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LITERATURE SEARCH
DOT Uses of Root Cause Analyses

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October 2024

Summary of Results: Of the 92 citations covering the auto, aero, rail, and maritime industries, the majority of the articles are using root cause analysis in relation to noise levels for the passengers. Other areas include mechanical failures, fuel systems, brake systems, lubrication and other various mechanical issues. A few of the articles reference textiles, networks, or public transportation.

Links and abstracts are listed with the citations; links open to full-text documents, pages that allow PDF downloads, or abstract pages. Articles and papers not openly available full-text can be obtained through interlibrary loans.

Aemireddy, N.R. (2019) Root Cause Analysis and Impact of Unplanned Procurement on Truckload Transportation Costs. (Thesis/Capstone, MIT). https://ctl.mit.edu/pub/thesis/root-cause-analysis-and-impact-unplanned-procurement-truckload-transportation-costs

The tender rejection rate by primary carriers for the TMC division of CH Robinson nearly doubled from 2015-16 to 2017-18. An increase in tender rejection rates directly results in an increase in transportation costs for shippers. Increasing demand in the market from 2015 to 2018 was a major cause of the increase in tender rejections.

Bagga, Rajat; Badyal, Rochak; Rawat, Mohit; Pal, Kiran. Design Consideration of Liquid Fuel Tank System with Low Fuel Filling Circuit Position in Automotive Vehicle. SAE Technical Paper, 2024. https://trid.trb.org/view/2335001

Fuel system in a vehicle plays vital role in vehicle as it stores the fuel safely to facilitate vehicle running for desired range. Fuel system being a safety critical component is designed to endure varied environmental conditions and defined robustness for all usage conditions. Liquid fuel system consists of three major systems viz. filling system, storage system and vapor management system. Of the three, the filling system's major function is to assist proper re-fueling of the storage system. Pre-mature shut-off, spillage and fuel spit back are the three major risks associated to system performance. In general, fuel filling system is connected to fuel tank via inlet pipe which houses a flapper to avoid fuel spillage from filler neck during re-filling operation. Fuel filling creates positive pressure inside the tank which causes the tank to bulge. In the process of regaining the original shape fuel is pushed out of the inlet pipe to neck which might cause spillage. To avoid spillage a one-way valve mechanism (flapper) is added to the system. The filling performance of the system also depends on the height of liquid column i.e., height of fuel neck with respect to breather port in vehicle layout. If neck height is very low with respect to fuel tank breathing port position, addition of flapper causes hinderance in fuel filling. This hindrance further increases if breathing port height with respect to inlet pipe is large. This paper addresses the root cause analysis of the problem and counter measure action plan.

Baskar, Nithin; Mohammed, Riyazuddin; R, Prasath. A Simulation Approach for Identification and Design Optimization to Prevent Headrest Rattle. SAE Technical Paper, Volume 1, Issue 1, 2019, pp 126-132. https://trid.trb.org/view/1578798

Squeak and rattle concerns account for approximately 10% of overall vehicle Things Gone Wrong (TGW) and are a major quality concern for automotive OEM's. Seat is one of the major contributors of squeak and rattle issues observed in customer verbatim. Seat head rest rod and bezel are designed concentric to each other with a gap that allows free movement and a locking pin to position at different levels. Due to the design gap and weight of the head rest there is always tendency for relative displacement leading to rattle issues. Seat headrest, is close to the customer ear and any rattles at headrest will create annoying driving experience. Also, the contradictory requirements between efforts and rattle makes the scenario more difficult to fine tune the bezel specifications. The root cause for head rest rattle issues can also be related to free play between bezel and seat frame, free play between bezel and cap, looseness between locking pin and headrest rod etc. Identification of issue at physical testing is common practice subject to availability of test sample and road load data. Also, source identification and modification comes at the later part of the project. This paper establishes a process to perform the head rest rattle analysis by utilizing existing FE techniques. The FE analysis is performed using SNRD software available in hyper works platform. An older program seat FE model is built and validated with experimental results. Also, relative displacement measured between the headrest rod and bezel are correlated well with the simulation results. The occurrence and severity of rattle can be understood when the relative displacement is more than the design gap. Also, root cause analysis is performed by modal contribution analysis which gives an option for design sensitivity studies and compare relative displacements of different designs. The proposed methodology using FE techniques can help in identifying head rest rattle issues at early design stage.

Battikha, Mirrelle G. Reasoning Mechanism for Construction Nonconformance Root-Cause Analysis. Journal of Construction Engineering and Management, Volume 134, Issue 4, 2008, pp 280-288. https://trid.trb.org/view/859657

This paper describes how problem patterns can be identified and analyzed for diagnosing and/or predicting nonconformance of constructed facilities. This will enable appropriate actions to be taken for eradicating causes of nonconformance and preventing their recurrence and/or occurrence. A structure has been defined for representing construction projects information and organizing knowledge extracted from past experience to facilitate the analyses. Pattern analyses have been directed at deriving root cause classes of problems including 1) design, which relates to the assigned specifications, methods, and/or procedures; 2) execution, which involves errors or the inability to execute tasks; and 3) external, which includes unforeseen events or accidents. Highway pavement construction has been selected as an application and illustrative domain. Expert knowledge related to low density and roughness of constructed pavements has been assembled and organized to support the analyses. The approach provides a generic mechanism to conduct integrated root cause analyses with design, planning, construction, and quality management information. Its application is demonstrated and validated using case studies from various construction domains.

Biçen, S., & Celik, M. (2024). A deep learning approach to analyse ship inspection reports via natural language processing integrated with artificial neural network. Journal of Marine Engineering & Technology, 23(4), 291–304. https://doi.org/10.1080/20464177.2024.2353407

Maritime inspection analysis is recently an emerging topic. Practical solutions are sought to improve the post-inspection process (i.e. OCIMF SIRE) in tanker operations. This study aims at to analyse the reported observations based on natural language processing (NLP) integrated with artificial neural network (ANN). The developed methodology also takes the advantage of Maritime Root Cause Analysis Tool (MARCAT) to systematically initiate the potential causes database including the number of 2383 observations. Then, an NLP-based ANN classification algorithm was produced that predicts the causes of new entries to the inspection database. The classification algorithm gives high-accuracy results varying between 0.90 and 0.97 in different causation segments. An inspection analysis for prediction validation was carried out both by the company authority and by the algorithm. The results show that the model can predict with a high success rate. Consequently, this study developed a post-inspection analysis model with high accuracy that is expected to contribute maritime executives to improve fleet safety and efficiency. Providing a third-party solution to the tanker industry, further studies are planned to conceptualise the model as platform as a service (PaaS).

Bischof, Thomas. Root Cause Analysis of Acoustically Suspicious Transmissions During EOL Testing. SAE Technical Paper, 2012. https://trid.trb.org/view/1826573

Increasing requirements for comfort and lightweight design lead to higher acoustic target values for passenger car components, especially for automatic transmissions. The required increase of the acoustic tooth-mesh quality reduces the masking of tonal noises that are often the failure cause at the EOL test bench. Based on the mathematic transmission model that includes all orders and moments that are acoustically relevant, a database-based dynamic website supports the engineer with the localization of disturbing noises. After that, irregularities are extracted from the order spectra and are provided for the evaluation tool. A special search algorithm depicts all possible failure causes. On the one hand, refined entries allow the limitation of the solution sets; on the other hand, experience help to limit the solutions to acoustically relevant disturbance mechanisms.

Blampied, N. B., & Berkeley., C. (2018, October). *Parametric Functions for Conceptual and Feasibility Estimating in Public Highway Project Portfolios*. Bts.gov; University of California, Berkeley. https://rosap.ntl.bts.gov/view/dot/56588

Owners face challenges in setting priorities between potential projects to maintain, rehabilitate, and improve their infrastructure. The estimated cost of each potential project is a factor that owners use in setting priorities between projects and in developing their long-term maintenance and construction project portfolio. Owners face a dilemma: considerable effort is needed to develop accurate estimates of the cost of each project, but this effort will be wasted if the particular project is not selected for the long-term plan. They therefore need estimating methods that will enable them to develop reasonably accurate early stage cost estimates without an excessive amount of effort. These early stage estimates are "conceptual cost estimates" and "feasibility cost estimates." This research examines the tools that are available to owners for performing early stage cost estimates for infrastructure projects. It then compares alternative parametric functions that could be used for that purpose, using data from public agencies in California. These functions are the linear parametric, common exponential parametric, and modified Cobb-Douglas exponential parametric models. This research tests the models on 1 common type of project, pedestrian access facility projects on highways. In the United States (US) these projects result, directly and indirectly, from the Americans with Disabilities Act (ADA) that Congress passed in 1990. On highways, they produce three types of improvement: 1. wheelchair ramps at street corners to

allow people in wheelchairs to cross streets at designated pedestrian crossings, 2. wheelchair-accessible sidewalks, and 3. audible signals at signalized intersections to inform visually impaired people when a pedestrian signal is in their favor. The author developed a data set of 39 pedestrian access facility projects on state highways in California, used multiple regression analysis to find 4 best-fit versions of each of the 3 functions (i.e., 12 alternatives in all), and evaluated them using the Choosing By Advantages (CBA) method. The author then benchmarks the preferred state highway cost estimating model identified in the CBA against 10 city-street pedestrian access facility projects that had been completed by 4 cities in the San Francisco Bay Area.

Brosseau, Justin; Yuan, Wei; Singh, Vinod; Orzechowski, Jeff. Root-Cause Analysis, and Improvement of a Port Fuel Injected V6 Vehicle to Achieve Best-In-Class Sound Quality. SAE Technical Paper, 2021. https://trid.trb.org/view/1877143

This paper will communicate an in-depth investigation uncovering contributing factors defining the desired and undesired acoustic signature of a V6 Vehicle. A transfer path analysis tool is exercised to rank improvement opportunities. These results are used to drive design improvements with the goal of achieving best-in-class sound quality when executed as a system. A cohesive powertrain-vehicle-level acoustic improvement package is executed, improving air induction, intake manifold, both structure and air-core, exhaust-radiated and under-hood-acoustic encapsulation. The acoustic package was validated by jury testing to provide significant refinement enhancement improving predicted 3rd party scores.

Cagle, Robert. Frequency Inspection of Brake System Components. SAE Technical Paper, 2019. https://trid.trb.org/view/1653530

Frequency inspection has long been a tool utilized by manufacturers of brake system components as a means of quality control. This is important to combat perceived defectiveness of a system that experiences issues, such as brake squeal, as well as to identify actual defects in the parts going out to customers. Every component has its own resonance frequencies based on the dynamics of that component. Knowledge of the resonance frequencies of each component provides insight that can prevent manufacturers from sending out defective units, whether they be perceived defects or actual defects. NVH engineers who understand these phenomena perform theoretical analysis and acquire experimental data in the lab to gain insight into their parts that will eventually be produced on the assembly line. Unfortunately, the frequency requirements, and the consequences thereof, defined by the NVH engineers can still remain somewhat of a mystery to the manufacturing engineers who are tasked with applying them. Oversights in specifications can lead to avoidable scares that lead to delays and downtime. For example, differences in accelerometer placement on a brake rotor from the lab to the assembly line can lead to issues such as variable frequency reporting. This leads to inaccurate data reporting, which leads to poor Gage R&R. A basic understanding of vibration and how to analyze data would allow the manufacturing engineer to troubleshoot such an issue and prevent unnecessary delays. This paper will attempt to take these concepts beyond the specification sheet and into the science and mathematics behind the dynamics of the different components of the total brake system. The knowledge gleaned from this analysis allows for intelligent decision making for go/no-go on the production line, as well as root cause analysis in the lab.

Carlisle, Hugh W; Frew, Robert W; Mills, John R; Aradi, Allen A; Avery, Noyes L. The Effect of Fuel Composition and Additive Content on Injector Deposits and Performance of an Air-Assisted Direct Injection Spark Ignition (DISI) Research Engine. SAE Technical Paper, 2001. https://trid.trb.org/view/1790749

This paper presents the findings of some fundamental characterisation of the deposits that form on the injectors of an air-assisted DISI automotive engine, including the effect of these deposits on engine performance when operated in different combustion modes, with varying fuel composition and additive content. A root cause analysis was undertaken, including an assessment of injector temperature and deposit chemistry. Fuels from a matrix designed around the European year 2000 gasoline specifications for T90, olefin and aromatic levels were used to study the effect of fuel composition on deposit formation. Two commercial gasoline detergent additives, of different chemistries, were used to investigate the impact on deposit formation. The results of the fuels study and deposit analysis are consistent with published theories concerning fuel composition impact on combustion chamber deposit (CCD).

Cazenave, Pablo; Jimenez, Katina; Tandon, Samarth; Krishnamurthy, Ravi. Improve In-line Inspection Sizing Accuracy. Blade Energy Partners; Pipeline Research Council International; Pipeline and Hazardous Materials Safety Administration, 2023, 149p. https://trid.trb.org/view/2256380

This multi-phased Pipeline and Hazardous Materials Safety Administration (PHMSA)/Pipeline Research Council International, Inc. (PRCI) project aims to conduct a collaborative study (pipeline operators, In-Line Inspection (ILI) Technology Providers (TPs), subject matter experts, and consultants) to quantitatively measure and improve the detection and sizing capabilities of current corrosion In-Line Inspection (ILI) systems. A data-driven approach was used which identified problematic corrosion profiles based on the review of recent Root-Cause-Analysis (RCA) reports of corrosion-related failures to design and construct an ILI corrosion test string containing features having similar profiles. All such profiles were then documented using the best possible Non-Destructive Evaluation (NDE) techniques. Three participating ILI TPs proposed appropriate inspection tools based on limited knowledge of the integrity conditions in the test string. A series of blind pull-through tests of the ILI systems were carried out, where the TPs delivered standard ILI reports for performance evaluation. The ILI TPs receive detailed feedback identifying the detection and sizing gaps. They were given a limited sample of detailed anomaly profile data to identify potential sources of detection and sizing improvement. A second series of ILI tests were performed and the changes in detection and sizing are analyzed and quantified for each problematic corrosion profile, identifying the improvements and the remaining gaps. The results and findings of this 3.5-year-long project are presented in this Report.

Cella U; Nussey P. Root cause analysis of harmonic filter component failure in 2x25 KV traction power system. CORE 2018: Rail: Smart, Automated, Sustainable, Conference on Railway Excellence, 30 April-2 May 2018, Sydney, NSW, Australia, 2018, 11p. ; PDF. https://trid.trb.org/view/1594617

Aurizon's Central Queensland Coal Network is electrified at 2x25 kV, and has twenty connection points with the electric power transmission grid. The current drawn by electric locomotives has significant harmonic content which must not be transferred into the transmission grid via the connection point at the feeder station. The achieve this, harmonic filters are installed at each connection point. This article focuses on multiple failures of a harmonic filter reaction at one of Aurizon's feeder stations and on the process that Aurizon followed to identify their root cause, and concludes by describing the solution that was implemented. Fault evidence was collected from the field, and fault electrical data were sourced from the recordings of the fault transients. The data were sent to the manufacturer of the reactor and to the supplier of the filter for analysis. However, there was lack of agreement regarding the sequence of events that led to the last fault, which permanently damaged the reactor. Therefore, an in-depth field

investigation was conducted, and samples were taken from the reactor. Finally, Aurizon and the manufacturer agreed on a more robust design for the reactor. Because of operational constraints the healthy part of the filter was re-energised after the last field investigation: the process followed and the results obtained are described in the last section of this article.

Chandel, Abnish; Kadam, Rohit; Umbare, Deepak; Babel, Prashant. Methodology for Investigation and Resolution of Zero/Low/Unstable Brake Lining Gap Concern in S-Cam Brake System. SAE Technical Paper, 2020. https://trid.trb.org/view/1745884

S-cam air brake system is provided in almost all commercial vehicles having tonnage above 7.5-ton. In S-Cam brake system, drum to brake lining gap (henceforth referred to as 'brake lining gap' or simply 'gap' for convenience) range is an important factor which can impact braking behavior during brake application. Different OEMs (Original Equipment Manufacturers) define different brake lining gap ranges between S-cam brake lining and drum. This range depends majorly on the internal mechanism deployed in ASA (Auto Slack Adjuster). When these brake lining gaps start lowering i.e. when they fall in the range of 0 to 0.4 mm, or they become unstable (checked by feeler gauge at inspection window provided on dust cover of S-cam) then it starts impacting brake behavior in the subject vehicles. Unstable gaps can be defined as the phenomenon where gaps vary by a good margin of approx. 0.4 mm or more (as per subject vehicles study), between top and bottom brake linings or measured at different points (S-cam end, center & abutment end) of same brake lining. This paper defines a systematic methodology for root-cause analysis of zero/low/unstable brake lining gap concern between S-cam brake lining and brake drum in air brake system, by investigating a field concern. It gives a first-hand idea as to how manufacturer can ensure the appropriate brake lining gap range during concept stage of design, so that field issues related to low gaps like brake grabbing, brake drag, premature brake lining wear etc. are mitigated significantly. The study also gives an insight in identifying the design factors that must be considered during selection of auto slack adjuster as well as help in sorting out the low gap concern which may occur due to design error or assembly failure.

Chaudhari, Dipesh Ashok; Dasabai, Balavardhan Reddy; Bogue, Bradley; Faulkner, Scott E. Root Cause Analysis of Drive Noise in an Agriculture Machine End Unit. SAE Technical Paper, 2023. https://trid.trb.org/view/2134768

In any off-highway machinery throughout the product development cycle, noise is considered an important characteristic. This characteristic drives the product quality, safety, and productivity and meets the homologation requirements. Identifying the critical noise source and finding out the true root cause of the noise source is a very critical element in improving the design to reduce the noise levels. A systematic approach is needed to understand the behavior of the system, which can be achieved through collaborative efforts among the analysis, design, and testing teams. This paper describes how virtual analysis helps to determine the main source of noise radiation in the audible frequency range of the human ear. The sound pressure level (SPL) in the test data at the end unit drive of an agriculture machine showed high peaks at a few frequencies in the critical frequency range. The spectral content remains the same regardless of the backshaft speed. The noise goes away when the tensioner sprocket center nut is loosened. In the initial stage, the accuracy of the end unit drive finite element (FE) model is ensured by comparing the virtual driving point impedances with test data for both loose and tight nut conditions. In the later stage, the acoustic finite element method adaptive order (FEM AO) model is developed [1] and correlated with test data of SPLs. In the final stage, panel

contribution analysis is carried out to determine the critical noise-radiating component. This validated model will be confidently used to improve the design further.

Chauhan, Vandana; Ray, Amulya Kali. Root Cause Analysis of Discoloration of Polypropylene in Automobile Interiors. SAE Technical Paper, 2013. https://trid.trb.org/view/1828050

Presently Automobile industries are struggling to restructure their products to reduce the emissions and increase fuel efficiency. Plastics offering advantages over metals have led to the usage of wide range of polymers in automobiles. Their benefits include light weight, ease of fabrication, intricate shapes, and resistance to harsh chemical environment. Above all, the major advantage of plastics is that, the part can be manufactured in various colors depending on the needs of the designer. Currently the trend is shifting towards the light colored interiors, which make the car look more spacious and aesthetically upmarket. But with the usage of light colored interior plastic, problem related to discoloration of these parts has become prominent. Though this problem persists in dark colored plastics but not noticeable. Polymeric degradation may occur during raw material manufacturing, thermal processing and subsequent exposure to the environment. In vehicles with beige colored interiors phenomena of red color blooming out on the parts' surface (in very fine powder form) is observed. This paper explains the various causes of discoloration of Polypropylene parts along with root cause analysis and countermeasures.

Coldren, D; Schuricht, S; Smith, R. Hydraulic Electronic Unit Injector with Rate Shaping Capability. SAE Technical Paper, 2001. https://trid.trb.org/view/1796704

Caterpillar® Fuel Systems has developed a next generation hydraulically actuated electronically controlled unit injector with a direct operated nozzle for providing independent control of injection pressure and rate shape as well as multiple injections per cycle. These advanced features are considered important building blocks for future DI diesel engine emission regulations and performance improvements. Initial injector performance testing of the concept hardware identified several areas of concern, prompting root cause analysis and redesign work to derive solutions. The resulting improvements have been incorporated into the production injector design, and subsequent bench and engine tests have demonstrated the capabilities of this advanced fuel system. This paper documents the design, testing and analysis that led to the development of the new Caterpillar HEUI™ B fuel system for diesel engines.

Contet, Arnaud; Lhomme, Cédric; Zuckermann, Daniel; Fey, Arno; Rouaud, Cedric; Cimen, Tolga; Rabanser, Peter; Rost, Axel; Trache, Mario; Feng, Bing. Modeling and Sizing of a TEG with Half-Heusler TE Legs for Reducing Fuel Consumption in a Heavy Duty Vehicle. SAE Technical Paper, 2019. https://trid.trb.org/view/1598805

Following a historical increase in energy demand, the use of fossil fuels is causing irreversible damages to the environment, while local pollutant emissions must comply with ever more stringent emissions legislation. Waste Heat Recovery (WHR) devices and particularly Thermo-Electric Generators (TEG) using Seebeck effect have often been seen as levers to improve those conflicting objectives, but yet are so far limited to niche market due to the use of expensive, scarce or toxic thermoelectric (TE) elements (Bi, Pb, Te). Within the European project INTEGRAL, a consortium of 13 companies and research organizations tackling with upscaling the production of the next generation TE materials, a TEG dedicated to heavy-duty trucks using half-Heusler TE material is being developed. First, a TEG system integration model has

been developed and iterated in steady-state to provide TE Module (TEM) specifications. In this approach, typical truck operating points have been used, along with specific TEG impacts on both engine and vehicle, like additional weight and pressure drops, while aiming at a return of investment for the truck operator. Then, the TEMs were assembled and tested on a dedicated performance test bench. The measured TEM outputs including idle voltage, internal resistance, heat transfer and Peltier effect were compared to previous predictions. A root cause analysis was then conducted to explain the mismatches. The first step was to track and eliminate the errors in the test setup itself. The second step was to investigate local losses in the TEM, including layer-by-layer thermal contact and thermal by-pass of the TE material through conduction, convection and radiation. Lastly, the improved TEG model was used in a transient simulation platform to take into account the TEG thermal masses on the electric output. Finally, vehicle simulations were performed to update the fuel economy with TEG installed on a hybrid electric powertrain.

Cummings, Scott. Wheel Failure is Not an Option. Railway Age, Volume 213, Issue 6, 2012, pp 29-30. https://trid.trb.org/view/1143638

The railroad industry spends close to $1 billion a year replacing bad wheelsets. The article shows a very small but important minority of wheelsets fail in a way that can cause a train accident. According to the Federal Railroad Administration (FRA) safety data, the top two causes of wheel related train accidents are broken rims and tread buildup. To address wheel problems, the Transportation Technology Center, Incorporated (TTCI) is testing improved wheel steels that are designed to resist wheel shelling, and also conducting root cause analysis of broken rim and tread buildup failure modes. Domestic and overseas wheel manufacturers produce high performance wheel steels that have the potential to improve wheel life by offering increased resistance to shelling. The article discusses the testing, benefits, and results of eight types of these high performance wheels. The FRA has teamed with the American Association of Railroads (AAR) to co-fund research to better understand the conditions necessary to produce broken rims and tread buildup.

Dadam, Sumanth Reddy; Ravi, Vinod; Jentz, Robert; Kumar, Vivek; Sharma, Sanyam. Assessment of Exhaust Actuator Control at Low Ambient Temperature Conditions. SAE Technical Paper, 2021. https://trid.trb.org/view/1856252

Exhaust sensors and actuators used in automotive applications are subjected to wide variety of operating ambient conditions , the performance of these actuators is challenging especially at cold ambient operating conditions, active exhaust tuning valves with position sensors are used to adjust the sound levels, or noise, vibration and harshness (NVH) from a control unit within the vehicle that leads to an improved driving experience wherein the driver selects their preferred sound levels. However, the operating behavior is crucially influenced by the characteristics of the drive cycle and ambient temperature. The study in this paper is intended to evaluate the icing formation at the start of drive cycle and at different ambient temperature conditions. The test data were obtained through real road and chassis dyno testing at different ambient conditions. The results of the testing indicated that a drive cycle with low engine speed and engine load, like a typical city road and cold ambient temperatures, had a low probability of successful operation of active exhaust valves. However, information reported from the actuator could be used along with other engine parameters to evaluate the performance of the system. In this study, an example of how the water collected in the exhaust system on gasoline only powertrain impacts the performance of the exhaust tuning valve is discussed. Root cause analysis is

provided, noise factors of valve freezing is also evaluated, control software strategy is presented with vehicle validation results.

Dey, Soumya. Transforming Washington DC's Parking Meter Program Using Lean Six Sigma Based Asset Management. Transportation Research Board 93rd Annual Meeting, Transportation Research Board, 2014, 21p. https://trid.trb.org/view/1288760

The District Department of Transportation (DDOT) is responsible for maintaining and operating over 18,000 metered on-street spaces in Washington, DC. The program went through significant changes in 2009 and 2010 including two rate adjustments, reintroduction of meter enforcement on Saturdays and extending hours of meter operation to until 10 PM in some areas. These changes caused operational problems for the Department and frustration for the customers. This paper describes how DDOT applied lean six sigma (LSS) processes and techniques to dramatically transform its on-street parking meter program. The paper introduces the concept of LSS and discusses how some of the analytical techniques and concepts were applied. Techniques such as root cause analysis, process capability, mean testing, pareto analysis and process mapping were used to identify fundamental problems with the program and assets. Once the problems were identified, DDOT quickly developed a strategic vision for the future and aggressively implemented the vision. Applying lean six sigma techniques has reaped significant rewards for DDOT within a very short period of time. These benefits include higher customer satisfaction through enhanced payment options, lower number of service requests, better system uptime, more proactive management of assets, better executive visibility and increased revenue. Washington DC's parking program is now recognized as one of the most innovative, forward thinking programs in the country. The success of applying LSS in parking has encouraged DDOT to apply this concept in other program areas as well.

Developing an incipient fault detection system for electric vehice batteries. (n.d.). Retrieved October 22, 2024, from https://transet.lsu.edu/wp-content/uploads/sites/16/2021/08/21ITSOSU01.pdf

Lithium-ion (Li-ion) batteries are the primary power source for electric vehicles (EVs) due to their high energy and power density, and long life-cycle. The recent variants of the high-end plug-in EVs, with Li-ion battery pack, offer a range of approximately 300 miles on a single full charge close to their gasoline counterparts. Further, to bridge the gap between the fueling time of the gas-powered vehicles and the charging time of EVs, high power chargers have also been introduced, reducing the charging time to less than 30 minutes. The Li-ion battery packs operate at maximum limits to deliver the required power to achieve these optimal performances. The extreme operating conditions and abusive operations may lead to internal and external faults, such as short circuits, cell internal temperature rise, lithium plating and loss of lithium, and mechanical failure due to vibration. These internal faults have a cumulative effect on the battery's health, aggravating the vulnerability to thermal runaway. Although various external safety technologies are employed in the battery monitoring system and battery management system (BMS) to protect the battery from external fault conditions, it is still challenging to detect the internal faults from the available measurements (e.g., voltage, current, and surface temperature). The state-of-the-art internal fault detection approaches use Li-ion battery models with constant parameters to develop model-based fault detection algorithms, which may lead to inaccurate results since these parameters change with health degradation. In a companion research project funded by Tran-SET in Cycle-4, the research team proposed developing a real-time learning-based fault detection scheme. However, the scheme proposed in the TranSET Cycle-4 project requires significant improvements from the perspective of hardware implementation. Therefore, the development of an intelligent incipient fault

detection system, which addresses the challenges of the computational complexity of real-time machine learning using neural networks for the embedded-hardware implementation, is critical to exploit the advantages of the real-time learning schemes in the field of Li-ion battery management for EVs. The proposed research project's overall objective is to develop, implement, and validate an intelligent fault detection scheme capable of detecting a Li-ion battery's internal faults in its incipient stage. This involves significant intellectual challenges related to root-cause analysis for determining the interrelation between internal parameters and type of fault and develop a computationally efficient neural network algorithm for hardware implementation. The team will address these challenges by (1) developing failure mode analysis schemes to identify the root-causes, (2) developing computationally efficient fault detection algorithms using real-time machine learning, (3) developing Field Programmable Gate Array (FPGA)-based hardware architecture to implement fault detection scheme, and (4) validating the prototype experimentally. The success of the project will lead to a significant improvement in the safety of EVs. The research aligns with the vision of TranSET of overcoming transportation challenges in Region-6 by using innovative approaches. The proposed research is highly relevant to multiple disciplines, such as control systems, machine learning, and EVs. This project's success will provide necessary validation results and a prototype of the fault detection system for the safe operation of the Li-ion battery fostering its adoption by stakeholders. The project will also educate students and working professionals on this innovative multidisciplinary research and technology development. The team will also integrate the research results into mechatronics courses and reach out to secondary school students hosting lab visits and workshops to motivate them to seek STEM as a career.

Dobrzynski, Daniel S; Harper, Jason D. Development and Implementation of SAE J2953 for AC Charging. SAE International Journal of Passenger Cars - Electronic and Electrical Systems, Volume 7, Issue 1, 2014, pp 85-94. https://trid.trb.org/view/1433585

The purpose of this paper is to outline the development and implementation of SAE J2953. SAE J2953 contains the requirements and procedures of interoperability testing. Within SAE J2953 interoperability test articles are defined as an Electric Vehicle Supply Equipment (EVSE) paired with a Plug-in Electric Vehicle (PEV). SAE J2953 requires the development and application of test fixtures with the ability to monitor mechanical forces and electrical signals of a charge system without modification or disassembly of the EVSE and PEV under test. Electrical signal monitoring includes pilot, proximity, and line conductors of the SAE J1772 TM AC coupler. This paper will outline the requirements of the fixtures as well as a specific build. Data will be presented showing full implementation of the SAE J2953 procedures including root-cause analysis and standards gap discovery.

Doshi, Sohin; Taware, Girish; Kalsule, Dhanaji; Bijwe, Vilas; Naidu, Sudhakara. Bus NVH Refinement: A Journey towards Comfortable Future. SAE Technical Paper, 2021. https://trid.trb.org/view/1882625

The future of bus transit in new millennium is promising. This optimism is based on an anticipated long-term slowdown in growth of suburbs and revitalization of central cities. It reflects and escalates the public concern with traffic congestion, sprawl and pollution. This calls for double the use of public transport to address above issues. It calls for changing the mind-set of society towards public transports like buses, coaches etc. This could happen if bus design ensures right comfort, safety and TCO by ensuring refined bus transport. Hence, it is responsibility of OEMs to provide the new generation buses and coaches, which will ensure the public demands of comforts in terms of NVH refinement. This paper covers the unique approach used to convert the existing bus NVH refinement to next level as a short-

term solution and with the intention of articulating NVH strategies for new generation bus development. This work explains combined experimental and simulation approach deployed through advanced signal analysis tools, root cause analysis, source ranking and identifying the major potential sources. Vehicle measured with non-linear noise patterns, boom noise, inferior sound quality parameters and high tactile and floor vibrations. This was because of common chassis platform, common engine mount system, driveline system and clutch system for trucks and buses and the absence of acoustic material in different part of body. CAE analysis was carried out to identify structural weaknesses and resonances in chassis and power train as these were major transfer paths for higher in cab noise and vibrations. With all potential solutions updated on vehicle, it was found that cabin noise improved by 6-7 dB (A), articulation index improved by 20-25% and vibration improved about 70% at all load conditions. The bus was successfully demonstrated to juries for reduced noise and vibration levels and confirmed for class leading NVH refinement levels. It was possible with improvement in bus manufacturing processes, critical to quality component and subsystems for NVH improvement with minimum cost impact.

Durfy, Jennifer L; La, Chi Binh. Gear Whine Modulation Root Cause Analysis and Elimination. SAE Technical Paper, 2007. https://trid.trb.org/view/1812117

As engines and powertrains become quieter, sound quality becomes more important as an indicator of product quality. As a consequence, there is a heightened need to reduce gear noise. The objective of this work was to identify the source and cause of a modulated gear whine. The approach taken to identify the source of the modulation involved running a full powertrain on a spin stand and minimizing the number of meshing gear pairs until the offending pairs were identified. Further experimental testing and analysis models were employed to determine the cause of the modulation. From proximity probe measurements and backed up by the analytical model, it was determined that one of the gear mesh suffered from inadequate bearing support and off-center gear loads. This condition caused a tilt in one of the meshing gears which created a sideband that modulated with the primary meshing frequency of the transfer gear at cruise speed. The solution chosen was to separate the meshing frequencies by slightly changing the gear ratio. The slanting of the gear was also addressed by increasing the length of the under-gear support bearing.

Ferreira, José; Sousa, Paulo Ferreira; Tereso, Anabela. Problem-solving practices in the automotive industry: an initial framework. Procedia Computer Science, Volume 239, Issue 0, 2024, pp 429-436. https://trid.trb.org/view/2411480

This paper aims to contribute to both theory and practice by describing current problem-solving practices, proposed by various authors, as part of the quality management process of companies in the automotive industry. The paper, based on proposals from different authors, also includes a set of quality tools that can be used in the different steps of the problem-solving process. The results show that there is general agreement on best problem-solving practices, emphasizing root-cause analysis and the development and implementation of corrective actions, which are included in all the proposals analyzed. The analysis also shows that many quality tools can be used in the different steps of this process. In addition, the paper proposes an initial framework developed by the authors that can be used by organizations to improve their problem-solving practices.

Fey, C; Goebel, R; Totten, G; Bishop, R. Root Cause Analysis of A Piston Pump Failure: A Case History. SAE Technical Paper, 1998. https://trid.trb.org/view/1788419

In many situations, the root cause of a particular failure may be determined based on the observation of a single part, or perhaps a photograph, taken from the failed system. However, when failure analysis is conducted on the complete component, a different result often emerges. Such is the case described here for a piston pump that was operating on an anhydrous poly(alkylene glycol) - PAG at high pressure. Initial observation suggested the fluid was the root cause of the failure. However, when failure analysis was properly applied, it was learned that the root cause of the failure was due to mechanical failure caused by the motor-to-pump coupling. This analysis procedure is presented as a case history in this report.

Freight modal shift: mode shift impediments and opportunities. Australasian Railway Association (ARA); GHD Advisory, 2022, 48p. https://trid.trb.org/view/1938153

In terms of tonne kilometres, rail moves approximately 40% of the overall freight task in Australia, however rails share of inter capital non-bulk freight is closer to between 10-15%. The mode share of rail in and out of our ports also varies, however generally this share tends to be lower than Government aspirations and industry expectations. Rail's share of freight movements in and out of container ports is anywhere between 2-17% despite numerous state policies aiming to achieve up to 30% mode share at various times over the last decade or so. These higher mode share goals reflect the fact that the benefits of increased rail freight use is clear. Increased environmental outcomes, improved amenity, increased safety, and decreased road congestion are all outcomes worth achieving. This being the case, why has rail not achieved a higher share of the freight task, particularly in the non-long-haul or non-bulk markets? A key first step to answering these questions was identifying the opportunities as well as the impediments to increasing freight rail share. Following engagement with industry, a problem definition and root cause analysis, the key impediments were identified. A rail operations and cost model was then used by consultants GHD to analyse impediments quantitively, including understanding sensitivities between various attributes such as journey distances, train utilisation, handling costs, turn-around time and travelling speeds (to name a few). Both qualitative and quantitative analysis demonstrated there are few insurmountable impediments, and that largely to overcome one impediment, such as travelling short distances, other factors can be improved to counteract the effects on viability. This report is a summary of the identified impediments and opportunities to address them in enabling rail freight to achieve a higher market share of the overall freght task.

Gómez-Andrades, Ana; Muñoz, Pablo; Serrano, Immaculada; Barco, Raquel. Automatic Root Cause Analysis for LTE Networks Based on Unsupervised Techniques. IEEE Transactions on Vehicular Technology, Volume 65, Issue 4, 2016, pp 2369-2386. https://trid.trb.org/view/1404093

The increase in the size and complexity of current cellular networks is complicating their operation and maintenance tasks. While the end-to-end user experience in terms of throughput and latency has been significantly improved, cellular networks have also become more prone to failures. In this context, mobile operators start to concentrate their efforts on creating self-healing networks, i.e., those networks capable of troubleshooting in an automatic way, making the network more reliable and reducing costs. In this paper, an automatic diagnosis system based on unsupervised techniques for Long-Term Evolution (LTE) networks is proposed. In particular, this system is built through an iterative process, using self-organizing maps (SOMs) and Ward's hierarchical method, to guarantee the quality of the solution. Furthermore, to obtain a number of relevant clusters and label them properly from a technical point of view, an approach based on the analysis of the statistical behavior of each cluster is proposed.

Moreover, with the aim of increasing the accuracy of the system, a novel adjustment process is presented. It intends to refine the diagnosis solution provided by the traditional SOM according to the so-called silhouette index and the most similar cause on the basis of the minimum Xth percentile of all distances. The effectiveness of the developed diagnosis system is validated using real and simulated LTE data by analyzing its performance and comparing it with reference mechanisms.

Gout, Johan. White Light Scanning - Automating a More Comprehensive Inspection Process. SAE Technical Paper, 2005. https://trid.trb.org/view/1802817

Advancements in three-dimensional non-contact optical structured white light scanning (digitizing) technologies have proven successful in achieving the required accuracy to accomplish the majority of inspection tasks. Reaching this milestone, many companies are now complimenting their current metrology implementations with non-contact digitizing solutions. These systems provide additional benefits ranging from increased throughput, more complete geometry analysis, and a flexibility to interrogate inspection results independent of part set-up chosen during the measurement process. Structured white light scanning is not the same technology as the “laser scanning” group of metrology products that industry has tried to implement with varying levels of success. The non-contact structured white light data acquisition process has proven extremely useful when the object to be inspected is complex by way of compound surfaces, abundant number of features, size, or number of locations to be measured. Automating the inspection task has proven useful when requirements dictate many of the same or similar “family of parts” require inspection. First article inspections can also be performed in an automated fashion. Differing from traditional contact or tactile digitizing techniques that measure a discrete point upon contact or laser systems that measure either a point or a band of data when moved across the object surface, optical “whole field” measuring techniques acquire data in a manner analogous to snapping camera images of an object. The result is a digital representation of the object consisting of thousands, even millions if necessary, discrete X, Y, Z data points and is referred to as a point cloud. The number of points making up the point cloud is typically based on the size of the part, features to be measured and the required resolution (point density) to capture these features. With the object's point cloud representation and specifically developed inspection software architected to process the robust part definition, industry is obtaining more thorough part and assembly inspections with enhanced trouble shooting and root cause analysis capabilities. Inherent benefits of the non-contact white light solution over traditional contact digitizing systems such as CMM's are throughput, inspection thoroughness, flexibility, portability and an almost unlimited size capability i.e. full scale C130 aircraft. The process is also capable of delivering traditional CMM measurements with CMM style reports as well. The intent of this white paper is to present the effectiveness and flexibility of non-contact structured white light digitizing in multiple industry segments via various digitizing scenarios and inspection results for objects ranging from small precision parts (machined parts or turbine blades), typical automotive components (machined and stamped components to full body in whites), and up to extra large objects (full scale vehicles and aircrafts).

Gupta, Kapil; Vikram, MR; Manta, Eugenio. Study of Turbocharger Whistle Noise and Its Reduction Into Passenger Cabin. SAE Technical Paper, 2015. https://trid.trb.org/view/1831672

A turbocharger unit mainly consists of a centrifugal compressor and a turbine coupled together by a solid shaft. This is employed to boost the charge air pressure of the engine. Turbocharging in modern diesel and gasoline engines have become a common and essential operation to result higher power outputs, lower emissions, improved efficiency and refinements from a similar capacity of naturally

aspirated engines. The automotive turbocharger system is a source of synchronous and asynchronous noises that should be eliminated or reduced for passenger comfort. Subjectively, a high whistle noise was audible in the passenger cabin during in a mid-rpm range drive in all gears in a 4 cylinder diesel vehicle. Objective noise and vibration data confirm the issue as unbalance whistle. A detailed study has been carried out to identify the source and radiating part of the unbalance whistle noise generated in a 4 cylinder diesel engine running a passenger car. This paper presents the work carried out to reduce unbalance whistle in passenger cabin. The paper is categorized in three segments. First section describes the NVH aspects of turbocharger. Second section describes the root-cause analysis and concept formulation for the noise problem. The final section describes the solution which reduces the whistle noise in passenger cabin.

Hall, Thomas D. Application of Metrology, Statistics, Root Cause Analysis, and Cost of Quality to Enable Quality Improvements and Implementation of Statistical Process Controls for Acceptance of Large Complex Assemblies. SAE International Journal of Advances and Current Practices in Mobility, Volume 3, Issue 3, 2021, pp 1231-1239 https://trid.trb.org/view/1859081

For new aircraft production, initial production typically reveals difficulty in achieving some assembly level tolerances which in turn lead to non-conformances at integration. With initial design, tooling, build plans, automation, and contracts with suppliers and partners being complete, the need arises to resolve these integration issues quickly and with minimum impact to production and cost targets. While root cause corrective action (RCCA) is a very well know process, this paper will examine some of the unique requirements and innovative solutions when addressing variation on large assemblies manufactured at various suppliers. Specifically, this paper will first review a completed airplane project (Project A) to improve fuselage circumferential and seat track joins and continue to the discussion on another application (Project B) on another aircraft type but having similar challenges. The use of Project A and B is used here to ensure proprietary protection of internal and supplier propriety information. One particularly innovative idea on both these projects is implementation of statistical process control for product acceptance as this provided and continues to provide additional incentive to invest more aggressively in quality improvements. For Project A, costs across the build cycle were overlaid with process capability to not only focus corrective action but also enlighten the program as to where increasing tolerances allowed focus on where it was really needed and avoid “false alarm”. This paper will detail how process capability requirements were adjusted to balance manufacturing capability with engineering requirements. For the Project B, this paper will review how these same principles are currently being applied to a fixed leading edge in concert with six sigma to address out of control variation.

Hallowell, Alexandra; Stoy, Kelan. The Rent is Too Damn High: Parking and Affordability in Portland, Oregon. Transportation Research Board 94th Annual Meeting, Transportation Research Board, 2015, 12p. https://trid.trb.org/view/1338119

This study presents a mixed-methods analysis of the Portland, Oregon rental housing market to demonstrate the price impact that on-site parking has on the rental market. This is the first analysis of the impacts of parking on price of housing stock in the rental market. Using a dataset of 22 apartment buildings spanning zero-parking, low-parking, and more traditional 1:1 parking space to residential unit ratios, the authors conduct an ordinary least squared regression to evaluate the impact higher parking ratios has on rental prices while controlling for other variables. The authors' model demonstrates that when comparing a new rental housing development with zero on-site parking to an otherwise equal

development with one parking space per housing unit, there is 20% premium paid by tenants. This increase is despite the $70 to $180 per month parking fee paid at all sites with parking. This study contributes to the body of literature criticizing minimum parking zoning as inefficient, and even harmful, municipal policy. This analysis is then contextualized by interviews with Portland-area developers. The authors argue for the elimination of parking minimum zoning due to the cost burden such policy exacts on the rental market.

Hintze, Hartmut; Giertzsch, Fabian; Kusch, Alexander; God, Ralf. Approach for Digitalization of Maintenance Processes within the Aircraft Cabin. SAE Technical Paper, Volume 4, Issue 4, 2022, pp 1014-1026. https://trid.trb.org/view/1930460

Enhancing the comfort for passengers, airlines are constantly increasing the number of services within the aircraft cabin such as meal ordering directly from passenger seats. The payment and menu selection can be completely processed by means of a passenger-individual airline user account also considering the remaining inventory of the galley. The implementation of such type of services is supported by digitalization of cabin business processes. For these new services the airline requires a high availability of the process-related system functions to ensure airline's revenue and customer satisfaction. A possible approach to reach the target of high availability of these functions is to use the trend of digitalization for improving function-relevant maintenance processes within the aircraft cabin. This requires an introduction of flexible communication architectures to enhance the existing maintenance process by establishing an automated fault detection, root cause analysis, and/or even fault prediction. For implementation it is necessary to provide system data and parameters digitally, e.g. by sensor measurements or an online evaluation of already existing system data logs. An example is the working light within the aircraft galley used to create an appropriate working environment for the cabin crew to prepare ordered meals for the passengers. Currently, fault detection is only possible by identifying its failure effect, i.e. a not illuminating lighting unit. However, by measuring the current consumption of the light source via a digital sensor, it would be possible to detect a changing trend in the current consumption and, in turn, triggering a maintenance task to replace the light before it actually fails. The evaluation of such current measurement with the resulting fault prediction would expand the maintenance system by a new function. This paper describes how digitally supportable maintenance processes for any cabin system can be systematically identified and which system modifications are necessary for realization. Further-more, a methodology for cost and benefit assessment is introduced to find the right level of digitization for the cabin system under analysis.

Hubballimath, Nandesh. Cost Efficient Methodology to Optimize Battery Box Design to Counter the Field Failure. SAE Technical Paper, 2017. https://trid.trb.org/view/1446556

Battery Box is the housing unit for the Batteries in an automobile. The primary functions are to hold batteries in position and to assist periodic battery servicing. This unit contributes to vehicle curb weight considerably; it weighs in the range of 80-100 Kg for heavy duty commercial vehicles. Typically, battery box is rarely designed with regards to weight, cost and inherent fool-proofing measures during serviceability. This study provides a methodology adopted to design the Battery Box and its fixation with respect to Vehicle Dynamics and loading conditions. Brief discussions emphasizing design Root Cause Analysis for Field Failure in the Battery Box, selection and optimization of counter measures are enunciated in this paper. In this paper also provided the scope of improvement in existing design without increasing the total cost (Part Manufacturing and Assembly cost), this Optimal design outcome of Battery Box and Fixation assembly conformed to the standardized durability.

Intelligent Incipient Fault Detection System for Electric Vehicle Battery: Fault Isolation Schemes and Prototype Development. [Project]. Office of the Assistant Secretary for Research and Technology. Start date: 1 Aug. 2021. https://trid.trb.org/view/1904907

Lithium-ion (Li-ion) batteries are the primary power source for electric vehicles (EVs) due to their high energy and power density, and long life-cycle. The recent variants of the high-end plug-in EVs, with Li-ion battery pack, offer a range of approximately 300 miles on a single full charge close to their gasoline counterparts. Further, to bridge the gap between the fueling time of the gas-powered vehicles and the charging time of EVs, high power chargers have also been introduced, reducing the charging time to less than 30 minutes. The Li-ion battery packs operate at maximum limits to deliver the required power to achieve these optimal performances.

The extreme operating conditions and abusive operations may lead to internal and external faults, such as short circuits, cell internal temperature rise, lithium plating and loss of lithium, and mechanical failure due to vibration. These internal faults have a cumulative effect on the battery's health, aggravating the vulnerability to thermal runaway. Although various external safety technologies are employed in the battery monitoring system and battery management system (BMS) to protect the battery from external fault conditions, it is still challenging to detect the internal faults from the available measurements (e.g., voltage, current, and surface temperature). The state-of-the-art internal fault detection approaches use Li-ion battery models with constant parameters to develop model-based fault detection algorithms, which may lead to inaccurate results since these parameters change with health degradation. In a companion research project funded by Tran-SET in Cycle-4, the research team proposed developing a real-time learning-based fault detection scheme. However, the scheme proposed in the TranSET Cycle-4 project requires significant improvements from the perspective of hardware implementation. Therefore, the development of an intelligent incipient fault detection system, which addresses the challenges of the computational complexity of real-time machine learning using neural networks for the embedded-hardware implementation, is critical to exploit the advantages of the real-time learning schemes in the field of Li-ion battery management for EVs. The proposed research project's overall objective is to develop, implement, and validate an intelligent fault detection scheme capable of detecting a Li-ion battery's internal faults in its incipient stage. This involves significant intellectual challenges related to root-cause analysis for determining the interrelation between internal parameters and type of fault and develop a computationally efficient neural network algorithm for hardware implementation. The team will address these challenges by (1) developing failure mode analysis schemes to identify the root-causes, (2) developing computationally efficient fault detection algorithms using real-time machine learning, (3) developing Field Programmable Gate Array (FPGA)-based hardware architecture to implement fault detection scheme, and (4) validating the prototype experimentally. The success of the project will lead to a significant improvement in the safety of EVs. The research aligns with the vision of TranSET of overcoming transportation challenges in Region-6 by using innovative approaches. The proposed research is highly relevant to multiple disciplines, such as control systems, machine learning, and EVs. This project's success will provide necessary validation results and a prototype of the fault detection system for the safe operation of the Li-ion battery fostering its adoption by stakeholders. The project will also educate students and working professionals on this innovative multidisciplinary research and technology development. The team will also integrate the research results into mechatronics courses and reach out to secondary school students hosting lab visits and workshops to motivate them to seek STEM as a career.

Iyer, Ganesh; Prasanth, B; Wagh, Sachin; Hudson, David. Idle Vibrations Refinement of a Passenger Car. SAE Technical Paper, 2011. https://trid.trb.org/view/1822472

The idle NVH refinement gives the customer a feel of overall quality of the vehicle. The psycho-acoustic perception of the driver/passenger during idling is primarily influenced by the power train refinement and its isolation from the passenger compartment. Power train mounting system plays a vital role in attaining the required idle NVH refinement. The modern cars being designed for higher power to weight ratio, with more powerful engines and lighter frame work has made the task of NVH refinement more difficult. The response of the lighter structure to load variation at idle due to operation of ancillary systems like HVAC, and electrical systems such as head lamps, fog lamps, wipers etc. causes discomfort to the passenger. This paper describes an approach towards identifying the key factors governing the idle vibration of the vehicle in steady state as well as in transient operation. Increased steady state vibrations at idle was observed with engine in fully loaded condition while transient idle shake was observed with variation in the loading. Root-cause analysis consists of study of power train rigid body dynamics and tuning by varying the speed, mount stiffness to address the effect of transmissibility and the use of LRC alternator to improve loading pattern of the engine. The analysis indicates the power train pitching mode close to the fundamental excitation frequency at full load with elevated vehicle idling speed. This results in higher vibration transmissibility, which deteriorates perception with speed fluctuations. The proposed solutions improved the objective and subjective perception of tactile vibrations during idling.

Jawale, Pradeep; Karanth, Nagesh. Interior Noise and Vibration Reduction of BRT - Premium Segment Bus. SAE Technical Paper, 2016. https://trid.trb.org/view/1835646

Urbanisation has led to an increased need for mobility in public transportation. Sensing the unfolding worrisome scenario, many countries have taken up different mass rapid transit solutions to alleviate the problem and restore the free flowing traffic. BRT should have been the logical choice particularly considering the lower capital costs involved and faster implementation. Comprehensibly the expectations of this class of vehicles will be high in term of quality and comfort to the passengers. Level of vibration and noise is an important indicator to evaluate vehicle's ride comfort. The challenges are to design the high powered Powertrain and Air Conditioning system nonetheless low interior noise, vibration and harshness correspondents to personal cars. This paper is an invention of, development work done in interior noise refinement of a bus. A prototype bus manufactured to meet all the requirement of BRT - premium segment urban bus. The prototype was almost meeting the entire required specifications, excluding interior noise and vibrations. The rear zone of the interior was the major concern of NVH levels, which demands to carry out the root cause analysis. There were various structure-borne and air-borne sources contributing to increase in NVH levels. Design and development iterations were conducted on the vehicle to achieve the well significant noise and vibration reduction and increased comfort to the passengers.

Jawale, Pradeep; Karanth, Nagesh Voderahobli; Gaikwad, Atul Annasaheb; Mutalik, Keshav. Low Frequency In-Cab Booming Noise Reduction in the Passenger Car. SAE Technical Paper, 2019. https://trid.trb.org/view/1578784

In-cab booming noise is low frequency (20 Hz~300 Hz) phenomenon excites the cabin structure, which occurs mainly due to excitations from the powertrain, exhaust system, road input, etc. Annoyance due to booming noise affects the In-cab sound quality, which results in passenger discomfort. A diesel

passenger car observed booming noise issue when operated at stationary as well as dynamic run-up conditions. In order to increase passenger comfort, experimental root cause analysis conducted on the vehicle to investigate the dominant sources for the cavity boom. Exhaust hanger and one of the engine mount identified as major reason for the booming noise in the cabin. A detailed study was carried out on dynamic property optimization of rubber hanger and possibility to relocate the hanger to improve the vibration transmissibility. Operational measurements conducted on vehicle by attaching finalized exhaust mount to confirm the significant booming noise reduction in the cabin.

John Britto, Vijay Antony; Karmakar, Sudipto; Muthuveeraswamy, Madhan; Natarajasundaram, Balasubramanian. High Speed Booming Noise Reduction in Passenger Car by Application of Cost Optimized NVH Solution. SAE Technical Paper, 2012. https://trid.trb.org/view/1833908

NVH refinement of a vehicle with light weight structure[1] focusing on fuel efficiency is a challenging task. Resonance between the air volume of the cabin and revolving engine excitation generates booming. This booming noise affects the annoyance of sound quality in the cabin. Engine torque variation, penetration of air intake and exhaust system, and tire unbalance caused by engine auxiliary resonance are the most influential sources for high speed booming. This paper describes the booming noise level reduction between 100-200 Hz during high RPM driving conditions in one of the passenger cars. Detailed CAE iterations and testing has been done to identify the root cause of the booming noise. By considering the cost vs NVH performance trade off, the optimized NVH countermeasure has been chosen and validated. Modal analysis, operational deflection shapes, Input point inertance and Noise transfer function techniques have been used for root-cause analysis and counter measure proposal. Different solutions like addition of mass damper, mass and thickness improvement of the structure has been analyzed and the most cost effective NVH solution has been applied and validated. As a result, a standard methodology has been framed for booming noise analysis.

Kavarana, Farokh; Schroeder, Anna. A Practical CAE Approach to Determine Acoustic Cavity Modes for Vehicle NVH Development. SAE International Journal of Passenger Cars - Mechanical Systems, Volume 5, Issue 2, 2012, pp 1042-1049. https://trid.trb.org/view/1432512

The role of acoustic cavity modes in vehicle NVH (noise, vibration and harshness) development is well established in the automotive industry today. Prior knowledge of these modes can help prevent potential issues later in the development cycle, as well as aid in root cause analysis of vibro-acoustic issues. OEMs utilize them as part of their overall modal alignment strategy and cascade them to major system and sub-system suppliers for robust NVH designs. Today, acoustic cavity modes can be obtained rather easily using CAE (computer aided engineering) methods early in the development cycle. However, unlike acoustic modal testing, the CAE normal mode solution cannot scale the relative amplitudes of the modes. The sheer number of acoustic modal frequencies to be avoided can be a serious deterrent during the early design phase. This paper proposes an alternate approach for acoustic modal analyses using CAE to scale the relative amplitudes of cavity modes. An omni-directional acoustic source is placed at critical interior cavity locations and acoustic frequency responses are generated akin to an acoustic modal test. This approach is successful in scaling the relative importance of the acoustic cavity modes, and has a reasonable correlation with modes found from actual testing. This information holds much more value from a vehicle NVH development perspective because the relative strengths of the modes are known and the number of acoustic modal frequencies to avoid is greatly reduced. From a practical vehicle NVH development perspective, this approach has clear benefits over traditional CAE acoustic normal mode analysis methodology in use today.

Khatib, E J; Barco, R; Gómez-Andrades, A; Serrano, I. Diagnosis Based on Genetic Fuzzy Algorithms for LTE Self-Healing. IEEE Transactions on Vehicular Technology, Volume 65, Issue 3, 2016, pp 1639-1651. https://trid.trb.org/view/1401145

Self-organizing network (SON) mechanisms reduce operational expenditure in cellular networks while enhancing the offered quality of service. Within a SON, self-healing aims to autonomously solve problems in the radio access network and to minimize their impact on the user. Self-healing comprises automatic fault detection, root cause analysis, fault compensation, and recovery. This paper presents a root cause analysis system based on fuzzy logic. A genetic algorithm is proposed for learning the rule base. The proposed method is adapted to the way of reasoning of troubleshooting experts, which ease knowledge acquisition and system output interpretation. Results show that the obtained results are comparable or even better than those obtained when the troubleshooting experts define the rules, with the clear benefit of not requiring the experts to define the system. In addition, the system is robust, since fine tuning of its parameters is not mandatory.

Kim, Keunsoo. The Root-Cause Analysis of Engine Stall at Hot Ambient Resulted from Low Pressure Fuel Pump. SAE Technical Paper, 2022. https://trid.trb.org/view/1937922

In case of all gasoline vehicles such as the passenger vehicle, heavy duty truck and light duty truck etc., a fuel pump is located inside the fuel tank and transfers the fuel to an engine for stable driving, however, engine stall can be occurred by low pressure fuel pump. The boiling temperature of gasoline fuel is very low, the initial boiling point is around 40°C so fuel can boil easily while driving and end boiling point is around 190°C. It boils sequentially depending on the temperature. It becomes the criteria to determine the amount of vapor released inside the fuel tank at high temperature. The main cause of engine stall at high temperature is rapid fuel boiling by increasing fuel temperature. This causes a lot of vapor. Such vapor flows into the fuel pump which leading to decrease the pump load and the current consumption of the fuel pump continuously. This ultimately results in engine stall. The influence on Reid Vapor Pressure (RVP) was also investigated, but it does not seem to have a significant effect on engine stall. Since vapor pressure is involved in the amount of evaporation, it is judged that it does not absolutely affect the amount of vapor generated at high temperatures. The effect on fuel tank inner pressure was also evaluated. When the internal tank pressure abruptly decreases during driving, the boiling amount of the fuel suddenly increases, which leads to create a lot of vapor in the fuel, resulting in engine stall. In this study, the effect of the boiling point, vapor pressure, weathering of fuel on engine stall was also researched. This paper is the result of finding the root-cause of engine stall at hot ambient from a perspective low pressure fuel pump.

Kim, Keunsoo. The Root Cause Analysis of Steel Fuel Tank Cracking at a Fatigue Point and Test Method Development of Durability. SAE Technical Paper, 2017. https://trid.trb.org/view/1462053

Fuel tank in vehicle must hold the fuel in a stable way under any driving condition. However, the fuel tank might not conserve the fuel firmly in case a crack emerged while the fuel tank is exposed to different driving condition. Basically, when the engine is in purging at a normal ambient temperature before fuel boiling, the pressure inside the fuel tank decreases. However, the pressure inside a fuel tank increases while a vehicle is driven at extreme hot ambient temperature as fuel is boiling. This repetitive pressure change in the fuel tank comes with fuel tank's physical expansion and shrink, which would cause a damage to the fuel tank. The main purpose of this research is to investigate the root cause of

why fuel tank cracks at a fatigue point. We also aim to set up the method of how to test durability of the fuel tank in association with the pressure inside the tank.

Klarin, Borislav; Resch, Thomas; Grozdanovic, Ivan; Pevec, Denis. Root Cause Analysis and Structural Optimization of E-Drive Transmission. SAE Technical Paper, 2020. https://trid.trb.org/view/1745924

This paper describes the simulation tool chain serving to design and optimize the transmission of an electric axle drive from concept to final design with respect to NVH. A two-stage transmission of an eAxle is designed from scratch by the initial layout of gears and shafts, including the optimization of gear micro geometry. After the shaft system and bearings are defined, the concept design of the transmission housing is evaluated with the help of a basic topology optimization regarding stiffness and certain eigenfrequencies. In the next step a fully flexible multi-body dynamic (MBD) and acoustic analysis of the transmission is performed using internally calculated excitations due to gear contact and bearing interaction with shaft and gear dynamics for the entire speed and load range. Critical operating conditions in terms of shaft dynamics, structure borne noise and noise radiation are evaluated and selected as target for optimization in the following steps. Critical operating conditions are detected by a detailed root cause analysis (RCA) including operational modal analysis of assembled transmission, modal and panel contribution evaluation, operational deflection shape analysis (ODS), numerical transfer path analysis (NTPA) and transfer function (TF) evaluation. Based on the RCA result, the transmission housing design is exposed to the new optimization loop using different methods and tools and based on the dynamic loads. The design is optimized with the goal of reducing the emitted noise. The final housing design is verified by repeating the MBD and acoustic analysis. The developed simulation methodology and tools can successfully identify the main noise sources from the e-drive transmission. Followed by design optimization, the emitted noise is reduced, and the design can be improved.

Kopp, Gary E; Holzinger, Janet L. Portable NVH Dynamometers. SAE Technical Paper, 2003. https://trid.trb.org/view/1797238

Noise Vibration and Harshness (NVH) characteristics have become a key differentiator between “Good” vehicles and “Best-In-Class” vehicles. While all OEM's and most Tier 1 suppliers have on-site in-ground chassis dynamometers, a need was identified to design, develop and bring to market, a fully capable portable NVH full vehicle chassis system. The original concept entailed a device, which could be brought to the customer's location, be fully self contained, requiring no external power, and provide data acquisition using transducers that would not contact the vehicle. With traditional instrumentation taking several hours to install, non-contacting lasers would be used to provide significant timesaving, and prevent any possible damage to the vehicle from pinched wires. The new methodology should provide data acquisition in as little as 20 minutes. Analysis would be accomplished immediately following testing, with hard copies available before the next vehicle was ready to run. Full vehicle NVH root cause analysis, including system balancing would be done in minutes, at the customer's location, assembly plant, engineering center, or Visteon site. Along with the NVH capabilities, performance data would also be available including horsepower, fuel testing, etc. This paper presents history, design, development, implementation, use, and future developments for the Visteon Portable NVH/Performance Dynamometers that are now in service. Showcasing how the portable dynamometers support a vehicle level NVH design methodology is presented, which seeks an optimum balance of system design criteria. This is possible by providing bumper-to-bumper NVH root cause analysis, driveline imbalance sensitivity to first order forces, driveline imbalance cross-talk analysis, wheel/tire

imbalance and force variation sensitivity, system resonance identification, and dynamic mount transmissibility analysis.

KUMARAN, RAJASEKAR; m, Vadivelu; SG, Arun; Adepu, Rakesh; KC, Satheesh. Design and Development of Fuel Tank for High Mobility Military Vehicle. SAE Technical Paper, 2023. https://trid.trb.org/view/2212787

Fuel tank is considered as safety component in the vehicle, and it has to be tested to meet the safety requirements as per AIS 095. Earlier, fuel tanks were manufactured by using Hot dipped cold rolled steel material and the weld zones are applied with Anti-corrosive coating. Few fuel tanks were reported with Corrosion problems. The root cause analysis was carried out considering the raw material, manufacturing process, transpiration, storage and usage. As an improvement, the new fuel tank is designed to eliminate the limitations of the existing fuel tank. 3D modeling was done to check space and mounting requirement in the layout and used for volume calculations. FE analysis was performed to check structural stability. Emphasis given on Interchange-ability to cater the new fuel tanks in place of old as spares requirement. The fuel tank has developed with Alumina steel material. Alumina steel is a material with the strength property of steel and corrosion resistant property of Aluminium. The complete manufacturing process has critically studied and new check points and inspection stages were introduced. The Limitations of existing fuel tank has been taken in to consideration and the additional new features were introduced. After successful development, the fuel tank has submitted to M/s Global Automotive research centre for Type approval. The Alumina steel fuel tank underwent hydraulic test and over turn test as per AIS 095: 2007 and type approval obtained. The fitment and functional test was carried out on vehicle and regularized as a standard fitment.

Kumari, Sarita. Research to Explore Different Failures and their Countermeasures in Automotive Seating Fabrics. SAE Technical Paper, 2013. https://trid.trb.org/view/1827600

In automotive seating system, seat upholstery quality has an important role in defining the overall quality and aesthetics of vehicle interiors. Technical textiles for seating system used in automotive applications are generally categorized into woven or knitted type. An automotive textile material is a composite material made up of three layers; base fabric (top layer), foam (middle layer) and scrim (bottom layer) as shown in Fig. 1. There are many challenges to be overcome during development of fabric e.g. mechanical, physical and aesthetic issues have an impact on overall seat quality, appearance and performance. These issues get highlighted during testing, which takes place during development stage of fabric. The concerns mentioned above are found in automotive textiles in both woven and knitted types of fabrics sourced from different manufacturing set-ups. This paper focuses on identification of problems during testing, followed by root cause analysis. In technical textiles, design of the fabric, its structure and finishing plays a significant role in ascertaining overall property of the fabric, either enhancing or deteriorating it. In this paper, parameters affecting different properties were studied and evaluated.

Kurna, Srinivas; Jain, Rahul; Mathur, Arpit; Parwal, Mahendra; Legala, Adithya. Design Optimization of Engine Mounts for Commercial Vehicle Application to Avoid Failures. SAE Technical Paper, 2017. https://trid.trb.org/view/1446549

The Mounting system of component plays a major role in determining the structural durability, compatibility and synchronization of the systems with respect to each other. The major function of Engine mounts is to isolate the engine from the chassis and to align the power-train system of vehicle

according to needs. Here we exclusively deal with the failure case of a Heavy duty commercial vehicle Engine Mounts and its optimization. We do formulate a theoretical calculation for the estimation of engine loads, Center of Gravity (C.G) and characteristics of existing engine mount followed by a failure root cause analysis based on design and transmissibility parameters. This is then correlated with data from Computed Aided Engineering and Matlab for analysis of the existing model which is compared to the experimental transmissibility from Road load data Acquisition (RLDA). This is to validate the conditions and propose optimizations to reduce critical failures.

Lakshe, Shailesh; Chittilla, Kishore; Raut, Manoj; Titave, Uttam. Prediction and Resolution of Vehicle In-Cab Noise due to Powertrain Induced Excitations. SAE Technical Paper, 2019. https://trid.trb.org/view/1578787

Vehicle NVH is one of the critical performance quality parameter and it consists of vibration levels at tactile points and noise levels at ear locations for different vehicle running conditions. There are many sources of noise and vibration in a vehicle, and powertrain is one of the main source. Therefore, it is important to understand and resolve powertrain induced noise and vibration issues at early design stage with efficient simulation techniques. The work presented here deals with the use of systematic CAE approach for prediction and resolution of structure borne in-cab noise due to powertrain excitations. During NVH testing of SUV vehicle, boom noise is observed at low frequency. Detailed full vehicle level simulation model consisting of vibro-acoustic trimmed BIW, front and rear suspension, and driveline with powertrain modal model is built. Powertrain dynamic loads due to inertia and combustion pressure are applied at powertrain C.G. and in-cab noise at driver ear location (DEL) is predicted. Predicted in-cab noise shows good correlation with measured 2EO noise. Root cause analysis shows that front sub-frame has vibration mode in the frequency range of issue. Based on simulation, conceptual modification of rigid plate between sub-frame and vehicle body is suggested and gives significant improvement in vehicle in-cab noise when tested. Using simulation approach, other feasible design solutions are worked out.

Liu, C; Pawlowski, Roger; Orzechowski, Jeff. A New Method for Obtaining FRF of a Structure in Area Where Impact Hammer Cannot Reach. SAE Technical Paper, 2007. https://trid.trb.org/view/1812315

The Frequency Response Function (FRF) is a fundamental component to identifying the dynamic characteristics of a system. FRF's have a significant impact on modal analysis and root cause analysis of NVH issues. In most cases the FRF can be easily measured, but there are instances when the measurement is unobtainable due to spatial constraints. This paper outlines a simple experimental method for obtaining a high quality input-output FRF of a structure in areas where an impact hammer can not reach during impact testing. Traditionally, the FRF in such an area is obtained by using a load cell extender with a hammer impact excitation. A common problem with this device is a double hit, that yields unacceptable results. The new method provided in this paper is shown to be superior to the traditional method for several reasons: (i) it is simple and requires no new equipment, (ii) a double hit issue is avoided, (iii) the desired FRF is calculated using a closed form equation, provided in this paper, which results in a more accurate solution.

Massuchetto, Marco Antonio; Lodetti, Julio. Root Cause Analysis, and Influence of Environmental Characteristics on a Heavy Duty Diesel Engine Fault in High Altitude. SAE Technical Paper, 2014. https://trid.trb.org/view/1831110

The objective of this article is to present a root-cause analysis performed to support the fault trace of a heavy duty diesel engine breakdown, operating in high altitude. The process to elaborate a cause-effect diagram, also known as Ishikawa diagram is briefly described. Some factors that can influence the engine behavior and its reliability are listed in the cause-effect diagram. According to the failure mode analyzed, the selected factors are then described, and how they could interfere in the engine functioning.

Mehrabi, Mostafa; Weaver, Jonathan. Fault Identification of Assembly Processes Using Fuzzy Set Theory. SAE Technical Paper, 2020. https://trid.trb.org/view/1701553

Effective identification of sources of faults in modern manufacturing systems play a critical role in their performance and productivity. Tracking faults in a typical manufacturing system is inherently an inverse problem which makes it more challenging and difficult to solve. Presented in this article is the development of a new methodology for fault identification and root-cause analysis of complex assembly systems. A combination of a knowledge-based system and fuzzy set theory is used to develop this new technique, which is an intelligent system that mimics the behavior of an expert in the field, and can trace back the source or sources of the fault to the relevant station. Presented are the concepts of faults, their detection in an assembly line, and their generic characteristics. Study of the fault's fundamental properties reveals that there are certain levels of uncertainty involved in describing them. This has led us to the adoption of fuzzy set theory as a basic tool for development of this new technique. This article reports on recent progress made in this area and outlines some of the preliminary results obtained so far. It is shown that based on the characteristics of the faults and the type of operations, it is possible to relate the faults to the relevant station. Examples from real assembly operations are provided to show the effectiveness of this approach.

Michelotti, Alvaro; Penteado, Everton. Applying Modeling and Simulation to Evaluate Field Failure Modes: a Case Study in Starter Drive Application. SAE Technical Paper, 2011. https://trid.trb.org/view/1824334

In response to several field failures of a specific model of starter drive - which is a component of starter motors used in Internal Combustion Engines (ICEs), - for application in heavy duty vehicles, a systematic Root Cause Analysis (RCA) was conducted in warranty returned parts. Controlled laboratory tests were not able to successfully replicate the failure mode. The failure caused the disassemble of the starter drive and it has become a difficult task to determine the root cause and propose solutions to fix the problem, therefore a deeper analysis of the warranty data was carried out by using both finite element analysis (FEA) and lumped parameter dynamic modeling and simulation. The FEA model was used to check potential weakness of the structural design that could point out the failure cause. The dynamic model was developed in order to evaluate effects such as impact loads, much higher than that expected by the static analysis, by consequence of the high relative velocity and resulting accelerations of components in contact during the short period of time in which the startup process of ICEs occurs. A potential root cause was determined and experimental pull tests and engine bench durability cycle tests confirmed the accuracy of the simulation models. Hence, the use of simulation tools can be considered as important aid when non-obvious field failure analysis are needed to speed up the implementation of a more reliable and robust design. Moreover this strategy minimizes well known deleterious consequences generated by recurring field failures that remains for a long time without an effective solution.

Moetakef, Mohammad; Paul, Debabrata; Festag, Georg. Variable Cam Timing (VCT) Knock Root Cause Analysis and Failure Mode Prevention. SAE Technical Paper, 2019. https://trid.trb.org/view/1595247

Knock in the Camshaft Torque Actuated (CTA) in the Variable Cam Timing (VCT) engine can be a NVH issue and a source of customer complaint. The knock noise usually occurs during hot idle when the VCT phaser is in the locked position and the locking pin is engaged. During a V8 engine development at Ford, the VCT knock noise was observed during hot idle run. In this paper investigation leading to the identification of the root cause through both test and the CAE simulation is presented. The key knock contributors involving torque and its rate of change in addition to the backlash level are discussed. A CAE metric to assess knock occurrence potential for this NVH failure mode is presented. Finally a new design feature in terms of locking pinhole positioning to mitigate or eliminate the knock is discussed.

Muñoz, Pablo; de la Bandera, Isabel; E. J. Khatib; Gómez-Andrades, Ana; Serrano, Inmaculada; Barco, Raquel. Root Cause Analysis Based on Temporal Analysis of Metrics toward Self-Organizing 5G Networks. IEEE Transactions on Vehicular Technology, Volume 66, Issue 3, 2017, pp 2811-2824. https://trid.trb.org/view/1459904

By 2020, mobile networks will support a wide range of communication services while at the same time, the number of user terminals will be enormous. To cope with such increased complexity in network management, innovative solutions for the next generation of self-organizing networks (SONs) need to be deployed. In the field of self-healing, the heterogeneous character of future fifth-generation (5G) radio access networks (RANs) will provide a diversity of measurements and metrics that can be translated into valuable knowledge to support detection and diagnosis activities. The more complete the information gathered, the better the SON mechanisms will be able to effectively analyze and solve radio problems. However, temporal dependence between metrics has not been previously addressed in the literature. In this paper, a self-healing method based on network data analysis is proposed to diagnose problems in future RANs. The proposed system analyzes the temporal evolution of a plurality of metrics and searches for potential interdependence under the presence of faults. Performance is evaluated with real data from a mature Long-Term Evolution (LTE) network. Results show that the proposed method exploits the available data in the context of heterogeneous scenarios, reducing the diagnosis error rate.

Naygaonkar, Sumit S; Desai, Sandeep R. An investigation into steering wheel vibrations and design of solution to minimise the severity. International Journal of Vehicle Noise and Vibration, Volume 17, Issue 3-4, 2021, pp 178-200. https://trid.trb.org/view/1991544

The paper presents the current status of the vibration of the steering wheel of an agriculture tractor, the agricultural tractor driver survey, measurement and analysis of vibration and recommendation to reduce the severity. The key purpose of this work is to minimise the vibration of the agricultural tractor's steering wheel and to reduce the detrimental health effects on the driver's hands. The survey of agriculture tractor drivers gives information about the severity of steering wheel vibrations experienced by them. Measurement of vibration values of tractor shows the real problem of vibration experienced by drivers while driving a tractor. The study helps to know the severity of steering wheel vibrations through vibration measurements and to know the root causes of steering wheel vibrations. In line with the root cause analysis, the solution is designed to reduce the amplitude of vibration at the steering wheel of the tractors, using tuned mass damper.

Park, Joonhyung; Gu, Perry. A New Experimental Methodology to Estimate Chassis Force Transmissibility and Applications to Road NVH Improvement. SAE Technical Paper, 2003. https://trid.trb.org/view/1797512

The performance of structure-borne road NVH can be cascaded down to three major systems: 1) vehicle body structure, 2) chassis/suspension, 3) tire/wheel. The forces at the body attachment points are controlled by the isolation efficiency of the chassis/suspension system and the excitation at the spindle/knuckle due to the tire/road interaction. The chassis force transmissibility is a metric to quantify the isolation efficiency. This paper presents a new experimental methodology to estimate the chassis force transmissibility from a fully assembled vehicle. For the calculation of the transmissibility, the spindle force/moment estimation and the conventional Noise Path Analysis (NPA) methodologies are utilized. A merit of the methodology provides not only spindle force to body force transmissibility but also spindle moment to body force transmissibility. Hence it enables us to understand the effectiveness of the spindle moments on the body forces. The feasibility and applicability of the methodology was experimentally demonstrated. The accuracy of the methodology was verified. This methodology can be used for the benchmarking and system cascading for target setting to achieve a desired road NVH performance as well as for diagnosing root causes in the problem solving procedure. Two different vehicles were used for the demonstration of the root cause analysis implementing the method. The comparison of the chassis force transmissibility of these two vehicles is presented to show the merits of this methodology.

Phillips, Paul. The Adoption of Digital Twins in Integrated Vehicle Health Management. SAE EDGE™ Research Reports, 2023. https://trid.trb.org/view/2289455

To many, a digital twin offers “functionality,” or the ability to virtually rerun events that have happened on the real system and the ability to simulate future performance. However, this requires models based on the physics of the system to be built into the digital twin, links to data from sensors on the real live system, and sophisticated algorithms incorporating artificial intelligence (AI) and machine learning (ML). All of this can be used for integrated vehicle health management (IVHM) decisions, such as determining future failure, root cause analysis, and optimized energy performance. All of these can be used to make decisions to optimize the operation of an aircraft—these may even extend into safety-based decisions. The Adoption of Digital Twins in Integrated Vehicle Health Management, however, still has a range of unsettled topics that cover technological reliability, data security and ownership, user presentation and interfaces, as well as certification of the digital twin’s system mechanics (i.e., AI, ML) for use in safety-critical applications.

Pimpalkhare, N., and Mochizuki, S., "CAE Transfer Path Analysis and Its Accuracy Evaluation Using a Validation Method," SAE Technical Paper 2024-01-2740, 2024, https://doi.org/10.4271/2024-01-2740.

In-cabin Noise at low frequency (due to engine or road excitation) is a major issue for NVH engineers. Usually, noise transfer function (NTF) analysis is carried out, due to absence of accurate actual loads for sound pressure level (SPL) analysis. But NTF analysis comes with the challenge of having too many paths (~20 trimmed body attachment locations: engine and suspension mounts, along with 3 directions for each) to work on, which is cumbersome. Physical test transfer path analysis (TPA) is a process of root cause analysis, by which critical contributing paths can be obtained for a problem peak frequency. In addition to that, loads at the attachment points of trimmed body of test vehicle can be derived. Both these outputs are conventionally used in CAE analysis to work on either NTF or SPL. The drawback of this conventional approach is that the critical bands and paths suggested are based on the problem

peak frequency of test vehicle which may be different in CAE. Secondly, the force that is derived from measured acceleration, in physical test, when applied to CAE trimmed body will not produce the similar acceleration to that of Physical test. This is due to the correlation differences in transfer functions between physical test and CAE in trimmed body. The study presented in this paper replaces the conventional TPA carried out in physical testing with CAE TPA by using the transfer functions of CAE trimmed body. Hence, the critical bands and ranking of critical paths along with the loads derived through this method would be more accurate in carrying out the NTF and SPL analysis, respectively.

PRASAD, J; Damodar, N; Naidu, T. Clutch Hysteresis Maximization for Elimination of Gear Rattle in a Passenger Bus. SAE Technical Paper, 2013. https://trid.trb.org/view/1827608

The acceptable noise and vibration performance is one of the most important requirements in a passenger bus as it is intended for widest spectrum of passengers covering all age groups. Gear rattle, being one of the critical factors for NVH and durability, plays a vital role in passenger comfort inside vehicle. The phenomenon of gear rattle happens due to irregularity in engine torque, causing impacts between the teeth of unloaded gear pairs of a gearbox which produce vibrations giving rise to this unacceptable acoustic response. In depth assessment of the dynamic behavior of systems and related components required to eliminate gear rattle. During normal running conditions, abnormal in-cab noise was perceived in a bus. Initial subjective evaluation revealed that the intensity was high during acceleration and deceleration. Objective measurements and analysis of the in-cab noise and vibration measurements had indicated that the noise is mainly due to gear rattling. Further analysis led to the identification of coincidence of this abnormal noise encountered with a driveline mode. Root cause analysis indicated that the clutch had a major influence on gear rattle. As it was initiated by driveline mode, it was pertinent to change either the driveline mode or to reduce the energy being transferred to the gearbox to eliminate the noise encountered. Elimination of gear rattle was achieved by maximizing the hysteresis of clutch thereby absorbing the energy being transferred. This paper explains in detail the various steps followed during the initial investigation, analysis and solving the problem.

Prasanth, B; Wagh, Sachin; Hudson, David. Alternator Whining Noise-A Sound Quality Concern in Passenger Car. SAE Technical Paper, 2011. https://trid.trb.org/view/1822432

Quality of the sound is one of the major parameter for the occupants comfort. The vehicle noise can be broadly classified into airborne and structure borne noise contributed by numerous aggregates present in vehicle. Among different vehicle aggregates the alternator, which is an important component in vehicle electrical architecture, can be considered as a major source of airborne noise. Generally, the alternator noise is combination of mechanical, aerodynamic, and electromagnetic sources. The ratio of these sources in the overall noise varies with speed and loading pattern. The mechanical and aerodynamic noise normally depends on speed while the electromagnetic noise variation is load dependent. Alternator whining is an irritant perception of the sound quality due to electromagnetic noise. When the alternator is loaded with electrical loads (like head lamp, tail lamp, wiper and HVAC) the sound level increases further. This paper describes the systematic approach of problem definition, root cause analysis and measures to improve the sound quality of whining. The root cause analysis covers the electrical or mechanical disconnection of alternator and effect of belt tension variation on whining noise. The effect of loading pattern on the alternator whine was also studied. The paper also covers the solutions tried out and improvements recommended for the implementation.

Quddus, Noor. Development of a Prediction Model for Pipeline Failure Probability Based on Learning From Past Incidents and Pipeline Specific Data Using Artificial Neural Network (ANN). Texas A&M University, College Station; Pipeline and Hazardous Materials Safety Administration, 2022, 135p. https://trid.trb.org/view/2145527

On-site inspection, laboratory analysis and mechanical testing may to a certain extent provide information regarding likely failure possibility of a pipeline if exposed to a specific condition. In reality however, a range of diverse factors including particular environmental conditions, natural calamities, terrorist acts and even deficiencies in management's attempt to maintain the integrity can simultaneously influence pipeline operations and cause early failure. Influence of these numerous factors altogether are difficult to understand and predict and hence a deterministic prediction of failure based on laboratory findings and inspections can be misleading. Which factors can contribute to pipeline failure and to what extent they may contribute can be understood from root cause analysis of past incidents for better assessment and prediction of pipeline failures. Since a large variety of causes may arise from analysis of all past incidents, it is not possible to rely solely on experts to develop a model for pipeline failure that incorporates all the finding from the analyses of past incidents. For such cases, utilization of artificial neural network (ANN) seems promising. The suitability of ANN for this purpose lies in its ability learn from past records to produce a predictive model, model complex non-linear behavior that may exist in any socio-technical system, recognize or classify patterns in behavior and interaction of various contributing factors, and tolerate noises and deal with large data. Although artificial neural network has been used in the past for prediction of pipeline conditions, none of the models considered contribution of human and organizational factors behind failures. Yet, most root cause analyses find such factors as causes behind incidents. Current proposal looks at integrating information about technical, operational, human and organizational factors that have contributed to past incidents with current pipeline specific conditions to develop a model that utilizes artificial neural network to predict the failure probability.

Rager Mountain Well #2244 Casing Failure Root Cause Analysis | PHMSA. (2023). Dot.gov. https://www.phmsa.dot.gov/foia/rager-mountain-well-2244-casing-failure-root-cause-analysis

This report analyzes the root cause of the casing failure in Well #2244 at Rager Mountain Gas Storage field in Cambria County, Pennsylvania, whic is currently operated by Equitrans, L.P. (Equitrans). Blade undertook a systematic evidence-based approach to the RCA by dividing the process into three broad phases. The first phase was focused on data collation and analysis. The second phase focused on collecting and analyzing physical evidence. The third and final phase was the RCA. Blade utilized the Apollo RCA methodology that integrated logging, drilling/completion/workover analysis, well deliverability and kill attempts, failure analysis, metallurgical observations, microbiological assessment, internal and external standards and procedures, regulatory guidelines, Equitrans discussions, etc.

Rao, Sohan; Reddy, Hari; Ravi, Chandan. Identification of BSR Issues in Electronic Boards. SAE Technical Paper, 2023. https://trid.trb.org/view/2173436

Currently the world's transportation sector is experiencing a paradigm shift towards electric mobility where electric and electronic components form an integral part of the vehicle. The heavy usage of electronic systems needs large size printed circuit (PCB) boards with multiple subcomponents connected to it. Such a complex electronic system when excited by dynamic loads, would lead to generation of uncomfortable transient rattle events between the parts. As a result, there is an increasing

requirement to analyze these subsystems to eliminate any unpleasant noise generation mechanisms. In this study, a PCB has been considered for such an analysis. A linear transient analysis was carried out for a sine-sweep excitation. Risk and root cause analysis was performed, and critical locations were identified. Variation in parameters like material properties, connection stiffness, were considered and analyzed for the same. Finally, design modification iterations were performed in which the system behavior improved substantially. This study would provide a means to quantify the rattle events occurring due to the operating conditions and provide an insight about the performance of the component in the real-world operating conditions.

Rohde, Florian. Continuous Integration as Mandatory Puzzle Piece for the Success of Autonomous Vehicles. SAE Technical Paper, 2020. https://trid.trb.org/view/1701175

The transition to autonomous driving technology is widely discussed topic today. In order to make autonomous vehicles work safely in the long run it will be a necessity to keep their software up to date at any time. The challenge is that software released with today's traditional release methods for vehicle updates is not deployed fast enough. Newly discovered corner cases or glitches in the design could restrict the usage of entire fleets for long time. This paper discusses the use of continuous integration methods implemented into the automotive system development in order to keep up with the pace needed to make the new technology a success, and accepted by the users. The development process has to contain smart branching strategies for fast turn around. It is mandatory to have a frozen and stable branch to release hotfixes in case of need, a validation branch with feature lock in order to stabilize, and a feature branch heavy development space that is supported by full system regression testing from the very beginning. The change content for validation per test execution has to be limited to minimum in order to support fast issue identification and root cause analysis. A sophisticated end to end continuous integration and validation process applied on the highest system integration level can achieve turn around times measured in hours and not in weeks.

Santos, Elisa; Martinez, Josephine; Scinto, Philip R. Enhancement of the Sequence IIIG by the Study of Oil Consumption. SAE Technical Paper, 2004. https://trid.trb.org/view/1801204

The Sequence IIIG is a newly developed 100 hour test used to evaluate the performance of crankcase engine oils in the areas of high temperature viscosity increase, wear, deposits, pumpability, and ring sticking for the North American GF-4 standard. Data from the ASTM Precision Matrix, completed in the spring of 2003, along with early reference data from the Lubricant Test Monitoring System (LTMS) showed unexpected test results for selected oils and indicated that percent viscosity increase and pumpability were highly correlated with oil consumption. This correlation led to an intensive study of the factors that influence oil consumption and an attempt to compensate for non-oil related oil consumption through a model based adjustment of the results. The study and scrutiny of the IIIG data has led to more uniform oil consumption in the test and improved test precision, and has eliminated the need for a correction equation based on non-oil related oil consumption. While the adoption of a bias correction should not routinely substitute for quality root cause analysis, it can be a temporary practical solution that leads to reduced variability of a test, and therefore to better performance evaluation of the oil. The objective of this paper is to document the statistical methodology and the progress made during the IIIG development with respect to the application of a bias correction to reduce test variability. In the future, if similar problems arise, the paper may be used as a guide and facilitator for discussion towards possible expedient and practical solutions.

Sarkar, Subrata; Samuelson, Eric; Allen, Jordan; Spiekermann, Ryan. Root Cause Analysis of Limited Slip Differential Noise Vibration Harshness. SAE Technical Paper, 2023. https://trid.trb.org/view/2173396

The primary objective of this research was to identify the root cause of limited slip differential (LSD) NVH. The study examined the significance of different oils and additives that make up the lubrication mix in the axle. The impacts of gear marking compound type, friction modifier type, gear marking compound level, friction modifier level, reaction plate surface finish roughness, and friction material type were studied using Taguchi's Design of Experiment. Eaton's Vertical Friction Tester (VFT), a sub-system level test stand, was used to measure the performance characteristics of the clutch pack and oil mix. Sequential approximation and cumulative analysis methodologies were used to analyze test data where NVH was beyond the measurement capacity of the test stand. The DOE analysis showed that the type of gear marking compound used to set the ring gear mesh during axle build had the most significant influence on NVH levels.

Saxena, Saahil; Jadhav, Sourabh. Truck Front Cabin Mount Tuning for Cabin Noise Boom, Overall Interior Noise and Vibration Reduction. SAE Technical Paper, 2021. https://trid.trb.org/view/1882675

In today's automobile industry refined NVH performance is a key feature and of high importance governing occupant comfort and overall quality impression of vehicle. In this paper interior noise and vibration measurement is done on one of the light truck and few dominant low frequency noise booms were observed in operation range. Modal analysis was done for the cabin at virtual as well as experimental level and few modes were found close to these noise booms. Vibrations were measured across the cabin mounts and it was found that the isolation of front mounts is not effective at lower frequencies. Taking this as an input, the mount design was modified to shift the natural frequency and hence improve the isolation behavior at the lowest dominant frequency. This was followed by static and dynamic measurement of the mounts at test rig level to characterize the dynamic performance and stiffness conclusion. Finally the interior noise and vibration measurement is carried out on truck fitted with selected mounts and substantial vibration, overall noise reduction and drastic boom noise reduction was achieved. This paper takes up a real-time noise scenario, its root cause analysis and establishment of final solution for same. It covers various activities like noise, vibration measurement and analysis, virtual and experimental modal evaluation, mount transmissibility evaluation followed by design and tuning for corrects stiffness, and finally verification at rig and vehicle level. Hence this works runs through complete flow of NVH development cycle. The cabin mount design patent registration is approved.

Senapati, Uday; Dhage, Yogesh; Sawant, Vinaya; Saraf, M; Dodds, Collin. Accelerated Test Method for Validation of Vehicle Components Subjected to Fatigue Failure. SAE Technical Paper, 2007. https://trid.trb.org/view/1810660

This paper describes the procedure of root cause analysis and evaluation of the life of a component that is prone to fatigue failures. The durability testing of components subjected to continuous vibrations in their operating conditions tend to fail after long period of exposure. This makes it difficult and time consuming to test and analyse them in the actual operating conditions. This paper establishes a method of accelerated durability testing for failure modes and life cycle based on the results of Frequency Response Function and modal analysis. This helped in reducing the product development / improvement time.

Sethi, A., Titave, U., Vardhanan K, A., Zalaki, N. et al., "Analysis and Mitigation of Grunt Noise in Hydraulic Power Assisted Steering Systems," SAE Technical Paper 2024-26-0218, 2024, https://doi.org/10.4271/2024-26-0218.

This paper addresses the "Grunt Noise" anomaly in Hydraulic Power Assisted Steering (HPAS) systems, detailing an extensive effort to resolve this disruptive issue. HPAS, while cost-efficient, faces challenges as it adapts to customer demands for reduced steering effort and enhanced handling. Intensified HPAS intervention requires components to withstand higher pressures and tighter tolerances, leading to occasional anomalies.

"Grunt Noise" arises from Torsion bar (T-bar) resonance with fluid pressure pulsations. A comprehensive study identifies load conditions, transfer paths, and frequency bands, extending from vehicle to Pinion Valve assembly levels. Root cause analysis traces the issue from Steering Wheel to T-bar, validating the approach. The T-bar's twisting operation renders torsional stiffness crucial for Grunt Noise. Lower stiffness T-bar, when overpowered by liquid force, causes microsecond imprecise valve openings, leading to cavitation-induced Rack & Pinion vibrations. Varying T-bar stiffness (via diameter alteration) is assessed to minimize variability.

By enhancing T-bar's torsional stiffness and dimensions, the study effectively mitigates Grunt Noise in HPAS systems. In summary, this paper offers a thorough HPAS Grunt Noise analysis, emphasizing the pivotal role of torsional stiffness in resolution.

Sethy, Girija Kumari; Parikh, Ritesh. Finite Element Analysis based Investigation to Evaluate Sealing Capability of High-Pressure Fuel Line Joints in IC Engine. SAE Technical Paper, 2021. https://trid.trb.org/view/1882757

For better fuel economy and reduced emissions; fuel system plays a very important role. There are some major challenges related to development of suitable fuel system due to high static (~2000 bar) and fluctuating pressures in high pressure (HP) fuel lines. This enforces to design leak proof joints as they directly affect engine operation and can cause customer inconvenience. It is also critical from safety standpoint. Sealing capability of a joint is generally evaluated by sealing pressure, length of the sealing width and retaining capability of joint preload over time. Theoretically, it is known that preload loss at a joint is a combination of several factors such as; thread pitch, nut stiffness and friction at threads. In our current work the cause of leakage in HP fuel line joints is explored. Using fish bone diagram for RCA (Root Cause Analysis), probable causes are narrowed down and design parameters responsible for preload loss are identified. A parametric study has been performed for different designs to evaluate their preload retaining capability. Additionally; end form of fuel joints, collar and frictional coefficient are studied to understand their impact on sealing capability as the part of this work. Sealing capability of two different engine platforms are evaluated through Finite Element Analysis (FEA) simulation and analytical methods. The results are validated through testing. The key findings of the current work can be useful in FEA and analytical modelling of HP fuel lines to evaluate joint sealing capability and will be helpful in designing better fuel line system in future.

Shaik Mohammad, Asif Basha; M, Iyyappan; MR, Vikram. New Approach for Road Induced Noise Prediction in Battery Electric Vehicles. SAE Technical Paper, 2023. https://trid.trb.org/view/2173403

In general, in-cabin booming noise is low frequency (20 Hz~300 Hz) phenomenon which excites the cabin structure mainly due to excitations from the powertrain, exhaust system, road loads, etc. When a vehicle drives over road seams or a bumpy surface, low-frequency drumming noise is generated,

causing driver discomfort. The generation of drumming noise is due to road irregularities, transferred and amplified through the vibration characteristics of the suspension, body frame, and body panels, as well as the acoustic characteristics of the vehicle interior. It is therefore difficult to take measures to get rid of drumming, after the basic vehicle construction has been finalized. The regular practice in vehicle development is finite element method (FEM) to obtain acoustical transfer functions of the body, and multi body simulation to get suspension load characteristics. The full vehicle simulation needs more time for analysis and extracting data. So traditional computational aided engineering (CAE) will not support development timeline. Market has become very dynamic, benchmark changes very often, so getting complete data is difficult for very accurate analysis in 'early to market' project timeline. Most of the automotive companies are using computational tools for predicting road noise in simulation phase. But with the help of method, we developed can predict road noise at early design stage itself. It is a novel hybrid tool which can give strong directional results in comparatively lesser time. This user-friendly hybrid tool is developed for predicting and improving road noise at early stage with limited data, especially for new age battery electric vehicle. The inputs used during the initial stage of the program are vibration data of benchmark vehicle at body attachment points, targets, or simulation data (DPDS, NTF), etc. By the proposed methodology, overall trend of road noise can be predicted. In addition to that critical paths can be identified by using transfer path analysis. Once the project/program matures, we can use physically measured data (DPDS & NTF) of the trimmed body and perform the robust root cause analysis to identify the critical paths. Based upon the analysis, modifications to be made on actual body structure for effective drumming reduction. Hence new hybrid approach is proposed, which consists of mathematical model and design philosophy for better in cabin noise. It is worth to note that there are some limitations in the tool and results from the calculations such as granularity of benchmark test data availability, accurate trimmed body level test or simulation data.

Shi, Lijuan; Jia, Zuoning; Sun, Huize; Mingshu, Tian; Chen, Liquan. Analysis of the Factors Influencing on Bird Nesting and Its Impact on Railway Operation. 4th International Conference on Electrical and Information Technologies for Rail Transportation (EITRT 2019), Springer Singapore, 2020, pp 651-661. https://trid.trb.org/view/1975889

This paper studies the affecting factors on bird nesting on electronic railway catenary lines, and the impact of bird nesting events on railway operation. Firstly, with one year's bird nest events in form of unstructured natural language collected from Shanghai Railway Bureau, the records were structured with the help of Python software tool. Secondly, the method of root cause analysis (RCA) was used to identify all the possible influencing factors which are inclined to affect the probability of bird nesting. Thirdly, the possible factors then were fallen into two categories to meet subsequent analysis separately; category one was Outside Factors (i.e., geographical conditions-related factors), and the other was Inside Factors (i.e., railway-related factors). As to Outside Factors, such as temperature, vegetation coverage, population, longitude and latitude, nearby water, etc. by using some geographical APIs offered by Amap and the tools of ArcGIS, geographical data were processed in relation to nest events on the visual map and their correlationship was studied. It was observed that factors of city population, geographic position affect nesting observably. As to railway-related Inside Factors, statistic analysis method was used to disclose the significant influencing factors to bird nesting. Statistical result indicated that factors of season, rail location (station or section) and the specific equipment part of railway catenary lines had significant effects on nest events. Finally, it was demonstrated that both location and nesting on equipment part have no correlation with delay, while railway type had a significant but low correlation with delay. Two lognormal stochastic models were put forward which are

the best-fit models for delay caused by bird nesting events of both normal-speed and high-speed railway, which discloses the principle of impacts of nest events on railway operation.

Shin, Eun Gyeong; Ahlswede, Michael; Muenzberg, Christopher; Suh, In-Soo; Engel, Ferhat. Noise and Vibration Phenomena of On-Line Electric Vehicle®. SAE Technical Paper, 2011. https://trid.trb.org/view/1823537

It is a global research and development trend to introduce electric vehicle into the market in a prompt manner; however, there have been technological issues with batteries, or in general, an energy storage technology in moving vehicles. KAIST, a globally leading university majoring in science and technology in Korea, has been developing a break-through wireless power transfer technology by applying inductive power transfer technology, as demonstrated in a public park in March, 2010, which is referred to as "OLEV- On-line Electric Vehicle." With the technology, it is possible to drive the electric powertrain and charge its battery simultaneously while the vehicle is in operation on the road. In this paper, a couple of specific noise and vibration phenomena are introduced which have been observed during the development phase of the proto-type of test vehicle. This noise issue became noticeable because the customers' expectations on noise and vibration levels of the electric vehicles are much higher than those on conventional Diesel or CNG vehicles. In addition, the noises from other sources, such as power electronic components or auxiliary equipment, became more audible because these noises were masked by the IC-engine operation in conventional vehicles. There were two noise phenomena identified, 'high pitch whine' and 'back buzz.' In order to understand the root-causes of the noise and vibration, a series of test plans was prepared and performed applying the fundamental 'source-path-radiator' model. With the understanding on the issues, it was possible to develop a series of recommended actions, which was very helpful in developing noncontact charging vehicle, especially in deciding how to design and implement the noise path isolation from the motor room of the vehicle or from the power electronics compartments. Thus we present the noise and vibration phenomena, root-cause analysis and possible remedies of those two noises and vibration issues in this paper. For the high pitch whine, the reduction was noticeable by changing the switching frequency of the buck converter as identified from the test results.

Sikora, Marian; Goldasz, Janusz. Root cause analysis of rattle noise in twin-tube vehicle dampers. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, Volume 236, Issue 12, 2022, pp 2572-2581. https://trid.trb.org/view/2014770

The aim of this work is to provide an insight into the rattle noise phenomena occurring in double-tube (twin-tube) vehicle suspension dampers. In the dampers the particular phenomenon results from interactions between the valve(s) and the fluid passing through them. The rattling noise phenomena is known to degrade the vehicle passenger's perception of ride comfort as well as to influence the performance of the dampers at low and medium speeds in particular. In the paper the authors reveal the results of a DOE (Design of Experiment) study involving several design parameters known to affect rattling occurrence. By running a series of purpose-designed tests the authors investigate not only the contribution of each particular parameter but the interactions between them. The results are presented in the form of pareto charts, main effect plots as well as interaction plots. It is expected the outcome of the analysis will aid in a better comprehension of the phenomena as well the definition of valve configurations to minimize their performance degradation.

Sithick basha, Abubakker; Namani, Prasad; Sebastian, Ranjit George; Malekar, Amit; Vellandi, Vikraman. Experimental Investigation of Thermal Safety of the IC Engine in the Event of Coolant Loss. SAE Technical Paper, 2021. https://trid.trb.org/view/1889447

Power density (power/engine cubic capacity) of the latest passenger car Diesel and Gasoline engine keeps increasing with a focus to deliver best in class performance along with meeting CAFE and emission norms. This increase in power density increases the thermal load onto the coolant system. Coolant temperature sensor monitoring the coolant temperature, proper radiator sizing, optimum water pump flow capacity and thermostat tuned to the required coolant temperature range are the typical measures taken to ensure safe operation of the engine and avoid any over-heating. Typical cooling system failures are mostly due to low coolant level, a defective thermostat, non-operative water pump & fan and blockage in the coolant circuit, etc. Most of these failures can be detected with the help of a coolant temperature sensor and pre-emptive measures can be taken to avoid engine loss. However, in the event of complete loss of coolant in the engine, the coolant temperature sensor will become ineffective since there is no coolant in contact with the sensor probe. This paper presents an experiment that was conducted to see the effect of operating the IC engine without coolant. It is to be noted that the probability of a customer running a vehicle without having coolant at all is very less since he will be able to see overheating alarm in the cluster as soon as the coolant starts leaking. This experiment is conducted to assess the robustness of a system if it is run without coolant. There are several failures expected due to the running of an engine without coolant such as cylinder head gasket failure causing leakage of oil and gas, piston seizure, bearing seizure etc. It was noticed during the test that the coolant temperature sensor fails to detect the engine running in overheated condition and an eventual head gasket failure. The interesting part of this experiment is the consequential effects of this head gasket failure. Root cause analysis was performed to find the nature of the engine failure. Control measure to prevent catastrophic failure was designed and verified experimentally. Finally, a failsafe feature was suggested to prevent engine loss due to such failure.

Sivam, S P Sundar Singh; Saravanan, K; Loganathan, G B; Kumaran, D; Rajendrakumar, S. Root cause analysis for failure of door lock case assembly during caulking process. International Journal of Vehicle Structures and Systems, Volume 11, Issue 1, 2019. https://trid.trb.org/view/1645012

This paper details the failure analysis of deformed passenger car door lock case and presents a solution to avoid the part deformation during caulking process. This failure was observed during the assembly of case and its cover by caulking process. Mechanical properties and chemical composition of case (Zn Al4 material) has been checked by universal testing machine and spectra material analyser. The material composition having less aluminium content leads to the casting strength and cast ability losses. In order to get the exact load requirement for caulking process, analysis has been carried out by using finite element method. In finite element method, the case and its cover model has created by AUTODESK INVENTOR & stress analysis was carried using same software. The induced stress and deflection are obtained for various load conditions. The experimental measurement was taken from the machine by using load cells. By comparing the experimental data with FEM data the authors found that the problem happened due to the overload. From this result data the machine design was optimized by changing booster and cylinder which is used to generate the load. The hydro pneumatic circuit of the caulking machine has been optimized and redesigned to avoid future problems.

Sun, Yong; Xu, Zhentao; Zhang, Tianyu. On-Board Predictive Maintenance with Machine Learning. SAE Technical Paper, 2019. https://trid.trb.org/view/1598941

Field Issue (Malfunction) incidents are costly for the manufacturer's service department. Especially for commercial truck providers, downtime can be the biggest concern for our customers. To reduce warranty cost and improve customer confidence in our products, preventive maintenance provides the benefit of fixing the problem when it is small and reducing downtime of scheduled targeted service time. However, a normal telematics system has difficulty in capturing useful information even with pre-set triggers. Some malfunction issue takes weeks to find the root cause due to the difficulty of repeating the error in a different vehicle and engineers must analyze large amounts of data. In order to solve these challenges, a machine-learning-based predictive software/hardware system has been implemented. Multiple machine learning techniques, including CNN (Convolutional Neural Network), have been utilized in the proposed pipeline to: 1) decide when to record data. 2) decide what data to record. 3) root cause diagnostics on the spot based on time-series data analysis. A novel technique has been proposed to solve the lack of training data for the root cause analysis neural network. The root cause analysis will be further reviewed by engineers through an expert knowledge feedback system to guide the on-board AI. In this paper, the overall on-board preventive maintenance system will be introduced, and validation results will be shown.

Tanaka, Hiroyuki; Ihara, Hisashi; Satomura, Akira; Wada, Yasuhiko; Momii, Hideto; Suma, Tatsuya. Prediction and Analysis Technology Development for Impact Noise. SAE Technical Paper, 2014. https://trid.trb.org/view/1830183

In order to enhance product attraction, it is important to reduce the impact noise when a vehicle go over bumps such as bridge joints. Vehicle performance to transitional noise phenomena is not yet analyzed well. In this paper, a prediction method is established by vector composition and inverse Fourier transform with the combination of Multibody Dynamics (MBD) and FEM. Also, a root cause analysis method is established with the following three mechanism analysis methods; transfer path analysis, mode contribution analysis, and panel contribution analysis.

Taylor, Philip; Fraser, Gavin. Making Your Fleet Work -- Finding the Root Cause and Fixing It. 2008 American Public Transportation Association (APTA) Rail Conference, American Public Transportation Association, 2008, 10p. https://trid.trb.org/view/874574

This paper describes how many transit agencies are faced with highly visible issues that impact on service delivery and customer/stakeholder perception. The customer sees declining reliability and/or performance. Underlying the visible issues are often core issues of outdated management systems and workforce challenges. Agencies must address the areas under their control that can produce short term, visible improvements to support new/sustained funding and improve public perception. Getting the best possible performance from the vehicle fleet is often an easy way of improving the overall standard of service delivered to the customer. While many vehicle improvement programs focus on engineering reliability through overhauls, modifications, and changes in maintenance processes, experience shows that a successful improvement program will tackle both the technical and people issues. Only by addressing those issues surrounding leadership, behavior, values and knowledge can the foundations be laid for a sustainable improvement. Good data is the foundation for any improvement effort, but the quality of available data provides a challenge for every transit agency. One approach to addressing this is to use a Failure Review Group that includes representatives from Operations and Maintenance to ensure that an accurate account of every key event is recorded. Failure analysis tools utilize this data and help to drive to the root cause, enabling a prioritized action list to be developed. Actions can then

be implemented based on their relative cost and impact to performance. As poor performance can arise from a number of sources, the Failure Review Group must look for a diverse range of causes, including maintenance processes, poor fault finding, components, environmental factors and operator error or misunderstanding. Only by tackling all of these diverse causes of poor performance can real improvements be generated. However, to make the improvement happen, a strong governance regime which instills a culture of searching for improvement, with appropriate senior management support, is crucial. Such approaches have been effectively followed in the UK by private train operators where high levels of performance and cost effective maintenance are critical to their business survival. This paper outlines these approaches and places them into a context that can be equally effective in improving system performance on any transit system.

Thangapandian, Kasiraja; Rajkumar, Immanuel. An Empirical Approach Applied in Assessing the Software Product Quality through VPRS Analysis. SAE Technical Paper, 2015. https://trid.trb.org/view/1832062

In recent years the automotive industry is facing unprecedented influx of new technology advancements and ever-increasing consumer demands for media, entertainment and connectivity applications. This drives the automotive industry to deliver the products at a faster pace, thereby reducing time to market which results in issues from end users and dealers. Automotive industries are striving hard to keep pace with these radical changes with increase in software and electronics which in turn necessitates a systematic and effective software engineering approach to deliver high quality product from the core embedded software industry. This paper details how embedded software projects are developed globally and customer issues are collected and analyzed. It also discuss about the method used for performing effective Root cause analysis for identifying the systemic issues and formulating the systemic improvement actions. This paper will also guide you through the method implemented with Software Configuration Management (SCM) tool for a closed loop feedback mechanism for the systemic improvement actions to be inherited to all the projects and programs to meet the organizational objectives along with a process compliance approach to ensure that these actions were completely implemented and inherited.

Thawani, Prakash; Venkatappa, Suhas; Liu, Zhengyu. Automotive Refrigerant System Induced Evaporator Hoot. SAE Technical Paper, 2005. https://trid.trb.org/view/1804567

The automotive refrigerant systems can occasionally exhibit a transient hoot/whistle type noise under certain operating conditions. High pressure/velocity refrigerant flow through an evaporator core can readily excite the inherent acoustical and/or structural modes, resulting in audible transient tones. This condition if present can be experienced while driving away from a short stop and can last 2 to 10 seconds. The ambient conditions suitable for creating this noise are - moderate/high air-conditioning (A/C) load during days at 85-95° F temperatures with high humidity. Possible noise generating mechanisms have been discussed in earlier publications and our findings during this study indicate that they are excited by the high velocity superheated refrigerant vapor flow through the evaporator core plates. Examples of this transient noise and its spectral characteristics are presented to characterize this refrigerant system induced issue. This paper presents a systematic source identification study and root-cause analysis that ultimately led to an implementable design-fix for this hoot noise issue. Based on this study, an objective target was developed and cascaded.

Thiyagaraj, Anandan. Parasitic Battery Drain Problems and AUTOSAR Acceptance Testing. SAE International Journal of Passenger Cars - Electronic and Electrical Systems, Volume 11, Issue 2, 2018, pp 139-147. https://trid.trb.org/view/1560177

Battery Drain problems can occur in the vehicle due to improper network management between electronic control units (ECUs). Aim of this article is to identify the factors that cause transmission and cease of transmission of a network management message of an ECU along with its application messages that controls the sleep/wake-up performance of other ECUs in the network. Strategy used here is, based on the root cause analysis of problems found in Display unit in vehicle environment, the functional CAN signals impacting sleep/wake-up behavior is re-mapped along with the state flow transition of AUTOSAR NM Algorithm. A re-defined test case design and simulation for vehicle model is created. Especially it focuses on validating the impact of functional CAN signals on DUT's sleep/wake-up performance. The result includes, design and development of use case matrix (mapped with specification) to validate the impact of network management messages, its flow of transition as well as the impact of functional CAN messages on the sleep/wake-up behavior of DUT and on the system as a whole. Also a new set of system level defects identified across Audio and display units-based on the re-designed network management test procedure and simulation with Vector Canoe model (comprehensive software tool for development, test and analysis of entire ECU networks and individual ECUs.). This article provides relevant design guidelines for acceptance testing of any communicative network that follows AUTOSAR standard and this can be deployed across programs/products. It concludes validation of network management functionality (AUTOSAR) shall not be restricted only to the transmission of network management (NM) message of an ECU, as well as shall consider application messages that triggers NM messages of other ECUs in the network.

Titave, Uttam Vasant; Kalsule, Shrikant; Naidu, Sudhakara. A Design Approach to Optimize Suspension Clunking Noise in Passenger Vehicles. SAE Technical Paper, 2024. https://trid.trb.org/view/2334903

Designing a Passenger vehicles suspension system is a key challenge for all OEMs because balancing buzz, squeak, and rattle (BSR) acoustic performance at low-speed driving and improving ride quality at high-speed driving conditions are bet challenging. Suspension noise deteriorates in-cab acoustic quietness and overall vehicle performance. For this reason, optimizing these noises is becoming increasingly prioritized as a key design issue throughout the development process of suspension system. This paper studies the various components of suspension system and their noises in Passenger vehicles. Based on customer voice index and drive pattern, suspension anomalous Clunking noise was identified in Passenger vehicles. This noise phenomenon was cascaded from the vehicle level to BSR rig and eventually to the suspension rig for root cause analysis. At the vehicle level evaluation, Clunking noise problematic frequency identification was done for both near suspension source and in-cab with the help of a sound diagnosis analysis tool and time-domain wavelet transformation. Furthermore, this noise was cascaded at BSR rig level for subsystem frequency analysis and intensity quantification. Eventually, this noise was cascaded at the suspension rig level and the major component, and its critical frequency was identified by time-domain wavelet analysis tool. After this investigation, design modification was done on the suspected suspension component and significant noise improvement was found in overall noise level subjectively and objectively in the defined frequency range. This modified component with suspension system performance was assessed at BSR rig and vehicle level for Clunking noise improvement validation purposes. The output of this work was a reduction in overall Clunking noise in vehicle in-cab as well as a significant increase in overall acoustic performance of the

car without affecting ride and handling quality. In additional to that, this cascading methodology could be used to address various suspension noises.

Umbare, Deepak; Kadam, Rohit; Chandel, Abnish; Babel, Prashant. Investigation and Resolution of Vehicle Brake Judder. SAE Technical Paper, 2020. https://trid.trb.org/view/1745915

One of the major discomforts while driving any medium to heavy commercial vehicle is brake judder. Brake judder can be defined as vibrations felt on steering wheel or brake pedal or cabin floor, when brakes are applied at certain speeds and pressures. The frequencies of this judder lie as high as 100 Hz to as low as 20 Hz. The brake judder is caused by a number of factors, which makes providing a universal solution difficult. Some of the causes are related to part fitment, part quality, material selection, manufacturing process, Design consideration, environmental factors, etc. This paper gives us a brief idea about resolution of judder problem in intermediate commercial vehicle by series of trials and this methodology can be applied in heavy commercial vehicles also. This paper gives reader an insight about step by step root cause analysis of brake judder on actual vehicle and an approach in resolving the judder problem.

VARUN KUMAR, D; Sathish, PB; Vellandi, Vikraman; M, Sudhan; Vijayarangan, Deepak. Optimum Solution for Reduction of Clutch Pedal Vibration and Groan Noise Observed During Clutch Pedal Actuation. SAE Technical Paper, 2021. https://trid.trb.org/view/1889452

In emerging markets like India, manual transmission vehicles are still most preferred & contributes to 85% of passenger vehicle sales due to its cost benefit. However, customer expects good NVH behavior for comfortable driving experience in the vehicle to maneuver effortlessly in the highly congested traffic conditions in India. Clutch & its hydraulic release system in manual transmission of IC engines are the significant components which affects the NVH behavior & maneuverability of the vehicle and the driver comfort significantly. This paper focuses on the clutch pedal vibration & groan noise concern observed during clutch pedal actuation in high power density SUV vehicle developed for Indian market. The vehicle had highly efficient & light weight engine which has high engine axial vibrations. Axial vibrations are caused due to engine firing impulses & crankshaft bending causes flywheel axial movement. This movement in turn leads to vibrations in clutch cover diaphragm fingers which are transmitted to clutch pedal through hydraulic fluid pulsation via clutch release system which comprises of CSC, bleeder, clutch high pressure pipe & CMC. Engine vibrations which are transferred through clutch system to clutch pedal is felt on driver foot and causing discomfort during clutch pedal actuation/modulations while launching, creeping and for shifting of the gears in the vehicle. During pedal actuations at higher rpm for shifting gears, low frequency vibrations becomes high frequency and heard as groan noise inside the passenger cabin which results in uneasiness to driver and passengers. This paper describes the literature available, root cause analysis of the concern, effect of clutch disc, cover assembly, hydraulic release system design variables and the optimum solution which does not affect the other performance of the clutch function while reducing the clutch pedal vibration & groan noise concern through simulation & vehicle measurement results.

Veiseth, M; Olsson, N; Saetermo, I A F. Infrastructure's Influence on Rail Punctuality. Urban Transport XIII. Urban Transport and the Environment in the 21st Century, WIT Press, 2007, pp 481-490. https://trid.trb.org/view/840634

This paper focuses on the possibilities for root cause analysis of rail delays and estimation of effects of delay-causing incidents by linking infrastructure data and operational data. Such information could be used to prioritize improvement and maintenance activities and to quantify the effects of improvement measures. The authors have analyzed and compared data from two infrastructure databases and one punctuality database in Norway. Linking of data between the databases should theoretically and technically be possible but the analyses have shown that this is challenging. In order to make linking of information possible it is recommend that the railway industry develop a general code-system for all three databases that directly ties the information together.

Vikram, MR; Gehringer, Mark; Patil, Ramesh. Dual Degree of Freedom Vibration Damper (DDVD) for Driveline Noise and Vibration Issue Resolution. SAE Technical Paper, 2014. https://trid.trb.org/view/1832926

Powertrain and driveline systems interaction in rear wheel drive vehicle development has recently gained attention for the improvement of interior noise and vibration in emerging markets. The driveline is a significant path for engine-generated noise and vibration to reach the interior occupant interfaces, where it affects refinement perception. The interaction of powertrain excitation orders and driveline resonant responders covers a wide range of frequency and vehicle operating conditions. This interaction poses significant challenges during vehicle development. With recent increased demand for higher specific power from diesel engines, driveline refinement has become even more challenging, especially for rear wheel drive vehicles. Two driveline related refinement issues were observed during evaluation of a RWD vehicle. Root cause analysis determined that the first issue (lower rpm boom noise and vibration) was due to engine torsional excitation of the driveline. The second issue (higher overall noise at higher rpm) was due to a propeller shaft bending resonance. Separate solutions using known technology were available for the two issues; a Torsional Vibration Damper (TVD) for the torsional boom and an Internal Tuned Damper (ITD) for propeller shaft bending resonance. The challenge was to find a new single solution which could mitigate both issues without affecting current driveline architecture. A Dual DoF Vibration Damper (DDVD) was developed to solve the above mentioned driveline noise and vibration issues. The DDVD is designed and tuned to work as torsional vibration damper in the rotational direction and as linear vibration damper in the radial direction. The paper describes the design and tuning of the DDVD to reduce the two critical driveline induced noise and vibration issues. The problem description, root cause steps, and alternate solutions prior to DDVD development are also discussed.

Wei, Wei; Ghoreishi, S. Engine Cooling Fan Noise and Vibration Problem Caused by a Switching Power Supply. SAE Technical Paper, 2003. https://trid.trb.org/view/1797088

A 50 Hz Solid-State Relay (SSR) was used to provide pulse-width-modulated power to engine cooling fans for continuous speed control, to reduce airflow noise and improve efficiency. However, this caused the cooling fans to vibrate at the switching frequency and harmonics, thus degrading vehicle NVH performance. This paper describes the problem associated with SSR- powered cooling fans, including root-cause analysis, and identification of areas sensitive to vibration affected by the switching power supply. Based on our analysis, we found several solutions to the problem. Our production solution and some generic recommendations for shroud design are presented in the paper.

Wellmann, Thomas; Pruetz, Jeff; Ford, Alex; Govindswamy, Kiran; Tomazic, Dean. NVH Methodologies for Electrified Drive Unit Development. SAE Technical Paper, 2021. https://trid.trb.org/view/1877193

The automotive industry continues to develop new powertrain and vehicle technologies aimed at reducing overall vehicle-level fuel consumption. Specifically, the use of electrified propulsion systems, including electrified and electric drive units (EDU), is expected to play a significant role in helping OEMs meet fleet CO2 reduction targets for 2025 and beyond. The change to vehicles propelled by electrified powertrains leads to a reduction in vehicle noise levels. Despite the overall noise levels being low, the NVH behavior of such vehicles can be objectionable due to the presence of tonal noise coming from electric machines and geartrain components. In order to ensure customer acceptance of electrically propelled vehicles, it is imperative that these NVH challenges are understood and solved. Specifically, this paper discusses the EDU NVH development process. This includes considerations for CAE/test-based development and validation processes to ensure optimal NVH development. The CAE-based processes will include examples based on the use of advanced multi-body systems analyses coupled with finite element methods, addressing both electromagnetic as well as geartrain-related forcing functions. Further, the development of a novel electric drive sound level (EDSL) approach to test-based characterization of EDUs will be presented. Noise shares from the geartrain, broadband mechanical noise, primary electromagnetic forcing, and switching are extracted through novel transfer function calculations. The overall approach gives any EDU development team the ability to compare noise shares against scatterbands, conduct root cause analysis on specific noise issues, and predict sound levels at untested loads. Results from case studies are utilized to highlight the details of the developed methodology. Finally, aspects of EDU integration into the vehicle to assure refined vehicle-level NVH behavior will be discussed.

Williams P. Requalification of EMD d29/d31 traction motors in QR. CORE 2010, Conference on Railway Engineering, Wellington, New Zealand, 12-15 September, 2010, 2010, 10p. https://trid.trb.org/view/1300881

This paper presents a case study of the methodology undertaken by QR Limited to restore Electro Motive Diesel (EMD) D29 and D31 traction motors to their original OEM builds. QR operate a fleet of CL22C and CL26C narrow gauge EMD locomotives in 80 km/h heavy haul coal, and 100 km/h long haul freight environments. Prior to the year 2000, the freight fleet operated at 80 km/h, and the coal fleet operated at 60 km/h. When the operational speeds were increased in 2000, the flashover rate of the motors increased as well. Root cause analysis of the failure modes indicated that the build of the machines could not operate with the increased power and speeds for sustained periods. The failure rate of the traction motors after the speed increases were approximately 4.5 & 5.5 failures per 100,000 km. After the rebuild program this rate decreased to about 1.

Winter, Darren; Ashton-Rickardt, Paul; Ward, Carwyn; Gibbons, Paul; Mcmahon, Chris; Potter, Kevin. An Enhanced Risk Reduction Methodology for Complex Problem Resolution in High Value, Low Volume Manufacturing Scenarios. SAE International Journal of Materials and Manufacturing, Volume 9, Issue 1, 2015, pp 49-64. https://trid.trb.org/view/1779291

This paper reports on a methodology for risk reduction, developed and tested at a brand new aerospace manufacturing facility, producing high value aero-structures. The facility was formed as part of a 'Risk Sharing Partnership' between Airbus and GKN for production of the Airbus A350 'Fixed Trailing Edge' (FTE). Whilst operating in New Product Introduction (NPI), the challenge for GKN was to increase production volume for each successive year of operations. At the time of writing, the facility was producing FTE structures at a rate of 4 per month i.e. Rate 4, and attempting to transition to Rate 6. The ultimate aim was to produce FTE structures at Rate 13 within an 8 year period whilst concurrently

engineering the product and improving its processes. For schedule adherence, elimination of process failures was critical and often manifested at the final stage of assembly (integration cell). The 'integration cell' comprised of turnkey solutions where, on attempting to increase to scheduled rate, failures increased impacting on cycle times. Most failure types encountered were considered complex, since their permutations were often unknown i.e. caused through varying interactions between hardware, software and staff. To explore the problem further, a conventional Failure Mode and Effects Analysis (FMEA) was conducted but proved subjective, since the standard template was restricted to ordinal and qualitative outputs. A process FMEA (PFMEA) was then developed to account for the risks posed through safety, quality, cost, delivery and people (SQCDP). Utilising SQCDP criteria enabled a means of quantitative analysis for capturing optimal RPN values. Further, whilst the enhanced PFMEA proved effective, the method was limited for in-depth determination of root cause, apparent from the permutations of failure observed. The literature provided options, where the properties of Fault Tree Analysis (FTA) were deemed most suitable for identifying critical path, common cause and probability of failure on demand. Combining enhanced PFMEA with FTA provided a holistic means for quantitative risk prioritisation, plus in-depth determination of root cause when faced with complexity. From the root cause analysis, a set of functional requirements were derived that detailed how the solution would perform in practice. The methodology was then effectively completed once the solution had been implemented, validated and verified delivering improved Value Stream performance over the life cycle of the aircraft programme. Two cases are provided where the outputs have delivered marked reductions in process cycle time and predictability.