Automotive

EXCELLENCE

Spring 2018

TABLE OF CONTEXT

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LETTER FROM THE CHAIR

Ken Coll,
2018-2019 Chair,
ASQ Automotive Division

As I begin my term as ASQ Automotive Division Chair, I would first like to extend my thanks to the many dedicated Member Leaders and longtime Division Members, who have been the foundation of this division over the years. Your diligent efforts have created a legacy of a vibrant, active division, and you have been directly involved in developing so many of the very industry standards and methods that are such a key part of our daily working lives.

I would like to send a warm welcome to the new members who have joined us during the past year, and welcome you to a group of key industry influencers, who take delight in being on the forefront of what is happening in the Automotive and Transportation Industry. I extend greetings to students and young professionals beginning your career, and invite you to participate in an organization of people who love to mentor, share their knowledge and experience, and help others to be successful.

This is a time of change and upheaval in the Automotive and Transportation Industry, the like of which has not been seen before. The advent of Electrification and Autonomous Vehicles is causing a complete reassessment of the whole approach to personal transportation and how we will get from place to place.

Over the next months, we will be providing webinars, conferences/symposiums, training, and information that will help you understand and be part of what is happening in our industry. These are made available free or at minimum cost in order to provide the maximum value and benefit to you. Watch our website at www.asq-auto.org for details about upcoming events.

I hope to meet as many of you as possible over the next two years. I would love to get your input on what is happening in the industry and what are the ways that the automotive Division can better help you.

Sincerely,

Ken Coll,
2018-2019 Chair,
ASQ Automotive Division

LETTER FROM THE PUBLICATION CHAIR

Mohammadsadegh Mobin, Publications Chair, ASQ Automotive Division

Dear ASQ Automotive Division Members,

Welcome to the Spring 2018 issue of the Automotive Excellence Newsletter. In this exciting edition, we have five technical articles authored by practical experts in the area of quality, reliability, maintenance, risk, safety, etc. The topics include reliability in autonomous vehicles, risk in automotive design process, reliability test design, reliability and security, and functional risk assessment in automotive industry.

A letter from the 2018-2019 ASQ Automotive Division Chair, Ken Coll, has a welcome message and a few updates about our division. The newsletter contains valuable information about ASQ E-learning and a summary of 2017 ASQ Automotive Division Award Banquet.

To introduce the cutting-edge and academic research efforts to experts in the automotive industry, a new section, called "Doctoral Dissertation Highlights", has been added to the Automotive Excellence Newsletter. Several graduate students from different universities present their research in this section.

The *2018 Guangbin Yang Reliability Symposium* will be held at *Oakland University* on Thursday, August 30, 2018. This year, there will be several knowledgeable presenters with interesting and up-to-date topics. In addition to this, we will host an expo session followed by a poster presentation session this year. More details about the presenters, registration, etc. are provided in this newsletter. I am looking forward to meeting many of ASQ Automotive Division members at the symposium this year.

I would like to thank the ASQ Automotive Division leadership team, authors of articles published in this newsletter, Ph.D. students and their academic advisers, and reviewers of this issue for their wonderful contributions to this edition. This edition, as well as past publications, can be found on our website at ASQ-auto.org.

To have a continuous improvement in our newsletter, please provide us with your valuable comments by sending an e-mail to: mobin.sadegh@gmail.com. Also, if you are interested in publishing your practical articles and promoting your research, please reach out to me. Thank you for your support of the newsletter and I look forward to hearing from you.

Best Regards,
Mohammadsadegh Mobin,
Publications Chair, ASQ Automotive Division.

HOW RIDE SHARING AND AUTONOMOUS VEHICLES IMPACT CUSTOMER USAGE AND RELIABILITY

JAMES WASILOFF; CEO, AUTONOMITE LLC;

Jim is a leading expert in vehicle test design methodology. He is a thought leader in the autonomous vehicle development and testing ecosystem. Jim is the founder and CEO of Autonomite, an AV development consultancy. "Autonomite is shaping the future of Autonomous Vehicles. Through voice of the customer data mining and our highly acclaimed Autonomous Vehicle Community of Practice, Autonomite is the first to understand what future consumers of Autonomous Vehicles determine as fundamental and expected system characteristics.

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, twenty-four 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.

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 (i.e., "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 1, we see a "bathtub" characterization that bears resemblance to the well known reliability bathtub curve depiction of failure rates as a function of time.

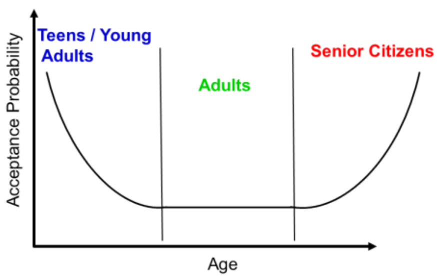

Figure 1: Test of Hypothesis: AV Acceptance Can be Characterized with a Bathtub Curve

The infographic in Figure 1 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.

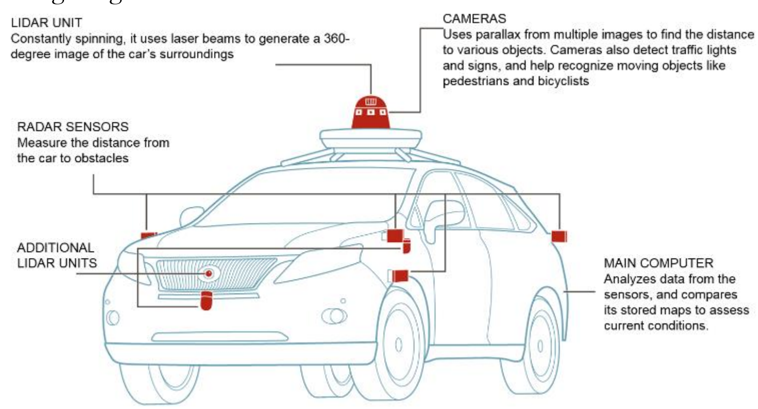

Figure 2: How an Autonomous Vehicle Drives Itself

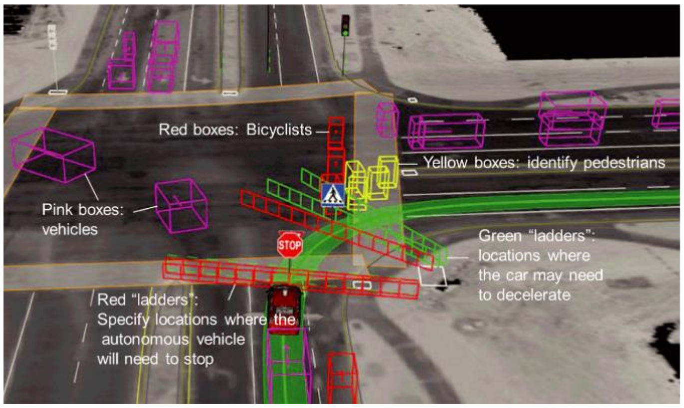

Figure 3: Detection and Categorization of Typical Objects

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.

	Youngest				Oldest
Most Concerned about:	Reliability	Reliability	Safety of Occupants	Hidden Costs or Charges	Reliability
	Loss of Spontaneity	Cost of Ownership	Safety of Pedestrians	Cost of Ownership	Transitioning from traditional cars to AVs
	AGE CONTINUUM				
Least Concerned about:	Software Updates	Weather	Not being fun to drive	Loss of Spontaneity	Privacy
	Vehicle Theft	Maintenance Needs	Pride of Ownership	Pride of Ownership	Loss of Spontaneity
	Privacy	Underage Users	Crime	Hackers / Virus	Impaired Users

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. 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).

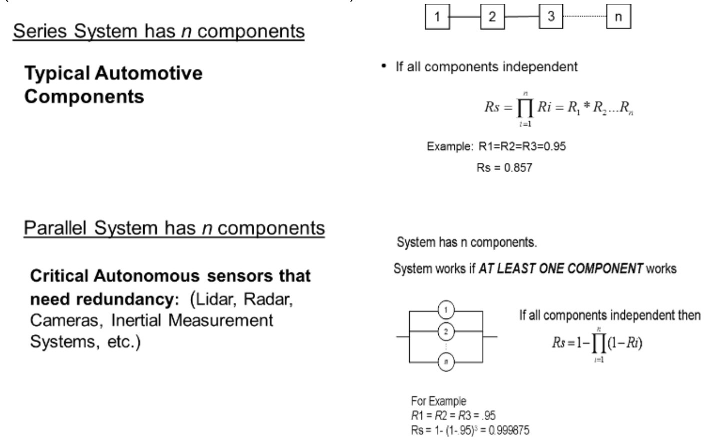

Figure 5: Reliability Models Applied to Autonomous Vehicle Technology

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.

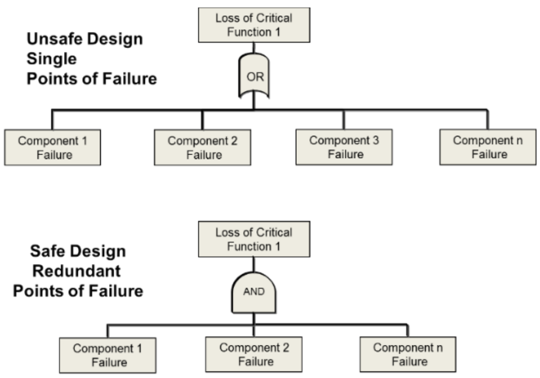

Figure 6: Fault Tree Risk Reduction via Identification of Single Points of Failure – Impact of Redundant Components

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 as shown in Figure 7 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.

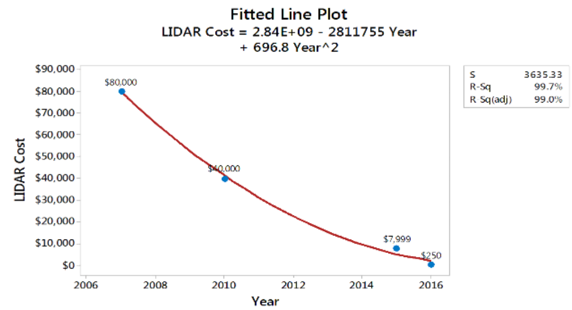

Figure 8: Autonomous Vehicle Technology Cost is Decreasing Exponentially – LIDAR Example

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.

REFERENCES

Autonomite – Everything Autonomous; at http://autonomite.com/
Autonomous Vehicle Community of Practice; at https://www.linkedin.com/groups/4860027

MEASURING RISK IN THE AUTOMOTIVE DESIGN PROCESS

RICHARD HARPSTER; PRESIDENT OF HARPCO® SYSTEMS INC;

Richard Harpster is president of Harpco® Systems Inc. which he founded in 1987. Harpco® Systems specializes in providing software, training and consulting for Risked Based Product Lifecycle Management (RBPLM®). Over the past 30 years Mr. Harpster has helped hundreds of companies implement improved risk-based design and manufacturing systems in a wide variety of industries. He is a recognized expert in the application of FMEAs and invented several new concepts including the linking of Design FMEAs to Process FMEAs in 1990 which became an automotive industry standard eighteen years later. His latest inventions in the field of RBPLM® include Requirements Risk Assessment™ (RRA®), Usage Risk Assessment (URA™), Multiple Integrated Cause Analysis (MICA™) and Rapid Integrated Problem Solving (RIPS®). He has published several papers on the topic of RBPLM®. Prior to starting Harpco® Systems, Richard spent 14 years at Ford Motor in a wide variety of positions including Plant Manager. His education includes a B.S.E.E. from Penn State University, M.S.E.E from the University of Detroit and an M.B.A. from Eastern Michigan University. He is a registered PE in the State of Michigan.

ABSTRACT

IATF 16949:2016, the automotive international quality standard for quality management, requires the use of risk-based thinking in the management of processes that have an impact on the quality of a company's products. Risk-based thinking is the use of risk to identify, prioritize and remove the sources of potential problems that expose the company and its customers to the greatest harm. To effectively implement risk-based thinking the company must be able to properly measure risk.

The design of products is an important process in the automotive industry where the proper implementation of risk-based thinking is critical. The purpose of this paper is to define:

1) what design risk is;
2) the accuracy of design risk measurement required;
3) the key steps to measuring design risk;
4) the role of the Design FMEA and design verification in design risk measurement;
5) common mistakes made in measuring design risk.

Keywords: Risk, Risk-based Thinking, Design FMEA, ISO 9001:2015, IATF 16949:2016, Prototype Control Plan, Design FMEA Severity of Effects Table, Class Symbol, Risk Matrix, Risk Policy, Design Control, Design Verification, Design Verification Plan.

INTRODUCTION

Since the release of ISO 9001:2015 and IATF 16949:2016 which requires compliance with IS0 9001:2105, risk-based thinking has received a lot of publicity in all industries including the automotive. Although the use of risk-based thinking has always been implicit in the two standards, proof of the use of risk-based thinking is now required.

Risk-based thinking can be used when making a wide variety of business decisions including pursuing new business opportunities, releasing product designs and modifying manufacturing processes. The good news is risk-based thinking is something most companies do automatically. If a company asks the question "What are the risks?" before taking an action, the company is using risk-based thinking. The bad news is that most companies do not use risk-based thinking as effectively as they could.

One of the main sources of a company's inability to effectively implement risk-based thinking is an inability to accurately measure risk. The purpose of this article is to examine how to measure risk in the design process. If a company can define the hardware specifications and software code (if applicable) that represent the greatest sources of risk, company resources can be targeted to make the necessary changes before design release to improve design performance and prevent future design failures.

KEY FACTOR IN DETERMINING REQUIRED RISK MEASUREMENT ACCURACY

For the sake of the discussion, we will assume the product has hardware and software components. The required accuracy of risk measurement is dependent on the type of decision one is trying to make. In the design process there are three decisions where using risk-based thinking can be extremely powerful.

The first decision is to define which hardware specifications and software code must be considered for possible change to reduce future design failures and thereby reduce risk. The second decision is the priority for working on the potential hardware specification and software code changes. The third and final decision is if or when the hardware specifications and software code should be released for manufacture. The ability to measure design risk must allow us to make these three decisions correctly.

DEFINITION OF RISK

Risk is comprised of two components. The first is the level of harm that can occur when an objectionable incident occurs. The second component is the probability of exposure to the harm. The combination of both components is used to define risk.

DEFINING AND MEASURING THE HARM COMPONENT OF RISK

Harm occurs when an objectionable incident occurs. In the design process an objectionable incident is when the design fails to meet a design requirement. Various types of harm can occur at different probabilities when the design failure occurs. Although one can do a reasonable job identifying the different potential types of harm, knowledge of their individual probabilities can be lacking. For this reason, it is recommended that the worst-case harm be selected regardless of probability when determining the severity of harm for a design failure. The potential financial damage to a company due to overstating potential harm due to design failure is typically much less than understating it.

The Design FMEA is the most common tool used in the automotive industry to manage design risk. To assist in the measurement of harm, the Design FMEA has a Severity of Effects table identifying types of harms that can be experienced when the design fails. Design FMEA Severity of Effects tables can come in various sizes. Typical sizes are ten and five rows. The automotive industry uses 10 rows. Table 1 is a typical "Severity of Effects" table.

Description	Rating
Possibility of injury or violation of law without warning.	10
Possibility of injury or violation of law with warning.	9
Loss of primary function.	8
Reduction of primary function.	7
Loss of secondary function.	6
Reduction of secondary function.	5
Noise or appearance issue detected by customer that results in return.	4
Noise or appearance issue detected by customer that does not result in return.	3
Noise or appearance issues typically not detected by customer.	2
No effect.	1

Table 1: Severity of Effects

The Severity of Effects Table Rating indicates a relative ranking for each type of harm identified. Due to the need to identify ten different types of harm, it is not uncommon to see Severity of Effects Tables where individual harm types have the same cost impact. As an example, the cost of repair or replacement for a product that fails completely or partially are typically the same. In the Severity of Effects Table, the complete failure is typically given a higher rating than partial failure. Since they have the same financial impact, an additional grouping of the harm descriptions is required to assign a financial cost to the harm. Although there are ten different harm descriptions, it is not uncommon to see companies group them into three or four cost zones. Table 2 is a "Severity of Effects with Cost Zone" table that could be used to define the cost categories for the types of harm defined in Table 1.

Cost Zone	Description	Rating
Safety/Legal Zone	Possibility of injury or violation of law without warning.	10
	Possibility of injury or violation of law with warning.	9
Return Zone	Loss of primary function.	8
	Reduction of primary function.	7
	Loss of secondary function.	6
	Reduction of secondary function.	5
	Noise or appearance issue detected by customer that results in return.	4
Conditioned Response Zone	oise or appearance issue detected by customer that does not result in retur	3
	Noise or appearance issues typically not detected by customer.	2
	No effect.	1

Table 2: Severity of Effects with Cost Zone

Safety and legal issues are the most expensive problems that a company can have. The "Safety/Legal Zone" contains harm descriptions that describe physical injury or violation of a law.

The next cost zone is the "Return" zone. The harm descriptions contained in this zone involve harms that involve return of the product. Typical harm descriptions include loss or reduction of a primary function, loss or reduction of a secondary function or noise and appearance issues that result in a return. The multiple harm descriptions are placed in the same zone because their cost to the company to resolve are typically very close and are significantly less than Safety/Legal zone cost issues.

The final cost zone is the "Conditioned Response Zone". This zone includes harms that the customer is currently conditioned to accept as normal and consequently does not return the product for repair. The zone also includes problems with the product the customer may not be aware of. The is no cost of return of the product for repair or replacement for harms in this zone.

DETERMINING THE PROBABILITY OF HARM EXPOSURE COMPONENT

Once a measurement of harm is developed, the focus can be moved to determining the probability of harm exposure. Since it is being assumed that the worst-case harm will occur if the design fails, the probability of exposure to harm becomes the probability of the design failure creating the harm.

To determine the probability of design failure, one must first identify the potential root causes which are the hardware specifications and/or software code that if incorrectly specified can lead to the design failure. Once the potential root causes of the design failure are defined, a method or methods must be identified to determine the probability of the design failure due to the causes. The methods are called design verification controls.

The proper design of the design verification controls is the most important factor in accurately determining the probability of design failure. When designing a design verification control, three key factors that must be considered.

It is important that the design control closely approximate the environmental conditions under which the objectionable incident is expected to occur during actual usage. It is not uncommon to find companies using methods that do not include expected conditions of usage that can play a significant role in the performance of a product. One example of this was a hydraulic component company that would do testing with clean hydraulic oil rather than oil that contained typical levels of contamination when they knew that the contamination could have a significant impact on the performance they were evaluating. When asked why they did not use oil with typical contamination levels to include actual usage conditions in the evaluation, they explained that the oil would contaminate their test equipment and they would have to clean it after each test.

When attempting to determine the risk due to a hardware specification, it is important to remember that you are trying to determine the probability of design failure when the product is built anywhere within the specification. Consequently, it is important that the products are evaluated at worst case specifications if possible. If physical prototypes are used, attempts should be made to build them to worst case for the hardware specifications being evaluated. If it is not possible to build prototypes to worst case, it is important that the hardware characteristics whose specifications are being evaluated for possible cause of design failure be measured so adjustments can be made in the actual test procedure or the analysis of the results to compensate for the measured values positions within their specification ranges. The Prototype Control plan is the key tool in accomplishing this task by requiring the measurement of the hardware characteristics to be evaluated during the prototype build.

The final key factor when designing design verification controls to determine the probability of design failure is sample size. The sample size has a direct impact on the confidence level one can have on the design control's ability to assess the adequacy of the hardware specifications and software code to prevent design failure.

While one would like to know the actual probability of design failure due to the failure cause being evaluated, it can be very difficult and sometimes impossible. The good news is that it is typically possible to define a confidence level that the design failure will not occur due to the cause. Consequently, when determining the probability of harm exposure to arrive at a risk measurement, it is not uncommon to use a combination of probability of failure data if available and confidence levels when probability of failure data is not available. Table 3 "Occurrence of FM Due to FC" is a table where either "probability of design failure due to the cause" or "confidence that design failure will not occur due to the cause" can be used to arrive at a rating that is indicative of probability of harm exposure.

Description	Rating
>/= 1 in 10; Confidence Level: <70%.	10
1 in 20; Confidence Level: 70%.	9
1 in 50; Confidence Level: 75%.	8
1 in 50; Confidence Level: 80%.	7
1 in 500; Confidence Level: 85%.	6
1 in 2,000; Confidence Level: 90%.	5
1 in 10,000; Confidence Level: 95%.	4
1 in 100,000; Confidence Level: 99%.	3
1 in 1,000,000; Confidence Level: 99.9%.	2
Failure is eliminated.	1

Table 3: Occurrence of FM due to FC

When a Design FMEA is being used, the rating from Table 3 is used to populate the Occurrence column. It is important to recognize that this table is providing a rating that is indicative of the probability that the design will fail due to the potential failure cause. It is not the probability of the potential failure cause occurring which the majority of FMEA reference manuals including the AIAG 4th Edition FMEA Manual and 2012 VDA FMEA manuals define it as. The probability of the potential failure cause occurring by itself is not a component of risk measurement.

When using design control results the challenge one faces is that a single design control typically is assessing the probability of a design failure due to multiple hardware specifications and/or software code when we want to know the risk impact due to individual hardware specifications and/or software code. Consequently, when design control results indicate an objectionable risk is present one must subjectively determine which of the hardware specifications and/or software code being evaluated by the design control they believe is most likely causing the design failure and perform the initial improvement activities on them while ignoring the potential causes that are deemed less likely. If it found that the selected hardware specifications and/or software code are not the source of the failure, the other potential causes are then evaluated.

DETERMINING TOTAL RISK

Once the severity of harm and probability of exposure to harm components are defined, the next step is to define the risk. A Risk Table (Table 4) must first be constructed. The Risk Table is matrix where the "Y" axis size is determined by the number of rows in the Severity of Effects Table (Table 1). The "X" axis size is determined by the number of rows in the Occurrence of FM Due to FC Table (Table 3). Symbols are defined to identify the cost zone that the severity rating falls in (S/L=Safety/Legal Cost Zone, R=Return Cost Zone). The appropriate cost zone symbol is placed in any combination of severity of harm (Severity rating from Design FMEA) and probability of exposure to harm (Occurrence rating from Design FMEA) that the company identifies as unacceptable risk. The Risk Table cost symbol determined by the ratings is placed in the Class column of the Design FMEA. Table 4 is a typical Risk Table.

10		S/L	S/L	S/L	S/L	S/L	S/L	S/L	S/L	S/L
9		S/L	S/L	S/L	S/L	S/L	S/L	S/L	S/L	S/L
8				R	R	R	R	R	R	R
7				R	R	R	R	R	R	R
6				R	R	R	R	R	R	R
5				R	R	R	R	R	R	R
4				R	R	R	R	R	R	R
3										
2										
1										
Sev/ Occ	1	2	3	4	5	6	7	8	9	10

Table 4: Risk Table

USING RISK TO ANSWER THE THREE DESIGN PROCESS QUESTIONS

Design failure and cause combinations with cost zone symbols are issues that must be worked on because their risk is unacceptable. The priority on which they are to be worked on is based on the cost zone the combination occurs in and the Occurrence rating. Items in the highest cost zone must be worked on first (red zone). Items within a cost zone are to be prioritized based on the Occurrence rating with the highest ratings (lowest confidence factor) being worked on first.

The final question that must be answered is when the design can be released for manufacture. It is very difficult for a company to remove all sources unacceptable risk. Consequently, the company must define how much risk is acceptable. As a result, a risk policy must be developed. A typical risk policy may be "no designs may be released with design issues in the Safety/Legal cost zone or with design issues in the Return zone with Occurrence ratings greater than 4". Table 5 is a typical "Risk Policy" table that is a graphical representation of such a policy.

10		*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L
9		*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L	*S/L
8				R	*R	*R	*R	*R	*R	*R
7				R	*R	*R	*R	*R	*R	*R
6				R	*R	*R	*R	*R	*R	*R
5				R	*R	*R	*R	*R	*R	*R
4				R	*R	*R	*R	*R	*R	*R
3										
2										
1										
Sev/ Occ	1	2	3	4	5	6	7	8	9	10

Table 5: Risk Policy (*=No Design release)

ROLE OF DESIGN FMEA COLUMNS IN MEASURING RISK

Table 6 shows the columns from the Design FMEA that are used to measure risk. When used correctly, the Design FMEA is very effective tool for managing risk and keeping a record of the current measured risk of the current hardware specifications and software code.

Column Headings	Item/ Requirement	Potential Failure Mode (FM)	Potential Effect(s) of Failure (FE)	Sev	Class	Potential Cause(s) of Failure (FC)	Occ	Design Prevention Controls	Design Detection Controls
Design FMEA Content	Product/Design Requirement	Objectionable Incident (Design Failure to Meet Design Requirement)	Description of Harm Due To FM	7	R	Improperly Defined Hardware Specification or Software Code	4	Method of Determining Probability of FM due to FC	Method of Determining Probability of FM due to FC

Table 6: Design FMEA Columns Used for Risk Measurement

The Class column is used to capture the risk symbol from the Risk Table. A common mistake made in the automobile industry when populating the Design FMEA is to determine the Class column entry only using the severity of harm.

The Det (Detection Rating) and RPN (Risk Priority Number) columns from the Design FMEA are not shown as being used for risk management. The reason for this is as follows. Unlike the Process FMEA where one can reduce harm by implementing a product inspection (Detection Control) to keep an out of spec product with a safety related defect from being shipped, there is no such type of control in the Design Process to contain a design failure due to the design. Once the design is released, there are no detection controls to revoke the design release. Since RPN uses the Detection Rating in its determination, it cannot be used for risk measurement.

The proposed AIAG-VDA FMEA Manual recently made available for public comment includes an Action Priority (AP) column for risk measurement in the Design Process. The AP rating includes the Detection Rating in its determination and thus should not be used for risk measurement.

CONCLUSION

Risk-based thinking can be a powerful tool for defining where company resources should be applied to provide the greatest design improvement. To effectively use the technique, one must be able to accurately measure risk. To accomplish this task, one must understand the impact of design failures, identify the hardware specifications and/or software code that cause designs to fail and possess a strong product design verification plan.

RELIABILITY TEST DESIGN: LINKING FATIGUE AND RELIABILITY

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ABSTRACT

Reliability and durability fit together in product validation testing. Often, the product's life requirement is being able to withstand loading over a specified duration with reliability and confidence requirements, like this: *"The part must be free of visible cracks with a reliability greater than 90% with a 90% lower 1-sided confidence bound after being subjected to loading representative of 4,000 service hours."* Durability, life data and reliability analyses can help engineers answer critical questions like how long to test and how many parts to test in order to meet these life requirements. In this article, we discuss the important link between testing to prove durability and testing to demonstrate reliability.

CREATING DURABILITY TEST SPECIFICATIONS

Product validation testing is an important step in the design process. The goal of validation or durability tests is to prove that the part is indeed capable of withstanding the loading that it will see in service. These tests are often the last step before approving the part for production. This means the tests are crucial to understanding both the durability and reliability of the product. Durability tests are often run in the controlled environment of the test lab, and can be specified in a number of ways. Typically, these test specifications are built around the concept of specified excitation or loading over a prescribed duration. The test spec may call for quasi-static loading (i.e., time-independent loading in which inertial effects can be ignored) or dynamic loading (i.e., time-dependent loading in which inertial effects are important). Note that it is important to ensure that the loading in the lab creates the same failure modes as one would expect in the field.

Validation tests need to be correlated to service loading. This correlation can be quantified using the concept of fatigue damage equivalence, in which the loading profile described in the lab test spec is tailored so that the test specimens will accumulate the same fatigue damage as the product sees in service. This fatigue damage correlation allows us to 1) link test time to service life time, so a potential failure in the lab can be correlated to hours or miles in the hands of the customer, and 2) replicate long service lives in a short test duration.

Durability analysis techniques can be used to reduce complicated service loading into an equivalent damage test spec. For example, consider a product like a lifting implement that is subject to cyclic loading. This loading can be measured in service and used to define the durability test spec. Figure 1 shows an example of service loading on a lifting implement measured in the time domain:

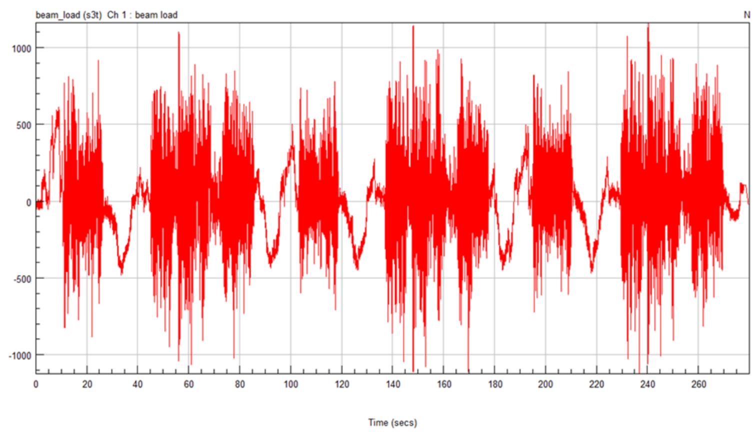

Figure 1. Measured service loading on a lifting implement.

Notice that it is highly variable in cyclic content. It may be advantageous in terms of both cost and timing to replicate the fatigue damage of this variable amplitude loading in the test lab with a simple cyclic load called a *constant amplitude spec*. The use of the SN curve and fatigue damage analysis allows us to calculate the cyclic range and number of cycles for an equivalent damage test spec.

Shown below in Figure 2 is an example of this. The measured service loading is in the upper left. The lower left represents a simple fatigue cycle that can be easily reproduced in a lab durability test. This latter loading is called constant amplitude due to its simplicity. Fatigue analysis completed in the top middle of Figure 2 is used to quantify the fatigue damage accumulation under these two loading scenarios. The fatigue damage incurred from one instance of service loading (which ranges from -1124N to +1163N) is 1.00E-3, while the fatigue damage from one cycle of constant amplitude (+/-850N) loading is 4.91E-6. Thus, fatigue analysis shows that 204 constant amplitude cycles (1.00E-3 / 4.91E-6 = 204) are needed to produce the fatigue damage of the measured service loading.

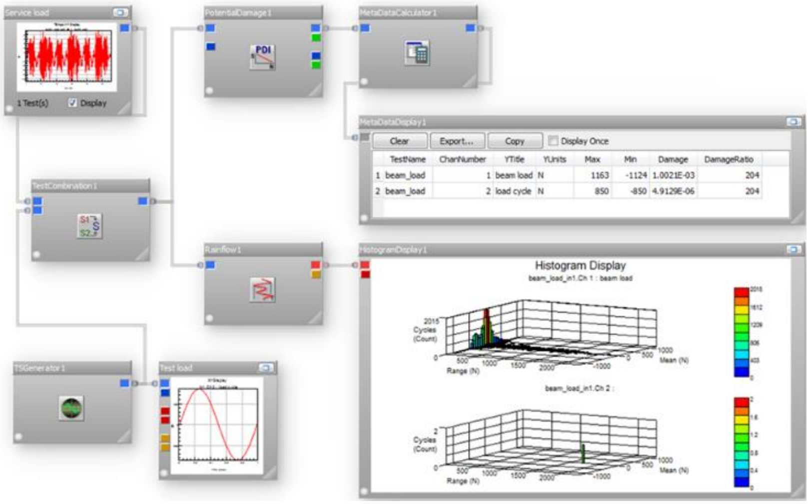

Figure 2. Fatigue damage analysis for test specification.

These techniques allow engineers to create a test spec that addresses product durability through fatigue damage equivalence. However, these lab tests should demonstrate both product durability and reliability. Take, for example, this stated durability requirement: *"The part must be free of visible cracks with a reliability greater than 90% with a 90% lower 1-sided confidence bound after being subjected to loading representative of 4,000 service hours."* If the world were deterministic, we could ignore reliability and the equivalent damage validation test could be run on a single part. Pass a single part without failure and we could consider the design validated — at least, deterministically. However, variability in material strength, loading, etc. is present all around us, and we need to recognize this in order to meet the stated durability and reliability target.

INTRODUCING RELIABILITY TO THE DURABILITY TEST

WEIBULL AND OTHER LIFE DISTRIBUTIONS

Time-to-failure data can be quantified and modeled using life data analysis concepts. Failure times are analyzed to understand trends in the product's failure rate behavior. These relationships can be modeled using life distributions, such as exponential, lognormal and Weibull. The lognormal and Weibull distributions are often used for durability failure modes because the shapes of their probability density functions can model failure modes associated with wearout. We will discuss the use of the Weibull distribution in the remainder of this article.

The Weibull distribution is characterized by two important parameters: eta and beta. These are illustrated in Figure 3. Eta is called the "characteristic life" and represents time to 63.2% of the population having failed. Beta is the shape parameter, which describes the slope of the probability of failure curve on Weibull probability paper. Different values of beta can have marked effects on the behavior of the distribution. The beta parameter plays a critical role in linking durability and reliability in the validation test.

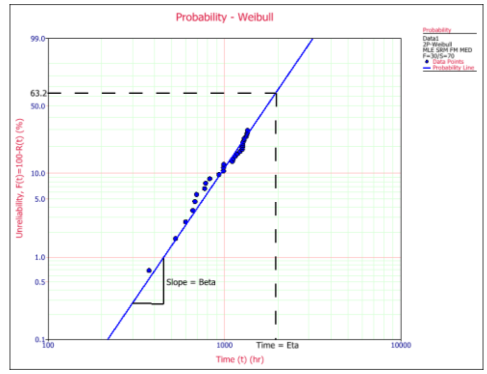

Figure 3. Example Weibull analysis.

RELIABILITY AND CONFIDENCE LEVELS

Reliability is defined as the probability that an item survives to a particular time. For example, 90% reliability at 500 hours implies that if 100 brand new units were put in the field, then 90 of those units would not fail by 500 hours. Confidence level is a measure of possible variability in an estimate due to only taking a sample of a larger population. From a practical perspective, it provides a way of ensuring that a sufficient number of units were tested before computing a reliability value. For example, to demonstrate a 90% reliability at a 90% confidence level requires more specimens (and/or test time, if a distribution is assumed) than demonstrating a 90% reliability at a 60% confidence.

Reliability at specific confidence levels can be demonstrated by testing a number of samples. Consider the case where the reliability target is 90% with a 90% lower 1-sided confidence level at 100 hours. We could test 22 parts and if every part survived 100 hours, then we would have demonstrated the reliability requirement. However, this sample size may be prohibitively large. We could consider decreasing the sample size, but the tradeoff is that a reduced sample size would require a longer test time. Alternatively, the test time of 100 hours might be too long. We could consider decreasing test time, but the tradeoff is that more parts would need to be tested.

Statistical analysis and the binomial distribution can help answer these questions:

- How many samples should we test?

- How long should we test?
- How are reliability targets at specific confidence levels related to the number of samples and test duration?

RELIABILITY TEST DESIGN

In this example, let us assume that the durability test spec has been established using fatigue damage equivalence, and that 10 hours in the test lab is equivalent to the product's target service life. We will also assume that the product's failure rate behavior is well characterized by a Weibull distribution with a beta value of 3.15 (based on prior experience from field and test data).

If the reliability requirement is 90% reliability and 90% confidence at 1 life, test design methodology shows that we need to test 22 samples to 1 life with 0 failures, as shown in Table 1:

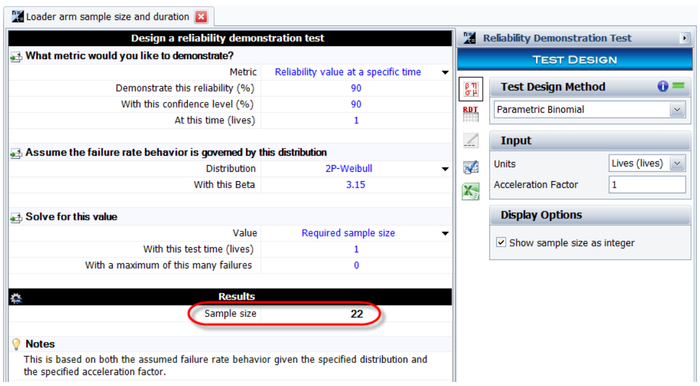

Table 1: Demonstrate R90C90 @ 1 life by testing 22 samples to 1 life

This number of samples may not be acceptable in terms of cost or timing. One way to address this concern is to run longer with fewer samples. For example, if we can run 2 lives (20 hours) on each sample without failure, the number of samples drops drastically, as shown in Table 2:

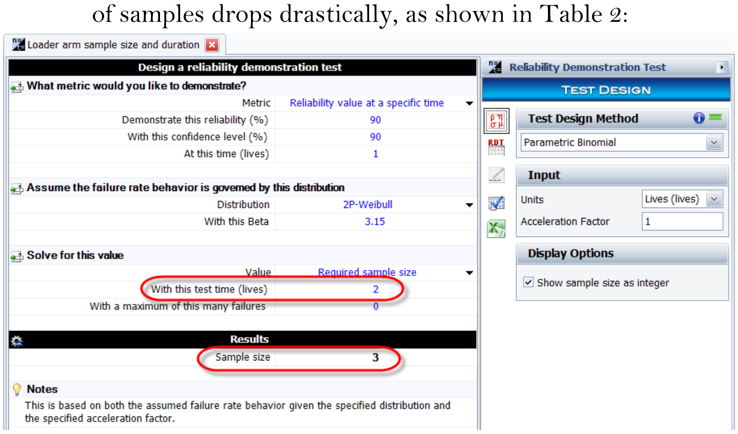

Table 2: Demonstrate R90C90 @ 1 life by testing 3 samples to 2 lives

This illustrates that we can demonstrate the same reliability and confidence with fewer test specimens by running durability tests longer. We have a tradeoff between the number of samples to test, duration of test and demonstrated reliability and confidence level. This is particularly useful if it is difficult to obtain a large number of test articles. We can make up for the lack of test articles by testing a smaller quantity for a longer time.

The key parameter needed to quantify this balance is the Weibull shape parameter beta. Beta must be used anytime the test duration and reliable life times are different, as it quantifies the benefit to demonstrated reliability that is gained by testing longer. Mathematically this can be expressed for a zero failure test as shown in Equation 1:

$$n_{units} = \frac{\ln(1 - CL)}{\left(\frac{t_{test}}{t_{required}}\right)^{\beta} \ln(R_{required})}$$

Equation 1: relationship between number of test articles, test duration, and reliability demonstrated

where:

- n_{units} is the number of articles on test
- t_{test} is the test duration, meaning how long the test will run
- $t_{required}$ is the time associated with the reliability target, meaning the reliable life time
- $R_{required}$ is the target reliability at $t_{required}$
- CL is the confidence level associated with the reliability target
- β is the Weibull shape parameter

CONCLUSION

Reliability and durability fit together in product validation testing. Durability can be addressed by creating fatigue damage equivalent test specifications that correlate to service loading. Fatigue analysis techniques can be used to shorten the duration of a test by creating a loading profile with equivalent fatigue damage to a service loading history. Reliability can be addressed by testing multiple samples. Statistical analysis and the binomial distribution can be used to assess the tradeoff between the number of samples to test, duration of test and the demonstrated reliability and confidence.

RELIABILITY AND SECURITY ARE NECESSARY CONDITIONS FOR SAFETY

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ABSTRACT

This article highlights some of the challenges in preventing safety related issues from showing up in the increasingly complex systems that dominate our lives. Of significant importance is the ever increasing complexity of vehicles that are reported to be trending toward full autonomous operation. Reliability and Security are necessary but not sufficient conditions to ensure safe operation of such complex systems. In these complex systems Safety is defined as an emergent property of the system. Loss of a Safety function can occur without hardware, software or security failure. These ideas are explored within the context of the current prevention tools and additional comments are offered on evolving methods to enhance the ability to ensure safety in complex systems.

Key Words: Safety Reliability, Security, Complex, Systems

THE DILEMMA OF EVER GROWING SYSTEMS COMPLEXITY

This article begins with a prologue on the general topic of complexity in systems that we are exposed to. In the process of making things so feature loaded, function rich and highly integrated, they have reached a level of system complexity that borders the ability of engineers to comprehend it fully. The automotive industry has built, and plans to build, systems that go beyond an individual's technical competency. Automobiles are already loaded with an abundance of processors, driven by millions of lines of software code, and manufacturers are constantly adding more. This trend will continue. The drive to add more features and functions is ever present. Competition to be first to market, or at least not be left too far behind, is compressing schedules to such a degree that there is the potential for additional risk being introduced. The risk is that there is simply not enough time to perform the preventive tools and methodologies needed to achieve an appropriate level of confidence prior to release. This creates a unique challenge for the Reliability, Quality and Safety engineers. How to build the risk prevention tool plans and provide reasonable estimates, early testing and analysis so that resource commitments, loading and identifiable milestones are understood, accepted and planned into the project.

THE PRESENT CHALLENGE

To summarize the title of this article, one cannot say that a system is safe unless they can say that it is reliable and secure. Safety is a general blanket term for most, and is subject to some interpretation depending on the disciplinary viewpoint. Wikipedia offers a definition of automobile safety as "the study and practice of design, construction, equipment and regulation to minimize the occurrence and consequences of traffic collisions". The United States Code for Motor Vehicle Safety (Title 49, Chapter 301) defines motor vehicle safety as "the performance of a motor vehicle or motor vehicle equipment in a way that protects the public against unreasonable risk of accidents occurring because of the design, construction, or performance of a motor vehicle, and against unreasonable risk of death or injury in an accident, and includes nonoperational safety of a motor vehicle." A defect includes "any defect in performance, construction, a component, or material of a motor vehicle or motor vehicle equipment." This definition mentions "defect in performance", which includes the unpredictable behavior of a vehicle in an unsafe way when no assignable cause such as a hardware, software, or operator failure is evident. If the elements of the system are unreliable then there will be failures, and those failures will include loss of safety functions. The definition of reliability is the probability that a product, system or service will perform its intended function adequately for a specified period of time, operating in a defined operating environment without failure. The same is true of security. As defined by the Systems Engineering Body of Knowledge, security is "an element of system engineering that applies scientific and engineering principles to identify security vulnerabilities and minimize or contain risks associated with these vulnerabilities". If the system is not secure then there is a potential for compromise, and those who compromise a system intentionally likely have malicious intent. Reliability and security are disciplines that need to be demonstrable. Quality is a term that is conspicuously missing from this article due to its distinct separation from reliability and security. Complexity in systems within automobiles that the general public use on a daily basis is well masked for the end user and for the most part, taken for granted by that user. For the engineer that has to deal with complex system failures, the challenges can be daunting. It is a complexity that has been growing since the early 1980s. In those early years of growth, computers were being integrated into all facets of systems. Integrating these elements of computing into these systems which were, for the most part, electro mechanical, provided extensive benefits. Along with these benefits immediately came new challenges of failure analysis. It was not unusual to have Mechanical engineers and Electrical engineers exchanging accusations with Computer engineers and Software engineers on whether it was hardware or software that was responsible for a failure. Even at this early stage of computer introductions, problem analysis and causal attribution became significantly more complex. It was not inconceivable to blame the problem on some unexplained sporadic behavior of the software or the semiconductors. Failures, faults, and erroneous outputs that were random in appearance and difficult to attribute to either hardware or software was becoming too common. Major release of computer software included overlapping revision release initiatives because developers understood that they were not preventing all issues and that they would eventually show up in the user domain. The strategy was to start exhaustive testing in parallel with the major releases and include feedback from the user community on what problems were found. The situation is not so different today, with failures that defy reasonable expectation and challenge the most seasoned investigators. A cursory review of published automotive safety incidents will reveal the challenge being faced. Obviously, development processes of these failed systems included the investigation of probable failures, using tools like Failure Modes and Effects Analysis (FMEA), Quality Function Deployment (QFD), Fault Tree Analysis (FTA), etc. These tools have been around for a long time and arguably they have not evolved to meet the challenges of these increasingly complex systems. These traditional tools of course don't address the software challenges unless you consider something like Software Failure Modes and Effects Analysis (SWFMEA). Such an approach, taking the viewpoints of ISO 12207, can be useful in identifying and reducing risk in the software, but due to the inherent deductive approach of FMEA, this approach does not address the combinational failures that can and do occur in complex systems. It is accepted today that complete testing of software, that is, all failure cases, is not practical, and in some cases not possible. Software may include elements of artificial intelligence and include sophisticated algorithms that make decisions based on programmed learning capability. The various aspects of the software may have been written by numerous teams working independently. Considering the sheer magnitude of code and the variety of processors that are integrated into a modern automobile, one can appreciate that completeness of testing can be viewed as impossible. The only resort is to assess what level of coverage to apply to the software and to what depth of analysis can practically be pursued, based on the potential risk assessment.

INTERIM STEPS TO DEVELOPING MORE SOPHISTICATED ANALYSIS METHODS

Given this ever growing complexity and the absolute need to deliver safe product, both in functionality and in operability, risk prevention practitioners will find the tools of yesterday will not fulfill the needs of today. Tomorrow promises to bring even more complexity, with autonomous vehicles, including artificially intelligent elements, self-learning systems, and perhaps even intelligent, thinking systems. The present situation includes two needs. The first, to be able prevent any unsafe response from the system, in this case, the automobile. Focus is on safety, yet the tools that we have been using to date treat safety implicitly. For one of the most applied preventive tools, FMEA, we find safety in the severity ranking at levels 9 and 10. One might conclude that safety coverage is adequate because of this severity coverage. What thought leaders are discovering is that modified approaches such as Systems Theoretic Process Analysis (STPA) give risk analysis practitioners insights that are missed by restricting the approach to something like FMEA. Unfortunately, STPA is not a systematic, step wise approach like FMEA and so the FMEA facilitator will not be able to simply add the STPA analysis to their tool box. It presents a similar challenge that one encounters if they add safety as a requirement in FMEA. This then introduces the general failure mode of "loss of safety function". With this additional requirement of safety one now has to look backwards into the design, from the perspective that the system has just failed to perform safely, and seeks an answer to the question of what caused this unsafe response. The preventive measure for this failure mode is that the FMEA has been performed and all severities of 9 and 10 have been cataloged and addressed. Yet this safety requirement addition forces a retrospective analysis, one that requires the FMEA team to look at the problem from another viewpoint. It is similar to the logic problem of the water lilies and the pond. The problem is presented like this, if water lilies growing on a pond double in size every day, and on day 60 the pond is completely covered by water lilies then on what day was the pond only half covered by the water lilies? Some readers may be inclined to say that this problem is not solvable. We don't know enough about the initial conditions, like what size is the pond? How big is a water lily? Are they all the same size? The problem becomes simplistic when viewed from the retrospective. If water lilies double every day and the pond is covered on day 60, then the pond was half covered on day 59. Some readers see the answer immediately, but I have been running problem solving, root cause analysis and decision theory workshops for several years now and have to report that the majority of the attendees do not see the answer readily. The problem is typically posed with an option, asking attendees if they can solve the problem and if not, then why is it not solvable? The responses vary across the entire spectrum of possible answers. So looking backwards into the FMEA after all the failure modes and causes have been explored, and assume that the system has just failed into an unsafe state, and asking "how and why?" expands the thought process. This also makes safety explicit in the FMEA which again adds some benefit to the exploration. Yet the singular fail mode approach of the FMEA does not allow for combinatorial failures, or functional safety failures where no component has failed and the control system has done exactly what it was programmed to do. FTA will provide additionally needed coverage of combinatorial failures, but with it comes the additional necessity to be able to construct a representation of the systems in all its complexity, assign realistic probabilities to the failures and do the Boolean algebra to sort out the dominant contributors. I think everyone can attest to having seen some embarrassingly poor FTAs done by experienced teams working on high profile projects. Even with the FTA, there is still a need to look back into the process and assume a functional safety failure to gain the benefit of this retrospective in spite of the argument that the analysis seems to be adequate as it is. Another approach that is finding renewed interest is Causal Learning. The possibility of learning causal relationships through an inductive method of causal discovery that integrates elements like counter factuals, propensity scoring, directed acyclic graphs, etc. This is a process that requires expertise and the command of new language notation that is still emerging and being defined (redefined). It only finds mention here but no overview is offered due to the scope of the work. It is sufficient to say that investigation into this area is intended to take on the challenges of system complexity when the only offered cause is something like "spurious anomaly". Human machine teaming is yet another emerging process that as would be guessed, is finding its place in the defense industry. This emergent process endeavors to better define how robots and humans will interact in the future. Investigating how the human-robot teams will be able to function as a single, integrated system. This approach calls on the strengths of both the human and the robot, asking each one to perform what they do best. This article only mentions the topic, but any science fiction movie will bring the reader up to speed on the potential for this area of investigation and implementation.

BOUNDARIES OF THE ANALYSIS

An additional contributor to the loss of safe operation of an automobile has to be the operator. FMEA does not ask the question about potential operator behavioral modification. Take for example the advertisements on television of cars that will brake automatically, to the surprise and delight of the driver because they have avoided running someone over or crashing into something. A closer inspection of the human behavioral scenario creates a suspicion as to how automated systems subtly modify, or can modify, the driver's behavior. Maybe an extreme view here, but it seems plausible that people could come to the conclusion that it's now ok to text while driving, or allow for other distractions that previously were unacceptable. Operators are likely to conclude that the car knows when to stop, so consequently the level of cognitive effort can be relaxed. As new features get added, such as lane departure warning (LDW), lane change support (LCS), adaptive cruise control (ACC), automatic parking, etc. Will the driver become so dependent on these features that their cognitive effort levels will diminish to such an extent that they will not be able to adequately respond when the system fails? When required to take control, it is likely they will react rather than respond, and take the wrong action. Cameras instead of rear view mirrors might be a good example. Lane changing based on camera images and LCS can condition a driver over time, where now they rely on the system to inform them on lane change. On a congested multilane highway at 60 mph, making a quick change into an adjacent lane and now imagine that the camera frame has frozen, showing an open lane, but with the LCS signaling it is not an open lane, what will the driver do? Having been conditioned to rely on the system, it's likely that they will either freeze up for a few seconds, staring at the camera bewildered as to what this conflicting signal means, or they may make a snap reactive decision and execute the lane change in spite of the conflicting information. At 88 feet per second, that is somewhere in the range of about 6 car lengths a second. One gets an appreciation of how important a single second can be in such a situation. The inclusion of such active safety systems are most likely covered by FMEAs and maybe FTAs in the early stages. It is not likely that the question about the driver conditioning gets asked during the course of these tools. As noted earlier, the FMEA tends to leave the operator out of the loop. Functional Safety standard ISO 26262 (https://www.iso.org/standard/43464.html) adds the ability to explore scenarios and takes controllability (by the operator) into context, yet the implicit assumption seems to be that the operator will make the appropriate decisions in the fractional amount of time allotted. Everyone has had experiences where they were confronted with unexpected scenarios and found themselves either taking the wrong action, or freezing up while trying to cognitively resolve the presentation issue. When the presented information is in contradiction to the expected information, even in low pressure situations where there is plenty of time to think, there seems to be some limitations in human ability. This will be even more pronounced when a driver is using more than one vehicle, and the vehicles have different safety assist features.

CAUSAL ATTRIBUTION OF FUNCTIONAL FAILURES

It appears that the consequences of compressed schedules, shrinking budgets, demand for innovation, competitive challenge, etc. are going to result in problems that will only be discovered in the customers' domain. Minimizing the risk, especially safety related risk, will require a commitment to the discipline of front loading and risk/quality/reliability/safety tool discrimination and execution. This will be especially true with regard to software development. Software is never fault free, and careful considerations need to be given to coverage, functions, structure and depth of analysis. A refinement in the way that root cause analysis is done will also need to be reconsidered for its effectiveness and efficiency, demanding that the analysis be evidence based. Global and cultural considerations need to be included in the thought process to make sure that understanding, interpretation and prioritization are communized both in language and in thought. Global enterprise strategic goals need to include transcultural normativity and transcontextual efficacy in order to exploit the limited resources and unique competencies required to meet these future challenges. Unfortunately, there are decision makers and resource managers who have come to a trivial conclusion that the problem solving process needs to be simplified and streamlined. That is to say, use the same tools so as to avoid the need to increase competency, and simplification is then defined by cutting out areas of investigation where it appears that risk is low. There is also the great hope that simulation in place of testing will be the answer to the problem, but evidence to date seems to suggest otherwise. This view demonstrates a lack of appreciation of the problems at hand, a failure to emerge from single loop organizational learning (keep doing what you're doing, only faster) and an excursion into the world of Orwellian inversions. The logical proposal is quite a bit different, in that it is a call to meet the challenge by developing a cadre of highly skilled, competent and experienced Quality/Reliability/Safety/Security tool facilitators that are a shared resource within the global landscape. Finding individuals that have an innate talent as facilitators, training them in the disciplines of Quality, Reliability, Safety and Security and then let them 'have at it'. This requires good strategic planning, another tool of the experienced facilitator. The single biggest mistake that is made regarding strategy is to think that all actions, objectives, goals, spending, resource alignment, etc. somehow all roll up into a strategic plan. When in fact the opposite is true, the strategic plan needs to come first.

CONCLUSION

Complexity will continue to grow in fashion similar to Moore's law. Failures of safety functions that defy evidence based explanations (no failed parts, no software bugs) will grow in frequency (e.g. March 19, 2018 – Bloomberg Technology report -Uber Halts Autonomous-Car Testing after fatal Arizona crash). Enhancements and extensibility of the traditional prevention tools will not be sufficient in preventing this emergent property of "un-safety". The discipline of risk prevention that includes physical testing will need to be legitimized again as it has fallen victim to the compressed schedule and constrained budget. Rapid and parallel component and subsystem testing methods need to be included in the development such that the component/subsystem would, for all intents and purposes, not know that it was in a test chamber as opposed to being on a vehicle. New tools and methodologies to improve upon evidence based causal attribution, which will include new ways of thinking, need to find their way into the organization with dedicated resources that have natural talents for such challenges.

FUNCTION DECOMPOSITION FOR PRODUCT RISK ASSESSMENT

JOHN BESSMAN, SENIOR RELIABILITY ENGINEER, THE PACCAR TECHNICAL CENTER

John Bessman is a Senior Reliability Engineer at the PACCAR Technical Center in Mount Vernon, WA, the primary validation facility for PACCAR Powertrains and Kenworth and Peterbilt trucks. He is also the chairperson of the PACCAR Reliability Expertise Group and Six Sigma Coordinator for the facility. John has spent the past 5 years at PACCAR, working both to improve the reliability of products currently on the market as well as evaluating the reliability of in-development vehicles. Prior to joining PACCAR, he was a Test Engineer at the Emerson Innovation Center for Fisher Valves for 9 years where he built custom test rigs to evaluate industrial control valve reliability across a wide range of applications. He received a BS in Mechanical Engineering from Iowa State University, and an MS in Reliability Engineering from the University of Maryland

Keywords: Function Tree, Requirements, System Engineering, Risk

ABSTRACT

Function trees are useful tools for understanding and managing the requirements of complex systems. This article will lay out a basic framework for creating and using function trees. The benefits to new product development programs, continuous improvement projects and engineer talent development is also discussed.

INTRODUCTION

Engineered systems have been getting more complex for decades. Technical specialization and manufacturing globalization mean that, though product quality can increase while costs decrease, no single person or organization can realistically be expected to have total control over every design characteristic. This is particularly true in the semi truck market, where customers often require significant customization direct from the factory. Instead of controlling the designs of various engine, transmission and axle suppliers, the organization controls the requirements for those components. By controlling the requirements, the organization can ensure that their products will be successful without having to control every design characteristic.

To develop the component requirements, the necessary function(s) of each component must be understood. When component functions are tied to requirements, the manufacturer can begin to understand the tradeoffs associated with design decisions. This can also highlight system interactions that may not be readily apparent when engineers are focused on a particular design characteristic of a single component.

THE FUNCTION TREE FRAMEWORK

The manufacturer has to identify the customers' requirements. Customers may include government agencies such as the Environmental Protection Agency, California Air Resources Board and National Transportation Safety Board in addition to end users. Example user requirements for a Class 8 truck end user may include:

- Performs all tasks necessary for the application
- Low operating costs
- Durable
- Easy to drive
- Comfortable overnight accommodations

These are *very* high level user requirements. Though they adequately describe the attributes that will lead to satisfied customers, repeat sales and high resale values, they do not yet provide value for the engineering groups or suppliers who need metrics for validation. These customer requirements need to be decomposed into their associated vehicle functions. Figure 1 shows examples of a first level requirement decomposition.

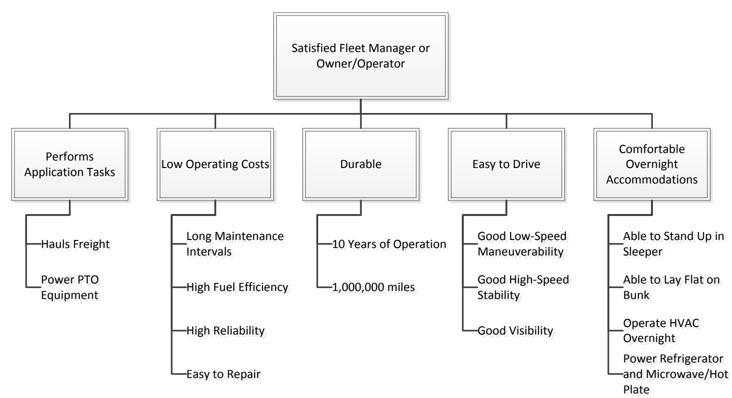

Figure 1: First level functional decomposition of Customer Requirements

Even at this first level of decomposition, the foundations of design requirements and validation metrics are coming into focus. This helps in creating program budgets and schedules as well. The functions are further decomposed into progressively lower levels until no further decomposition is necessary to understand how the system operates. Function decomposition typically ends in one of two states: a single part that is designed by the manufacturer, or a component or assembly that is purchased from a supplier. If the process ends at a manufacturer's part, the manufacturer can proceed to a Design FMEA. If it ends with a supplier, then the manufacturer already has a comprehensive list of requirements for procurement to use in soliciting bids. Figure 2 shows an example of this continued function decomposition for a portion of the function tree from Figure 1.

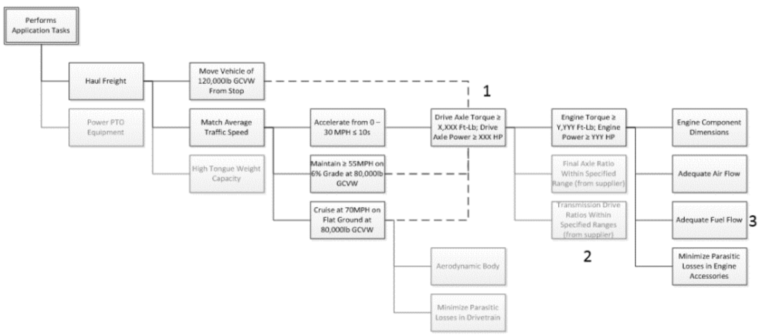

Figure 2: Continued Function Decomposition for one of the customer requirements. Greyed out boxes would also require additional decomposition but were abridged for brevity.

In this example, only the drivetrain branch is developed. In an actual function tree all branches would need to be developed to a lower level than is shown here. Even in this small function tree there are a few interesting items to point out.

1. There are multiple higher level functions that are affected by the Drive Axle functionality; each higher level function may have its own minimum Drive Axle torque and power requirement. In this case, the final Drive Axle torque and power must be at least equal to the highest requirement. Suppose all the functions required to Match Average Traffic Speed can be accomplished with 1200 lb-ft at the axle, but moving 120,000 lbs GCVW requires 1400 lb-ft. If the final drivetrain design yields 1350 lb-ft, then some heavy-haul customers will not be able to use the vehicle.

2. In this case, the drive axle(s) and transmission are provided by a supplier rather than designed by the manufacturer. This means that little more decomposition can be done on these components. However, the necessary functions can be used to identify potential suppliers and product lines that would be suitable for this vehicle.

3. While not explicitly shown here, the function tree can illustrate competing functional requirements. This tree shows that the fuel flow rate must be high enough to support the engine performance requirements. However, High Fuel Efficiency is also a function within the Low Operational Costs customer requirement. The fully developed tree brings these competing functional requirements into view and highlights opportunities for optimization. In this case, fuel consumption must be high enough to satisfy the customer's performance needs but low enough that they are not going broke at the fuel station.

Further decomposition of these functions will eventually yield the information necessary for a DFMEA. The final decomposition level will be a failure mechanism which is the DFMEA Cause. The DFMEA Failure Mode is the inability to perform the function that precedes the failure mechanism. The DFMEA Effect is the inability to perform the next higher level function. Figure 3 shows how the function tree items can be used to initiate a DFMEA.

ID	Item/ Function	Potential Failure Mode	Potential Failure Effect	SEV	Classification	Potential Cause	OCC	Current Design Controls		DET	RPN
								Prevention	Detection		
1	Provide Adequate Air Flow to Engine	Insufficient Air Flow	Engine Performance Does Not Meet Requirements			Air Filter Does Not Meet Flow and dP Requirements					0
						Intake Pipe Diameter Too Small					0
						Intake Pipe Has Too Many Bends					0
						Intake Pipe Bend Radius Too Small					0

Figure 3 Sample Design FMEA initiated from function tree analysis.

BENEFITS OF FUNCTION TREES

At this point the function tree probably seems like a lot of work just to end up with a DFMEA. And yes, a function tree *is* a lot of work. However, it provides additional product insights that a DFMEA cannot and it is able to provide those insights before concepts are even generated. As already discussed, the function tree is able to illustrate the relationships between various systems. By exploring these relationships at the functional level, prior to the concept phase, problems can be identified and resolved before any money is spent on prototype parts or tooling.

If problems do make it through the concept phase, the full impact of mid-program product changes are easier to understand. As budget and schedule realities inevitably affect the development program, is it easier to mitigate the resulting risks.

It also provides an early framework for the system validation tests that should be performed before taking a product to market. This makes program budgeting and scheduling more realistic during the planning phase. This is especially useful for organizations that follow a "V" development cycle.

The difficulty in creating a function tree is directly related to the complexity of the product. Fortunately, for many complex products the underlying functions do not change very often so a large portion of a function tree can be copied across many different models. Complex products also rarely undergo a complete "clean sheet" redesign. Instead, they evolve as subsystems are continuously improved over time. When this is the case, only those parts being changed need to have the function tree reexamined. For example, if a new engine is being developed for the semi truck it is not necessary to recreate the function tree for the sleeper ergonomics (unless they are impacted by the engine, of course). And again, the function tree will tell you if any functions of the sleeper ergonomics *are* impacted by the engine.

Function trees can serve to preserve the tribal knowledge that will be lost as large portions of the workforce continue to move into retirement. The function tree documents the thought processes and reasoning that the most experienced engineers use when preparing an FMEA. The system interactions that they discovered years ago can be documented so the new engineers do not have to learn the same lessons at the customers' or manufacturers' expense. The next generation engineers will have their own lessons to learn as the industry continues to evolve.

SUMMARY

Function trees are tools for investigating the requirements within a complex system and how they interact with each other. They are design-agnostic; they can often be completed even before concepts are generated. This early examination of the necessary system functions makes it easier to design validation plans and create associated budgets and schedules. Though not always simple to create, they are valuable tools for ensuring that all product requirements are met and design tradeoffs are understood when conflicts arise. They can also help engineers who are new to the organization get familiar with the product quickly.

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2018 World Conference on Quality and Improvement,

Seattle, WA, USA

Javad Seif
Ph.D. candidate, Industrial Engineering
Department of Industrial and Systems Engineering, University of Tennessee-Knoxville (UTK)
Advisor: Dr. Andrew Yu
Graduation Date: May, 2018

Dissertation Title

THE INTEGRATION OF MAINTENANCE DECISIONS AND FLOW SHOP SCHEDULING

My dissertation topic was motivated by a common problem I had encountered in industry prior to my graduate studies. I designed and implemented computerized maintenance information software (CMMS) for various companies. It has been my observation in many cases that regardless of the complexity and comprehensiveness of maintenance plans and maintenance management software systems, preventive maintenance activities are very likely to be deferred, or refrained from, due to production priorities. In my research, I strive to solve this problem by integrating production scheduling and maintenance decisions. The outcome is a schedule that simultaneously optimizes both production and maintenance objectives. This effort has led to four publications in high-rank journals of industrial engineering.

In the conventional production scheduling problems, it is assumed that the machines can continuously process the jobs and the information is complete and certain. However, in practice, the machines must stop for preventive or corrective maintenance, and the information available to the planners can be both incomplete and uncertain. In my dissertation, the integration of maintenance decisions and production scheduling is studied in a permutation flow shop setting, where a number of jobs (orders) are to be processed consecutively on a number of machines in series. The machines should undergo various types of maintenance after operating for certain number of hours. The objective is to minimize the completion time of the jobs with respect to their due times, and minimize the maintenance costs. In the mathematical models and solution algorithms that I have developed, I consider the technical nuances that increase the practicality of these models: having various types of maintenance activities, combining these activities, and how maintenance affects the performance of the machines.

Through extensive case studies and computational experiments, I have shown that my proposed models and solution methodologies are reliable, robust, and independent from commercial solvers. This independence facilitates the incorporation and automation of these solutions in the existing information systems found in manufacturing and service industries. By using the results of my research and implementing my proposed solutions, manufacturing and service industries can 1) resolve potential conflicts between production and maintenance, 2) minimize maintenance planning costs (spare parts and workforce), 3) improve the health of the machines (physical assets), 4) increase the readiness and performance of the production lines, 5) increase customer satisfaction through optimal production scheduling, and 6) improve the utilization of existing information systems such as ERP and CMMS. All of these benefits can be attained without reliance on commercial solvers that are financially and computationally expensive.

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Graduation Date: May, 2018
Adviser: Dr. Zissimos P. Mourelatos

Dissertation Title

IMPROVED FATIGUE RELIABILITY AND ACCELERATED TESTING

METHODS FOR VIBRATORY SYSTEMS UNDER GAUSSIAN AND NON-GAUSSIAN EXCITATION

Fatigue life estimation, reliability and durability are important in acquisition, maintenance and operation of vehicle systems. Fatigue is considered as one of the most important failure modes of a mechanical system. Fatigue life is random because of the stochastic load, the inherent variability of material properties and the uncertainty in the definition of the S-N curve. Degradation of the material properties of a system throughout time may cause unexpected fatigue failures that eventually increase the lifecycle costs due to warranty costs, repairs and loss of market share.

The performed research has two main parts. In the first part, fatigue life prediction methods are investigated for linear and non-linear systems excited by Gaussian and non-Gaussian loading. For the latter, a general methodology to calculate the statistics of the output process considering the effects of skewness and kurtosis is used. Real operational conditions of ground vehicles involve non-Gaussian loading whose characterization is challenging. The excitation is first characterized using the first four moments (mean, variance, skewness and kurtosis) and a correlation structure. Then, the first four moments and the correlation structure of the response process are calculated using Polynomial Chaos Expansion (PCE) and Karhunen-Loeve (KL) expansion. Simulated trajectories from the response stochastic metamodel are rainflow counted to obtain realizations of the fatigue life random variable based on Miner's damage model. Finally, the Saddlepoint Approximation (SPA) method provides the PDF and percentiles of the fatigue life.

In the second part of the research, we developed a new Accelerated Life Testing (ALT) methodology using Gaussian or non-Gaussian excitations without assuming the type of life distribution or the relationship between life and stress level. The accuracy of fatigue life prediction at nominal loading conditions is affected by model uncertainty (system model and fatigue model error) and material uncertainty such as the coefficients of the S-N curve. The uncertainty of fatigue life prediction is reduced by performing tests at higher loading levels, reducing therefore, the test duration. We developed an ALT methodology to minimize the cost of testing while improving the accuracy of fatigue life prediction. All developments were demonstrated with representative examples.

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Dissertation Title

RELIABILITY OF REPAIRABLE SYSTEMS AND WARRANTY FORECASTING METHODS

Most engineering systems are repairable. If a component or system fails, a repair (renewal or replacement) may occur so that the system can be put back in service. The repair strategy affects the repair effectiveness, which in turn, determines the number of Expected Number of Failures (ENF). The latter is a critical measure in warranty forecasting, depot maintenance and inventory logistics, among others. In this research, we developed forecasting methods to predict the ENF, and its error bounds, for a repairable component/system, using observed data. The latter is used to estimate the parameters of a proposed modified Generalized Renewal Processes (GRP) reliability model. This GRP model accounts for the "clean-point", "production-pattern", "useful life" and Limited Failure Population (LFP) concepts. Manufactured products produced in different Months Of Production (MOP) may have different failure statistics because of supply chain differences or different skills of production workers, for example. The "production pattern" provides a failure propensity trend per MOP for all produced units. In addition, during the warranty period, there may be a time called "clean point" where a defective component/system is detected and replaced with a new more reliable unit for all products produced thereafter. This introduces a different statistical behavior before and after the detection of the "clean point."

The developed modified GRP model also allows us to estimate the "useful life" of a component or system which indicates the time after which the component is not worth repairing and must be replaced. The "useful life" defines the "planning horizon" or "lifecycle." All repairs are performed only within the "planning horizon". The modified GRP reliability model was applied to populations partitioned into defective and non-defective subpopulations by introducing the principle of Limited Failure Population (LFP) theory in the GRP model. For that, a Hybrid-LFP-GRP model was developed. We observed and proved with examples that the widely used Maximum Likelihood Estimation (MLE) approach may provide inaccurate estimates of the LFP parameters. To address this issue, we introduced a new method which is much more efficient than MLE. The new method more the production pattern more accurately.

Finally, we extended the classical definition of reliability to repairable components using a random process approach. Such a definition does not currently exist despite its significance for repair and depot maintenance strategies.

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Graduation date: April 2018
PhD Advisors: Dr. Nagi Gebraeel and Dr. Kamran Paynabar

Dissertation Title

PREDICTIVE ANALYTICS FOR COMPLEX ENGINEERING SYSTEMS USING HIGH-DIMENSIONAL SIGNALS

Tremendous maintenance and operational expenditure are incurred due to unexpected failures, and inefficient maintenance and operational practices. Consequently, many capital-intensive assets used in the energy, manufacturing, and service sectors (such as gas turbines, boilers, paper mills, and steel mills) are equipped with numerous sensors that generate large amounts of data related to the physical performance and the operational characteristics of the asset. For example, optical sensors on modern gas turbines generate 600 gigabytes/day—almost 7 times Twitter daily volume. This data comes in various forms, (a) multivariate time series, (b) profile data where a single data observation represents upwards of 2,000-3,000 data points, and (c) image data (collectively referred to as high-dimensional data). One of the key Big Data challenges stems from the need to analyze high-dimensional data, in real-time, to detect faults and predict the future state-of-health of critical assets. If modeled properly, this information can inform operations and production schedules as well as optimize maintenance activities and spare parts logistics.

This doctoral dissertation focuses on addressing several key challenges in predictive analytics for asset management and optimization. The first research challenge revolves around the development of prognostic methodologies (for predicting asset health and remaining operational life) that can scale with the size and complexity of high-dimensional data. In contrast, most existing research focuses on single time-series data applications or multivariate applications where only small-sized time-series vectors are considered. Furthermore, the limited research efforts that involve more complex data structures like profile and/or image data are limited to fault detection, and do not extend to prognostics—two fundamentally different problems. The second research component focuses on computational efficiency of analytic models. Specifically, we pursue fundamental research aimed at speeding up matrix computations of conventional statistical methodologies that enable their application in real-time prognostic applications. Many of the existing models have been validated utilized small-sized data sets, and thus computational challenges have often been overlooked. The third challenge, one that has traditionally been neglected due to lack of real-world data, deals with data quality and its impact on the accuracy and fidelity of the resulting analytics. Harsh industrial environments have a significant impact on the quality of sensor data that range from missing and fragmented data observations to corrupt values and outliers that often result in significant false alarms—a problem that plagues many industries. In this thesis, we focus on developing models that are relatively robust to applications that exhibit poor data quality. We also consider this problem for Big Data settings where the problem is much more profound.

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Dissertation Title

HIGH DIMENSIONAL DATA ANALYSIS FOR ANOMALY DETECTION AND QUALITY IMPROVEMENT

Nowadays most manufacturing processes are instrumented with sensing systems comprised of hundreds of sensors to monitor process performance and product quality. Common types of the sensor information include profile data, waveform signals, images, and videos, which are challenging to analyze due to the high dimensionality (volumes), high variety and high velocity. Furthermore, the complex variational patterns such as spatial and temporal patterns are also very challenging to analyze. In Chapter 3, we develop an anomaly detection method for image sensors. This research is inspired by the vision-based defect detection problem in the composite material and aims to automate the defect detection process. This method is able to remove the noise of sensors and detect the potential defects or anomalies simultaneously within seconds for noisy high-resolution images. Chapter 4 extends this approach to spatial-temporal data. For example, in the rolling inspection and solar flare monitoring, video data are used for online monitoring. We are able to detect the potential defect automatically from the dynamic and changing background in real time. Chapter 5 considers the case where the observation data cannot be obtained in one shot. For example, in the point-based measurement system, the data can only be collected one point at a time such as for touch probe coordinate measuring machines and laser-based measurement systems. To reduce the data collection time for these systems, we developed an adaptive sampling algorithm. This adaptive sampling method is able to quickly search and locate all defect in a large sample within a short amount of time. In chapter 6, we propose to model the 3D shape of the products with the certain process variables. For example, in the turning process, the cutting depth and rotation speed can change the mean shape and surface roughness of the 3D product. After obtaining this model, we are able to optimize the performance of the process by giving the best parameter setting.

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Ph.D. Advisor: Dr. Zhaojun Li

Dissertation Title

PROGNOSTIC METHODOLOGIES FOR REPEATED MEASUREMENT DATA OF MULTIPLE UNITS

This research investigates prognostics modeling methods on repeated measurement data of multiple units in order to improve the prediction accuracy and facilitate effective predictive maintenance. Engineering systems deteriorate in performance over time and are subject to the stresses in operation. Predictive maintenance (PdM) is one of most effective maintenance policies, where maintenance actions are planned based on the actual system performance. Remaining useful life (RUL) prediction is the keystone of PdM. Prognostics and health management (PHM) is involved in PdM due to its strength in the system's RUL prediction and related health management. Prognostics is the core process of PdM and PHM, that aims to predict the RUL based on available performance data. Multiple uncertainties, such as input uncertainties and model uncertainties, undermine the prediction performance of prognostics models. To characterize the inherent variability in the degradation process, repeated measurement design is exercised, where repeated measurement data of multiple units is obtained. This research aims to develop adequate prognostics models to quantify multiple-source variability in this type of data and develop robust algorithms for complex data structure with unbalanced data.

Based on the way of modeling the multiple-source variability, four prediction methods are proposed to model the prognostics process based on repeated measurement data of multiple units. General mixed effects models (GMM), containing fixed and random effects, are widely used to account multiple sources of variability in repeated measures. The combination of fixed and random effects illustrates the variability in a stochastic process. Fixed effects describe the characteristics of the population average over units and the random effects demonstrate the variation of units. Because of the difficulty of linear mixed effects model dealing with unbalanced data, a joint modeling method (JMM) is proposed where the degradation process of each unit is interpreted as multivariate normal distribution. The concept of joint modeling is that the mean and covariance are decomposed firstly and then unknown parameters of the mean function and covariance matrix are estimated jointly. In the proposed method, mean, variance, and correlation of measurements are firstly decomposed based on Cholesky decomposition. Trigonometric functions are used to parameterize the correlation matrix. A penalized maximum likelihood estimation is proposed for parameter estimation in JMM. The expensive computation in GMM and JMM due to the high dimension covariance matrix necessitates the dimension reduction techniques. For this purpose, functional principal component analysis (FPCA) is deployed in this research. FPCA applies the concept of functional data analysis in principal component analysis to reduce computation complexity. Finally, a general spatio-temporal model is proposed, where spatial, temporal trends and their dependency will be quantified. Spatial trends can be analogized as the difference between units, while temporal trends illustrate the degradation process.

To reduce the model error, physical understanding is incorporated into the models. Covariate selection for all the proposed methods is done based on physics-based model. With the degradation model, the distribution of time to failure (TTF) can be estimated through simple numerical simulations. This research aims to apply and validate the proposed methods in battery capacity degradation to provide accurate prediction on cycle to failure and elucidate the mechanism of capacity fade.

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If so, please help to give them the recognition they deserve!

The Automotive Division of the American Society for Quality taking nominations for TWO different leadership awards; The **QUALITY PROFESSIONAL OF THE YEAR** and the **QUALITY LEADER OF THE YEAR AWARD.**
Each winner will receive a complimentary admission to the 2017 Automotive Division Awards Ceremony. They will be honored guests where they will receive their awards.

2017 QUALITY PROFESSIONAL OF THE YEAR AWARD: This annual award is established to recognize professionals that have enabled:
- Significantly effective Quality systems and/or Continuous Improvement
- or Furthered services provided to the community by enhancing the understanding of Quality systems across **2017**
- or Implemented new and innovative quality system ideas with a high regard for team benefits in **2017 QUALITY LEADER OF THE YEAR AWARD:** This annual award is established to recognize an outstanding Automotive Industry Leader who outwardly supported and enabled quality leadership contributions in **2017**.

**Neither the nominator nor the nominee need to be a member of ASQ to win.

To make a nomination for either award, please complete the attached form and submit it to Jd Marhevko, the Automotive Division Awards Chair, at Jd.Marhevko@Frontier.com. The form is also located on the Automotive Division website at http://www.asq-auto.org/asq-auto-division-awards/ . **The deadline is Friday, September 28th, 2017.**

Justin G. Jarvis Award

The Jarvis Award was established by the Automotive Division to honor Justin G. Jarvis in recognition of his many years of service to the Automotive Division, especially Program Planning Committee. The Jarvis Award is presented to the individual who earns recognition by others, participates in the functions of the Automotive Division and makes the most significant contribution to the success of the Automotive Division events.

This year's ASQ Judson G. Jarvis award is presented to:

Jd Marhevko is the VP of Quality/Lean and EHS for Accuride Corporation. Four Accuride sites have won the AME Lean Excellence Award. She has been in Operations, Quality and LSS efforts for almost 30 years. Jd is an ASQ Fellow and Shainin Medalist. She holds an ASQ CMQ/OE, CQE, CSSBB and is an ASQ Certified Trainer. She is an MBB and Baldrige Assessor. Jd is a 2016 STEP Ahead Awardee as one of the top 100 women in manufacturing by NAM. Jd is a Past-Chair of the ASQ QMD with 24,000 members and supports several ASQ divisions. Jd is a QMD's Howard Jones Award recipient. She holds a BSE from Oakland University in MI and an MSA from Central Michigan University.

Cecil C. Craig Award

The Cecil C Craig Award has been established by the ASQ Automotive Division to recognize excellence in the development of outstanding technical and managerial papers. The award is granted to members of the Automotive Division. It is intended to acknowledge those who have authored papers, which enhance the knowledge and application of Quality and Reliability related topics. In support of the intent that these papers serve to further educate and enlighten the membership, they will have been presented at Automotive Division sponsored or affiliated events.

The award was named after Dr. Cecil C. Craig, Professor Emeritus, Mathematics Department and the Statistical Research Laboratory, University of Michigan in recognition of his many years of dedicated service to the Automotive Division. Dr. Craig was a close associate of Dr. Walter Shewart in World War II and worked to promote the use of statistical methods in quality control. He was one of the originators of the intensive SQC courses offered to industry each summer by the University of Michigan. Dr. Craig made extensive contributions to the field of quality control as an original investigator, theoretical and applied scholar, teacher and consultant.

This year we have 5 ASQ Cecil C. Craig award recipients:

Vasiliy Krivtsov is the Director of Reliability Analytics at the Ford Motor Company. He also holds the position of Adjunct Professor at the University of Maryland, where he teaches a graduate course on advanced reliability data analysis. Krivtsov has earned a PhD degree in Electrical Engineering from Kharkov Polytechnic Institute (Ukraine) and a PhD in Reliability Engineering from the University of Maryland (USA). He is the author of over 60 professional publications, including 3 books on Reliability Engineering and Risk Analysis, 9 patented inventions and 6 trade secret inventions on statistical algorithms for Ford. He is a Vice Chair of the International Reliability Symposium (RAMS®) Tutorials Committee and a Senior Member of IEEE. Prior to Ford, Krivtsov held the position of Associate Professor of Electrical Engineering in Ukraine, and that of Graduate Research Scientist at the University of Maryland Center for Reliability Engineering. Further information on Dr. Krivtsov's professional activity is available at www.krivtsov.net

Jd Marhevko is the VP of Quality/Lean and EHS for Accuride Corporation. Four Accuride sites have won the AME Lean Excellence Award. She has been in Operations, Quality and LSS efforts for almost 30 years. Jd is an ASQ Fellow and Shainin Medalist. She holds an ASQ CMQ/OE, CQE, CSSBB and is an ASQ Certified Trainer. She is an MBB and Baldrige Assessor. Jd is a 2016 STEP Ahead Awardee as one of the top 100 women in manufacturing by NAM. Jd is a Past-Chair of the ASQ QMD with 24,000 members and supports several ASQ divisions. Jd is a QMD's Howard Jones Award recipient. She holds a BSE from Oakland University in MI and an MSA from Central Michigan University.

John Casey is a quality expert with years of experience in the Automotive, Aerospace and Medical Industries. He is a nationally recognized expert in Error Proofing and has multiple publications and a Patent on how to methodologically drive simple devices that help operators Succeed Every Time. In his career, he has led the global supplier quality organizations for Honeywell Aerospace and General Motors. He was a Program Manager for Toyota in their NUMMI operation. John also is the Past Chair of the American Society for Quality (ASQ) Automotive Division, he is a Shainin Red X Journeyman and he is an

ASQ Fellow. Currently John is the National Quality Director for Proterra the world leader in the production of Electric Buses.

Dennis Craggs has Masters in Engineering Mechanics and Operations Research from Wayne State University; is a Professional Engineer and a Quality and Reliability Engineer; and worked for NASA, Continental Aviation Engineering, Ford, and Chrysler. He taught statistics and reliability at Wayne State University and, as an independent trainer, taught Minitab seminars. He helped to develop the SAE SAE-J1879 robustness validation standards and represented Chrysler to USCAR. Currently, retired from Chrysler, he is writing articles on engineering data analytics and providing consulting services.

James McLeish is a Senior Quality/Reliability Consultant at DfR Solutions. James has 30 years of automotive electrical/electronics (E/E) experience, having worked in systems engineering, design, development, production, validation, reliability and quality assurance of both components and vehicle systems. He currently holds three patents, is the author or co-author of three General Motors E/E validation and test standards, and is credited with the introduction of Physics of Failure engineering techniques to General Motors. He holds a Bachelor degree in Electrical Engineering from Wayne State University, and a Masters in Electrical Engineering from Lawrence Technological University.

William P. Koth Award

The Koth Award was established by the Automotive Division in recognition of William P. Koth, A. O. Smith Corporation for his many years of dedicated service to the division. The Koth Award is presented each year to a currently active Automotive Division member who has given outstanding personal service for the promotion of the division and the American Society for Quality.

This year's ASQ William P. Koth award is presented to:

Mary Beth Soloy received her BS in Industrial Engineering and Operations Research from the University Michigan and her MBA in International Marketing from John Carroll University. Her professional career includes positions in Manufacturing, Engineering, Reliability and Quality at General Motors Corporation and Ford Motor Company. She is an ASQ Certified Quality Engineer (CQE), Reliability Engineer (CRE), Six Sigma Black Belt (CSSBB) and Certified Master Black Belt (CMBB). Mary Beth was the first Six Sigma Corporate Master Black Belt for Ford Motor Company in Dearborn, Michigan where she was responsible for the selection, communication, training and continuing education for over 400 Master Black Belts. In her current position in Failure Mode Avoidance, she is responsible for coaching Powertrain teams in Quality disciplines and working on the harmonization of the AIAG/VDA FMEA Handbook.

Mary Beth has been active in ASQ for over 30 years. In 2012, she achieved ASQ Fellow status for "significant contributions to the development of Six Sigma at the local, national, and society levels; for ongoing mentoring and coaching of others in continual improvement; and for dedication in leading by example in continual learning efforts." She was the first Chair for the Certified Master Black Belt (CMBB) Exam. Currently, Mary Beth is the Chair for the ASQ Six Sigma Forum Advisory Council as well as a member of the editorial review board for ASQ Six Sigma Forum Magazine. She also serves as Voice of the Customer Chair and Secretary for the ASQ Automotive Division.

Quality Professional Award

The Quality Professional of the Year Award has been established to recognize individuals in the automotive industry who have made significant contributions in the following areas:

Leadership or managerial skills in implementing continuous improvement in quality, services provided to the community towards furthering the understanding of quality systems and techniques, support and encouragement of the new and innovative ideas leading to never ending pursuit of excellence, demonstrated high regard for team benefits and results.

This year's Quality Professional of The Year award is presented to:

Shady is Quality Manager at General Motors China, Middle East Executive Director of American Society of Quality, Quality Management Division (ASQ-QMD), and founder of Auto-Dictionary. In 2012, Shady had been selected by Society of Automotive Engineering (SAE) as recipient of "2012 Young Industry Leadership Award." Shady's strong work ethic is underscored by his commitment to education; he has a bachelor degree in Automotive Engineering and Master in Business Administration. He is Lean Six-Sigma Master Black Belt and Red X Master. Shady's research is focused on continuous improvement process, Six-sigma, Lean transformation, and Quality culture development. He has published manuscripts in refereed journals and conferences. His latest book "Critical Success Factors of Six-sigma Implementation" had been published in March 2013.

Quality Leader Award

The Quality Leader of the Year Award is presented to recognize the quality leadership contributions of an outstanding automotive industry leader who is not a member of the quality profession. The recipient will be an executive in any organization associated with the automotive industry who has consistently demonstrated a customer-faced quality philosophy and a defect-prevention oriented vision that is universally applied to every aspect of the business.

This year's Quality Leader of the Year award is presented to:

Scott Gray joined AIAG in February, 2013 and was promoted to his current role in January 2016. Scott represents AIAG on the International Automotive Task Force (IATF). Scott previously served as Sr. V.P. Corporate Quality at Eaton Corporation from 2007 to 2011, where he was responsible for leading enterprise-wide quality improvement strategies and performance. Prior to that, he was Director of Quality for Eaton's Automotive Group. He has also held quality leadership roles with Freudenberg-NOK General Partnership, Borg-Warner Automotive, Medeco Security Locks, AVEX Electronics, Motorola and Buick Motor Division of General Motors. Gray holds a bachelor's degree in industrial engineering from General Motors Institute in Flint, Michigan. Scott is an ASQ Certified Manager of Quality/Organizational Excellence.

2018 Call for Nominations

Cecil C. Craig Award
ASQ Automotive Division

The ASQ Automotive Division is seeking nominations for the 2018 Cecil C. Craig Award. If you are a member of the Automotive Division, have published a paper relating to quality/reliability in 2017 or later, and would like your paper to be considered, please e-mail the paper to asqautodiv@gmail.com with ASQ Membership number by **August 1, 2018**.

The Craig Award was established by the Automotive Division in recognition of the many years of dedicated services to the division by Dr. Cecil C. Craig, who was a professor in the Mathematics Department, at the University of Michigan. The Craig Award is presented annually to the best technical/management papers relating to quality and reliability, written by Automotive Division members.

The purpose of the Craig Award is to promote interest and encourage the writing of technical/management papers by the Automotive Division membership and to promote their presentation at Automotive Division sponsored programs.

2018 GUANGBIN YANG RELIABILITY SYMPOSIUM

Sponsored by ASQ Automotive Division

THURSDAY, AUGUST 30, 2018, 7 AM – 5 PM
OAKLAND UNIVERSITY
ROCHESTER, MICHIGAN

GYRS 2018
GUANGBIN YANG RELIABILITY SYMPOSIUM

The 2018 Guangbin Yang Reliability Symposium will be hosted by *Oakland University*. This year's event features a key note speaker, several speakers form industry and academia, lunch, a debate session, a poster session, expo session, and a networking session.

SPEAKERS

Noah Lassar, Head of Reliability, Waymo
Reliability Challenges in Autonomous Vehicle Fleets

Dr. Julio Pulido, Sr. Director of Quality and Reliability, Nortek.
Reliability Testing in Heat Exchangers

Carl S. Carlson, Consultant and instructor / GM Retiree
Good FMEAs, Bad FMEAs, What's the Difference?

John Phillips, "Powertrain Applications for FCA
"Variance Estimate from a Single Emissions Test"

Dr. Andre Kleyner, Global Reliability Engineering Leader, Aptiv.
Applying Failure Prognostics to Reduce the Duration of Automotive Electronics Reliability Testing

Dr.Kamran Paynabar, Assistant professor, Georgia Tech University
Machine Learning Meets Prognostics: Analysis of High-Dimensional Data Streams for Time-to-Failure Prediction

Dr. Qingyu Yang, Associate Professor, Wayne State University.
From Micro to Macro: Reliability Analysis and Failure prediction of Advanced High Strength Steels considering Material Microstructure Image Information

Scott Sterbenz, Six Sigma Master Black Belt, Ford Motor Company
Strategies for Successful DMAIC Problem Solving

Please contact Dr. Mohammad Hijawi at mshijawi@gmail.com (Symposium Chair) or Dr. Mohammadsadegh Mobin at mobin.sadegh@gmail.com, if you are interested to present a case study at the poster session or present your product/service at the expo session. All ASQ Automotive Division members will receive an invitation via e-mail with the detailed instruction to register.

The Alphabet Soup of Core Tools

APQP, FMEA, PPAP/CP, MSA & SPC

What do all of those acronyms mean? How do they relate to ISO 9001 or IATF 16949? Attend this FREE 2 hour WebEx facilitated by Jd Marhevko of the ASQ Automotive Division. This session will review the basics on:

1. **APQP: Advance Product Quality Planning:** Guidelines for a product quality plan to develop a product or service that satisfies the customer
2. **FMEA: Failure Modes and Effect Analysis:** Methodology used to ensure potential problems have been considered and addressed throughout the product and process development process (Ex. APQP). This traditionally includes the Control Plan (CP)
3. **PPAP: Production Part Approval Process:** Ensures product consistently meets customer engineering specification requirements during production run at the quoted production rate
4. **MSA: Measurement Systems Analysis:** Guidelines for assessing the quality of a measurement system where readings are replicated
5. **SPC: Statistical Process Control:** Basic graphing statistical tools that enable process control and capability for continual improvement

Register for this 2 hour session on Saturday, November 3rd, 2018 from 9 -11 am EDT at https://attendee.gotowebinar.com/register/4689112917738087426

After registering, you will receive a confirmation e-mail containing information about joining the webinar. For questions, contact Lisa Rosenbaum at ASQAutoWebinar@gmail.com.

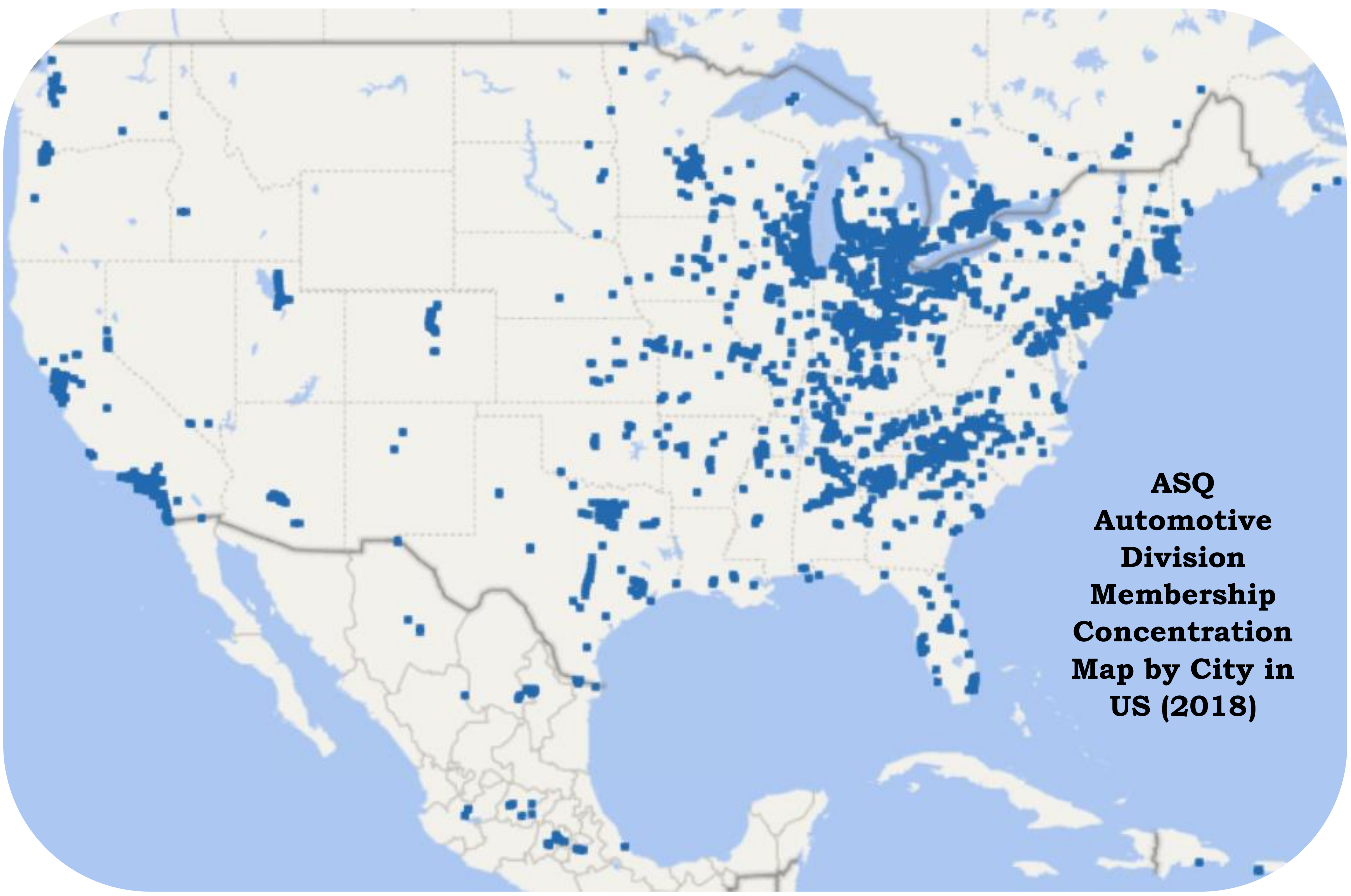
Jd Marhevko of the ASQ Automotive Division is an ASQ Fellow, Shainin Medalist, MBB, CMQ/OE, CQE and ASQ Certified trainer. She is an SVP of Quality, Lean and EHS for Accuride Corporation. Jd was recently honored by Crain's as a most notable woman in manufacturing in MI. Jd holds several volunteer roles in various ASQ divisions

Automotive Division
ASQ The Global Voice of Quality

Spring 2018

Automotive Excellence

BECOME A MEMBER OF ASQ AUTOMOTIVE DIVISION TODAY!



CALL FOR PAPERS

Publish your practical papers in Automotive Excellence Newsletter!

If you are interested to publish a summary of your practical works as an article in the ASQ Automotive Division newsletter, please send your request to the Publications Chair, Mohammadsadegh Mobin (mobin.sadegh@gmail.com).

Undergraduate and graduate students are very welcome to submit the abstract of their senior project, master thesis, or PhD dissertation to be considered as a potential article in the upcoming issues of ASQ Automotive Division newsletter.