International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 07 | July 2019 www.irjet.net p-ISSN: 2395-0072

# Development of Vehicle Dynamics for Passenger Cars

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**Abstract -** *The automotive industry has been on the rise consistently from the very start, all over the world. As the field is expanding into a much larger scale, the user feedback and consumer requirements are to be taken into great consideration. Vehicle Dynamics Development starts from the initial visualization of the plans and is done based on various parameters such as, performance goals, customer requirements, financial constraints and so on. The determination of each and every component of the vehicle can be linked to the customer requirements and much largely, the Vehicle Dynamics. Handling of the car to be designed must be done taking the customer requirements into considerations. This paper aims on giving an insight on the process of considering customer requirements and how they are to be implemented in the design stage of automobiles. A case study which better helps in understanding this concept is also presented*

***Key Words***: Vehicle Dynamics, Development, VOC, VTS, SSTS, CTS

## 1. INTRODUCTION

The need for innovation is virtually unchallenged. This holds particularly true for the automotive industry and the current context of a crisis-colored global environment. After the 2008–2009 global economic crisis, mature markets in the USA and Europe experienced a massive plunge in vehicle sales resulting in overcapacities and financial problems [1].

In terms of the customer experience, buying a car isn't quite the same as dining at a restaurant or checking into a hotel. You don't end up buying a car in the evening after having the thought occur to you in the morning. This makes the process of purchasing automobiles a very daunting experience. Multiple factors that come in after purchasing need to be considered by the customers such as loans, maintenance cost, insurance and so on.

According to a 2014 study by J.D. Power [2], automotive shoppers spent an average of 14 hours researching cars online — visiting dealership sites, reading reviews, making price comparisons, using online shopping tools — before making a purchase decision.

A 2013 poll commissioned by AutoTrader.com [3], meanwhile, found that 75 percent of the time that consumers devoted to buying a car was spent online

They don't stop interacting on digital channels after buying a car, either; automotive shoppers are also increasingly active when it comes to leaving online reviews and feedback about their customer experience.

According to automotive research site Cars.com, the breakdown, by type of car, for reviews and customer feedback is as follows: used-car sales at 38 percent, new-car sales at 37 percent, and service at 24 percent [4]. According to the 2016 J.D. Power report, customers on average will positively recommend the dealership from whom they purchased their vehicle six times, with younger buyers being slightly more likely to recommend (6.2 times) than those older than 55 (5.2 times). These numbers can be improved when dealers provide an outstanding customer experience: getting 10 points on a 10-point scale in terms of experience can lead to a rise in the average of recommendations to eight positive comments.

Although all these factors cannot be controlled by the companies at the design stage, some factors can be taken into considerations to satisfy. The largest one being the Vehicle Dynamics

## 2. VEHICLE DYNAMICS

Vehicle Dynamics is the engineering subject about vehicle motion in relevant user operations. It is an applied subject, applied on a certain group of products, namely vehicles. Vehicle Dynamics always uses theories and methods from Mechanical engineering, but often also from Control/Signal engineering and Human behavioral science [5].

Vehicle motions are mostly due to the forces generated between the tires and road, and aerodynamics effects. In this article, the main focus is on suspension design and development, and aerodynamics effects are not considered. The tire forces can be divided into three directions: lateral, longitudinal, and vertical. Hence, vehicle dynamics performance can be divided into three aspects according to the force direction, illustrated in Figure. 1

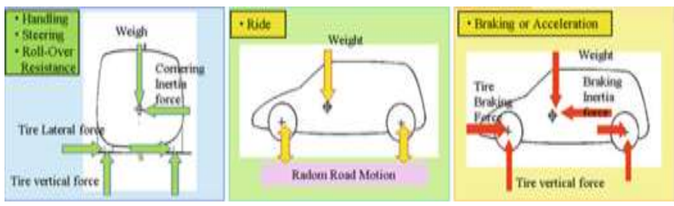


**Fig -1:** Vehicle Dynamics Performance

## 3. VEHICLE DYNAMICS

Development of a vehicle is driven by requirements which come from:

• Use case-based needs of the customer/users

• Legislation from the authorities and Rating from consumer organization, and

• Engineering constraints from the manufacturer's platform/architecture on which is it to certain vehicle should be built.

We will be concentrating on the customers' requirements in this article as this is the most crucial aspect of determination of the vehicle handling characteristics in a commuter car.

Vehicle dynamics development is generally divided into three major phases Figure. 2


**Fig -2:** Vehicle Dynamics Development

### 3.1 Phase 1: VOC to VTS (Voice of Customers to Vehicle Technical Specifications)

The first phase is to set the performance goals. Target setting is based on design experience of the vehicle development team as well as translating market requirements into vehicle dynamics requirements. Typically, vehicle dynamics specifications include as ride, handling, and braking. This phase requires a lot of benchmark objective testing as well as subjective assessment to support target setting.

### 3.2 Phase 2: VTS to SSTS (Vehicle Technical Specifications to Subsystem Technical Specifications)

The second phase is to develop the subsystem requirements from the vehicle dynamics specifications. The subsystem-level synthesis and performance tests are required in this stage to provide data to support subsystem target setting.

### 3.3 Phase 3: SSTS to CTS (Subsystem Technical Specification to Component Technical Specifications)

The third phase is to transform the subsystem specifications into component design parameters. This requires more precise simulation modelling tool for analysis in order to understand the design parameters of key chassis components effect on overall vehicle dynamic performance.

Once the hardware prototype is procured, in both vehicle level and component level, chassis tuning work begins. The goal is to refine the component specifications while balancing many chassis design parameters in order to meet the vehicle specifications. Although the second and third phases of the process are done early in the development, it is normal to iterate the process until an optimum design is completed. The specifications are occasionally modified as the vehicle program progresses, especially during the vehicle prototype phase of the development process. This can be caused by durability issues, simulation model discrepancy with actual performance, or marketing new trends.

## 4. PHASE 1 (VOC TO VTS)

### 4.1 Voice of Customer (VOC)

Voice of the Customer (VOC) is a term that describes your customer's feedback about their experiences with and expectations for your products or services. It focuses on customer needs, expectations, understandings, and product improvement.

VOC programs have gained traction over the years and are fast-growing segments of a core business strategy for organizations. They work exceptionally well for brands as customers demand more direct engagement with a firm and because capturing and acting on customer feedback is critical to understanding a prospect's complex decision-making process.

The customers feedback and requirements form the first stage of the Vehicle Dynamics Design process.

### 4.2 Vehicle Technical Specification (VTS)

The Vehicle Technical Specifications is a consolidated view of the main parameters at the General level. This lays the groundwork for which the further developments in the design process take place.

These include the specifications such as - Body type, Suspension type and setup, Type of drivetrain, Safety features, and so on.

### 4.3 VOC to VTS

Voice of customer is the first step from which the performance goals of the vehicle is set. These goals form the framework around which the vehicle, down to each component's specification, depends on. First, the engineers have to understand what the customer is explaining in layman terms, and then accordingly relate it to the vehicle specification ie, the major characteristics that define the car.

Consider Table 1, given below which shows an example of how the voice of customer can be linked to a vehicle's technical specification.

**Table -1:** VOC linking to VTS

| Voice of Customer | Vehicle Technical Specification |
|---|---|
| Ease of driving over potholes and poor roads | Higher ground clearance and wheel travel |
| Good highway handling | High speed stability |
| Handles well in all conditions | Setup to handle all weather conditions |
| Easy Maneuvering in traffic and for parking | Steering setup for less effort |
| Shorter braking distance | Effective braking setup |
| Good corner handling | Setup to suit high speed corner stability |

## 5. PHASE 2 (VTS TO SSTS)

### 5.1 Sub-System Specific Technical Specification (SSTS)

The System/Subsystem Specifications provide a detailed description of the system/subsystem functions. It defines in detail the interfaces with other systems and subsystems and the facilities to be used for accomplishing the interfaces.

SSTS talks about the characteristics of the car at the subsystems level (Suspension system, Brake System and so on). These are specifications that define the behavior and action of the subsystem to perform as required.

### 5.2 VTS to SSTS

Once the VTS has been defined, the subsystem design is planned and executed such that it fulfills the VTS.

The second phase is to develop the subsystem requirements (SSTS) based on the vehicle dynamics specifications (VTS), see Table 2. The subsystem-level synthesis and performance tests are required in this stage to provide data to support subsystem target setting.

In this phase, the subsystem's specifications are defined in such a way that the pre-defined vehicle technical specifications are fulfilled. The table below shows how Subsystem Specifications are defined base off the Vehicle Technical Specifications.

**Table -2:** VTS linking to SSTS

| Vehicle Technical Specification | Subsytem | Sub-System Technical Specification |
|---|---|---|
| Higher ground clearance and wheel travel | Suspension | Shock absorber with adequate wheel travel<br>Mounting shock absorber at lower point for increased ground clearance |
| High speed stability | Suspension/ Steering | Stiffer Suspension<br>Positive Castor angle<br>Increased force required for steering |
| Setup to handle all weather conditions | Suspension | Negative Camber angle |
| | Brakes | Good tyre grip in different conditions<br>High performance brake components |
| Steering setup for less effort | Steering | Steering wheel designed to require lesser effort<br>Positive Scrub radius |
| Effective braking setup | Brakes | High Performance Brake components<br>Dual Pot Caliper |
| Setup to suit high speed corner stability | Suspension/ Steering | Negative Camber angle<br>Positive King-Pin inclination |
| | Chassis | Stonger(Stiffer) Chassis |

## 6. PHASE 3 (SSTS TO CTS)

### 6.1 Component Technical Specification

Component Technical Specification talks about the characteristic of the vehicle at a component level. These are defined for those components which play a major role in determining the performance of the subsystem, which in turn affects the overall performance of the vehicle. For example, Travel of a coilover, Type of caliper, and so on.

### 6.2 SSTS to CTS

The third phase of the process is to transform the subsystem specifications into component technical specifications, see Table 3. This requires more precise simulation modelling tools for analysis in order to understand the effects of design parameters on performance.

By varying small parts of components, the effect brought about by these are reflecting largely when the entire vehicle's operations are considered. Hence, it is very important to accurately and rightly vary component characteristics which forms the core for the design of the subsystems. If the components are inaccurately chosen, then the desired vehicle specification cannot be obtained and hence, the voice of customer will not be satisfied.

**Table -3:** SSTS linking to CTS

| Sub-System Technical Specification | Component Technical Specification |
|---|---|
| Shock absorber with adequate wheel travel<br>Mounting shock absorber at lower point for increased ground clearance | Longer coilovers<br>Smoother damping setup |
| Stiffer Suspension<br>Positive Castor angle<br>Increased force required for steering | High Spring rate<br>Power steering effect minimized |
| Negative Camber angle | Unequal A-Arms |
| Good tyre grip in different conditions<br>High performance brake components | All weather tyres<br>Disc designed to operate in all conditions |
| Steering wheel designed to require lesser effort<br>Positive Scrub radius | Larger steering wheel<br>Power steering effect chosen appropriately |
| High Performance Brake components<br>Dual Pot Caliper | Sintered brake pads<br>Dual Pot Caliper<br>ABS, ESP |
| Negative Camber angle<br>Positive King-Pin inclination | High Spring rate coilover |
| Stonger(Stiffer) Chassis | Compact, lower centre of gravity chassis design |

## 7. CASE STUDY

### 7.1 Hybrid Mavericks, India

Hybrid Mavericks, a hybrid vehicle team from JSS Academy of Technical Education, Bangalore that takes in competition is currently taking part in SAE REEV – 2019. In this competition the team was required to submit their VOC to SSTS plan, which was prepared by the author, Nandan Rajeev.

It is shown in Table 4.

**Table -4: VOC to SSTS of a hybrid car**

| | Voice of Customer | Vehicle Technical Specification | Subsytem | Sub-System Technical Specification |
|---|---|---|---|---|
| HANDLING | Ease of driving over potholes and poor roads | Higher ground clearance and wheel travel | Suspension | Shock absorber with adequate wheel travel<br>Mounting shock absorber at lower point for increased ground clearance |
| | Good highway handling | High speed stability | Suspension/ Steering | Stiffer Suspension Positive Castor angle Increased force required for steering |
| | Handles well in all conditions | Setup to handle all weather conditions | Suspension | Negative Camber angle |
| | | | Brakes | Good tyre grip in different conditions<br>High performance brake components |
| | Easy Maneuvering in traffic and for parking | Steering setup for less effort | Steering | Steering wheel designed to require lesser effort<br>Positive Scrub radius |
| | Shorter braking distance | Effective braking setup | Brakes | High Performance Brake components<br>Dual Pot Caliper |
| | Good corner handling | Setup to suit high speed corner stability | Suspension/ Steering | Negative Camber angle<br>Positive King-Pin Inclination |
| | | | Chassis | Stonger(Stiffer) Chassis |
| PERFORMANCE | Low running cost | Better fuel efficiency | Powertrain | Running engine at optimum RPM |
| | | | Powertrain | Regenerative Braking System |
| | Good Pick up | Higher acceleration | Powertrain | High Torque gear setup |
| | High cruising speed | Higher Top Speed | Powertrain | High Speed gear setup |
| | Multiple drive modes | Low and High Power modes | Electrical | Microcontroller |
| ERGONOMICS | Driver ease of access | Designed for quick ingress and egress times | Chassis | Design adhering to Cockpit and Percy templates |
| | Comfortable | Seating position | Chassis | Design adhering to 95th percentile male rule |
| | | Seating comfort | Seat | Padded seats |
| | Suit different drivers | Adjustable Seats | Seat | Mounts to change seat position |
| | Smoothness | Vibrations minimized | Packaging | Use of insulation sheets |
| | Driver Vision | Providing larger field of view | Seat | Raised seat mounting |
| SAFETY | Good strength of car | Chassis designed to handle heavy impacts | Chassis | Strong material<br>Impact analysis |
| | Crash protection | Crash protection members and driver safety attachments | Chassis | Use of strong impact attenuator<br>Fulfilling 95th percentile male rule |
| | | | Seat | 7 point seatbelt |
| | Brake failure protection | Prevent loss of complete brakes system | Brakes | Diagonal Brake system |
| | | Cut power in case of brake failure | Electrical | Brake overtravel switch |
| | Safety from Fire Hazards | Insulation between driver and powertrain components | Packaging | Appropriate design of firewall and battery casing |
| | Safety after the event of a crash | Easy access to shutdown all components | Electrical | 3 Emergency Kill Switch |
| | | Prevent electric shock from exposed wires | Electrical | Inertia sensor which cuts current supply in the event of an accident |
| | Prevention of electrical hazards | Isolation of HV and LV wires | Electrical | Opto Isolater used to isolate the HV and LV wires |
| | | Short circuit protection | Electrical | Grounding of all electrical components Proper insulation provided to all wires |
| | | Prevent leakage of high currents | Electrical | Inbuilt IMD(Insulation Monitoring Device) |
| OPTIONAL FEATURES | Navigation Sysetm | Integration of GPS System | Accessories | GSM Module |
| | Reverse gear | Option to reverse the car | Electrical | Motors polarity reversal |
| | Mobile charger | Provision of charging port | Electrical | 12V Socket |
| | Luggage compartment | Storage areas | Accessories | Panniers and top box |
| | Radio | Audio System | Accessories | Midi System |

### 7.2 Pan Asia Technical Automotive Center, China

To better understand this process of vehicle dynamics design, we can look at the steps followed by the engineers of Pan Asia Technical Automotive Center, China in designing their suspension system [6].

Roll dynamics is used as an example in this article. From determination of roll gradient to developing of front and rear roll stiffness, and roll stiffness to suspension component specifications.

#### 7.2.1 VOC to VTS

As already explained above, from the VOC, the VTS are framed

#### 7.2.2 VTS to SSTS

Roll gradient is used as an example here to illustrate the VTS flow down process.

Based on input from benchmarking study and development team input, the VTS roll gradient target for a new compact passenger vehicle is ≤ 5 deg/g.

The roll gradient is contributed by the front and rear suspension roll stiffness. While achieving the roll gradient of ≤ 5 deg/g, the limit handling performance requirement has to be met. The stability at the limit handling condition (typically greater than 0.6 g lateral acceleration) is an important factor in vehicle handling. The front roll stiffness and rear roll stiffness have to be balanced correctly. This is typically done by selecting a Tire Lateral Load Transfer Distribution (TLLTD). In this case the TLLTD is selected to be 60 % to ensure stable cornering at the limit. In this case, the basic vehicle information is listed Table 5.

**Table -5:** Vehicle Information

| | |
|---|---|
| Mass | 1040 Kg |
| Mass Distribution | 61% |
| Roll Centre Height | Front 55mm, Rear 150mm |
| TLLTD Requirement | 60% |
| Roll Gradient | ≤ 5 deg/g |

Figure 3 shows the output from a synthesis tool showing relationship of the suspension roll and rear roll stiffness vs. TLLTD. In order to meet the design requirements: 780 Nm/deg and 410 Nm/deg are selected (the points with circle) for the front and rear roll stiffness respectively. The front roll stiffness and rear roll stiffness are the part of the suspension subsystem technical specifications.

### 7.2.3 SSTS to CTS

Roll performance is used as an example here to illustrate the SSTS to CTS flow down process. In the second process, the vehicle technical specification of body roll gradient of 5 deg/g is the design target. 780 Nm/deg front roll stiffness and 410 Nm/deg roll stiffness are set as part of front and rear suspension subsystem specifications. The third phase of the process is to set the design parameters for the front and rear suspensions individual components in order to achieve the roll stiffness while meeting all the other subsystem specifications such as ride rate. In order to meet the roll stiffness requirements, suspension key parameters such as spring rate, roll-center height, and stabilizer bar size are defined. In the process of defining these key parameters, suspension ride frequency and packaging requirements need to be balanced carefully to obtain an optimum chassis performance. In order to determine the suspension components specification, suspension simulation model ADAMS [7] is used to determine the roll stiffness of the suspension from the suspension components. Figure 4 shows the ADAMS model of the front and rear suspension of a compact passenger vehicle.

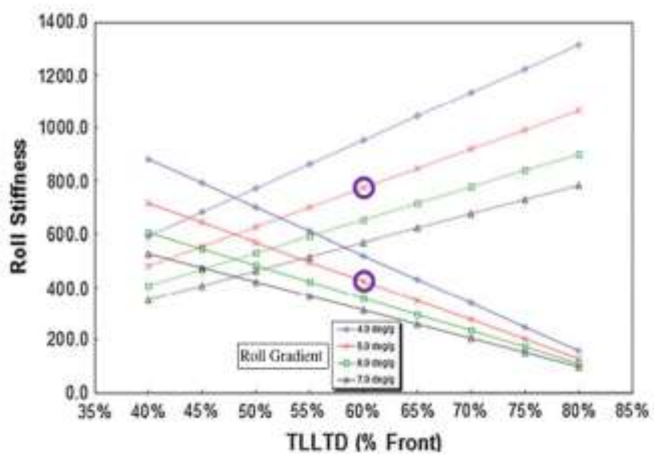


**Fig -3:** Relationship of the suspension roll and rear roll stiffness with TLLTD

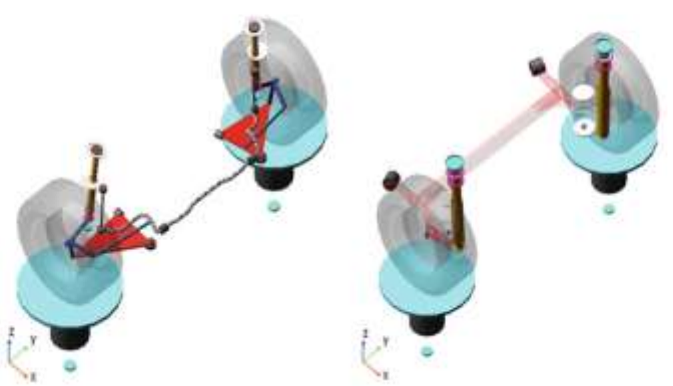

**Fig -4:** Suspension models on MSC Adams

Suspension Component Specifications to meet SSTS Requirements is depicted in Table 6.

**Table -6:** CTS to meet SSTS

| Parameter | Front | Rear |
|---|---|---|
| Spring Rate | 19 N/mm | 18 N/mm |
| Stab Bar Size | 22 mm | None (Solid Twist axle) |

Once the stabilizer bar mounting point and stiffness are determined, the mount point stiffness requirements have to be provided to the body structure development team as a body structure design criterion. The first round of the three phases of the vehicle dynamics development is completed. All the component design specifications are defined. Prototypes are then built followed by subjective evaluation and objective testing. Once the hardware prototype is procured, subjective evaluation and tuning begin. The goal is to refine the component specifications while balancing chassis design parameters to meet the vehicle requirements. Subjective evaluation and objective testing work hand-in-hand with simulation analysis in the prototype development stage. Through this process, a well-balanced chassis performance can be achieved.

## 8. CONCLUSIONS

The importance of the initial planning phase, much before the procurement of the hardware is very vital as discussed. In doing so, this allows the designers to analyze possible problems which could arise later on and provide the end users the desired vehicle. This is a very tedious and long process as it involves feedback from customers which needs to be taken on a large scale as well as the studies to be done at the smallest components level.

However, this process is vital for the production of the car which satisfies customers' requirements which is the main selling point. Another important parameter which is often considered along with Voice of Customer, is the Voice of Technician (or, Engineer) which deals with designing parts and determining layout of components which enable easy access for maintenance and repair works.

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