Tesla Motors Quality Engineering Application and Implementation

by: Nick Kwan

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California Polytechnic State University, San Luis Obispo

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Checked by: ________________ Approved by:_____________

Table of Contents

Abstract

Tesla Motors, in Winter 2013 during the author's co-op, had a variety of potential improvement areas regarding their quality engineering team. There were too many overall defects on the vehicles. Those defects were recognized as the cars were passing through inspection, coming off the line, as well as brought by customers to after-purchase service. One of the defects was the Charge-port Door Malfunction, in which the door of the Model S would not open on command. An additional defect was the Windshield Wiper Malfunction, in which the fluid was not hitting the car at the desired angle. Both of these defects at the time were two of the top 5 defects with respect to "End Of Line" repair, which is an inspection and repair area at the end of the production line, as well as with customers bringing their cars in. In addition, the process in which the quality engineering team went about their decision making in terms of which defects they decided to work on with limited resources was also improved. This report includes the problem statement broken down into specific quality defects that were reduced, the steps taken to detect the issue, the changes proposed both short and long term, the design of experiment to test if the defect condition improved, as well as the results. With regards to research, there is an in-depth literature review and a section on environmental impact.

Introduction

This senior project is a series of Quality Engineering activities completed at Tesla Motors in Fremont, CA. The majority of tasks were completed during a co-op in Winter 2013 and the rest during Spring quarter of 2015.

As of January 2013, Tesla was aiming to report its first profitable quarter in company history. But, a higher than desired amount of cars were getting brought to service from customers from a variety of defects. The two defects addressed in this project were the Charge-port door and the Windshield Wiper malfunction. There were .13 Charge-port door Defects per Vehicle, or 13 defects for every 100 cars. These were defects found before the car got to the customer. This was also the second most common reason why customers brought their cars into service for that financial quarter. With windshield wipers, 2 out of every 100 cars had the defect in house and it was the fourth most common reason customers brought their cars in.

Tesla was searching for many cost-saving, throughput increasing, and quality improvement solutions. The specific methods used were to find the reasons why the defects were so high and eliminate the reasons for special cause variation. In addition this project created a better way for the quality engineering team to decide on what defects to work on.

This project used quality engineering techniques such as the 5 Why's and FMEA to produce the deliverables of a change proposal for the short and long term.

This report presents a few defect step by step process flows up until elimination of "special cause variation" and a new quality defect reprioritization strategy. Tesla took and implemented various proposed changes, and many were onto the line within days.

Also included is a literature review, environmental impact, methodology, methods used to test, and the results of the projects.

Literature Review

Tesla Motors, in its first few quarters of mass production of the Model S had a very high number of defects. However, some of the defects were due to a misalignment of customer expectations and could have been reduced (which will be explained), especially the defects in which the customer brought their car back. In researching how to determine the true customer wants of a product, even if it is as simple as a windshield wiper, Quality Function Deployment could have been implemented.

The concept of quality function deployment was developed in the 1960s in Japan. During World War II statistical quality control was introduced, which had roots in the Japanese manufacturing industry. Notable scholars emphasized their importance, which lead to total quality control and total quality management. Taking these concepts at their foundation Professors Shigeru Mizuno and Yoji Akao developed the idea of "Hin-shitsu Ki-no Ten-kai". This translated into English quite literally means "Quality Function

Deployment", "QFD." The purpose behind the missions of Professors Shigeru Mizuno and Yoji Akao was to ensure customer satisfaction for a product before it was manufactured.

Eventually QFD became the comprehensive quality design system for product and business processes. In 1983 QFD was introduced to America and Europe. The American Society for Quality Control published Akao's work and invited him to give a seminar in Chicago. Because of its flexibility and comprehensiveness the methodology was embraced by business which faced at the time faced heavy Japanese competition. Today QFD is used on a large scale to transform customer needs into engineering characteristics for a product or service. Although Japan has embraced QFD to a further extent than in the United States there is much to benefit and learn from the various and substantial and successful applications of QFD.

QFD is typically done before a product is launched to capture the voice of the customer and implement their desires into product design. This mindset was used in the development of the quality prioritization strategy.

In normal QFD, there are multiple steps which include Product Planning, Concept Selection and Product Design, and Process Design.

What makes this process rather unique is that customer needs are already taken into consideration while developing the product rather than after introduction to the market. QFD forces the development team to consider and come to agreement upon every aspect of a product, from product creation to product and process controls and improvement. The QFD process outlines the steps necessary for a team to create a product that is valued by its target

customers. The producers must hone in on what the customer requirements, and consequently, the product design requirements, are. This ultimately results in a more efficient process that produces a product that is more likely to meet or exceed the customer's expectations. Additionally, valuable time and resources are not needlessly wasted producing a product that doesn't listen to the voice of the consumer. In order to maximize both quality and customer satisfaction developers must work through four main phases: product planning, assembly and part deployment, process planning, and process/quality control.

Customers will not pay for something that they do not need or want. While this should be obvious, too many product developers spend both time and money creating new products that fail in the marketplace because of a lack of customer satisfaction. When developing a quality product, the first and most important activity is to "define and prioritize customer needs." This can only be achieved by effectively communicating with potential buyers. The product developers will use the customer input in outlining the key functionalities of their new product. The team must agree upon the requirements for each stage of production, including the tools, parts, and labor required to successfully complete at each step. After deciding on what the product is, the manufacturing process must be developed. Finally, the development team must agree on control methods that will ensure the product is made within the accepted specifications.

After identifying the customer's unstated and stated needs, an engineer may now construct the product planning matrix, which is commonly referred to as a "House of Quality matrix", or "HOC matrix". The purpose of this matrix is to organize information while

translating the needs of the customer into the product's technical requirements. Converting the customer's needs into tangible specifications for a product is not an easy task and requires a great deal of insight into both the customer and what is possible to achieve in reality with restrictions to consider such as finances and equipment. Therefore, those creating the HOC matrix should be knowledgeable about the company's operation, and what resources and capabilities the company is equipped with to meet these expectations.

Customer requirements are located on the left side of the matrix, and each requirement is rated on a scale from 1 to 5 on the customer's priority, with 1 representing the lowest and 5 representing the highest. This ranking method combined with a competitive evaluation, which compares the company's product to those of its competitors, helps to identify key areas of focus. You may think of the customer requirements as the "what" components and the design requirements are the "how" that makes meeting these requests possible, allowing the product to be more competitive. Figure 1 displays an example of a House of Quality Matrix for a Mercedes sedan. For this specific car, we imagine the consumer's needs and desires. It seems likely that families and businessmen and women are potential consumers; we can imagine that they will be willing to pay more than the cost of the average sedan, and expect style, comfort, and most importantly (especially with families), safety in return. Notice that the interactions are located at the top of our matrix, while the relationships are shown in the body of the matrix.

For any company to be truly successful in meeting and exceeding the expectations of their customers the company must learn and continually improve their product. Also the

company must compare their product to that of their competitors, and utilize this information to remain competitive. This can be accomplished through the use of feedback obtained through common survey methods such as focus groups and meetings. This can be helpful in identifying the strengths and weaknesses of your own product, as well as the strengths and weaknesses of the competitor's. Establishing this can reveal what areas should be prioritized in order to become more competitive. Also, it is important that, based on customer requirements and feedback, technical characteristics be noted. In order to allow for designer's creative freedom, these characteristics should be general and refrain from imposing excessive limitations.

Next, it is important to work to improve the relationship between customer requirements and product requirements. Three different symbols should be used to denote the strength of each relationship being represented in your HOC matrix. These symbols should assist you in determining whether you have met the customer's needs. It is important to then generate a list of both prior generation, or past, products, and those that are currently competition. Obtaining competitor products will allow you to perform benchmarking. Additional factors such as the length of a warranty, frequency of service repairs needed, cost of repairs, and the lifespan of the product are important to consider. Realistic target values for product requirements should be set and aimed for in the future. Once these steps are completed, identify possible positive and negative interactions occurring between product requirements by using symbols to indicate strong or mild positive, and strong or mild negative

relationships. Therefore, there should be four symbols that measure both the strength and sign of the relationships.

It is important to be very careful about having too many positive relationships, because it is possible you may be overrepresenting some relationships. Shift your efforts to the negative interactions and consider the advantages and disadvantages of each, as well as how these areas may be improved upon by, for example, improving technology. The next step is to apply a weighting factor to the relationship symbols. Afterwards these factors will be multiplied with the specific customer importance rating. The products are summed up in each column. Difficulty ratings need to be developed for each product requirement or technical qualification. Business, technical, personnel and other aspects should be considered. Too many risk items should be avoided since they will be likely to delay the development and exceed budgets. If a difficult item can be accomplished within the project, it needs to be assessed.

The last step of the process of product planning using QFD is to analyze the final matrix. The further actions need to be determined as well as the target values finalized. Also further QFD items need to be deployed. Less significant items may be ignored with the subsequent QFD matrices. The product planning matrix needs to be maintained as customer requirements or condition might change in the future.

While the product planning matrix is being maintained, concepts can be developed. The difficulty in turning a plan into a concept is that there are many different ways to get the same job done. QFD aids in the selection of the right alternative in the concept selection and

product design phase. In this phase, the development team analyzes which alternatives will have the greatest value with their target customers. Using a concept selection matrix, the team is able to weigh the benefits and limits of a resource while also considering how important each criteria is to the customer. Once this is done, a product concept diagram is created. This diagram allows the team to break up the production process into its most important subsystems.

Finally, a deployment matrix is developed. This matrix shows the relationships between the product design requirements and the critical part characteristics. In our example, we compared three types of auto body material (steel, aluminum, and carbon fiber) to best fit customer requirements listed in the HOC matrix above.

Process Design is a very integral part of the QFD Process and continues along directly after the Concept Selection and Product Design phase. That previous phase allows a team to quantitatively choose a concept and analyze the most important criteria of a product. In this Process Design phase, the Process Planning Matrix is one of the two important tools used. In the Process Planning Matrix, there are two main sections, the Critical Process Steps, and Critical Part Characteristics, which each have a specific "Priority," from 1 to 10. In terms of the matrix data, each has a quantitative relationship, from numbers 1 to 30. If a number is between 1 and 9, it is not included. If a value is between 10 and 19, it can be denoted with a "O," and a value in between 20 and 30, Θ.

The last column, part control parameters were the qualitative characteristics that bound each Critical Process Step with the Critical Part Characteristic. For example, size and

length of finished good are the two most important parameters. Other critical Process Steps were Cutting, Forging, Welding, Paint, and Installation.

Another matrix used in the Process Design phase is the Process/Quality Control Matrix. In this figure, the Critical Process Steps and Process Control Parameters from the Process Planning Matrix are used, but with Control Points, Control Methods, as well as Sample Size & Freq and Check Method. The result of these two matrices is that Manufacturing can concentrate on the most important and impactful procedures, dimensions, and characteristics, resulting in a more high quality product quantitatively.

QFD is a particularly large and complex system. Many companies have faced problems using this concept. There are three major groups of problems which occurred. There are methodological, organizational and problems concerning the product policy. One of the problems is the size of matrixes. If all relational matrices are combined into one, the size of this one would be very large. Furthermore it takes a long time to develop a QFD chart fully. Modern companies need to be agile and react quick on market changes.

Occasionally the time for a well developed QFD chart is available, and can be extremely advantageous in discovering or creating an edge over the competition. The mind of customers can change over a short period of time. You may even be serving multiple customers with different wants and needs. For example, a product for children must be appealing to both child and parent, likely for different reasons since both customers have

different expectations and desires . Even when the company is aware of customer needs, it is not easy to categorize their demands or connect them to technical properties.

QFD is not suitable for every single application. For a product of limited complexity and a small supplier base, the effort required to complete a thorough QFD analysis might be too big of an effort. Also some organizations tend to not extend the use of QFD beyond the product planning stage which does not justify the amount of work it needed to set it up.

While the QFD process can be difficult to implement, it has benefits that cannot be ignored. Using QFD, a development team is able to more accurately judge how well a product will be received by their customers, as they have received customer input throughout the process. Additionally, each stage of the process is agreed upon before the project begins, resulting in less conflicts down the line. These benefits could be enough to make this potentially difficult and time consuming process worthwhile.

Design

There are three main portions of the Design and Methodology of this senior project:

1. Vehicle Quality Priority Reorganization
2. Charge-port Door Defect Reduction
3. Windshield Wiper Defect Reduction

Design I: Vehicle Quality Priority Reorganization

There were multiple issues with Model S quality:

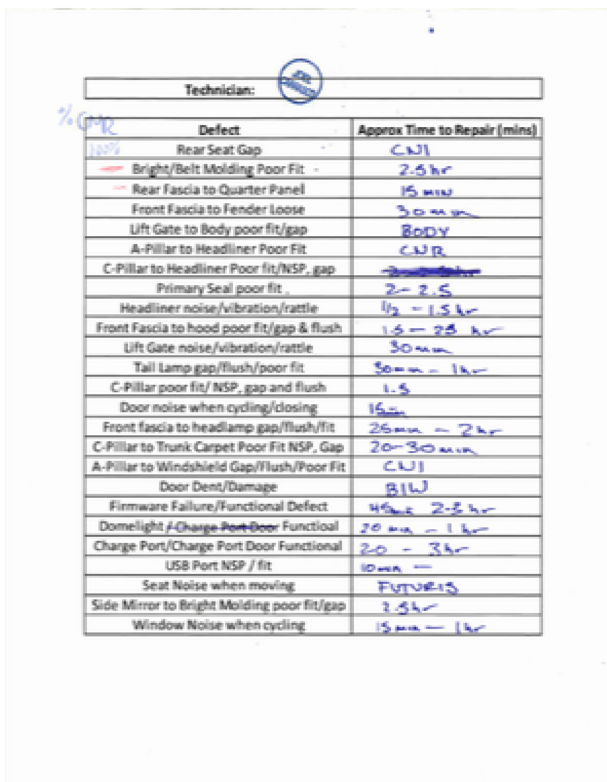
- High number of manufacturing production defects.
- Varying degree of seriousness of defect.
- Misaligned priority of defects (team of engineers were working on minimizing gaps between seats when charge-port doors were being stuck).
- Customers were bringing their cars into service for various defects, and those issues were not taken into account at all on the production end.

The current process of deciding which defects to eliminate were just based on overall defect count on production. The solution that was proposed, which was implemented in less than a week, was to create an algorithm that prioritized defects based on multiple factors. Those factors included:

1. Production defect cost
    a. Quantity of particular defect in production
    b. Time to complete particular repair * Hourly wage of technician
2. Service defect cost
    a. Quantity of particular defect in service
    b. Time to complete particular repair * Hourly wage of technician

3. Management weight (VP of Quality would give weekly ranking between 1-10 on his urgency to eliminate the defect. For example Elon was a huge proponent of eliminating a front hood gap, which led our VP to rate this very high.

While the formula was not too difficult to create, there did require a large amount of data collection. There was no data on how long repair times in service took, so different technicians, as well as the technician manager, were asked to report how long the repair took because many of the technicians used different tactics. The “EOL Repair Time” was influenced by 6 repair technicians, Victor Vacca of body shop, and EOL Supervisor, Anthony Wells. See Figure 1 for an example of a form that was handed out to technicians.



Technician:

Defect	Approx Time to Repair (mins)
Rear Seat Gap	CWI
Bright/Belt Molding Poor Fit	2.5 hr
Rear Fascia to Quarter Panel	15 min
Front Fascia to Fender Loose	30 min
Lift Gate to Body poor fit/gap	BODY
A-Pillar to Headliner Poor Fit	CWR
C-Pillar to Headliner Poor fit/NSP, gap	[illegible]
Primary Seal poor fit	2 - 2.5
Headliner noise/vibration/rattle	1/2 - 1.5 hr
Front Fascia to hood poor fit/gap & flush	1.5 - 2.5 hr
Lift Gate noise/vibration/rattle	30 min
Tail Lamp gap/flush/poor fit	30 min - 1 hr
C-Pillar poor fit/ NSP, gap and flush	1.5
Door noise when cycling/closing	15 m
Front fascia to headlamp gap/flush/fit	25 min - 2 hr
C-Pillar to Trunk Carpet Poor Fit NSP, Gap	20-30 min
A-Pillar to Windshield Gap/Flush/Poor Fit	CWI
Door Dent/Damage	BIW
Firmware Failure/Functional Defect	45 min 2-3 hr
Domelight ~~/ Charge Port Door~~ Functional	20 min - 1 hr
Charge Port/Charge Port Door Functional	20 - 3 hr
USB Port NSP / fit	10 min —
Seat Noise when moving	FUTURIS
Side Mirror to Bright Molding poor fit/gap	2.5 hr
Window Noise when cycling	15 min — 1 hr

Figure 1: EOL Repair Defect Time Log

In addition, as certain items were not repairable, a replace percentage which would be considered, creating the final production repair table. The averaged times of the repairs can be seen in Figure 2.

Defect Type	% Replace	Replace Time (hr)	% Repair	Repair Time (hr)	Downtime	Average Time (hands on)
Rear Seat Gap						0
Bright/Belt Molding Poor Fit	80.00%	2	20.00%	0.25		1.65
Rear Fascia to Quarter Panel	50.00%	1	50.00%	0.5		0.75
Front Fascia to Fender Loose			100.00%	0.25		0.25
Lift Gate to Body poor fit/gap			100.00%	1.5	12-Jun	1.5
A-Pillar to Headliner Poor Fit	15.00%	0.5				0.075
C-Pillar to Headliner Poor fit/NSP, gap			100.00%	0.25		0.25
Primary Seal poor fit	5.00%	2	95.00%	0.25		0.3375
Headliner noise/vibration/rattle	25.00%	4	75.00%	1.5		2.125
Front Fascia to hood poor fit/gap & flush	10.00%	1	90.00%	0.75		0.775
Lift Gate noise/vibration/rattle			100.00%	1		1
Tail Lamp gap/flush/poor fit			100.00%	0.5		0.5
C-Pillar poor fit/ NSP, gap and flush	50.00%	1.25	50.00%	1.25		1.25
Door noise when cycling/closing			100.00%	1		1
Front fascia to headlamp gap/flush/fit	75.00%	1	25.00%	1.25		1.0625
C-Pillar to Trunk Carpet Poor Fit NSP, Gap			100.00%	0.5		0.5
A-Pillar to Windshield Gap/Flush/Poor Fit	CNI					
Door Dent/Damage	?					
Firmware Failure/Functional Defect	?					
Domelight / Charge Port Door Functioal	100.00%	0.75				0.75
Charge Port/ Charge Port Door Functional	80.00%	1				0.8
USB Port NSP / fit	100.00%	1.25				1.25
Seat Noise when moving	5.00%	1				0.05
Side Mirror to Bright Molding poor fit/gap	100.00%	2.5			4	2.5
Window Noise when cycling			60.00%	1.5		0.9

Figure 2: Final EOL Repair Log (all times in hours)

As repair is technically the only thing keeping a car from being shipped to the customer, this is the bottleneck station, as many cars spend much more than 10 minutes, the official Model S cycle time, in repair.

After including in the production defect costs, the process of recording the defect entails to the other side of the factory, finding who maintained all the service records, linking up their databases to automatically update into the production excel sheets, pulling in a lot of

the correct columns via VLookups. See Figure 3 for a Service Sample for the brake noise defect.

	Tech Name	Compl Description	Correction Narrative	Store	Missing Co	P&L Burden	Labor Cost	Estimated (
2	Aaron Smith	Exterior Noise Or Vibration	Advise Customer To Use Brakes For Stopping Rather Than Regen Periodically To Clean Surface Rust Off Of Rotors	Dania Beac	no	46.2	46.2	
3	Anthony Medina	Tesla Maintenance / Scheduled Service	Perform Brake Inspection, Brakes Are Performing Fine, Brake Pad Dust Is Causing Noise.	Los Angele:	no	0	0	
4	Anthony Medina	Tesla Maintenance / Scheduled Service	Performed Brake Inspection, Brakes Are Fine Customer Advised That Noise Caused B By Brake Pads.	Los Angele:	no	0.01	0	
5	Anthony Medina	Tesla Maintenance / Scheduled Service	Performed Brake Inspection, Brakes Are Fine Customer Advised That Noise Caused B By Brake Pads.	Los Angele:	no	0	0	
6	Anthony Medina	Exterior Noise Or Vibration	Performed Brake Inspection, Brake Pads Are Fine Noise Caused By Brake Pads At End Of Stop.	Los Angele:	no	0	0	
7	Anthony Medina	Tesla Maintenance / Scheduled Service	Test Drove Vehicle To Seat Brake Pads	Los Angele:	no	46.2	46.2	
8	Bruce Bird	Exterior Noise Or Vibration	Test Drove Car And Brakes Are Functioning Normaly. No Brake Noise Was Heard.	Menlo Park	no	46.2	46.2	
9	Bruce Bird	Poor Brake Performance	Test Drove Car For Ten Miles And Could Not Duplica Te Problem. Engineers Noted Record In Logs Of Brak E And Accelerator Signal	Menlo Park	no	46.2	46.2	
10	Casey Van Gundy	Poor Brake Performance	Replaced Parking Brake Control Module, And Performed Firmware Update. Fault Did Not Occur While With Service, Modul	Denver	no	83.57	0	
11	Casey Van Gundy	Poor Brake Performance	Replaced Parking Brake Control Module, And Performed Firmware Update. Fault Did Not Occur While With Service, Modul	Denver	no	46.2	46.2	
12	Christian Hernandez	Exterior Noise Or Vibration	Sand The Pads Down Front And Rear	Queens	no	46.2	46.2	
13	Christian Hernandez	Touchscreen Fault / Warning Lamp	Replace Parking Brake Control Module	Queens	no	46.2	46.2	
14	Christopher Bade	Exterior Noise Or Vibration	Road Tested Vehicle For Brake Noise. Found Noises Characteristic Of Vehicle.	Menlo Park	yes	18.48	18.48	1
15	Cole Fisher	Exterior Noise Or Vibration	Braking System Is Functioning Properly. Brake Pads Glazed Causing Noise.	Fremont	no	25.41	25.41	2
16	Cole Fisher	Exterior Noise Or Vibration	Removed Brake Pads To Remove Glaze Surface, Also Removed Glaze Surface From Rotors, Cleaned Pad Contact Surface.	Fremont	no	25.41	25.41	2
17	Cole Fisher	Exterior Noise Or Vibration		Fremont	no	27.72	27.72	2
18	Danny Melville	Exterior Noise Or Vibration	Duplicated Concern. Took Vehicle Out And Performe D Multiple Near Abs Stops To Remove Glazing From T He Brake Rotors. No N	Seattle	no	46.2	46.2	
19	Danny Melville	Tesla Maintenance / Scheduled Service	Heated Brakes Through Low-regen Braking. This Action Significantly Corrected The Noise Experience By The Client	Seattle	no	46.2	46.2	
20	Dave Schoephoerster	Exterior Noise Or Vibration	I Road Tested The Vehicle. I Verified The Noise It Is Considered Norma At This Time And Should Improve As The Brakes Wear I	Menlo Park	no	32.34	32.34	3
21	Jack Batson	Tesla Maintenance / Scheduled Service	Test Drove, Heard Noise Once. Instected Brakes Ok	Chicago	no	46.2	46.2	
22	Jack Batson	Tesla Maintenance / Scheduled Service	Test Drove And Inspected Rear Brakes, Ok At This Time.	Chicago	no	46.2	46.2	
23	Jason Bermudez	Exterior Noise Or Vibration	Glazed Pads And Rotors & Chamfered Brakes To Reduce Brake Noise. Some Noise May Occur With High Performance Brake:	Costa Mesa	no	41.58	41.58	4
24	Javier Ramirez	Exterior Noise Or Vibration	Performed Brake Inspection And Test Drove Vehicle To Seat Brake Pads To Reduce Noise	Los Angele:	no	0	0	
25	Javier Ramirez	Exterior Noise Or Vibration	Performed Brake Inspection, Front And Rear Brakes Check Fine Noise Caused By Brake Dust.	Los Angele:	no	0	0	
26	Javier Ramirez	Tesla Maintenance / Scheduled Service	Performed Gateway Reset. Fault Is Related To Firmware.	Los Angele:	no	46.2	46.2	
27	John Gardelius	Exterior Noise Or Vibration	Inspect For Brake Noise At Low Speeds. Brake Pads Are In Good Condition. This Is A Normal Brake Glaze Noise At This Ti	Menlo Park	no	18.48	18.48	1
28	John Gardelius	Interior Noise Or Vibration	Inspect For Brake Noise From Abs Unit. Makes A Thump Noise When Abs Pump Turns Off. Loosen Bracket And Reposition P	Menlo Park	no	18.48	18.48	1
29	Jorge Velasco	Exterior Noise Or Vibration	Performed Test Drive To Help Seat In Brakes To Try And Help Quite Brake Noise.	Los Angele:	no	46.2	46.2	
30	Jorge Velasco	Poor Brake Performance	Performed Brake Inspection And Test Drive. Brake Pads Are Fine And During Test Drive Found Brake Perform Fine And N	Los Angele:	no	0	0	
31	June Valenton	Exterior Noise Or Vibration	Glazed Pad & Rotors & Chamfered Brakes To Reduce Brake Noise Slight Noise May Occur With Performace Brakes	Costa Mesa	no	41.58	41.58	4
32	Kasey Carll	Exterior Noise Or Vibration	Checked Function Of The Brakes. Located The Noise. Cleaned And Performed Rotor/brake Pad Treatment A Nd Performed Anoth	Dania Beac	no	30.03	30.03	3
33	Kyle Armstrong	Exterior Noise Or Vibration	Re-seated Brake Pads, No Brake Squeak At This Time	Fremont	no	25.41	25.41	2
34	Lawrence Schmidt	Exterior Noise Or Vibration	Inspected As Per Vehicle Concern #4629	Chicago	no	43.89	43.89	4
35	Mat Boarman	Tesla Maintenance / Scheduled Service	Test Drove, And Noticed No Noise At This Time May Be Due To Condensation On The Rotors From The Mornings	Washingto	no	0	0	
36	Mike Panici	Poor Brake Performance	No Corrective Action Needed Normal Operation	Chicago	no	46.2	46.2	
37	Pete Cappelli	Tesla Maintenance / Scheduled Service	Inspected And Found Small Metal Piece Between Backing Plate And Rotor. Removed Peiece, No More Noise Present	Washingto	no	0	0	
38	Smith Sipaseuth	Exterior Noise Or Vibration	Customer Rescheduled Appointment For 11/27th To Address Brake Noise.	Costa Mesa	no	0	0	
39	Teddy Artonian	Tesla Maintenance / Scheduled Service	Pereformed Brake Inspection, All Brakes Are Good, Performed Test Drive To Seat Brakes In Customer To Report Back On H	Los Angele:	no	46.2	46.2	
40	Teddy Artonian	Exterior Noise Or Vibration	Performed Test Drive To Seat In Brake Pads To Try And Reduce Brake Noise.	Los Angele:	no	0	0	

Figure 3: Brake Noise Service Log

Finally, the data was presented in an efficient manner. Figure 4 has a portion of a data table used by the executive team to prioritize defects.

Issue Description	EOL Repair Time	Service Count	GA Dpv	Defect Count (Wk 11)	EOL Weekly Avg Repair Time (hrs)
Hood Assembly - Poor Alignment/Gap/Flush	0.8	5	0.38	206	154.5
Door - Charger Port - False Open	1.0	6	0.13	69	69.4
Panoramic Roof Creak Adjustments	1.8	22	0.06	31	55.1
Wheel Alignment - Drift to Right	0.9	4	0.07	36	31.2
Panoramic Roof - Failure	1.5	4	0.02	13	19.9
Lift Gate overflush to Roof	1.5	5	0.02	9	13.5
Front Door Fixed Glass - Wind Noise	0.5	15	0.04	22	11.2
P/S DR - Hard to Close [Latch - Door - Front - RH - Adjustment]	0.5	5	0.04	22	11.2
Seal - Opening - Panoramic Roof	1.5	6	0.00	2	3.6
Nozzle - Windshield Washer Jet - Aimed Too Low	0.3	5	0.02	12	3.0
Headlight - Adjust	0.8	2	0.00	1	1.0
Seat Belt Assmembly - 2nd Row	0.3	3	0.00	1	0.3
Wheel Balance	0.2	4		0	0.0

Figure 4: Excerpt of Executive EOL and Service Defect Spreadsheet

Design II: Process to reduce Charge-port Door Malfunction defect

After recognizing that the charge port door was a very common defect in production as well as out in the field where customers were bringing their cars in, it was decided to attempt to eliminate the special cause variation of the defect.

The first step in eliminating special causes is finding out what are the failure modes. The author was able to go through our quality reports, do some Excel pivot table work, and find out which cars had been marked with the defect but were not already fixed in repair. Once it was identified which cars had the defect, the next process was examining the failure.

In this case, the charge port door was hitting the inner headlamp. From examining multiple cars, it was determined that there had to be a minimum gap value in order for the door to clear. See Figure 5 for an in-depth view on how this was measured.

Figure 5: Points of Measurement for Charge-port Door Defect

Once identifying the issue, the next step is to eliminate the problem and come up with a fix. In this case, because the route cause could have been either Man (operator was performing the assembly task wrong), Material (supplier of the light was providing faulty goods), Machine (the tools to assemble were not of good quality), or Method (process in which the operator was working was not standardized), a temporary countermeasure needed to be instated that would stop the defects from occurring as soon as possible.

Since the defect was already being fixed by End Of Line Repair, the technicians who would repair all defects before sending out to the customer, as well as the customer-interfacing technicians in Service, they were interviewed. In both cases, the repair method was to remove the taillight, and insert a few washers onto the screw to give some extra spacing in between the light and body of the car (bottom right of below of Figure 6).

Figure 6: Placement of Rubber Washer

To fix this, a step was added to the tail-light assembly point, where there was a bit of extra capacity. Additional rubber washers were added. A detailed process of testing and implementation will take place in the Methods II section.

Design III: Process to Eliminate Windshield Wiper Malfunction Defect

In a similar fashion, another of the top 5 customer defects (customers bringing their car into service) was windshield wiper malfunction. From checking the customer complaints over at service, it seemed to be that customers were complaining that the windshield wiper fluid was being shot over the cars and not hitting the actual windshield, or it it was hitting, the very top of the glass.

The first step was to analyze the cars that were being brought back. Interestingly, when checking the manufacturing in-house defect reports, there were little to no defects on the actual line. It was possible that the defects were occurring over time, perhaps, or some deformation of the actual wiper.

The next standard step was to check out what was coming out on the line and where it was being tested. We found out that the wipers were being tested at the last 10% of the manufacturing cycle of the car, and that they were tested while the car was actually driving on the track. The cars were put through a test drive and found that during a second test the liquid was going above the car and not hitting the glass perfectly. It seemed that the car had to be in motion for the wipers to be sprayed correctly.

From taking data and running capability studies, it was found that there was variation though, and different cars had different sprays. It was very easy to modify the spray angle, on purpose, or on accident which most likely led to some customers bringing their cars in.

In fact, it was possible to modify the wiper blade by only a few millimeters using a needle afterthe wiper hit the windshield while the car was at rest and on the move.

However, the modifying the angle with a needle was very difficult to measure exactly, and was done with trial and error. After taking a closer look, it was found that another way to guarantee that the spray hit lower enough on the windshield was to make the actual blade lower. It was tested to see if the distance actually played a significant part, and found that any blades that were under 23mm from the bottom of the blade to the windshield would cause the stream to be deflected and not fully hit the windshield. Thus, bending the blade was an option. Figure 7 includes some of the data that was taken.

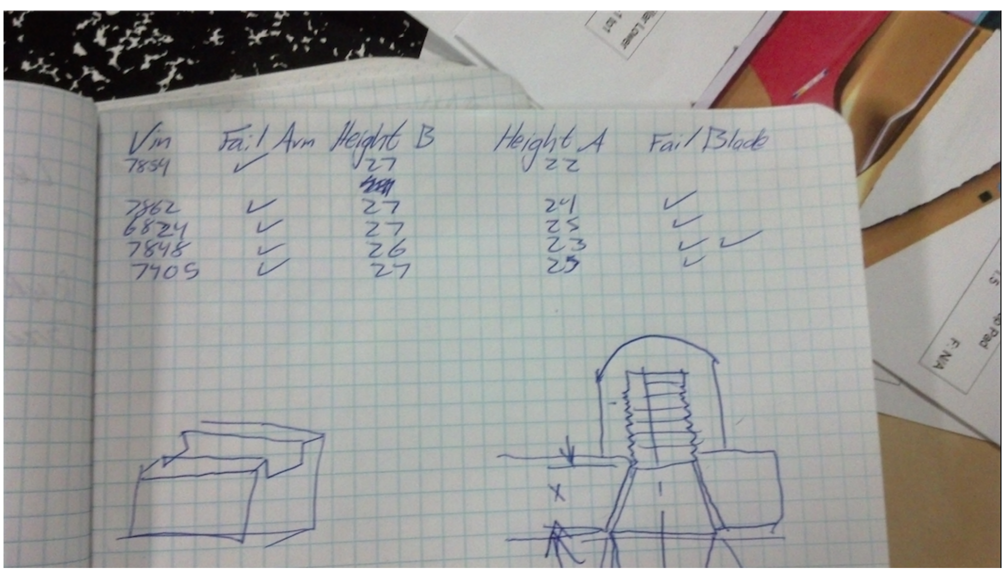


Figure 7: Windshield Wiper Defect Data

Methods

Methods I: Charge-port Door Defect Reduction

The temporary change was tested on the line. 50 cars were initially tested. Our null hypothesis was that there was no change in the gaps of the door and aluminum body (H0: u1=u2, and our alternative hypothesis was H1: u2<=u1). 1 was denoted as the standard sample, and 2 with the new cars with the added washers. We looked at the quality inspection sheets of all these cars and were pleased to see that not one car had a charge-port door that was unable to open.

To make this a true short term fix, it was explained to the operator of both day and night shifts the issue and that we needed to temporarily add the attaching of washers to his assembly process. A quick signature from the operator, the manager from that portion of the factory, as well as the taillight engineer, and the temporary countermeasure was immediately in place.

For the long term solution, each of the 4M's were analyzed. To analyze Man, there was no significant difference in the defect count of the two operators. For Machine, they used the same tools which showed no noticeable difference, so that was valid. From watching both of the operators' methods, everything was compliant. That left material. The engineer who designed the light and compared lights to their desired size was contacted, and everything

checked out. After confirming that the supplier material was of desired quality, the body of the car was considered. The operator who was responsible for the robot who completed the weld of the issue was consulted. From multiple conversations, it was determined that the robot was actually completing its welds a few millimeters to the left which led to the difference, and elimination of the special cause variations of the defect.

Methods II: Windshield Wiper Defect Reduction

The long term fix was to change the specifications of the blade's bend curvature from the supplier. However, there was a large amount of inventory that was still a bit out of Tesla's desired tolerances. However, the design engineer that collaborated with the supplier who was able to change the tolerances, but the new blades wouldn't hit the line for another 4 months. That was approximately 8 thousand cars that would have these blades. Tesla did not have the money to expend on new blades.

The mid-term solution was to speak to service to make sure all technicians knew to tell the customers that brought their cars in that the wipers were made for cars on the move.

However, there were still cars that were leaving the line every 10 minutes with a part that would not meet specifications.

From speaking with each of the technicians who have done the repair (some vlookup filter work). Each technician's repair processes was examined. Almost every one of them used the needle approach, but there were a few night technicians in service that did use a different

tactic and detached the wiper and actually applied light pressure and bent the wiper which worked well (no repeat service orders whereas the needle adjustment approach did lead to some).

For the short term approach, a fixture was designed that would allow for consistent, accurate, bending of the windshield wiper. This was designed, manufactured, and put on line in a weeks time.

Results

There are three main portions of the Results of this senior project:

1. Vehicle Quality Priority Reorganization
2. Charge-port Door Defect Reduction
3. Windshield Wiper Defect Reduction

Results I: Vehicle Quality Priority Reorganization

In a recent earnings report, Elon was quoted saying, “Every week I have a product excellence meeting, which is a cross-functional group, so we've got engineering, service and production, and we go about all the issues that the customer is reporting with the car. The action items that we address are to get the car ultimately to a perfect car, that's what we're

aiming for… a car that never needs to be serviced. And I think we're getting there quite rapidly."

Before the internship, service and production were two very separate entities. Now, they took the original idea, slightly iterated on it, and are using the prioritization strategy to handle defects that affect the whole company instead of just within vehicle manufacturing.

Results II: Charge-port Door Defect Reduction

The special causes of variation were eliminated, leaving only common causes. The average repair time was 1.03 hours per Charge-port door malfunction in between both service and end of line repair. Thus, multiplied by the repair wage, a savings per vehicle can be calculated, which is the standard Tesla cost savings calculation. Multiplied by projected production, this defect reduction has saved over $20,000 a quarter since the welding fix change was made.

Results III: Windshield Wiper Defect Reduction

In a similar fashion to the charge-port door, savings from the windshield wiper can be calculated. The repair time was about 20 minutes for the adjustment, and based on the repair wages, this was an average of $1.47 cost per vehicle to fix the one defect. There were .14 defects per vehicle on the line, or about 7/50 vehicles had the defect that was needed to be

fixed, only to have various others appear actually in the field. After the change, however, defects dropped to about 14% of what they were to .02, and thus, saved an average of $1.31 per vehicle, $655 a week, or almost $8000 per quarter. Once the actual engineering supplier change will go into effect, we expect the defects to drop even more.

Another result of our work was creating an official quality standard so that quality inspectors knew exactly what was being reported, and how to check it. Figure 8 is of that quality standard.

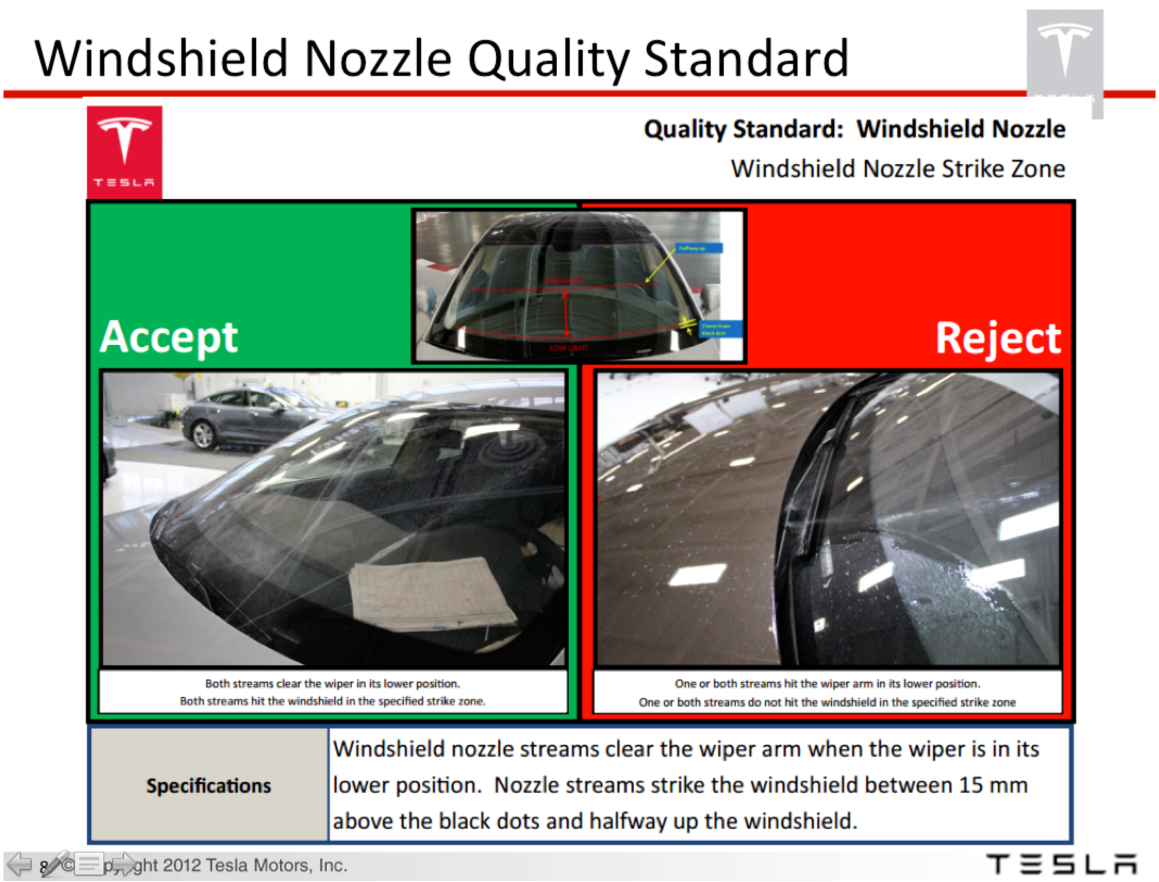


Figure 8: Windshield Nozzle Quality Standard

Conclusion

The most important results were that all special cause variation was eliminated for both of the defects.

The topic of Quality Engineering can be done in a very-process oriented manner. In solving problems, many of the solutions can be created just from speaking with everyone that could possibly be involved. In a large manufacturing setting, it may be easy to just email everybody and hope for responses, but many times it takes the initiative to go up and speak to them in person to get specific information.

In improving the Quality Defect Re-Prioritization, the author would have liked to create an automatic form that pulled in data worldwide to helped prioritize issues as well as a an accurate way for technicians submit that information from whichever service center they were at.

Social and Environmental Impact

By improving the overall quality of the car, the quality team that the author was a part of and Tesla as a whole is making electric vehicle more of a common option. No longer are people seeing Tesla as a prototype and unsustainable car. There are many small defects that may not seem to affect the functionality, but these small changes affect perceived quality. Sure, there can be small gaps between the rear door panel and the aluminum body, but subconsciously people can recognize these and when a car is truly perfect, there is a much more calming feeling. Tesla obviously was at a very high price point with the Model S and Roadster, but by proving that there was an actual market and customers willing to pay, it was a proof of concept.

Elon has been quote multiple times speaking that competition has been good for electric vehicles: “It’s sort of counterintuitive, because, why do we want all these competitors?” said Musk, 43, during a Tuesday appearance at the Automotive News World Congress in Detroit. He then reiterated the real environmental benefits will only happen “if the big car companies make risky decisions to make electric vehicles. I hope they do. We’ll try to be as helpful as we can.”

The author thinks that Elon has done all he could have possibly done for electric vehicles. In a CleanTechnica.com report, the below graph shows that the overall electric vehicles on the road has grown linearly from 2009 to 2011, but at 2011, when the Model S

began to be mass-produced, multiple countries experienced exponential growth (See Figure 9). That being said, as the reader can see in Figure 10, 2014 Tesla only had a 13% Market Share in the US (Loveday, InsideEvs.com). This tells me that other companies piggybacked on Tesla's market validation of Electric Vehicles and Tesla is not worrying about that as a whole.

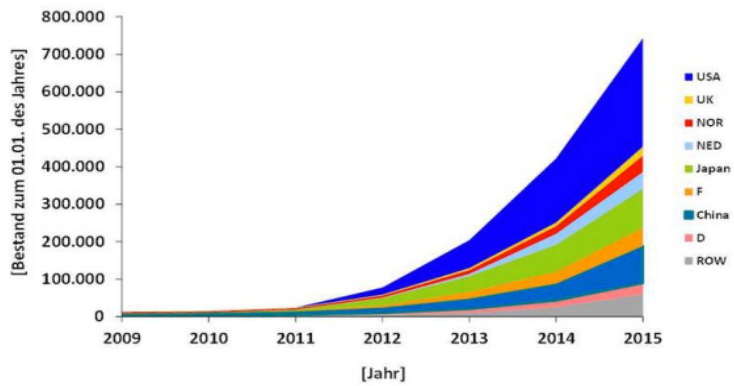


Figure 9: Electric Vehicles per Country per Year

Tesla's supercharger network has also grown significantly which will lead to company growth. On the world stage, as of March 15, Tesla now reports 396 Supercharger stations with more than 2,150 individual chargers (Parrott, Greencarreports.com). From January through April last year, Tesla opened 39 Supercharger sites with a total of 104 charging points. Then from May through August, it added another 20 sites with 122 charging cables. Then the pace ramped up from September through December, with another 37 sites encompassing 264 charging points. This infrastructure is something no other electric vehicle company has done and I, as well as many industry experts, believe that other companies will start adapting their cars to Tesla's hardware which will allow them to use the network.

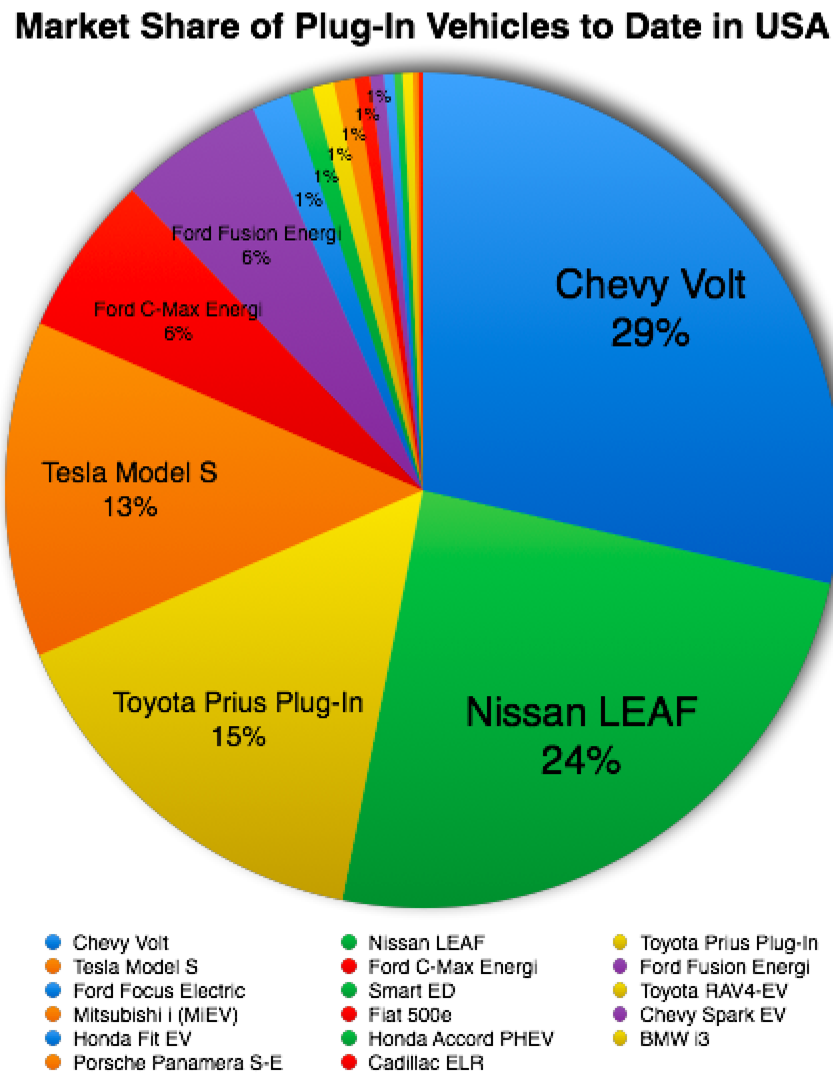


Figure 10: Electric Vehicles per Model

Lastly, Tesla is having a large impact environmentally with just cars. They have just released powerwall which will allow houses to literally become their own power centers. While other smaller, portable batteries have been created before, none have been at this low of a price point and created under such a reputable brand name.

All this being said, there are multiple sources asking if a Model S is actually green, due to the footprint required to produce the electricity. That being said, many of the articles do not report the energy needed to produce gasoline, either. From looking at multiple reports, even including the energy required to produce electricity, the Model S saves 50% CO_2 emissions compared to the output average mid sized sedan, which does not include the energy required to produce the gasoline. An in-depth blog post by an EVstories.com user said: “435 kilograms of CO_2 put out by my old gasoline car, is an amazing saving of 58% in CO_2 emissions.”

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