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Role of Statistical Thinking and Methods in Product Creation Process in Engineering

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Abstract

I worked as a faculty member in post graduate Department of Statistics for 24 years (June1980-Dec 2004) at University of Pune, Pune, India and from Jan 2005 onwards working at Engineering Research Center of TATA MOTORS, at Pune as a Reliability Analyst. This combination of job roles gave me opportunity to meet academicians as well as practitioners in engineering and statistics. What follows is not a research paper but my today's views about what may be the role of statistician/data analyst in the development of automobile. These are based on my experience at TML and it's supplier base. To me, role of statistics in product creation process (PCP) is to create models to explain variations in physics of failures. There is a good scope to develop a good graduate level course for engineering students which will help them to design and manufacture more robust products. After brief introduction of PCP, we have proposed a course in statistical methods for engineering students.

Keywords: New product introduction, prototype, testing of physical parts, robust design, accelerated testing, doe, noise factors, FMEA, reliability management

Introduction

As mentioned in abstract, my role was in Engineering Research Centre (ERC). ERC is design & develop center of TATA MOTORS, in India. It interacts with Marketing and customer Service to get inputs on requirements on new product and complaints on current products, Works with Manufacturing and Purchase Departments to understand difficulties/ new technologies in assemblies and manufacturing. All such inputs are used from concept to creation of new product.

If the company was to make only one car, the question would have the limited to nominal values of part dimensions which will determine the performance of the car. The car could had been a golden car. However, an average automobile company produces about thousand cars a day! Hence the question is about how the car to car variation can be minimized. Hence the quantifications of potential variations are upmost important. Further, car making is a four years project. To begin with work horses/mules are assembled using parts made up using soft tools. Once these cars meet designers' intentions, tooled parts are made to assemble salable prototypes. Once these are tested to ensure that customer requirements are met/exceeded, the manufacturing starts.

That means, drawing is a product of design engineer. The designer is responsible for selection of materials, dimensions, tolerances, and profiles. Further, the design needs to be manufacture/assembly and service friendly. This is thinking ahead of potential sources of variations due to service/assembly and manufacturing practices. In engineering such an approach is known as design for six sigma (DFSS). Understanding and quantifying potential variation at upfront, concept stage of engineering design and using that while selecting materials, tolerances on dimensions/profiles to avoid the failures during mission time of the vehicle, is "Statistical Engineering" for me.

I believes strongly that making of a car is a business which needs understanding of "Statistical Engineering".

In this short article, we give glimpse to the engineering activities and potential way to use statistical thinking and methodology.

To begin with, we give broad structure related to product creation, then give product life cycle, role of warranty analytics, state how assembly parameters depend on component parameters and lastly propose a course on statistical thinking/ methods in engineering curriculum.

Structure of an engineering industry:

Roughly, a structure of an automobile company that designs, manufacture sales and provide after sale service through dealers in India and abroad is as given in Table 1.

Table 1: A glance at Product creation in Engineering Industry- Departments and major activities

Department	Activities
Marketing	support sale, Offer AMC, determine advertisement policy, provide inputs to Design department on voice of customer and competitor information
Customer Service	Support after sale services, collect field complaint data, settle warranty complaints, conduct customer surveys,
Manufacturing	Manufacture parts, assemblies, and integrate vehicles, responsible for incoming/built in part/assembly quality, and outgoing vehicle quality, also
Design and development	Built in quality in design, and verification and validation of engineering quality-using virtual, digital and physical prototypes

It is to be stated that the departments and their activities in Table-1 are indicative and limited to direct product creation only. A sketch of product creation process (PCP) is given in Figure-1. In Statistical tools are embedded on PCP in Figure-4. The PCP starts with understanding customer requirements, commonly known as Voice of customer (VOC). Concept formulation, design, development, testing prototypes, manufacturing salable vehicles on production line, actual sales and after sale service are next mile- stones of PCP and are commonly known as voice of business (VOB)

In 1984, Kano et. al. [1], put forth a philosophy that there are two aspects of VOC, namely subjective and objective. Further, they developed a model where in the VOC is plotted on two dimensions, ‘state of physical fulfilment and state of satisfaction’. Based on the plot it is possible to categorize VOC as either “Must be” or “desirable” or an “attractive” feature of the customer satisfaction. Many automobile use Kano’s work on Attractive quality and must-be quality at concept stage of the product. For excellent review on this topic refer Lars Witell e.t al. [6].

During product creation, learning of earlier projects, in terms of things gone right/wrong (TGR/TGW), is used continually in current development. In most of the companies vehicle level customer complaint is analyzed till component level and root causes are documented on intra-web. Flow of such information is indicated in Figure-3. Managerial and statistical techniques used for problem solving are well-known as DMAIC/8-D methods. There is AIAG supplementary document called "Guidelines for Effective Problem Solving methods. Such information gets shared between the departments continuously, using IT based systems and becomes input for analyzing field complaints. Sometimes such an activity is called,' From field to bench'.

Product life cycle:

Many a times customer's requirement from an automobile product is, "a product that does what I want (function), when and where I want to use it (conditions), for as long as I want to use it (time/mileage)." It is macro level understanding of reliability/durability. Further customer does not want unscheduled failures, whenever there is a planned service he wishes to have down time as small as possible. Such customer needs, VOC, form the list of vehicle level (TOP) requirements. Planned third party surveys of existing and potential customers is one of the commonly used tool to collect VOC. JD Power conducts third party surveys [7] for passenger cars which are widely known in automobile world.

JDP surveys have various elements, namely, Apeal, Initial quality (IQS), Customer Satisfaction (CS), and Vehicle durability (VDS). These surveys are annual across all the continents and summary of these reports is available on the website of the company. Generally such surveys generate multi dimensional (about 225) attribute data and analyses of such data is a statistical problem. Design engineer cascades these vehicle level requirements to system, subsystem, aggregate and ultimately at component and software level requirements. While verifying the order is reversed. Verifying starts at component, software level and ends at vehicle level. Such a model is known as "V" model and is shown in Figure-1A and Figure-1B below.

Figure-1A: Requirements vs Testing

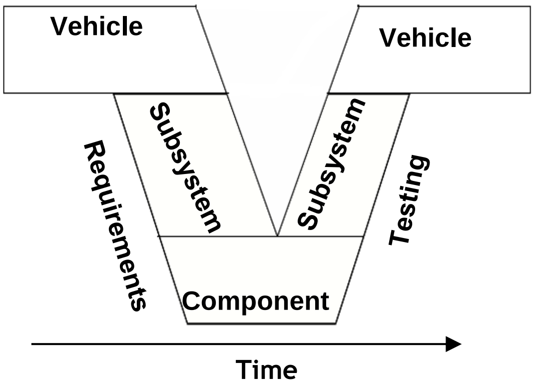
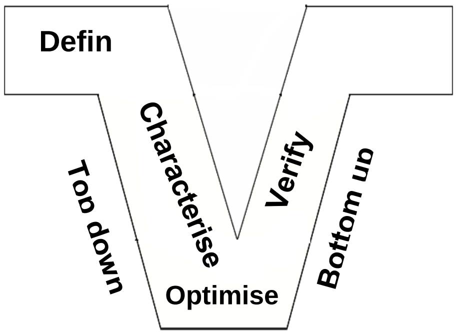


Figure-2B: Requirements vs Testing: Activities



At design stage, the aim of the designer is to design components and systems, which are reliable. Hence the designer may interpret the word reliability as,' "The ability of a component to perform a required function under stated conditions for a stated period of time." For example, if she is designing a starter motor, the function of Starter motor (SM) may be summarized as Number of cranks the SM is supposed to do with in specified time, under specified battery charge balance, thermal, vibration, and water/dust ingress conditions, which are voice of business (VOB).

Warranty data analytics:

At the beginning of design phase, designer has failure history of reference vehicle at his disposal. Such a data is available from field during warranty data (WD). Such a warranty data, has censored, missing values and there is lot of literature dealing with warranty analytics, refer, Wu [2,3] for detailed review.

Using warranty data, designer does the root cause analysis, as shown in Figure 4, generally, the root causes are specific characteristics of components. In general analysis is a complex statistical problem and needs support of numerical algorithms. Kristsov and Case [4], engineers from FORD MOROT company have given industrial practices to analyze warranty data. Such data contains following information.

1. Vehicle number, 2. month of manufacture, sale and complaint, 3. Type of complaint, 4. Repair- time, part and labor cost 5. Service station details

Such a data is used to answer many questions, two prominent of them are, first, what is the life of a specific component in terms of month in service and the second, what is the life of a specific component in mileage.

Life prediction using analysis of right and randomly censored data in presence of missing observations are primary tools to answer these questions. Once the component distributions are predicted, essentially using the structural approach of series and parallel systems, reliability of higher level systems can be predicted. Reader may refer Suzuki et al [5] for related references. Notionally, let $R_c(t)$ indicate the reliability of component 'c' at the end of age t, where t may represent month in service or life in mileage, as applicable.

The predicted reliability, $R_c(t)$ is base line indicator of what may happen in field if same component is mounted in same way and exposed to similar vehicle, in similar usage and environmental conditions. Comparing the usage and environmental changed conditions a call is taken whether the old component can be carried over or need a replacement. Reliability apportionment is a tool used at this stage to decide the minimal reliabilities of components to meet the target reliability of the higher level systems.

Hence 'design and development' of a component with the aim to surpass the targeted reliability becomes a process of 'reliability management', as shown in Figure 2.

Further, as shown in Figure 2, there are three major stages of 'Reliability Management', namely, 'Concept, 'Design and Development', and 'Manufacturing and Service. Activities, data sources and methods (Tools), used at each stage are summarized in Table 2.

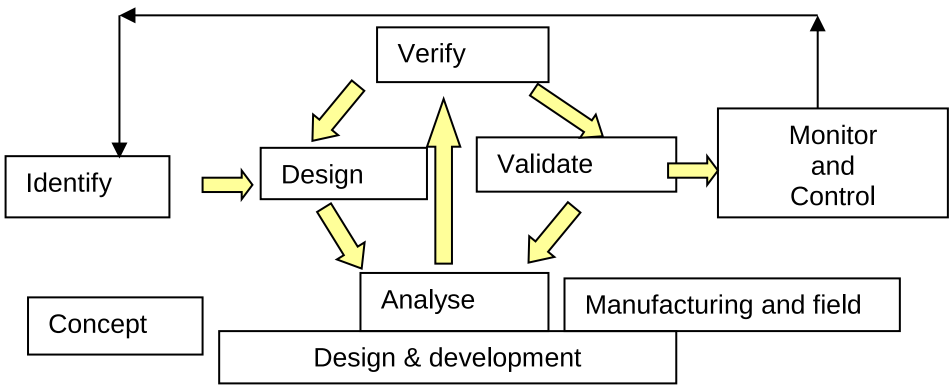


Figure 2: Reliability Management

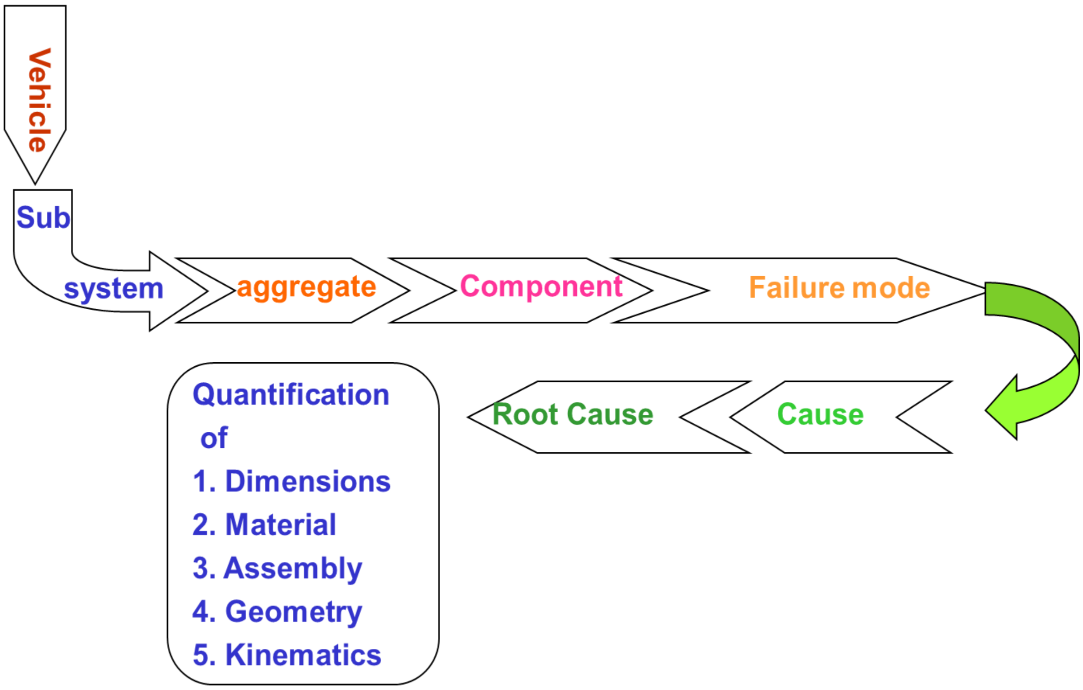


Figure 3: Relationship between Vehicle failure mode and actionable root causes.

Table 2: Data Sources and tools useful in reliability management

Stage	Activity	Data sources	Tools
Identify	The present status of reliability, Customers expectations, Environmental / usage conditions, Technology limitations/constraints, Required reliability	field failures, Internal/ supplier rejections, Third party surveys	House of Quality, Bench marking, Warranty data analysis, Reliability evaluation, Reliability Apportionment
Design	Drawings/circuit layouts	historical stackup tolerces, manufacturing scope-C_p/C_{pk}, service history	Fault Tree Analysis, DFMEAs: Product, system, subsystem, components

Stage	Activity	Data sources	Tools
Analyses	First cut rough estimates of product life / reliability / durability / serviceability	Digital validation: Strength, tolerance, thermal, NVH, durability	Reliability block diagrams, Reliability predictions: based on historical data / standard data bases, DOE- Parameter design & Tolerance design at digital level
Verify	Manufacture: 'PROTO' as per drawing, Verify weather the protos meet designer's intentions (fitment, functions, performances)	Parts with Design intended dimensions, profiles, material	Proto: Characteristic matrices, Process flow charts, PFMEAs, Highly accelerated physical tests (HALT), Accelerated tests, Test till failure using customer cycle and environment, Degradation tests using customer cycle and environment, Sample size determination, DOE, Prediction of reliability growth
Validation	Ensure that products made at production rate using final drawings meet customer requirements	Vehicles made using tooled up parts	All tools of verification, Production PFDs, PFMEAs and Control plans
Monitor and control	Assurance of quality over the period of time	Line/ field/service data	Acceptance sampling schemes, On line control charts, Audits / Ongoing reliability testing, C_p, C_{pk} studies, 8 D analyses based on field/ EOL complaints TGW /TGR leanings

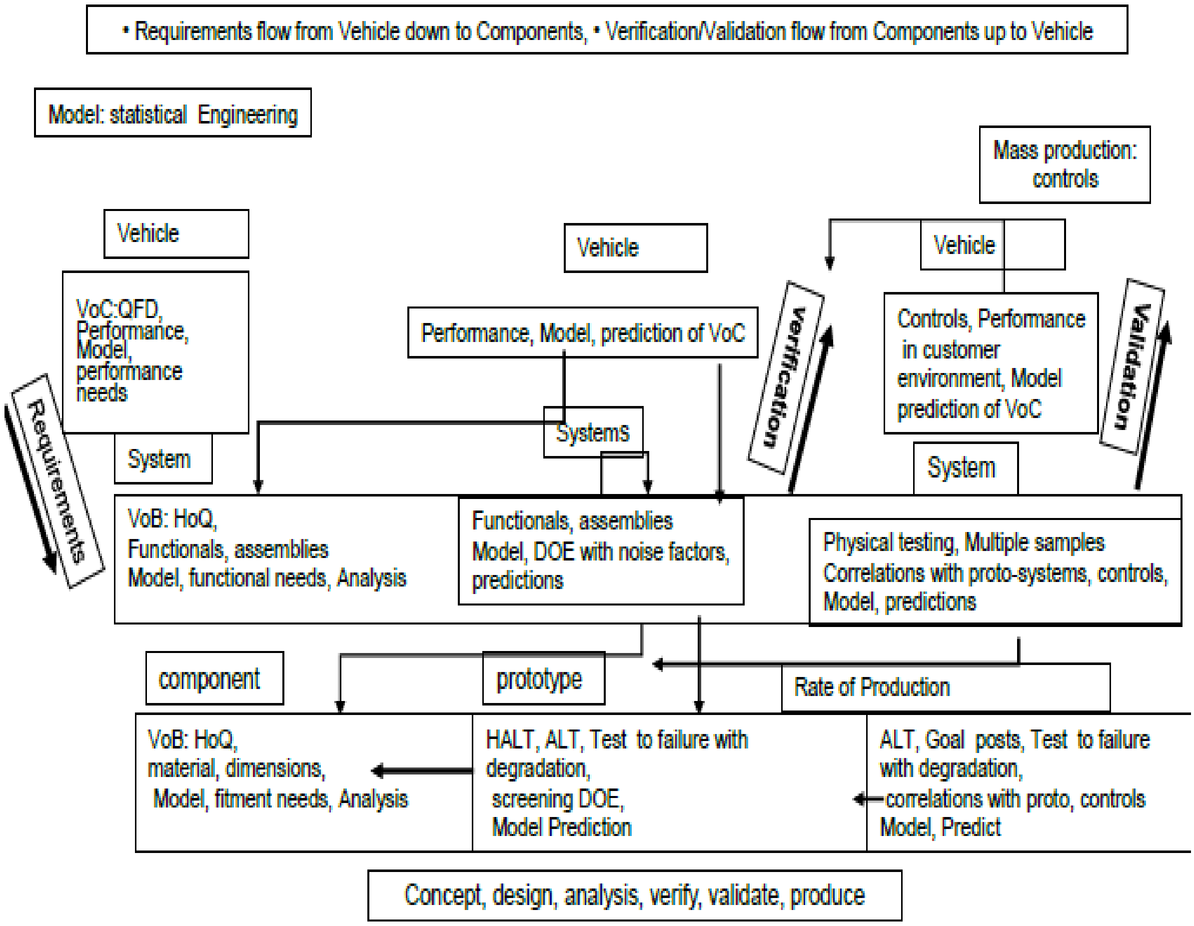


Figure 4: ‘V’ model with potential statistical tools

‘Requirements’ is a technical word used to state functional, performance and fitment related requirements to be fulfilled by a vehicle.

A vehicle is a coherent system of subsystems and components, and soft wares. Naturally, requirements flow from top (vehicle) to bottom (components/software), where as validation of these requirements flow from bottom to top.

Such a flow with the techniques needed to validation are shown in Figure 4.

Engineering Dependability structure

Dependability of downstream (TOP) parameters on upstream (bottom) parameters:

Consider the comfort and ride as a down stream parameter (Y5), it depends upon suspension geometry (y4), which depends upon compression/rebound forces of shock absorber (Y3), stiffness of bump stopper (y2), and spring (y1). Further spring stiffness depends upon free length (x1), coil diameter (X2), spring diameter (X3) and spring material (X4). In this case there is a hierarchical relationship between down stream parameter, Y5, and upstream parameters X1,…, X4. Many a times there are no close form known relationships. DOE at CAE level becomes one way to estimate the relationship of these parameters as well as effect of tolerance on upstream on down stream parameters. Such a branch is known as Design for six sigma (DFSS), Figure 5 A-C are used to indicate such dependability.

Figure- 5A:

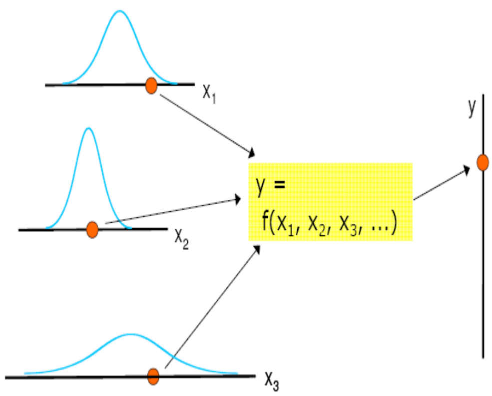
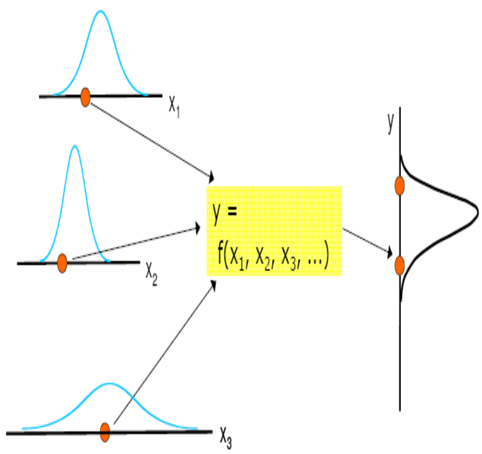


Figure-5B:



Dependability of down stream parameters on upstream parameters

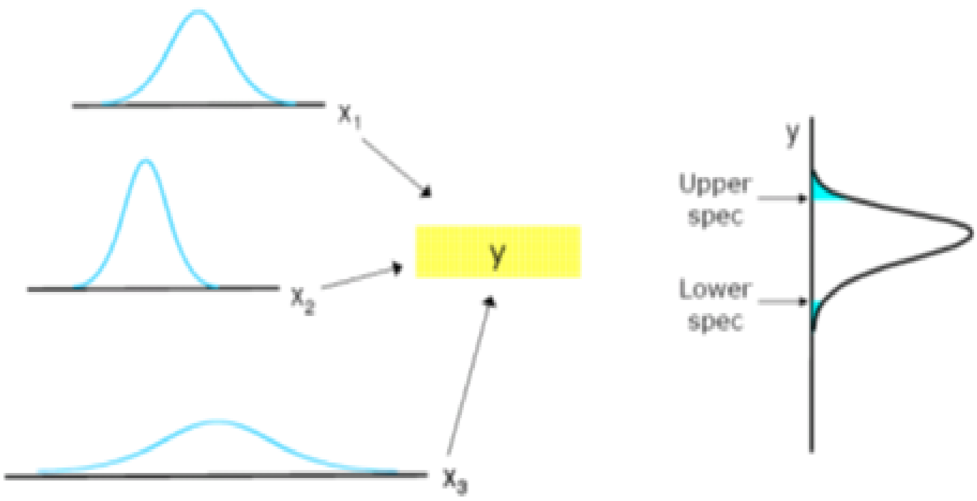


Figure 5-C: Ability to quantify the % fall out due to dependability

The development of transfer function (response surface) models and their use in managing interfaces is integral part of DFSS. Transfer function may be deduced from physical knowledge/geometry/ or estimated empirically by regression methods. (MBC module of Matlab)

To summarize, from Grove et al [8] we reproduce a pictorial, Figure 6A & B, as well as Tabular presentation, Table 3, of major engineering deliverables and potential statistical methods useful to carry out these tasks optimally.

Table 3: Statistical methods to enhance the quality of engineering tasks

Section	Engineering deliverable(s)	Statistical content
1	A product design concept that can achieve the functional target	Least squares fitting (straight line and quadratic curve) Residuals Statistical model for x/y data, incorporating random variation
2	A robustness assessment of the design concept	Introduction to designed experiments Two level orthogonal arrays Effect plots and sensitivity analysis

Section	Engineering deliverable(s)	Statistical content
3	An objective measure of piece -to-piece variation for an existing similar product	Run charts Probability distributions The normal distribution family, mean and st. dev. Statistical model of stable process variation Normal probability plots Sample mean and standard deviation
4	A transfer function for the product An optimized product design and an assessment of its functional performance	Transfer functions represented by quadratic response surfaces Contour plots Three-level full factorial designs Fitting a response surface transfer function by least squares Coded factor levels Interaction and the shape of the surface Statistical models with regressors
5	An estimate of the useful life of the product	Life data modeling Weibull distribution family Weibull plots Estimation of survival probabilities and percentiles Precision of estimates Use of simulation to study the effect of sample size on precision
6	A list of the manufacturing process parameters that affect an important product characteristic	Location and dispersion effects Use of a two level experiment to investigate location and dispersion effects Full and half normal plots of effects The link between regression analysis and effects analysis Confounding in small experiments

Section	Engineering deliverable(s)	Statistical content
7	A first draft of the transfer function for the manufacturing process	Response surface experiments Standard response surface designs Optimal response surface designs (brief treatment) Standard errors of regression coefficients Lack of fit
8	A measurement system with acceptable performance	Repeatability and reproducibility Statistical models of measurement system output Additive properties of variances Sums of squares and degrees of freedom One-way ANOVA
9	A refined version of the transfer function for the manufacturing process	Residual plots Options for reacting to outliers Use of t-ratios and p-values to identify redundant terms
10	An on-target manufacturing process optimized in terms of cost	Functional optimization subject to constraints (informal treatment)
11	An acceptable level of variation in process parameters	Capability indices Statistical model of unstable process variation Special and common cause variation Shewhart control charts

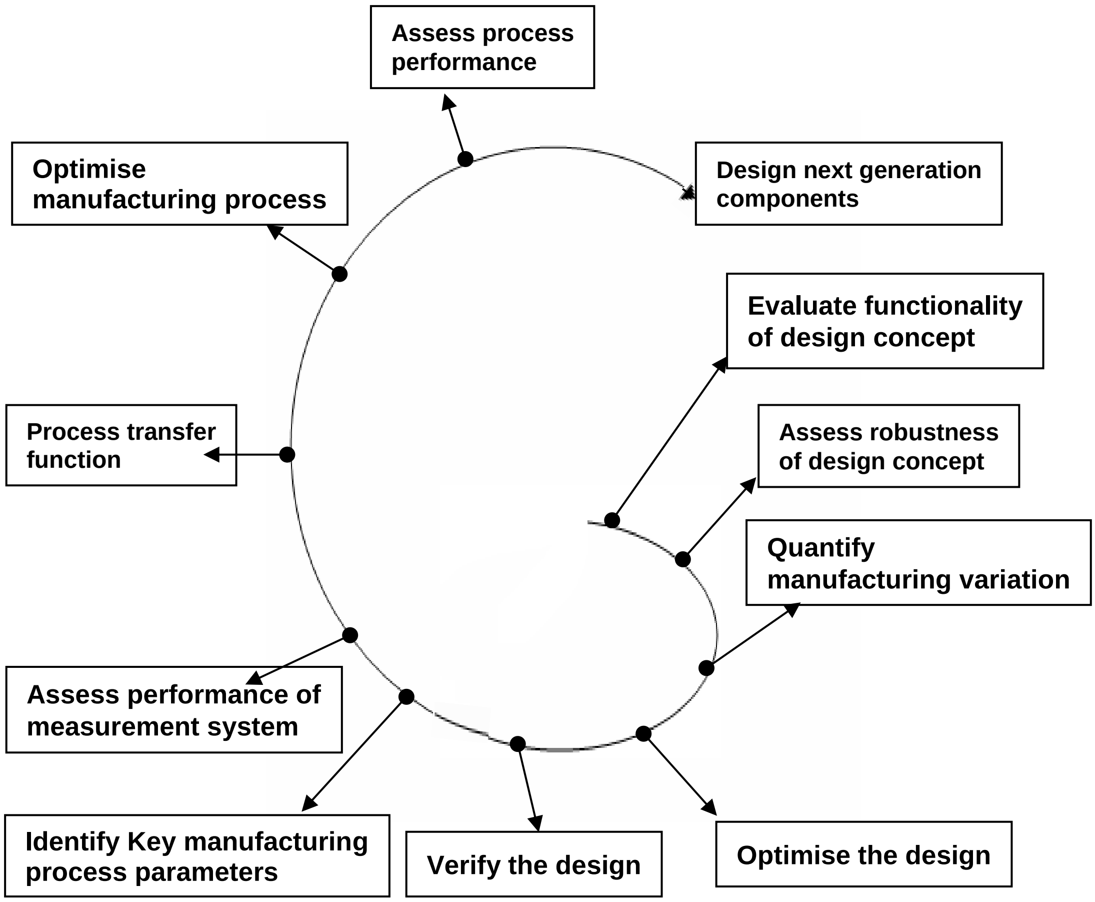


Figure-6A: Map of Engineering activities

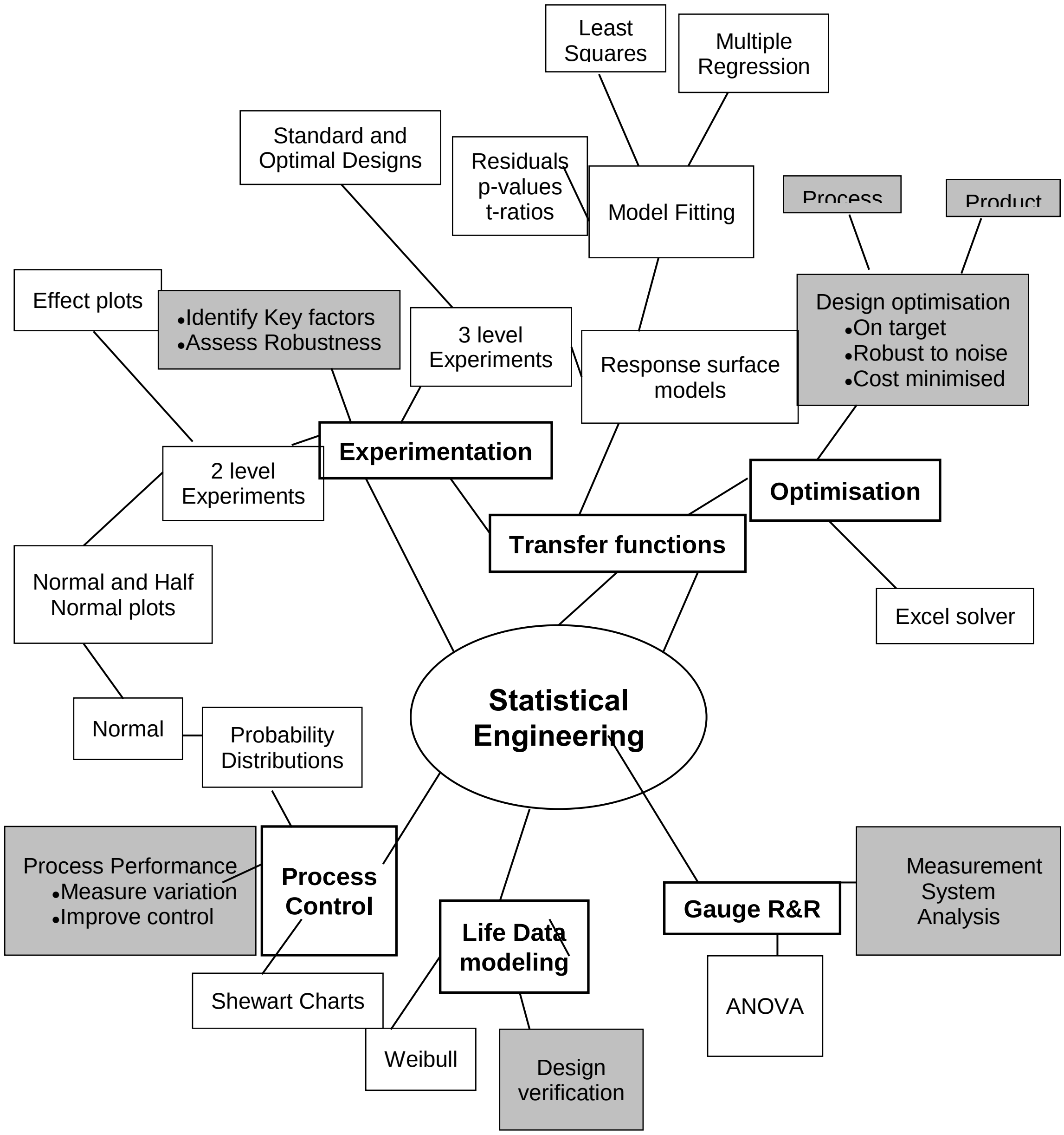


Figure-6B: Map of the relationship of engineering activities with statistical tools

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