QFD Applications in the Automotive Steering System Development

Zhibin BAO[1, a], Rui MIAO[1, b], Qi WU[1, c], Tingting SONG[1, d], Yujiao LIANG[1, e]

[1] School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, 200240, China

[a]:mrxxdeng@qq.com,
[b]:miaorui@sjtu.edu.cn, [c]:lanshanwq@163.com, [d]:ttingsong@163.com, [e]:joeyu814@163.com

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Abstract. Converting the customer's need into product requirements and making effort to realize the initial need in all phase from concept design to serial product is the key that automobile can fulfill consumer's need before introduction to the market. Applying quality function deployment to summarize the customer's need on vehicle and using analysis hierarchy process to rank need according to need's importance, converting the vehicle need to steering system need by method of 2nd deployment and evaluate the benchmarks' performance and degree of satisfaction to set up the target for every steering system need, special designs for the typical needs with parametric adopt to different vehicles. Define task for each member of project team by work breakdown structure and archive the quality target for each work package into documents, set up regular project meeting to track and monitor the issues solving progress. It really makes very good effort on the design results.

Introduction

China's auto industry sales has increased from 5710000 of 2005 to 23500000 of 2014 in the last decade, volume of vehicle sales raised up 311%, China has been the world's first automobile consumption country since 2009 for 6 consecutive years. Along with expansion of the market, the world's major automobile manufacturers and the domestic brands manufactures pay more attention in sales and market share, listen to consumer's demand and more care about end user comments. There are more and more specified models tailored for Chinese consumers. Consumers' spending trends are becoming increasingly mature; product homogeneity phenomenon is more and more serious. How to quickly respond to the needs of the consumers, shorten the production cycle of the products, introduction the new product ahead of the competition, occupying the market become the key to OEMs' success. Compared with consumer products, automotive has characteristics: long development and verification duration, long life cycle. It requires the product development consider platform design, especially the power train, chassis and other complex systems. Platform design can shorten the verification on the variants system by saving the long cycle endurance test time for system (only for vehicle level road durability test, system and sub components durability testing conduct just once), create the possibility for rapid launch of new models meeting consumer's demand. Nowadays, SUV is always the hottest in China Automotive market. Major OEMs have invested a lot of resources on the R&D of SUV, expecting to be able to better seize the market, increase sales and elevate brand market share. But even the platform of product development, the complex systems still require to parameterize some key performance to adapt to different auto models. Using automotive steering system as an example, SUV vehicle chassis overall elevated, body height increased, widened, tire diameter increased, definitely the parameters of steering system requirements changes. This thesis is studying based on above situation, proposes at the initial stage of platform development, the parameters of these effects are taken into account, reducing design change in the future. The performance of variants the platform becomes the key of the platform success.

Identify the needs of automobile steering system

Quality function deployment (QFD) is a tool for the needs of customers, is the product design and the improved method for customer driven, and is a specific application of the thought of system engineering in the design of new products and old product improvement [1]-[6]. QFD has been applied to vehicle development projects by the major car companies in the past 3 decades in automotive industry, ensuring the quality of products to meet customer demand. With the popularization of QFD application, QFD has integrated into each stage of auto development. Through the method of interviews, VOC (voice of the customer) summarize the customer needs, and ranking the importance of customer needs by using of AHP (analytic hierarchy process) [7]. Vehicle engineer convert the consumer's need of vehicle into the needs of different system or sub components, consolidating into survey table of the need of certain system or sub component. Conduct customer interview and rank the importance of customer needs on system or sub components by AHP. According to the potential customer subjective evaluation on competing products related the specification to establishing reference value; provide the basis for the demand of goal setting. Before set up the HOQ (House of Quality) of creation system of auto, the vehicle requirements must be clear. When Q Company developed compact segment vehicle platform (CSVP), the customer needs were collected and ranked by means of VOC customer survey, customer interview and AHP analysis [7] .The top 10 consumer's need of compact car and compact SUV were obtained by conducting the online survey on the automotive website taking advantage of internet massive data. And then evaluate the bestselling benchmarks' values of above 10 needs and record. In the end, the customers' needs were ranked and prioritized by the survey of benchmarks. The top 10 needs of both sedan and SUV are ranked as table 1.

Table 1.Q Company compact Sedan and compact SUV top 10 needs and ranks

Automotive detail requirements	Sedan Rank	SUV Rank	Automotive detail requirements	Sedan Rank	SUV Rank
Cabin spacious	1	1	Selling price from 100K to 150K	6	NA
Safety ,ENCAP 5 star Rating	2	2	Power is enough for routine use(urban street)	9	10
Infotainment features rich, Internet， Easy operate, Beauty UI	3	3	Handling well, stable	8	9
Elegant design, Simpler design	4	5	Comfort	7	NA
Oil efficient,6.5L/100KM,China MITT's oil consume test	5	NA	Oil efficient,8L/100KM,China MITT's oil consume test	NA	7
Seat position high, good vision	NA	4	Selling price from 130K to 180K	NA	8
vehicle passability	NA	6	Easy to maintain, cost is low	10	NA

Consolidating the top 10 needs of both sedan and SUV, there are total 12 customers' needs of CSVP. The 12 customers' needs have been converted into needs of steering system. In order to avoid the converting of needs isolated with engineering solution, conducting the brainstorm in the relevant department of company is the best. Furthermore brainstorm could also avoid the engineer inherent thinking ignores tiny consumers' needs leading to non-satisficed customer's needs. The steering system needs converting from top 12 customers' needs of CSVP as table 2. Translate the 2nd level needs to the details requirement could help consumers understand much easier and decide whether they are important. Using interview to avoid the company decide the rank and priorities of needs. Apply Expert Choice to calculate the result more efficiently. The AHP weight calculate requires consistency coefficient <0.1, the result of calculation was: CI =0.0816; CR=0.0579. It was effective. The weights of top 8 steering systems' needs are as table 3.

After converting of the vehicle needs into steering system needs and calculated the weight of each need by methods of customer's relative importance of needs by AHP. In order to set the reasonable target of top 12 needs of CSVP, conduct bestselling compact sedan and compact SUV evaluations and understand the degree of satisfaction on these needs .Potential customer will conduct on road drive test with 4 major competitors in same road condition, implementing the evaluations and degree of satisfaction on these needs of 4 major competitors. There is not sufficient to just get consumers feedback when set up targets of needs. Vehicle engineering department will

arrange road test as well, and record the parameter of 12 needs out of 4 major competitors and select the best as target. The stroke and loading curve of 4 major competitors need to be improved, so the target needs set higher than the best of benchmarks. In the end, Calculate the absolute importance and relative weight of the consumers need, the absolute importance= customer needs importance (CNI) x product quality level rise rate x product characteristic coefficient (PCC) [8].Vehcile Steering system quality plan is as table 4.The scores of table 4 is different to normal quality plan due there was no existing product so far at that moment, all company product performance scores were 1.

Table 2.The steering system needs converting from top 12 customers' need of CSVP

CSVP needs	*Steering system needs*
Cabin spacious	Able to support vehicle
Safety ,ENCAP 5 star Rating	Safety
Infotainment features rich, Internet，Easy operate, Beauty UI	Not related to Steering
Elegant design, Simpler design	Not related to Steering
Seat position high, good vision	Not related to Steering
Oil efficient, below 6.5(sedan) and 8(SUV)L/100KM,China MITT's oil consume test	Low energy consumption
vehicle passability	Not related to Steering
Selling price from 100K to 180K RMB	Economy
Comfort	Handling Light
Handling well, stable	Responsive, good road feel
Power is enough for routine use(urban street)	Not related to Steering
Easy to maintain, cost is low	Easy to maintain, cost is low

Table 3.The weights of top 8 steering systems' needs

Steering Force Sufficient	Column Energy absorption	EPS	Moderate cost	Light in Low Speed	Easy to adjust Tilt/Telescopic	Stable in High Speed	Structure Simple
0.254	0.371	0.061	0.021	0.104	0.053	0.104	0.033

Table 4.Steering System Quality Plan

	Quality Plan							
	CNI	Q's product	Benchmark performance	Target Quality	Level rise rate	PCC	Absolute importance	Customer need weight %
Steer Force Sufficient	0.254	1	3	4	4	1.2	1.22	20.80%
Column Energy absorption	0.371	1	4	5	5	1.5	2.78	47.41%
EPS	0.061	1	5	5	5	1.5	0.46	7.78%
Moderate cost	0.021	1	3	3	3	1	0.06	1.06%
Light in Low Speed	0.104	1	4	4	4	1.2	0.50	8.47%
Easy to adjust Tilt/Telescopic	0.053	1	3	4	4	1.2	0.25	4.32%
Stable in High Speed	0.104	1	4	4	4	1.2	0.50	8.47%
Structure Simple	0.033	1	3	3	3	1	0.10	1.70%

Set up HOQ of Steering system and Specification

Engineer need to convert the above 8 needs of steering system into actual technical solutions with clear set targets. Build the prototype with these pre set targets and then test on the actual vehicle and evaluate them whether meet the original customer needs and modify the system targets to the final version which could meet needs. Engineer need dig into the detail design of each component. The steering system design is not from sketch, the common requirements of steering system are same. The only 2 designs meet these requirements: Rack& pinion steering gear and recirculating ball type steering gear (old design). 95% of the passenger vehicles are using rack & pinion steering gear, the CSVP select former as well. Customers' needs can't cover all requirement of steering system. Engineer has to consider the regulation and homologation requirement for steering system. The other system of vehicle requires somehow needs of steering system which required consideration. With the development of electrics and software technology, driver assistance,

semi-automatic drive, and automatic drive have become the future trend. Considering the long duration of steering system, engineer requires reserving the above functions in steering system which requires the control rights of steering ECU. The steering system requirements as below table 5.

Establish the Q Company CSVP steering system solution aspects are as table 6. Evaluate the related relationships between the steering system requirements and technical measures, using score 0-5 to showing the related relationship, 0 means the demand and measure is irrelevant, 1-5 said the measures and requirements related to technology, 1 technical measures and requirements related to meet the needs of the impact is not big,5 said that the technical measures and requirements conform to and directly influence to meet demand. According to above criteria, the steering system needs and measures relationship matrix showing as table 7.

Table 5.Steering system needs

D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11
Steer Force sufficient	Column Energy absorption	EPS	Moderate cost	Light in Low Speed	Easy to adjust Tilt/Telescopic	Stable in High Speed	Structure Simple	Steer angle signal	Anti-Theft	Control Steering ECU

Table 6.CSVP Steering system technical solution aspects

M1	Rack force 9 KN	M5	Colum tilt and telescopic adjustment	M9	Column steer angle sensor
M2	Stroke Curve defined and stroke≥80mm	M6	Clamping force of adjust locking mechanism	M10	Three structure which meet regulation
M3	Column EPS	M7	Handle can't loosen during crash	M11	Electronic compatibility and software scalability
M4	Calibration of motor output	M8	Tie rod broken before Rack house		

Table 7.Matrix between steering needs and solutions aspects

Method / Demand	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11
D1	5	0	3	5	0	0	0	0	0	0	0
D2	0	5	0	0	0	1	3	0	0	0	0
D3	0	0	5	3	0	0	0	0	0	0	0
D4	0	0	5	3	0	0	0	0	0	0	0
D5	0	0	0	5	0	0	0	0	1	0	0
D6	0	0	0	0	5	3	3	0	0	0	0
D7	0	0	0	5	0	0	0	0	3	0	0
D8	0	0	0	0	0	0	0	5	0	0	0
D9	0	0	0	0	0	0	0	0	5	0	0
D10	0	0	0	0	0	0	0	0	0	5	0
D11	0	0	0	0	0	0	0	0	0	0	5

The customer's 11 requirements of steering system were transformed into major technical measures of steering system which engineer can understand. Furthermore the targets of these 11 aspects have to be set. When set the targets, all staffs keep the steering system is not only an independent system which servers others and entire vehicle in mind. The sub-system specifications covers sub-system needs and have clear targets which consider customers satisfaction and other system's needs. Steering system development has to adapt to platform requirements, have to meet both compact sedan and compact SUV. After analysis, the differences of steering system for different vehicles are in below aspects: rack force, column collapse stroke, tilt adjust angle, install position and geometry etc. Different parameters for variants are as table 8.

Table 8.Steering system aspects& parameter for different vehicles

Aspects and Parameter	Value（unit）	Sedan	SUV
Minimum rack force（routine use）	[Newton]	9000	9700
Collapse stroke (force 2.5-4 N)	[mm]	80-100	70-100
Tilt angle range（Up/Down）	[Degree]	+2 to -1.75	+2.25 to -1.5

The application of project management method in a CSVP steering system development

Apply the project management method to achieve the goals which set above. Project management manages timing, quality and cost. How to achieve the specification which created base on HOQ of QFD? A project team has to be set up to guarantee the relevant work to deliver the steering system which meets the specification and put on the vehicle to start validation and future serial production. In general, the project team is a cross function team in OEM organization. The team of steering system was a cross-function between OEMs and steering system supplier in order to project success as OEM can't succeed without supplier involvement.The initial design is very important which could guarantee the project quality (wide quality, not specified product quality) meet the specification from the design phase which conducted by supplier. Regarding the designs which have deviations, OEM clearly requires the deviations are under control or have improvement plan to mitigate the deviations. The general quality requirements were defined and constrained by <Tech Proposal>, <Compliance Matrix>, <Action plan of deviated technical design to spec>, <RASIC>, <DVP&R> which are all aligned between OEM and supplier.Other general requirements are easier for both parties which are not related to product development. In summary, they are the number of samples and sample plan, supplier quality system requirements and quality standards. The RASIC is very similar to work breakdown structure (WBS) which is a project management skill. The RASIC is more focus on the development responsibility of product development, while WBS is more related to the work of dismantling and to implement by the right person. It is actually different approaches but equally satisfactory results, guarantee the product development work can have a person or peoples responsible for.

In the automotive industry, the quality system set up in an earlier time, higher requirements, OEM will require the entire phase from product design to manufacturing delivery in accordance with the requirements of TS16949. Using FEMA to analysis product design and production procedures, to avoid the failure and minimize the failure impact. There were weekly open issue reviews conducted among the project team to review the status of relevant work progress. If there were problem which need more resources, the relevant project manager will escalate to both parties' top managements to get better resources and solutions avoiding delays.There are always new structure, new material in vehicle development which consume the most time in the automobile development. During the CSVP development, the energy absorbing of steering column was the critical technical needs of steering system due the vehicle architecture and energy absorbing path are unique for every individual vehicle. Base on the RAISC, OEM was in charge of vehicle timing; supplier need deliver the sub system according to vehicle timing and finished all relevant testing. Nowadays, both OEM and supplier will use finite element analysis by computer, and durability simulation and bench test (the bench referred here is vehicle simulation bench which could simulate vehicle driving on the road environment) innovation methods to reproduce testing condition and environment which could just by the test drivers in real road test environment or to complete the test field in past. The new testing measures can greatly reduce the verification time and cost of vehicle durability and modules, to create the conditions for the synchronous test for both system and vehicle.

Conclusion

The first vehicle XX 3 produced out of Q company CSVP get the second best ENCAP rating, which also get 60.5 score (Full score 62) in the first batch of year 2015 C-NCAP evaluation, 5+ Star overall rating. The media also gave a lot of praise on XX3.In summary，the sequence of vehicle sub system development: (1) Market Survey, understand the customer need on different vehicles and rank them by AHP. Combine the same needs, list the different needs of vehicle variants, and establish the platform needs. (2) Convert the vehicle into system needs. Consider regulation and homologation needs, take account into other system needs, and establish the 2nd level needs. Engineer translates the need easier to understand, conduct the potential customer survey, confirm

and rank the needs by method of AHP. (3) Analysis the existing and competitor performance on certain system and understand customer feedback and set the targets. (4) The engineering department to establish HOQ, specify requirements into technical measures and requirements, document them as system specifications. In the same platform, analysis the specified need on certain technical measures for different vehicles, and record in specifications. (5) Need qualified supplier to establish the system development cross function team between OEM and supplier. Using documents to define and constrains the reasonability and right between OEM and supplier. Conduct regular meeting to track the progress and issues, record the issues and progress into documents. Wish all related experience can help Chinese car practitioners design, produce better products according to customer demand. China could have a strong auto industry.

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