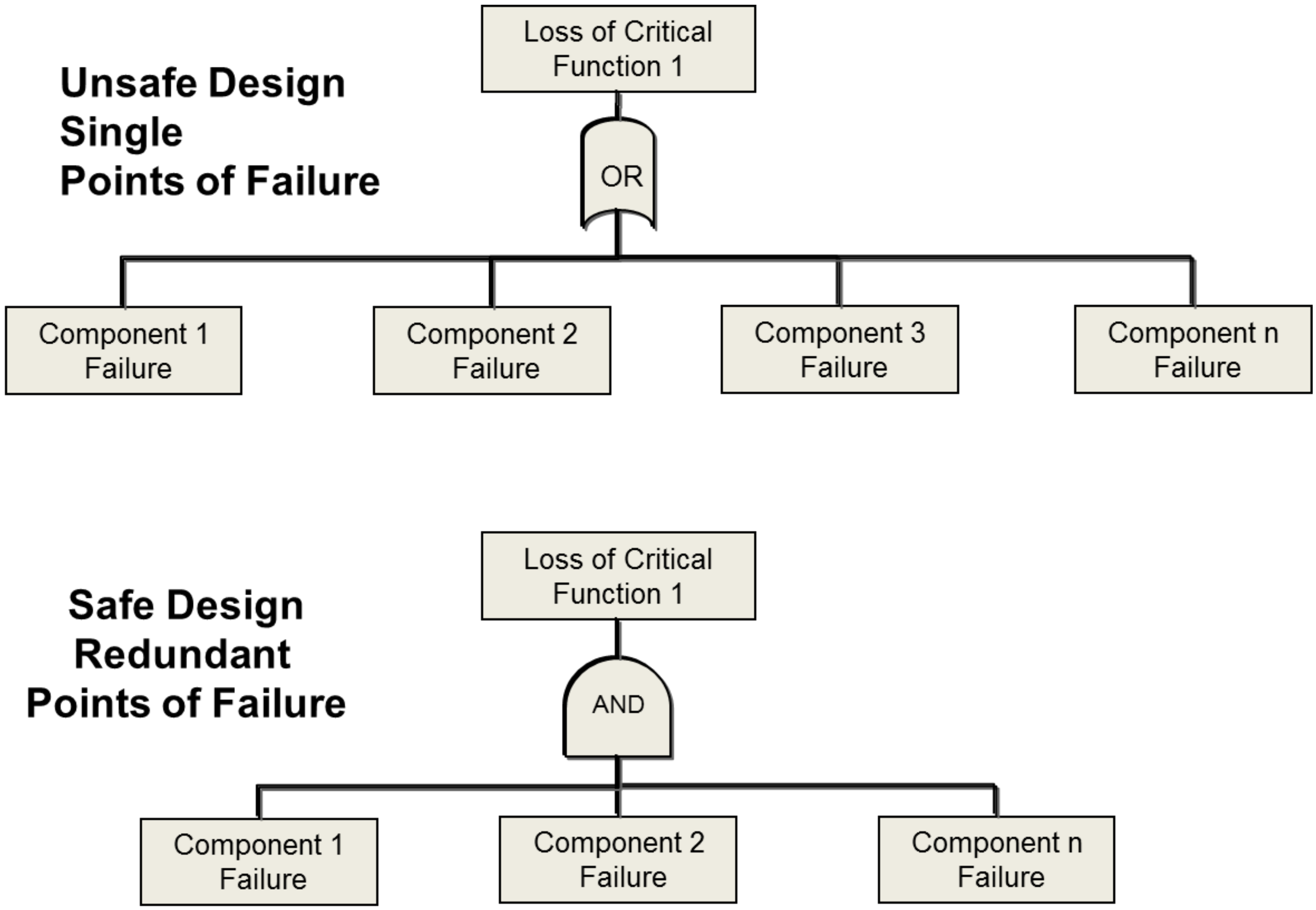

Figure 6: Fault Tree Risk Reduction via Identification of Single Points of Failure – Impact of Redundant Components

No Redundancy

Single-Motor Steering System	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Design Controls	Detec	R.P.N.	Recommended Action(s)
Steering Rack Motor	Motor Failure	Loss of Steering Control	10	Motor Winding Short	4	Steering Durability Testing	6	240	BIC Automotive Motor

2 Level Redundancy

Double Motor (Redundant) Steering System	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Design Controls	Detec	R.P.N.	Recommended Action(s)
Steering Rack Motor 1 Steering Rack Motor 2	Motor Failure	Secondary Motor Takes Full Load	6	Motor Winding Short	2	Steering Durability Testing / Fault Injection	5	60	BIC Automotive Motor

Figure 7: DFMEA – Failure Modes, System Behaviors, Risk Mitigation and Validation Actions

Fault Trees and DFMEAs can be introduced to confirm the redundant systems are fully independent, such that the failure mechanism of one does not also affect the others. It is critical to verify latent faults in the primary, secondary and tertiary systems that they are detectable at all times, throughout the vehicle life cycle. Safe and reliable operation require that we investigate the effects of transferring to the secondary system to ensure no additional risk created with redundant systems and confirm existing test plans are sufficient to detect such events.

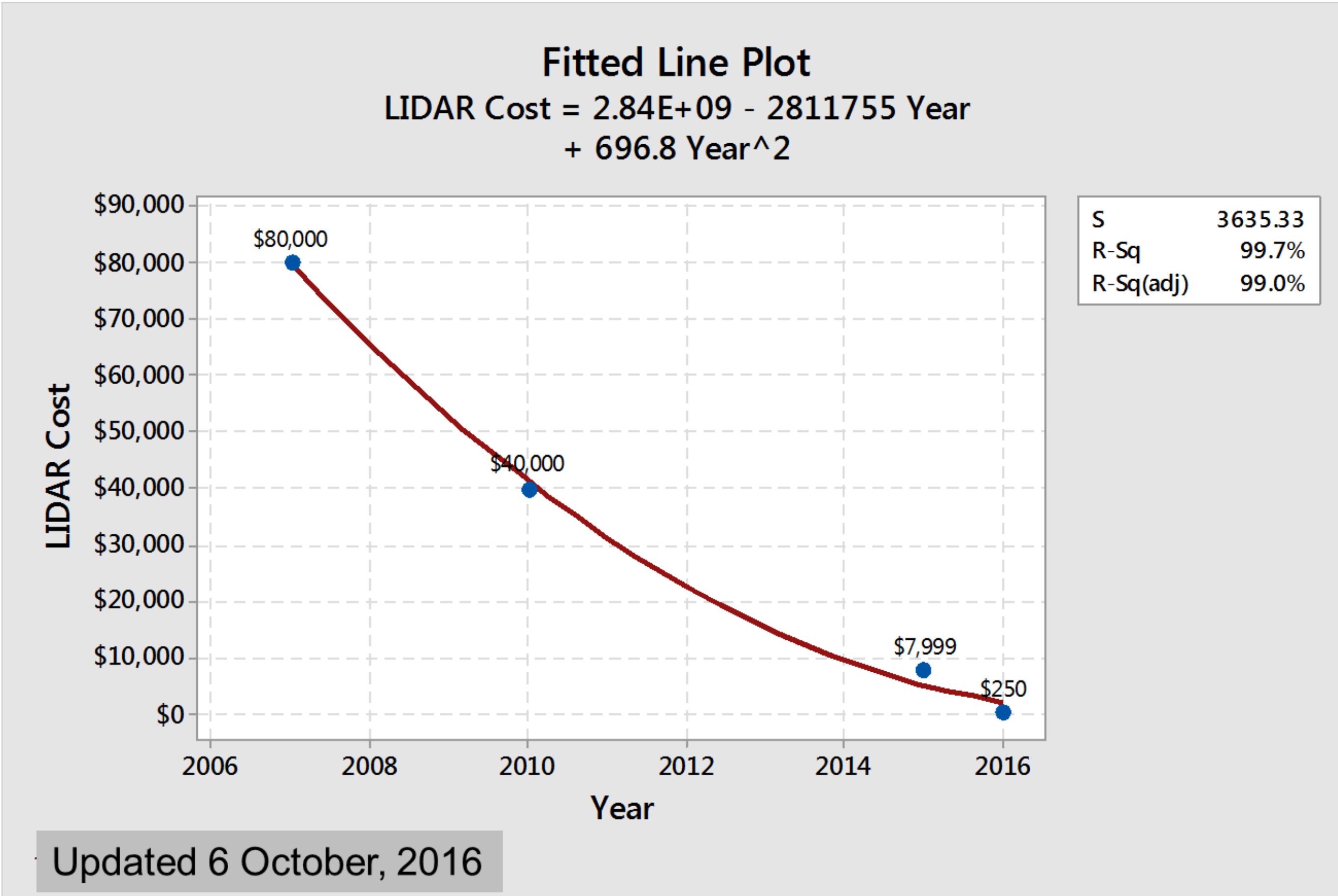

Figure 8: Autonomous Vehicle Technology Cost is Decreasing Exponentially – LIDAR Example

Voice of the Customer indicates resolving the perception of higher cost as paramount to Autonomous Vehicle acceptance. However, real world data indicates as shown in Figure xx that the cost of critical components such as LIDAR are dropping rapidly as a function of time. It is expected that additional layers of redundancy will add cost but the total life cycle cost of transportation per mile will actually drop with shared mobility operations.

CONCLUSIONS

.Evidence is beginning to emerge that suggests automotive manufacturers are now beginning the transition into "mobility providers". New business opportunities are on the horizon as a result of such transformations that may effect the entire supply chain construct. NHTSA Autonomous Technology Levels 1-3 represent increasing reliability risk (low to medium). Full implementation of NHTSA Autonomous Technology Level 4 represents high reliability risk. Perhaps mapping failure modes to physics of failure and failure acceleration variables would be beneficial? Strategic synthesis of "Voice of the Customer" critical to delivering reliable and robust AV systems Extreme variation in the prediction of when full autonomy will materialize will converge. Voice of the Customer data trends imply user acceptance predicted to grow exponentially. Technology growth is changing paradigms with time (Google / Waymo patent application exponential growth). Cost will continue to decline exponentially as technology matures. There is an opportunity to benchmark and analyze current "Hyper Use" vehicle fleets (i.e. Shanghai taxi fleets). Ultra-Reliable Autonomous Vehicle system mandate highly comprehensive reliability programs, with clear requirements, careful in-depth analysis, rigorous testing at the component and system levels, and extensive real-world validation testing.

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