

Customer Focus in EPS Steering Feel Development

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ABSTRACT

The automotive industry is one of the most competitive enterprises in the world. Customers face an ever-expanding number of entries in each market segment vying for their business. Sales price, brand image, marketing, etc. all play a role in purchase decisions, but the factor distinguishing products that consistently perform in the market place is the ability to satisfy the customer.

Steering character plays a critical role in the customer driving experience and can be one of the most heavily debated topics during a new vehicle program. The proliferation of EPS steering systems now allows engineers to calibrate steering feel to almost any desired specification. This raises a key question: What subjective & objective characteristics satisfy customers in a particular market segment? Answering this question requires continued research to develop objective metrics correlated to subjective steering attributes and increased understanding of customer preferences for objective performance parameters.

In five sections, this paper presents a process for developing engineering requirements for steering feel that will achieve customer satisfaction: (1) Defines the elements of a customer focus strategy in product engineering; (2) Discusses the importance of steering feel to the customer; (3) Describes the subjective components of steering feel; (4) Outlines objective tests to quantify the subjective attributes of steering feel; (5) The final section of this paper illustrates an engineered clinic to understand customer preferences, generate loss functions, and develop objective engineering requirements.

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INTRODUCTION

Over the last 10 years, Electronic Power Steering (EPS) systems have overtaken Hydraulic Power Steering (HPS) as the preferred solution for OEM passenger vehicles. The initial shift to EPS was motivated by improved fuel economy with an understood trade-off against steering feel. Over time though, technological progress has significantly improved the performance of EPS systems. Motor technology has advanced considerably, producing more powerful motors with reduced inertia. High accuracy steering angle and torque sensors along with more powerful microprocessors allow precise control of steering assist. In addition to these advances, performance algorithms have become more complex, enabling more control over desired steering characteristics.

With these improvements, modern EPS systems are now generally considered on par with HPS systems for feel [1], while providing a host of advantages beyond fuel economy. These advantages include speed variable assist, driver mode control, and the potential for integrated driver assistance systems (e.g. lane-keeping control).

Traditionally, steering feel development at major OEM's is guided based on subjective evaluation. Modern EPS systems simultaneously present an opportunity and challenge for steering development engineers. The degrees of freedom for steering feel performance has increased by an order of magnitude. This expansion has rejuvenated industry debate about the importance of steering feel to customer, how to objectively quantify performance, and what are the attributes making up "great" steering feel.

The goal of this paper is to describe a process for an engineering organization to define, understand, and execute customer requirements for steering feel. The first section defines the elements of a customer focus strategy in a product engineering organization. The second section defines steering performance and discusses why steering feel is critical to the customer. The third section categorizes steering feel into five subjective attributes. The fourth section outlines standardized tests to objectively quantify the subjective attributes of steering feel. The final section of this paper illustrates an engineered clinic to understand customer preferences, generate loss functions, and develop objective engineering requirements.

WHAT IS CUSTOMER FOCUS?

"The purpose of business is to create and keep a customer." This was a popular quote from the prominent 20th century management consultant Peter Drucker and concisely states a strategic initiative still remaining for any businesses in the 21st century. Many businesses tout a goal to be "customer-focused", but it can be difficult to define and implement a strategy to accomplish this task. The first hurdle is defining what does "customer-focused" mean. Customer focus means different things to different functions within an organization. In sales, customer focus might mean providing fast service. In marketing, customer focus might mean developing and reinforcing a brand identity relevant to the target consumer. In a product engineering organization, a customer focus strategy has four core elements: (1) Understand product attributes critical to customer, (2) Translate these attributes into objective metrics, (3) Develop engineering targets based on an understanding of customer preferred performance settings, and (4) Execute the product to those specifications.

Kano Model of Customer Satisfaction

The number of entries and quality of products in the global automotive industry continues to rise, increasing the pressure to deliver differentiated products surpassing customer expectations. There are many philosophies for managing customer requirements during product development. The most widely applied model for delivering customer value is the Kano model developed in the 1980's by Professor Noriaki Kano [2], [Figure 1](#).

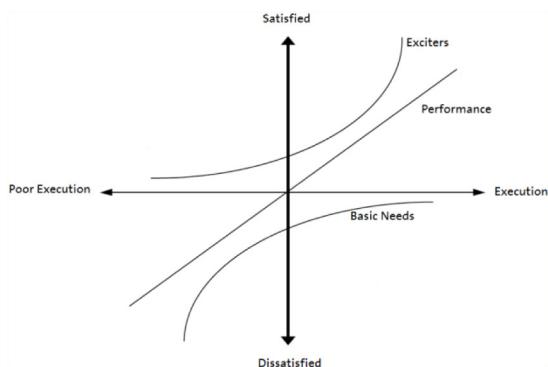


Figure 1. Kano model

The Kano model groups engineering qualities into three categories based on their capacity to satisfy or dissatisfy a customer:

1. **Basic Needs** - the qualities all customers expect from a product. If these requirements are not satisfied, the customer will be very dissatisfied or not even consider purchasing a product. Exceeding customer expectations for these qualities has only a minimal impact on customer satisfaction.
2. **Performance** - these qualities provide a proportional increase in customer satisfaction as product execution improves.

3. **Exciters** - these are qualities the customer may not expect or even imagine as possible. An increase in exciting quality provides a disproportionate increase in customer satisfaction.

This model compels an organization to develop a deep understanding of customer requirements, classify them, develop performance goals, and prioritize engineering resources for the best return on investment relative to customer satisfaction. These factors can combine to reduce engineering re-work and increase the likelihood of delivering a winning product to the market.

WHY STEERING FEEL MATTERS

Few areas of vehicle performance heighten passions and generate debate during the product development cycle like discussions of steering performance. Unlike many other development areas where objective testing can quantify performance (e.g. noise, acceleration, fuel economy), steering performance is a subjective experience.

To properly frame the discussion to follow, we begin with a clear definition of steering performance. At a fundamental level, steering performance is the harmonious relationship between two components: (1) Steering response and (2) Steering feel. Steering response characterizes the vehicle lateral, yaw, roll, and sideslip response to steering angle input. These responses are characterized by their gain relationship and temporal character. Steering feel is the haptic response felt through the steering in response to angle, lateral acceleration, and road texture. This response is characterized by torques felt at the steering wheel. This paper focuses on the steering feel component of performance.

The technical community recognizes steering feel as critical to driver safety, comfort, and handling performance [3]. The steering system is the driver's direct link to the front tire contact patch and provides primary information about cornering forces, tire cornering reserve, and road texture. Steering feel also plays a principal role in the driver's control authority. Lack of damping, non-linearity, and lash in the steering system all can reduce the driver's ability to precisely place the car on a desired path.

Another aspect to the discussion is the impact steering feel has on perceived vehicle character. Steering feel plays a core role in the compromise between driving comfort and driving engagement, and should be an integral part of brand image.

At major OEM's steering development relies heavily on subjective evaluation for final buy-off. During a product program internal experts frequently debate the attributes that make for great steering feel. A fundamental question often lost in the debate is: What attributes do customers desire for steering feel? This question can be difficult to answer because the way a person perceives steering feel is very personal, driving experience, market segment, and brand expectations.

all play a role in a person's opinion of steering. Despite these complications, the current buy-off process often leads to great steering performance in the eyes of the customer, but it is not without room for improvement.

A potential approach to the challenge is reliance on general customer surveys/questionnaires. Unfortunately, this approach may not yield results with sufficient detail or discrimination to drive engineering decisions related to steering performance. In the Kano model, steering feel likely relates to the Basic Needs curve. Customers generally focus on "things gone wrong" when asked questions related to steering performance (e.g. vehicle pulls to right). In modern vehicles steering feel is rarely of such poor quality to be identified as a specific dissatisfier in the context of a broad vehicle performance survey.

Given the preceding viewpoint, a logical follow-up question is: Is excellent steering feel important to the customer? The answer to this question may be surprising, but data taken at customer driving clinics indicate the answer is yes. The strong impact steering feel has on the driving experience is clear, but typically is not specified explicitly by customers under the heading of steering. The final section of this paper provides background supporting this statement.

SUBJECTIVE COMPONENTS OF STEERING FEEL

As introduced in the previous section, considerable debate about the right "recipe" for great steering feel remains. Fortunately, experts largely agree on the component attributes defining steering feel [3, 1]. The following section categorizes and discusses steering feel as five attributes: (1) Effort and Progression, (2) Hysteresis Feel, (3) Transient Torque Feel, (4) Returnability, and (5) Tactile Road Feedback. These attributes are evaluated over a wide range of lateral accelerations, vehicle speeds, and steering wheel velocities.

Effort and Progression

Effort and progression describes the magnitude of steering wheel torque and the progression of steering effort build-up with increasing lateral acceleration during low steering velocity events (<45 deg/s). Steering effort must rise in conjunction with cornering forces. The gradient of this effort progression with lateral acceleration is a defining character of "cornering feel". A more shallow progression may enhance driving comfort by limiting the magnitude of steering effort required from the driver. A steeper progression imbues a more sporting character and results in a more engaging driving experience. Regardless of how steep this progression curve is, the shape should provide a consistent perception to the customer that cornering forces linearly relate to steering torque.

Hysteresis Feel

Hysteresis feel describes the differences in steering torque required when steering away from versus returning to center. Hysteresis is the combined result of steering friction, steering wheel velocity damping, and steering inertia effects. At low steering velocities (<45 deg/s) friction is the main source of hysteresis. As steering velocities approach higher magnitudes (>90 deg/s), damping and inertia begin to add significant amounts of hysteresis feel. While generally friction is viewed as a negative for steering system components, some level of overall system hysteresis is required throughout the driving regime to provide a natural steering feel. With too little hysteresis the steering has a tendency to feel like a rotational spring. Inadequate hysteresis also limits how much steering effort progression is acceptable - the amount of driver steering torque required to maintain a given steering angle may be too high.

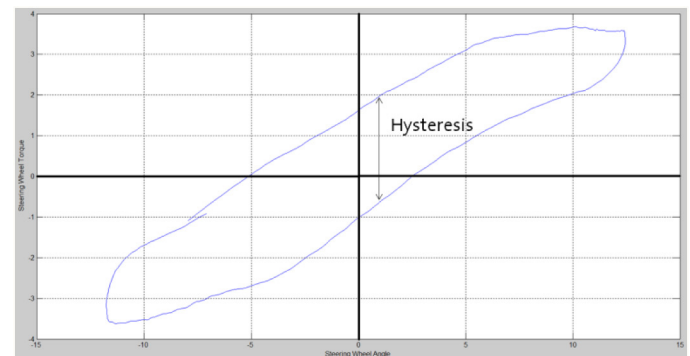


Figure 2. Steering Torque vs. Angle Hysteresis Loop

Transient Torque Feel

Transient torque feel describes how quickly steering effort changes during transient steering maneuvers (>90 deg/s). During transient maneuvers steering torque leads steering angle and lateral acceleration. The phase relationship of transient steering torque is the combined result of friction, inertia, and steering wheel velocity damping. Proper phase between steering effort and steering angle is critical to natural steering feel. If steering torque is phased too far ahead of steering angle it is perceived as "inertial" feel (i.e. steering wheel feels like it has high rotational inertia). If steering torque does not lead steering angle, the steering has a disconnected feel at the initial moment of steering input.

Returnability

Returnability describes the restoring torque felt when the driver is returning to the straight ahead position. A lack of restoring moment makes the steering difficult to place precisely and demands significant driver attention to maintain a straight line. Returnability is closely linked with steering effort and hysteresis feel. Too much hysteresis relative to steering effort results in inadequate restoring moment.