OPTIMIZATION OF WARRANTY PERIOD AND PRODUCT RELIABILITY FOR AUTOMOTIVE PART SUPPLIER

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The Graduate School of Thai-Nichi Institute of Technology has been approved and accepted as partial fulfillment of the requirement for the Master's Degree

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THEERAPONG CHAMNANSRI : OPTIMIZATION OF WARRANTY PERIOD AND PRODUCT RELIABILITY FOR AUTOMOTIVE PART SUPPLIER. ADVISOR : DR. KOROKOT HEMSATHAPAT, 57 PP.

Warranty claim is one of the major cost factors for automotive part manufacturers who consider to improving their competitiveness in quality, cost and delivery. Key indicator to measure the product performance in actual usage condition is the product reliability .The purposes and results of this research were;

1) To study the optimization of product reliability which is the opportunity for automotive part supplier to take action to improve quality level or supplier can sell extended warranty to requesting customers. Weibull ++ Nevada chart format is recommended method for this research. This method can yield various benefits such as minimize warranty reserve cost, minimize risk of reserve shortfall (hamper customer service and hence deteriorate customer satisfaction) by using real warranty data and forecast the number of potential product claims.

2) To study the optimization of warranty period in contract between automotive part supplier and OEM for applied the appropriate warranty period for calculating warranty reserve budget. Typically, automotive part makers face a greater risk than car makers as they need to maintain quality of products longer. The result was shown the optimum warranty reserve period is 65 months and extended warranty has been calculated and possible to extend warranty period by adding12 or 24 months by set selling price in market at least 26% or 31%, respectively, higher than normal price.

3) To propose a methodology for analyzing warranty claim data by using Weibull distribution. The research results of the proposed methodology yield better warranty reserve forecast than the traditional method that the company were using. Thus, the company can manage the idle capital more efficient.

Graduate School Student's Signature……………………..
Field of Engineering of Technology Advisor's Signature……………………..
Academic Year 2014

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Theerapong Chamnansri

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Chapter 1
Introduction

1.1 Background and Problem Statement

Trend of Thailand automotive makers has dramatically increased from 300,000 cars produced in 2002 to 900,000 in 2010 or 3-time expansion (see Figure 1.1) [1]. Automotive part suppliers are improving their competitiveness in terms of quality, cost and delivery in order to meet customer expectation and satisfaction for their creditability and future growth. Thailand is the world's largest one ton pick-up truck production base and will increase capacity for passenger car production in the next 10 years [1] to support the global demand. The quality level of automotive parts must definitely be ascertained with various working conditions of weather, geographies, road conditions, and usage styles of drivers around the world. Product reliability is an indicator for optimizing warranty period and car mileage usage to mitigate risk of automotive supplier warranty claim.

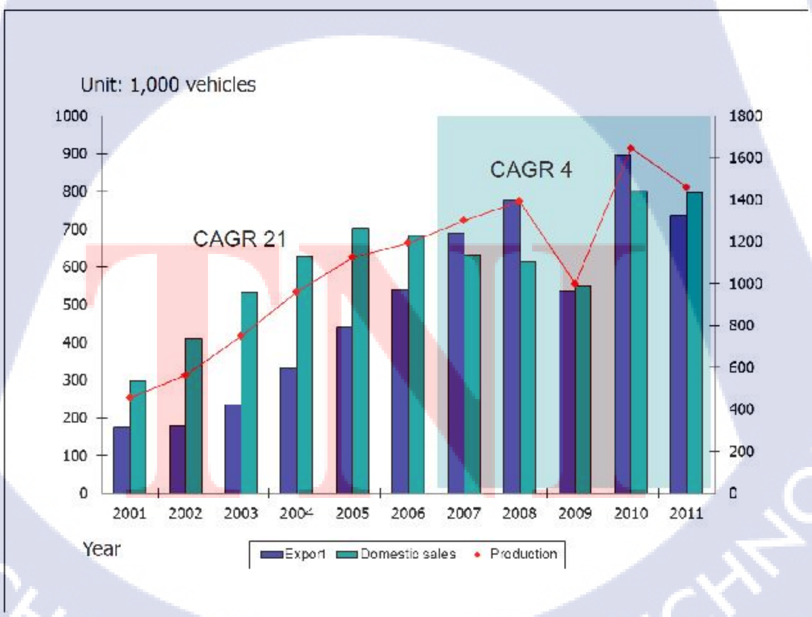


Figure 1.1 Trend of Automotive Business Growth in Thailand [2]

The aim of this study is an attempt to optimize product reliability and warranty period in order to minimize warranty reserve cost for overall cost reduction and feasibility study of selling extended warranty for users who require longer warranty period beyond normal warranty contract that Original Equipment Manufacturer (OEM) provided.

The optimum warranty period in customer contract can be one of the most important items to improve competitiveness of a company. A good warranty claim system including history tracking system which is a methodology for suppliers to analyze actual product reliability of each automotive part by using statistical tools to find probability of product reliability for usage condition in every state in unit of Month In Service (MIS). This information can be strategically used to set the suitable warranty period for a product.

Normally, car manufacturers assemble product for support global market around the world and Original Equipment Manufacturers (OEM) have requested automotive part suppliers to share warranty cost for field return products. Automotive part suppliers support this reason since they are aware of process and tool for forecasting warranty reserve cost based on sold part quantities to OEM. In addition, forecasting can be used to predict future part quantities that are going to sell to OEM for delivering to global market.

Literatures have been published regarding car owners are willing to pay additional cost for extended warranty period of their cars. OEM can include the extended warranty option up to 5-10% of normal selling price for support this special requirement from customer [3]. Automotive part suppliers also have a possibility to increase sale revenue and increase profit by selling extended warranty option without any additional cost. This research

63 attempts to propose a method for automotive part supplier to use warranty claim data to find optimization between warranty period and product reliability.

In a warranty contract between automotive part supplier and OEM, warranty reserve cost can be interpreted in two different viewpoints. High warranty reserve cost may be interpreted as low product reliability, risky business operation, or unstable production process causing the need of extra funding to support the future claims. On the other hand, low warranty reserve cost may be interpreted as high product reliability level, excellent product design, or high material cost which may exceed customer expectation. In some cases, unnecessary functions of over specification design can be considered as a waste.

Warranty data is comprised of claims data and supplementary data. Claims data is the data collected during the servicing of claims under warranty. Supplementary data is additional data such as production and marketing related data, items with no claim data that are needed for effective warranty management. Warranty data provide valuable information to indicate product quality and field reliability [4].

Product durability testing result is the significant factor for automotive part supplier to consider this input in order to use for predicting life time of product especially fatigue test. Fatigue is the failure of a component as a result of cyclic stress. The failure occurs in three phases: crack initiation, crack propagation, and catastrophic overload failure. The duration of each of these three phases depends on many factors including fundamental raw material characteristics, magnitude and orientation of applied stresses, processing history, and so on. Fatigue failures often result from applied stress levels significantly below those necessary to cause static failure [5].

Individual fatigue failures are impossible to predict. Failures from a given set of test conditions are distributed randomly within a fairly predictable distribution function. The most familiar type of distribution function is the normal or Gaussian distribution. Unfortunately, fatigue failures do not usually follow this type of distribution. Consequently, proper analysis requires more sophisticated statistical techniques. A normal distribution can be fully characterized with two parameters: mean and standard deviation. A more generic method of describing distributions is through the Weibull function.

This study utilizes Weibull distribution to find product reliability of an automotive part supplier according to its life data in order to forecast warranty reserve cost for each exporting market. Life data of a product can be briefly explained by a bathtub curve as shown in Figure1.2. The bathtub curve describes the relative failure rate of an entire population of products over time. Some individual units will fail relatively early (infant mortality failures), others will last until wear-out, and some will fail during the relatively long period typically called normal life. The first period is characterized by a decreasing failure rate and consists of failures caused by defects and blunders. The second period maintains a low and relatively constant failure rate and consists of random failures typically caused by "stress exceeding strength." The third period exhibits an increasing failure rate and consists of failures caused by wear-out due to fatigue or depletion of materials. In order to conduct life data analysis, warranty claim data is needed.

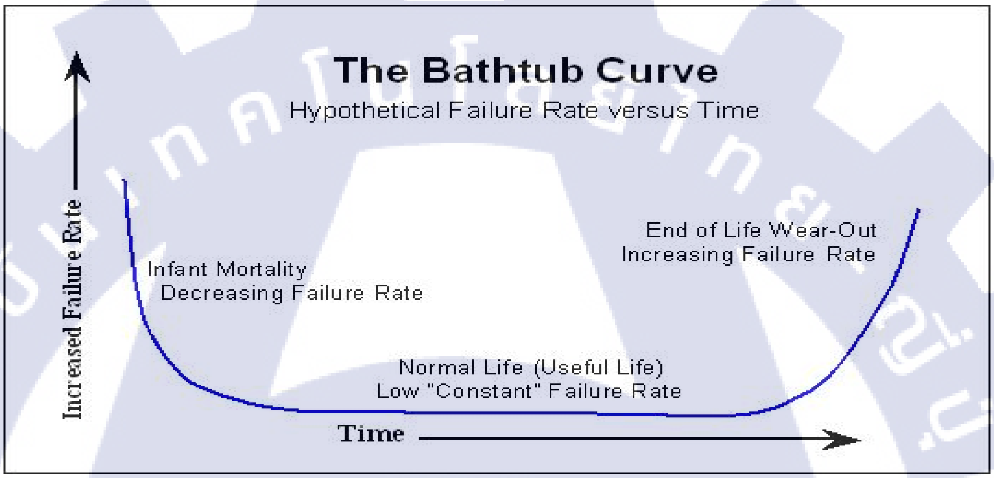


Figure 1.2 Life Data or the Bathtub Curve of a Product

One interesting point is the different warranty period between car manufacturer and automotive part supplier. Automotive part suppliers carry longer warranty period starting from an automotive part has been delivered from supplier location to car manufacturing plant plus lead time during car waiting for ship out from plant to dealer and dealer waiting for sale to the end user (see Figure1.3). Normally warranty term of a car is either 100,000 km mileage or 5 year warranty or 60 Month In Service (MIS) whichever comes first. One possibility of a supplier to mitigate warranty risk is to reserve warranty cost of a product longer than 5 years. For example, the warranty reserve can be 6 years (72 MIS) to absorb additional holding period in customer assembly plant and in dealer facility.

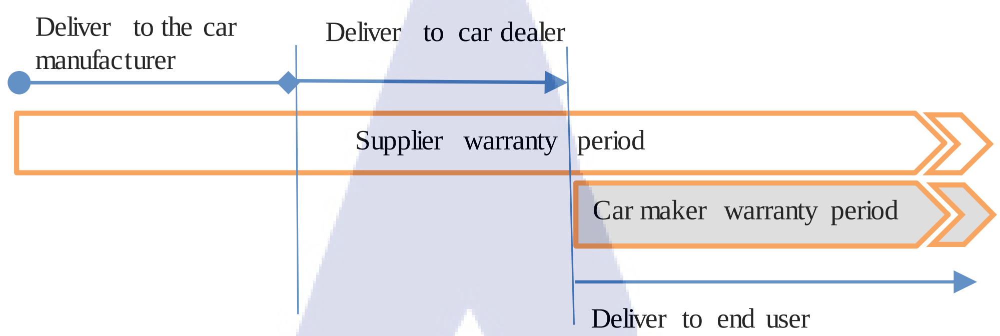


Figure 1.3 Differences in Warranty Period

The aim of this study is to find the optimization of automotive parts warranty period for the following benefits;

- Optimization of warranty reserve cost to reduce idle capital.
- Signaling of process capability improvement for the case of the reliability level of the product is lower than the warranty contract specification.
- Opportunity to re-grade product design application, re-design lower material grade in case of product reliability is higher than contract specification for cost reduction.
- Opportunity for selling extended warranty option in case of product reliability is higher than contract specification.

This researchuses a case study of one automotive part of asupplier who produce spropeller shaft for one ton pickup truck and Sport Utility Vehicle (SUV) which deliver to both domestic and oversea car manufacturers in order to assemble vehicle and sell to the end user saround the globe.

Normally a vehicle requires propeller shaft to drive power from engine through transmission that connect to the rear axle in order to transfer torque from engine to tract both rear wheel pass left shaft and right shaft for moving rear wheels based on differential ratio of rear axle in Front Engine Rear Wheel Drive (FR).

Four Wheel Drive (4WD) vehicle has higher traction than Two Wheel Drive (2WD) vehicle, and is able to prevent slip and slide while driving through unsmooth road condition, uphill road condition, wet and off road condition. Where the engine and axles are separated from each other like a four wheel drive and a rear wheel drive vehicle, it is the propeller shaft that serves to transmit the driving force generated by the engine to the axles (see propeller shaft layout in Figure 1.4).

Propeller shaft is one of the most important parts in drive train system which function is to drive vehicle in various conditions of user driving styles, road conditions, weathers and geographies. This has a direct impact to life time of propeller shaft that would be analyzed in this research.

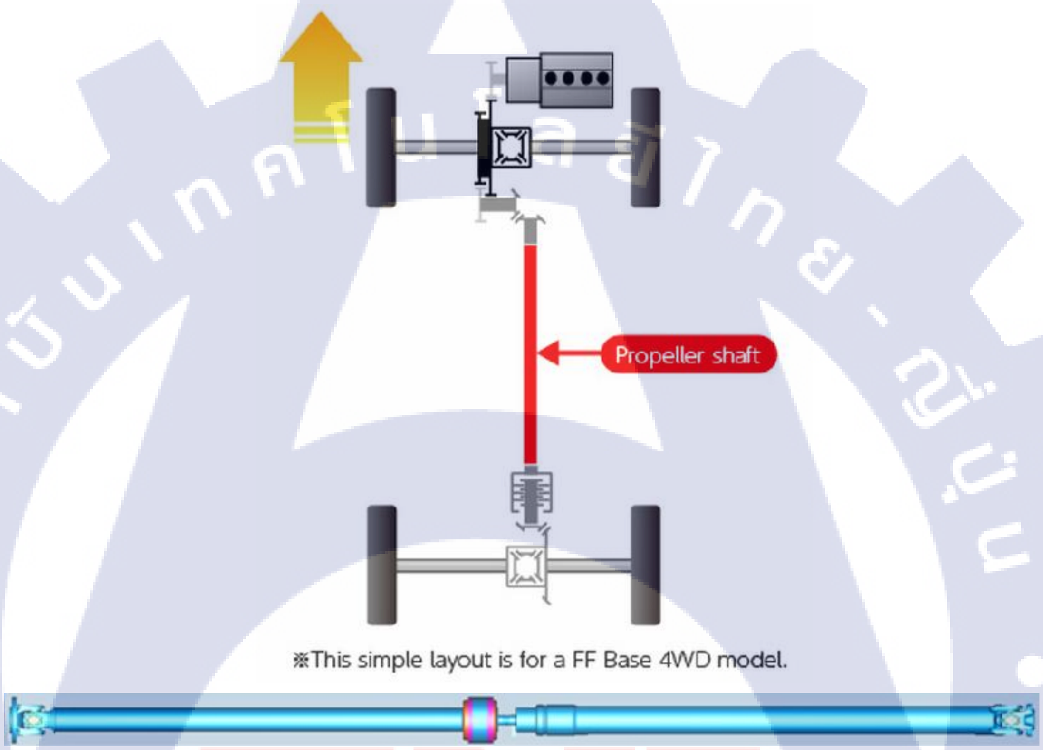


Figure 1.4 Propeller shaft layout

The difference sin countries, quality of road, vehicle usage culture, regulations and marketing directly lead to different warranty period setting specified by car manufacturer in warranty contract. Warranty period in Thailand, Taiwan, Korea, Malaysia, Indonesia, and Singapore is covered within 36 months/100,000 kilometers, whichever comes first. For Laos, Cambodia, Pakistan and India, warranty is covered within 24 months/50,000 kilometers, whichever comes first. For Australia, New Zealand and most European countries, warranty is covered within 36 months/100,000 kilometers, whichever comes first. In North America, warranty terms, conditions, and exclusions may be specified differently. Basic warranty, power trains, emission, paint and surface corrosion, and seat belt life may be covered differently based on term and condition such as mileage or Month In Service.

In this research, warranty term in Japan is reviewed and analyzed. Warranty coverage of 60 months/100,000 kilometers, whichever comes first in Japan is probably considered one of the longest warranty coverage in the world. The outcome of this research can be used in the real world business for setting warranty policy. Warranty analysis methodology can be proposed to automotive part manufacturers in Thailand for implementation to improve their competitiveness.

According to the warrant reserve policy, the manufacturer has to reserve a fraction of the sale price if any items fail within the warranty period. This implies that the manufacturer needs to set aside a fraction of the sale price to cover for subsequent refunds. The warranty claim costs are included in the cost structure of part automotive suppliers every single piece of products which are sold to customers. It would be kept warranty reserve budget in the warranty reserve fund for support warranty claim payment when customer shave issued invoice to request payment on monthly basis.

This warranty payment claim system is important for part automotive suppliers to ensure that company still have enough reserve budget and cash flow which are able to release payment to customers on time which related with credibility of supplier that likely affect to customer satisfaction and direct impact to supplier competitiveness when car manufacturers consider potential supplier for quoting their new parts on new business opportunity.

As mentioned in earlier, normally part automotive supplier is using traditional method to reserve warranty budget that higher reserve budget than normal warranty claim which actually receive from car manufacture. This case is creating over reserve budget which directly impact to cash flow of the company and may effect to variant of profitability which is not good for owner or stake holder of the company due to the real profit has not been reported in yearly balance sheet.

Estimating the reliability of products from warranty data, or field reliability estimation, is important for manufacturers as it can help in various aspects such as selecting warranty policy, planning maintenance regimes and preparing spare parts.

As warranty data reflect real operating environment and usage rate, they are more informative than testing data collected from laboratories. As such, estimating product reliability based on warranty data can provide manufacturers with more important information.[6]

Optimized warranty management deals with decisions making to optimize warranty period is reviewed and presented case study about methodology to calculate and compare various variation of warranty period which computed Weibull distribution by Weibull++ of Reliasoft software that vary warranty period base on possible warranty claim period between 60 months to 72 months. Then, comparison to find optimized warranty period by considering percentage error to compare result of warranty forecast estimation versus actual claim result in the specified period in order to use the information to considering for feasibility study of selling extended warranty.

Extended warranty calculation is reviewed in this research simulating longer period of warranty than original warranty contract that has been agreed with car manufacturers in order to serve some user who wanted longer warranty period for special usage propose. Also, extended warranty cost and warranty price setting are reviewed and calculated to presented opportunity for making profit improvement of part automotive supplier.

Organization will gain a competitive point when comparing with competitors in the same business which is probably able to increase customer satisfaction when company quote new part/new project to customer in a bidding process. This will be the only one additional option which proposes to customers during their decision making which could be strength of company to win the bidding of a big project in the future.

1.2 Objective

An optimization of warranty period methodology and feasibility of extended warranty sale for automotive part suppliers are proposed.

1.3 Scope of Research

Cycle of warranty process flow is described in this flow chart starting from product design, product manufactured and stored in a warehouse to deliver to keep in automotive manufacturer's warehouse and then assembled car in order to deliver to car dealer and end user. This study focuses on warranty data collection, warranty data analysis and product reliability analysis in order to forecast warranty reserve from the optimized warranty period to minimize warranty reserve and feasibility study for selling extended warranty.

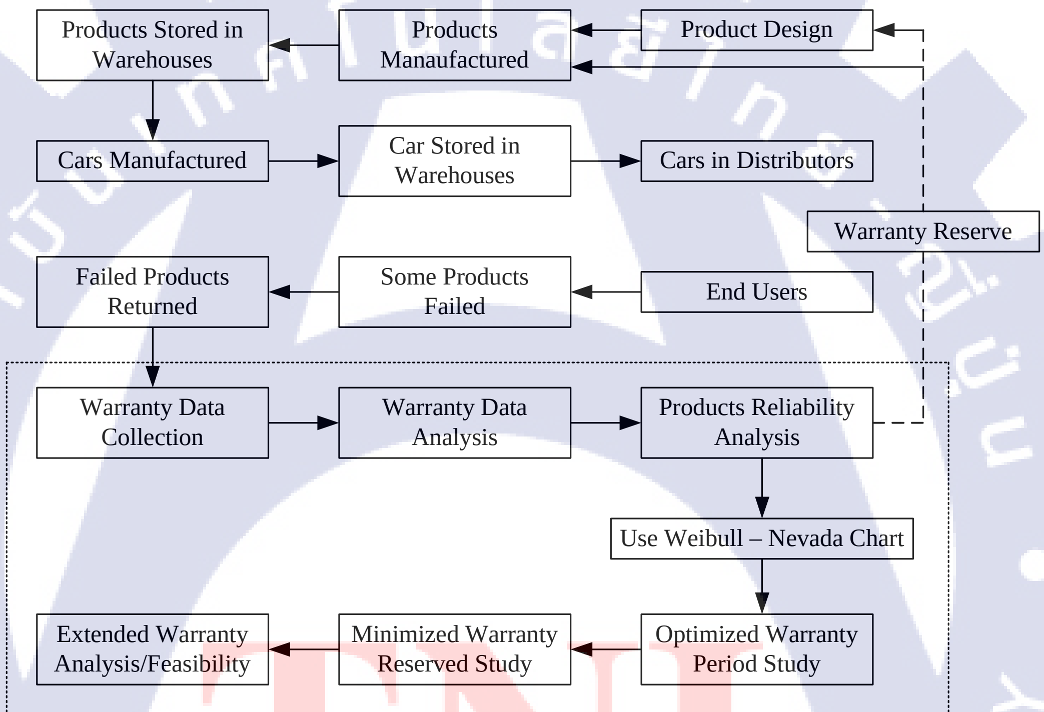


Figure 1.5 Warranty claim process flow chart of automotive part supplier

1.4 Expected Outcome

The outcome of this research is expected as the following benefits.

(1) Optimization of warranty reserve cost to reduce idle capital to improve company competitiveness in automotive business.

(2) Identifying reliability level of the product for product improvement and process capability either product reliability is lower or higher than warranty contract.

(3) Identifying opportunity for selling extended warranty in case of product reliability is higher than contract specification for increase income and sale revenue for company.

(4) Proposing warranty reserve analysis methodology to automotive part suppliers in Thailand.

1.5 Research Plan

The study began in the 3rd quarter of 2013as shown in table 1. The details of research plan are presented and shown the status of each step in the solid line.

Table 1.1 Research Plan

Task Name	2013						2014												2015	
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Meet advisor and discussed research tropic																				
Literature review																				
Optimize warranty cost - Research scope presentation																				
Research scope preparation																				
Study Markov theory and Reliasoft																				
Study Weibull distribution theory																				
Study current warranty claim - historical information																				
Prepare thesis proposal																				
Details of thesis																				
1) Analyse probability of warranty data by Weibull																				
2) Analyse probability of warranty data by Markov Chain & Revised to use Nevada format																				
3) Review result of warranty reserve for option A) , Option B) and Option C) with the																				
4) Compare result with current data A) VS B) and Option A) VS C)																				
5) Warranty extended study																				
Review result																				
International conference presentation at ICREN																				
Conclusion																				
Final thesis paper																				
Thesis defense																				

Chapter 2
Literature Review

2.1 Introduction

A warranty is a contractual obligation incurred by a manufacturer (vendor or seller) in a connection with the sale of a product. In broad terms, the purpose of warranty is to establish liability in the event of a premature failure of an item or the inability of the item to perform its intended functions [1]. Product warranty is becoming increasingly more important in consumer and commercial transactions, and is widely used to serve many different purposes [6]. Warranty data are comprised of claims data and supplementary data. Warranty claims data are the data collected during the servicing of items under warranty and supplementary data are additional data (such as production and marketing related, items with no claims, etc.) that are needed for effective warranty management [7].

Warranty data can be used to predict future claims, warranty cost and estimate product reliability for deciding on warranty policy. Reducing warranty cost improves the manufacturer's profit and helps to reduce the overall cost of the product. During the very early stages of product development is reviewed, however, traditional methods of warranty analysis are not well suited to predict the warranty costs during these early stages. Thus, product development personnel need better tools to make good predictions about the warranty costs so that they can make better decisions to reduce warranty earlier in product development [8].

Weibull distributions are the most commonly used distributions for analyzing life time data. Weibull distribution is considered to use in this research in order to calculate product reliability for predicting life time of a product.

2.2 Product Reliability

Reliability is the probability that a system will perform in a satisfactory manner for a given period of time when used under specified operating conditions. The meaning is the opposite with probability of failure shown in the below equation (2.1).

$$R = 1 - P_f \tag{2.1}$$

Where,

R : Reliability is the probability that unsatisfactory performance or failure will not occur.

P_f : Probability of failure is probability that a system will perform its intended function for a specific period of time under a given set of conditions which is able to explain by Figure 2.1.

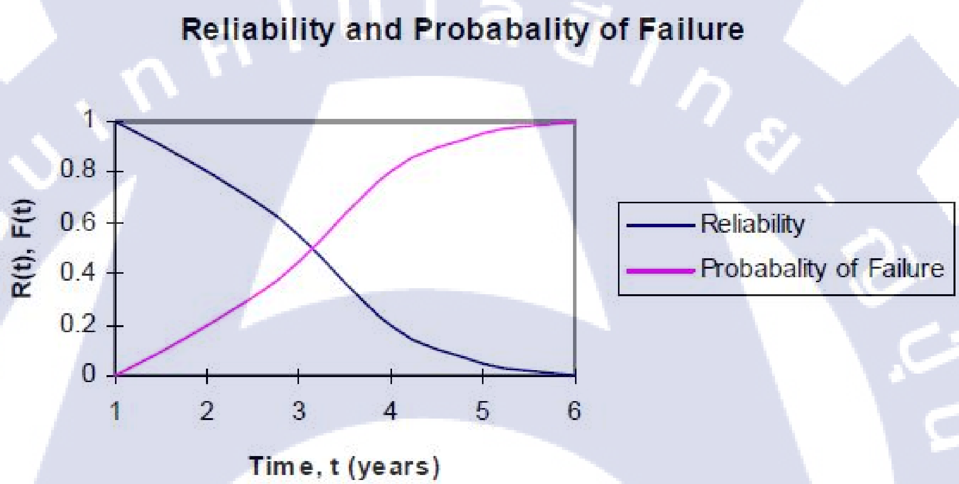


Figure 2.1 Relation between Reliability and Probability of failure

Definition of reliability is the probability of performing without failure, a specific function under given condition for a specified period of time. Reliability is a probability of performing without failure [9]. For this research, meaning of failure would be occurred after end user repaired and claimed to a car dealer in which, warranty contract is specified warranty condition, period of time and function of each components. It is possible to use various types of distribution for reliability analysis such as normal distribution, both one and two-parameter exponential distributions, and Weibull distribution.

Mathematical Definition of Reliability

The life of a device under reliability study follows a sequence that results in an observable time to failure. A new device is put into service, it functions acceptably for a period of time and then it fails to function satisfactorily. The observed time to failure is a value of the random variable T, which represents the lifetime of the device. T takes its values in an interval of the real numbers, R, most often in the interval [0, ∞). Since the lifetime of a device is represented by a random variable T, there is a probability distribution function (pdf) of T,

$$FT(t) = P(T \leq t), 0 < t. \qquad (2.2)$$

FT (t) is usually called the unreliability at time t. It represents the probability of failure in the interval [0, t]. The probability of failure in the interval (t_1, t_2] equals $F(t_2)-F(t_1)$.

Definition : The reliability function is:

$$R_T(t) = P(T > t) = 1 - FT(t) \qquad (2.3)$$

Thus, reliability is the probability of no failures in the interval [0, t] or equivalently, the probability of failure after time t. Sometimes T will take on only a countable number of values in R. This case, called the discrete case, occurs when T is a number of cycles, for example, or when the failure time can occur at only discrete points.

Most of the time, however, T will be a continuous random variable and its distribution F_T (t) will be a continuous distribution having a density F_T (t).

It is clear that to ensure good reliability the causes of failure need to be identified and eliminated [10]. Indeed the objectives of reliability engineering are:

• To apply engineering knowledge to prevent or reduce the likelihood or frequency of failures;

• To identify and correct the causes of failure that do occur;

• To determine ways of coping with failures that do occur;

• To apply methods of estimating the likely reliability of new designs, and for analyzing reliability data.

Reliability is important because unreliability has a number of unfortunate consequences and therefore for many products and services is a serious threat [10]. For example poor reliability can have implications for:

• Safety
• Competitiveness
• Profit margins
• Cost of repair and maintenance
• Delays further up supply chain
• Reputation
• Good will

2.3 Weibull Distribution

The Weibull distribution can be used to model failure time data with either an increasing or a decreasing hazard rate. It is used frequently in reliability analysis because of its tremendous flexibility in modeling many different types of data, based on the values of the shape parameter, β. This distribution has been successfully used for describing the failure of electronic components, roller bearings, capacitors, and ceramics. Various shapes of the Weibull distribution can be revealed by changing the scale parameter, α, and the shape parameter, β. The Weibull pdf (probability of distribution function) and cdf (cumulative distribution function) are commonly represented as

$$f(x,\alpha,\beta) = \frac{\beta}{\theta^{\beta}} x^{(\beta-1)} \exp\left[-\left(\frac{x}{\theta}\right)^{\beta}\right]; x>0, \alpha>0, \beta>0 \quad (2.4)$$

$$F(x,\alpha,\beta) = 1-\exp\left[-\left(\frac{x}{\alpha}\right)\right] \quad (2.5)$$

The two-parameter Weibull distribution has been extensively used in modelling failure times. A large number of models have been derived from the two-parameter Weibull distribution and are referred to as Weibull models. They exhibit a wide range of shapes for the density and hazard functions which makes them suitable for modelling complex failure data sets. [11].

Weibull distribution takes account of a non-constant hazard function. The survival function is

$$R(t) = e^{\left(\frac{t}{\eta}\right)^{\beta}} \tag{2.6}$$

where β is the shape parameter and η is the scale parameter or characteristic life. The characteristic life is the life at which 63.2% of the population will have failed. When β = 1, the hazard function is constant and therefore the data can be modelled by an exponential distribution with η=1/λ.

When β<1, we get a decreasing hazard function and

When β>1, we get a increasing hazard function

Figure 2.1 below, shows the Weibull shape parameters on the bath-tub curve.

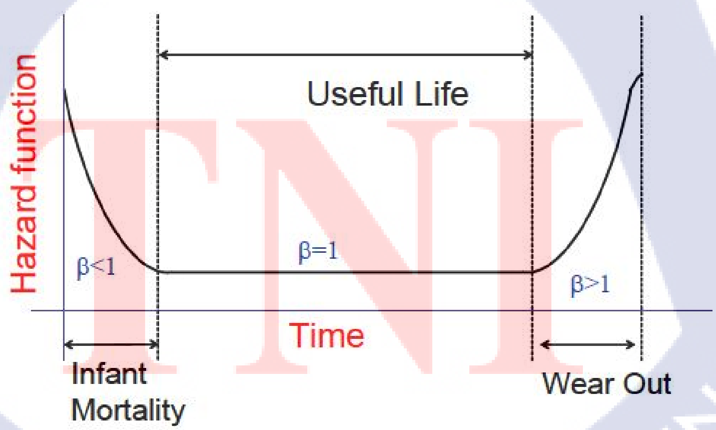


Figure 2.2 Bath Tub Curve and the Weibull distribution

There is also a three parameter version of the Weibull distribution and this is called the location parameter. It is sometimes called the failure free time or the minimum life. Other notation often used with the Weibull distribution is the B_n-life, this is the time by which n% of the population can be expected to fail (n is the proportion of failing) [10].

Weibull distributions are used for study reliability analysis for many researches, one of those have suggested a systematic approach to model selection to decide if one or more models from the Weibull models is appropriate to model a given failure data set [9]. By considering to choose Weibull modeling from various types such as Pseudo Weibull (Type II Model), models involving Weibull and inverse Weibull distributions and Bivariate Weibull models which using to analyze failure data. Weibull distribution are used for analyze many types of proposes such as data discrete versus life data, failure distribution analysis, failure forecasts predictions, engineering change test substantiation and maintenance planning [12].

The primary advantage of Weibull analysis is the ability to provide reasonably accurate failure analysis and failure forecasts with extremely small samples [12]. Also allow cost effective component testing. Another advantage of Weibull analysis is that it provides a simple and useful graphical plot of the failure data. The data plot is extremely important to the engineer and to the manager. The horizontal scale is a measure of life or aging. The vertical scale is the cumulative percentage failed. The two defining parameters of the Weibull line are the slope, beta, and the characteristic life, eta. The slope of the line, β, is particularly significant and may provide a clue to the physics of the failure. The characteristic life, η, is the typical time to failure in Weibull analysis. It is related to the mean time to failure.

This research also applied to use Weibull distribution for warranty data analysis. Calculating by two parameter Weibull distribution which is recommended distribution from the Weibull++ software. Both fatigue testing result analysis and warranty historical data analysis were featured in this software.

2.4 Field Reliability Estimation Based on Warranty Data

Estimating the reliability of products from warranty data, or field reliability estimation, is important for manufacturers as it can help in various aspects such as selecting warranty policy, planning maintenance regimes and preparing spare parts. As warranty data reflect real operating environment and usage rate, they are more informative than testing data collected from laboratories. As such, estimating product reliability based on warranty data can provide manufacturers with more important information [6].

When estimating product reliability from warranty claims data, however, we need to notice that warranty claims data are usually incomplete. Such incompleteness might result in biased inference. Warranty claims data are only collected from the early life of products and might provide little direct information about longer term reliability or durability. There are a series of research on estimating product reliability when incomplete censored data, for example, incomplete usage data, are presented. Approaches to dealing with the case of the incomplete usage data [6] such as Maximum Likelihood (MLE) is applied in this research for analyze warranty data without censored data for approach to estimating the parameters of survivor distributions.

2.5 Measuring Forecast Error

The overall accuracy of any forecasting model, moving average or other can be determined by comparing the forecasted values with the actual or observed values. If Ft demotes the forecast in period t, and At denotes the actual demand in period t, the forecast error (or deviation) is defined as:

$$\begin{aligned}\text{Forecast error} &= \text{Actual demand} - \text{Forecast value} \\ &= A_t - F_t\end{aligned} \quad (2.7)$$

Several measures are used in practice to calculate the overall forecast error. These measures can be used to compare different forecasting models, as well as to monitor forecast accuracy.

2.5.1 Mean Squared Error (MSE)

The mean squared error is arguably the most important criterion used to evaluate the performance of a predictor or an estimator. The mean squared error is also useful to relay the concepts of bias, precision, and accuracy in statistical estimation. In order to examine a mean squared error. Target is needed of estimation or prediction, and a predictor or estimator that is a function of the data.

$$\text{MSE} = \frac{\sum (\text{Forecast Errors})^2}{\text{n}} \tag{2.8}$$

2.5.2 Mean Absolute Deviation (MAD)

Mean Absolute Deviation (MAD) is method for measuring forecast error. MAD is most useful for independent measure of value. MAD can reveal which high-value forecasts are causing higher error rates. MAD takes the absolute value of forecast errors and averages them over the entirety of the forecast time periods. Taking an absolute value of a number disregards whether the number is negative or positive and, in this case, avoids the positives and negatives canceling each other out. MAD is obtained by using the following formula:

$$\text{MAD} = \frac{\sum [\text{Actual} - \text{Forecast}]}{\text{n}} \tag{2.9}$$

2.5.3 Mean Absolute Percentage Error (MAPE)

A problem with both the MAD and MSE is that their values depend on the magnitude of the item being forecast. If the forecast item is measured in thousands, the MADand MSE values can be very large. To avoid this problem, we can use the mean absolute percent error (MAPE). This is computed as the average if absolute difference between forecasted and actual values for n periods, the MAPE is calculated as

$$\text{MAPE} = \frac{\sum_{i}^{n} 100 \,|\, \text{Actual i} - \text{Forecast i} \,|}{\text{n}} (\text{Actual i}) \tag{2.10}$$

Chapter 3
Research Procedure and Methodology

In this Chapter, the research plan is described and discussed. The objective of this research is to examine product reliability from historical warranty claim data in order to find the optimum warranty period for automotive part suppliers. The proposed methodology of warranty data collection, calculation, and analysis are presented with a real data to specify the warranty period of a new part model based on historical data of the old model. The optimum warranty period will minimize the warranty reserve cost which is aligned with the product reliability and product life data.

3.1 Research Steps

The following 18 steps are the research procedure. They are as follows:

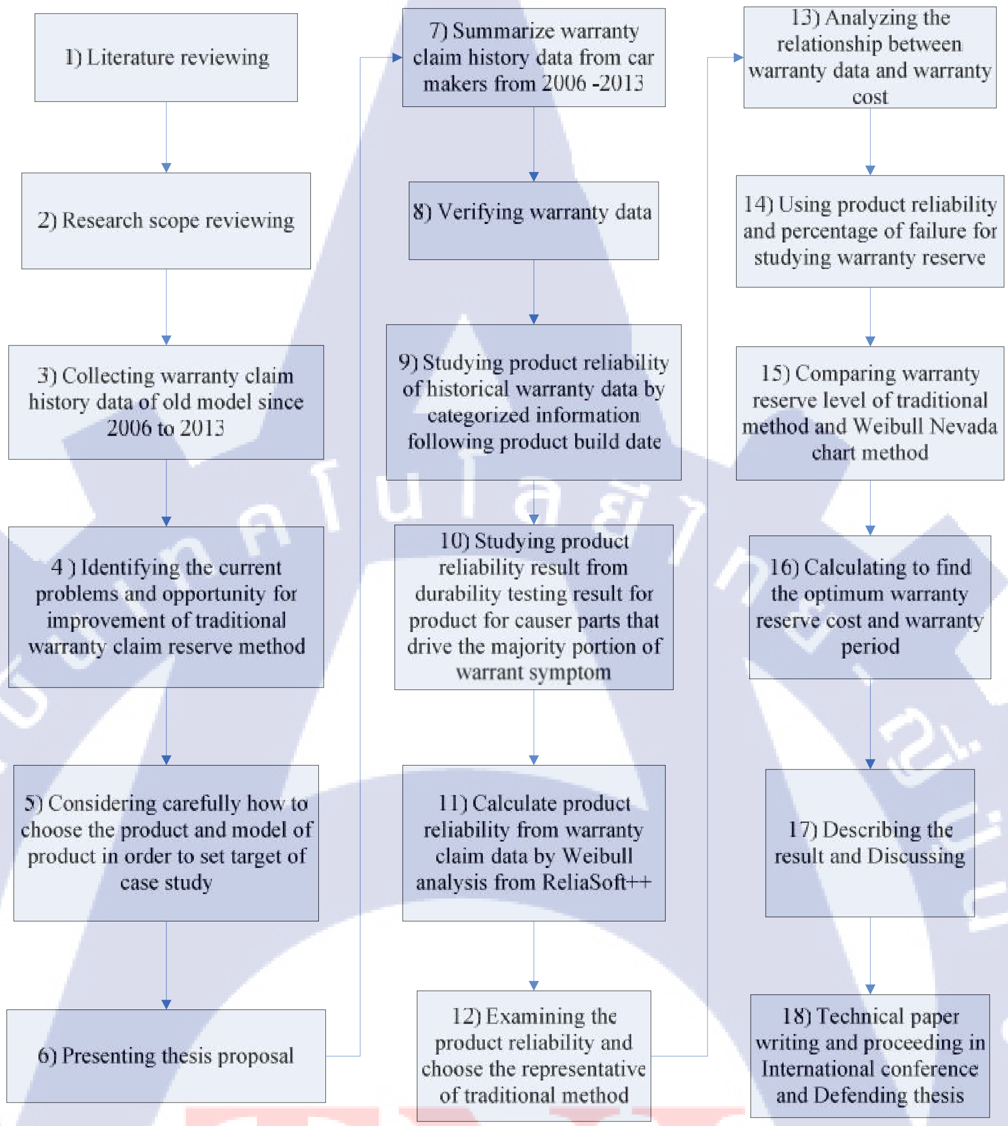


Figure 3.1 Research Steps

3.2 Warranty Claim History Data Collection

Normally, car makers return warranty claims data every month that includes information about part number, model, vehicle details, symptom of problem, occurrence date, mileage of occurrence, vehicle production date, MIS (Month In Service), claim cost and related component cost charged, invoice number and dealer ID. After receiving information, warranty engineer will investigate symptom of claimed parts. If the root cause of the symptom is from automotive part supplier, the warranty claim data will be recorded in the database by filling-in the following information as shown in Table 3.1 below.

Table 3.1 Warranty claim information from customer

A	P/N	37000JG300	37000JM100	37000JG00A	37000JM100	37000JM100
B	Model	TDBNLJW	FDBNLPZ	TDRNLFY	FDBNLSZ	FDBNLSZ
C	Vehicle T31: P32E S35: P32K	T31	S35	T31	S35	S35
D	CS	ZL	ZN	ZL	ZL	ZP
E	Replaced Parts	37000JG300	37000JM100	37000JG00A	37000JM100	37000JM100
F	QTY	01	01	01	01	01
G	Occurred Cost for Parts	59280	59540	59280	58500	58500
H	Occurred Cotst for labor	2927	5684	7621	7352	17454
I	Occurred Cost for others	0	0	0	0	0
J	Invoice amount for Parts	12745	25602	25490	25155	25155
K	Invoice amount for labor	629	2444	3277	3161	7505
L	Invoice amount for Others	0	0	0	0	0
M	Invoice amount Total	13,374	28,046	28,767	28,316	32,660
N	Dealer code	684	307	631	307	307
O	Milage	46	13	15	9	19
P	Vehicle Registration	803	807	0710	0803	0802
Q	Occurred Year Month	0905	0905	0803	0805	0807
R	Production Date	0711	0712	0705	0712	0711
S	Plant	W	W	W	W	W
T	Engine Type	QR25 528950	QR25 548754	MR20 372162	QR25 545991	QR25 529989
U	Chassis No.	6785	131540	002078	130299	124957
V	Invoice No.	5918569	6917717	4801662	78G2135	8841412
W	Reference No.	E9F00001	E9F00003	E9B00003	E9B00006	E9B00007
X	Market 1.Domestic 2.Oversea	2	2	2	2	2

Where;

A: Part Number of product

B: Model of Vehicle

C: Vehicle type

D: CS code (Customer symptom code)

E: Replaced parts

F: Quantity

G: Occurred cost for parts

H: Occurred cost for labor

I: Occurred cost for other

J: Invoice amount for parts

K: Invoice amount for labor

L: Invoice amount for other

M: Invoice amount for total

N: Dealer code

O: Mileage

P: Vehicle registration date

Q: Occurred month

R: Vehicle production date

S: Vehicle assembly plant code

T: Engine type

U: Vehicle chassis number

V: Invoice Number

W: Reference

X: Market of end user (Domestic or Oversea)

More details information from car manufacturer and dealer provide valuable information for automotive part supplier to use this information to investigate problem from the field in order to take immediate action and feedback this quality level status to their manufacturing process to correct, adjust, improve or monitor machine and/or process condition to prevent similar root cause problem for current production process. Also, details of warranty costs are reported and can be collected in warranty claim database for tracking status and forecast of warranty reserve.

3.3 Warranty Data Verification

Details of each warranty problem are investigated by warranty engineer whether it is related with the company component part or not by initial verified claimed parts from the CS code from customer report that can identify symptom of problem and problem characteristic. If the problem is not related, warranty engineer have to response back to the car makers and delete unrelated cases from warranty data. For some cases, warranty engineer requests car dealer to ship problem parts back for investigation including tear down all of components for conducting failure analysis. For the remaining cases, they will be used for warranty analysis and warranty reserve forecasting in the future.

3.4 Product Reliability Calculation by Weibull ++ Software

Product reliability and distribution can be calculated by Weibull analysis from Relia Soft++ using warranty data by input mileage of claimed parts in the software and specify details of distribution that fit the dataset. Then the software will automatically fit the product life data curve and generate the probability of failure (β) of the curve in every life cycle stage. In addition, conditional reliability, and conditional probability of failure, reliability life, mean life and failure rate can be obtained from the software. The critical point of this step is the result of product reliability that uses Weibull analysis for fitting and analyzing life data. Weibull analysis has an ability to provide reasonably accurate failure analysis and failure forecasts with extremely small samples and is able to provide a simple and useful graphical plot of the failure data that can explain product reliability characteristic by slope of graph, trend of the Weibull plot, and beta (β) indicator.

$\beta < 1.0$ indicates infant mortality

$\beta = 1.0$ means random failures (independent of age)

$\beta > 1.0$ indicates wear out failures

	Time Failed (Cyc)	Subset ID 1
1	77080	1010 Nm, 3Hz, 1:0.6 ratio
2	79442	1010 Nm, 3Hz, 1:0.6 ratio
3	83292	1010 Nm, 3Hz, 1:0.6 ratio
4	83703	1010 Nm, 3Hz, 1:0.6 ratio
5	95875	1010 Nm, 3Hz, 1:0.6 ratio
6	135046	1010 Nm, 3Hz, 1:0.6 ratio
7	198820	844 Nm, 3Hz, 1:0.6 ratio
8	238519	844 Nm, 3Hz, 1:0.6 ratio
9	243571	844 Nm, 3Hz, 1:0.6 ratio
10	243962	844 Nm, 3Hz, 1:0.6 ratio
11	390339	844 Nm, 3Hz, 1:0.6 ratio
12	408612	844 Nm, 3Hz, 1:0.6 ratio
13	726652	664 Nm, 3Hz, 1:0.6 ratio
14	779812	664 Nm, 3Hz, 1:0.6 ratio
15	855650	664 Nm, 3Hz, 1:0.6 ratio
16	1035973	664 Nm, 3Hz, 1:0.6 ratio
17	1123670	664 Nm, 3Hz, 1:0.6 ratio
18	1342075	664 Nm, 3Hz, 1:0.6 ratio

Figure 3.2 Data Input in Weibull++

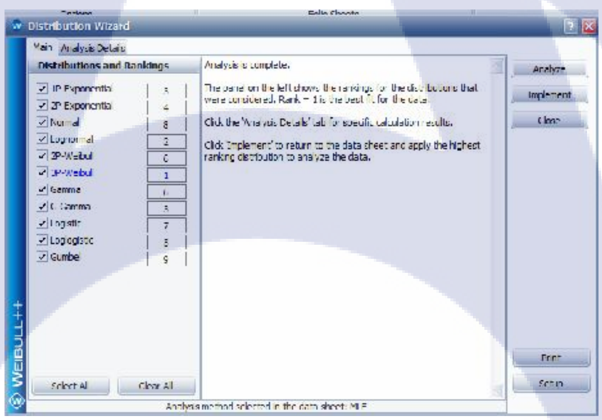


Figure 3.3 Distribution Analyzed by Weibull++

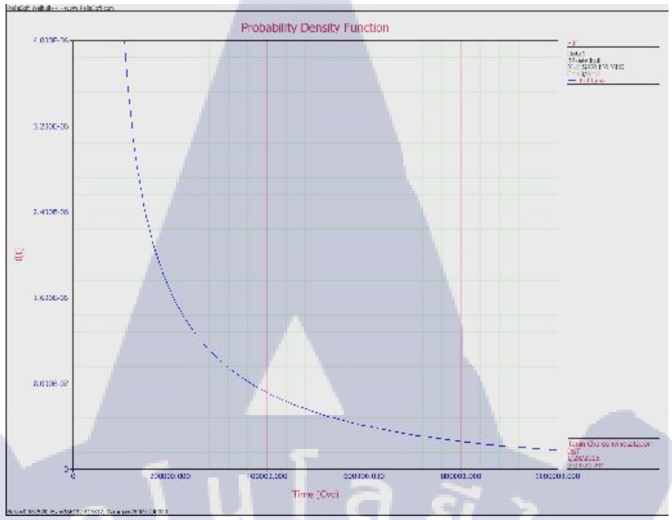


Figure 3.4 Example of GraphicalPlot by Weibull++

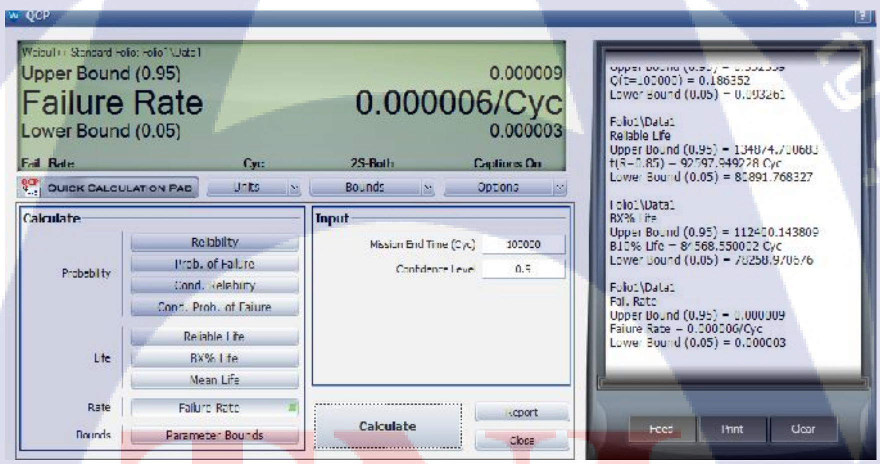


Figure 3.5 Quick Calculation Pad in Weibull++

3.5 Analysis by Nevada Chart Format

The product reliability is analyzed. Warranty claim data can be used to find product reliability by comparing with remaining product in service for warranty reserve cost estimation. Warranty analysis by Nevada chart format in ReliaSoft++ can be easily accomplished. The Nevada chart folio correlates two data axes by Y representing selling month and X representing MIS of warranty claim products. This Nevada chart format allows warranty engineers to monitor the level of product reliability closely.

Forecast of warranty return is calculated by Nevada chart format method that is really a good tool to minimize warranty reserve because we can input required reserve period that software can calculate and report out about quantity of claim forecast and warranty cases in the coverage period. Also, this method is suitable for automotive part supplier to monitor warranty reserve.

3.5.1 Input Quantity in Service of Each Production Month

Part population is the product sale quantity that automotive part supplier has sold to customers from 2006 to 2013.

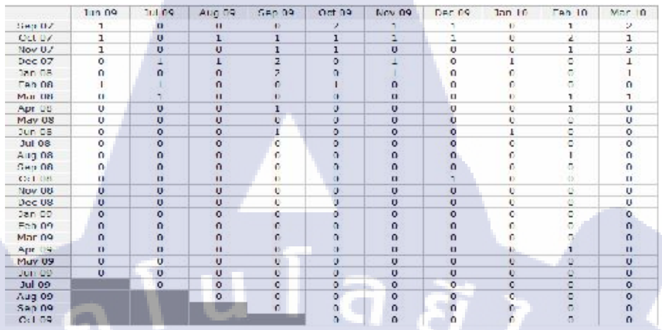
Period	Quantity In-Service
Jan 08	3168
Feb 08	3024
Mar 08	6120
Apr 08	5472
May 08	6352
Jun 08	8712
Jul 08	6858
Aug 08	12672
Sep 08	10872
Oct 08	9936
Nov 08	11664
Dec 08	9864
Jan 09	3456
Feb 09	8568
Mar 09	13536
Apr 09	7272
May 09	6984
Jun 09	15532
Jul 09	12600
Aug 09	12451
Sep 09	11880
Oct 09	14544
Nov 09	11016
Dec 09	7128
Jan 10	12240
Feb 10	12888

Sales | Returns | Forecast | Plot

Figure 3.6 Table for Input Quantity in Service in Weibull++

3.5.2 Input Warranty Claim Case of Each Production Month

Warranty claim case of each production month of warranty data by Y-axis is information that automotive part supplier receives from customer every month. After warranty engineer reviews the claim information including separate raw data following by part production month in X-axis of each individual claim case. Then summary of the claim cases of each production month is input in table every month after receiving warranty return from customer. Suspended period of warranty period is varied based on the following times: time since parts deliver to customer, time at storage at customer assembly location, time at vehicle storage at the office until vehicle has been sold to customer by dealer. For this study, we vary warranty period from 60 months to 72 months in order to find the optimum warranty period with the product reliability level.



	Jun 09	Jul 09	Aug 09	Sep 09	Oct 09	Nov 09	Dec 09	Jan 10	Feb 10	Mar 10
Sep 07	1	0	0	0	2	1	1	0	1	2
Oct 07	1	0	1	1	1	1	1	0	2	1
Nov 07	1	0	0	1	1	0	0	0	1	3
Dec 07	0	1	1	2	0	1	0	1	0	1
Jan 08	0	0	0	2	0	1	0	0	0	1
Feb 08	1	1	0	0	1	0	0	0	0	0
Mar 08	0	1	0	0	0	0	0	0	1	1
Apr 08	0	0	0	1	0	0	0	0	1	0
May 08	0	0	0	0	0	0	0	0	0	0
Jun 08	0	0	0	1	0	0	0	1	0	0
Jul 08	0	0	0	0	0	0	0	0	0	0
Aug 08	0	0	0	0	0	0	0	0	1	0
Sep 08	0	0	0	0	0	0	0	0	0	0
Oct 08	0	0	0	0	0	0	1	0	0	0
Nov 08	0	0	0	0	0	0	0	0	0	0
Dec 08	0	0	0	0	0	0	0	0	0	0
Jan 09	0	0	0	0	0	0	0	0	0	0
Feb 09	0	0	0	0	0	0	0	0	0	0
Mar 09	0	0	0	0	0	0	0	0	0	0
Apr 09	0	0	0	0	0	0	0	0	1	0
May 09	0	0	0	0	0	0	0	0	0	0
Jun 09	0	0	0	0	0	0	0	0	0	0
Jul 09		0	0	0	0	0	0	0	0	0
Aug 09			0	0	0	0	0	0	0	0
Sep 09				0	0	0	0	0	0	0
Oct 09					0	0	0	0	0	0

Figure 3.7 Table for Input Claim Quantity by Production Month in Weibull++

After choosing the appropriate parameter, the warranty forecast is calculated by software showing warranty case that has possibility to occur in the next 12 months period.

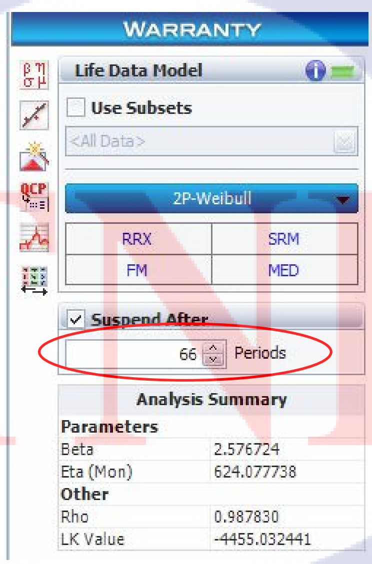


Figure 3.8 Input Warranty Period in Weibull++

	Mar 12	Apr 12	May 12	Jun 12	Jul 12	Aug 12	Sep 12	Oct 12	Nov 12	Dec 12	J
Mar 10	0	0	0	0	0	0	0	0	1	1	
Apr 10	0	0	0	0	0	0	0	0	0	0	
May 10	0	0	0	0	0	0	0	0	0	0	
Jun 10	0	0	0	0	0	0	0	0	1	1	
Jul 10	0	0	0	0	0	0	0	0	0	0	
Aug 10	0	0	0	0	0	0	0	0	0	0	
Sep 10	0	0	0	0	0	0	0	0	0	0	
Oct 10	0	0	0	0	0	0	0	0	0	0	
Nov 10	0	0	0	0	0	0	0	0	0	0	
Dec 10	0	0	0	0	0	0	0	0	0	0	
Jan 11	0	0	0	0	0	0	0	0	0	0	
Feb 11	0	0	0	0	0	0	0	0	0	0	
Mar 11	0	0	0	0	0	0	0	0	0	0	
Apr 11	0	0	0	0	0	0	0	0	0	0	
May 11	0	0	0	0	0	0	0	0	0	0	
Jun 11	0	0	0	0	0	0	0	0	0	0	
Jul 11	0	0	0	0	0	0	0	0	0	0	
Aug 11	0	0	0	0	0	0	0	0	0	0	
Sep 11	0	0	0	0	0	0	0	0	0	0	
Oct 11	0	0	0	0	0	0	0	0	0	0	
Nov 11	0	0	0	0	0	0	0	0	0	0	
Dec 11	0	0	0	0	0	0	0	0	0	0	
Jan 12	0	0	0	0	0	0	0	0	0	0	
Feb 12	0	0	0	0	0	0	0	0	0	0	
Total	27	28	29	30	31	32	34	34	35	36	

Figure 3.9 Warranty Forecast from Weibull++

3.6 Comparing the Warranty Forecast Between Traditional Methods and Weibull Method

The representatives of traditional warranty reserve methods are chosen by comparison results of 3 methods A, B and C.

A) Traditional method is using fixed percentage number of based on annual product-sale quantity in last year to forecast warranty reserve in the next year.

B) Using failure rate of product reliability which is calculated based on lowest reliability result of product build month by separating calculation from database of actual warranty return.

C) Using durability testing result and failure rate to find product reliability.

Then, comparing product reliability results of those 3 methods and choose the lowest reliability result for comparison with Weibull method in the next step.

After representatives of the traditional method have chosen, then using that method to comparing warranty prediction with Weibull analysis in Nevada chart format by calculated warranty forecast of Y2014 based on both methodologies.

In case of predicting failure rate from Weibull analysis method is lower than the prediction of failure rate from traditional method. The method that gives the lowest error of warranty prediction will be chosen.

To confirm correction of decision making by comparing among traditional method, Weibull method and actual warranty claim and validate the accuracy of warranty forecasting of both methods with real data which company actually have received warranty claim from market by separating them in different window time periods. In case of warranty prediction is within actual claim which mean, the calculation is correct and have no risk for cash short fall.

3.7 Calculating Optimization of Warranty Period

Calculation to find the optimum warranty period by comparing actual warranty reserve cost versus warranty reserve cost by Weibull analysis in Nevada chart format. The optimum warranty period should be obtained by varying the length of supplier warranty period from 60 months to 72 months. By considering warranty period that shows the lowest percentage error and stable overtime.

The optimum warranty period reserve is presented from the result of warranty forecast of different warranty period.

3.8 Warranty Cost Calculation

In monthly warranty claim report, car manufacturer receives information about claim cost that occurred during car dealer have repaired/replaced components to the end user. This information is used to calculate warranty cost per case for estimating the average claim cost of annual warranty reserve cost of automotive part supplier.

The simple calculation of cost by each problem symptom is by average mean of the warranty information which receives every month.

Table 3.2 Warranty Claim Occurrence by Symptom Code (CS Code)

	Code Name	**Claim Case**	**Average Claim Cost (JPY)**	**Average Claim Cost (THB)**
ZJ	Excessive Play	24	JPY 12,717	THB 3,523
ZL	Noise (Except BC, DD, ZM)	431	JPY 15,076	THB 4,176
ZN	Vibration (Except AH, EA, ZP)	265	JPY 15,487	THB 4,290
ZP	Judder/Chatter	17	JPY 19,894	THB 5,511

3.9 Feasibility Study for Selling Extended Warranty

Using the optimized warranty period to calculate and verify feasibility study of selling extended warranty (equation 3.1) by simulating order at 1,000 units be calculated amortization cost in selling price of extended warranty which required to include warranty claim cost that probably occurs in longer warranty period from original contract with customers. The possibility of increase sale revenue is reviewed by output of this study.

Example:

Warranty cost per case is X (THB)

Additional claim case forecast (Y2014) for optimized method is A (Cases)

The proposal of extended warranty selling price is

= Normal Selling price + Additional extended warranty cost + Profit (3.1)

Table 3.3 Proposal of extended warranty calculate equation

** Warranty cost per case is X (THB)	Additional claim case forecast (Y2014)	Additional cost for Warranty claim in THB (Y2014)	Extened warranty sell in THB/Unit (Minimum order 1000 Units)	Proposal for extended warranty by % of increase for selling price
72 Months warranty period	**A**	**A* X**	**= (A* X) / 1000**	**= Normal Selling price + Additional extended warranty cost + Profit**

Chapter 4
Result and Discussion

Based on a case study of an automotive part supplier who produces drive train system for SUV vehicles that currently exports from Thailand to assembly plants in Japan and Korea by considering historical data from 2006 to 2014 and testing data from laboratory in order to analyze warranty data and recommend a suitable methodology for monitoring product reliability and warranty reserve.

4.1 Traditional Method by Using Fixed Percentage Number of Claim

Traditional method by using fixed percentage number of claim number per annual product sale quantity from the last year to forecast warranty reserve in the following year. Traditional method of warranty reserve is calculated by using historical warranty claim data of the same product design that produces in another assembly plant to estimate percentage of warranty return and reserve warranty cost as shown below. Normally, the percentage of warranty return is set at 0.4%. Warranty reserve cost is calculated by this simple equation 4.1.

$$\text{Warranty reserve cost}_{\text{Traditional}} = (\text{Annual sale volume}) \times (\text{Percentage of warranty return}) \times (\text{Selling price}) \quad (4.1)$$

Based on annual sale volume in the future year, the warranty engineer is going to forecast in Y2014. Normally, sale deparment receives customer product requirement volume forecast every year. Then, annual sale volume is included to calculate warranty reserve cost.

However, warranty claim costs of each problem have a different value. Aver age claim cost is recommended for approximate number of warranty reserve case assisting automotive part suppliers to use warranty reserve fund for payment to customer when the warranty issues occur during the future year. All in formations for calculation are shown in Table 4.1.

Table 4.1 Overall information of warranty claim

Forecast sale volume in 2014	143697 units
Percentage of warranty return	0.4% of sale volume
Selling price average	3,500 THB
Calculation result of warranty reserve	2,011,758 THB
Average warranty claim cost per symptom	4,531 THB
Warranty forecast in 2014	444 case

Nonetheless, population of product in market of previous year production lot is on the road while we are studying warranty forecast in the future year. The possibility of warranty return a future year may come from previous year products. The accumulative number of warranty reserve per warranty period is used to calculate budget in order to keep stability of warranty reserve fund which is likely high level of conservative reserve method to keep more budget until ending of warranty period in original contract (5 years or 60 months).

Better methodology is considered to improve level of warranty reserve fund to minimize budget in yearly cost planning. Product reliability is the right indicator to identify level of product performance and useful for applying this indicator to support warranty reserve forecast.

4.2 Traditional Method by Using Failure Rate of Monthly Product Reliability

Traditional method by using failure rate of monthly product reliability to be subgroup that calculate warranty reserve based on part production month reliability by accumulative computation to find the lowest product reliability by production month basis be represented as a bottom line in worst case scenario in order to forecast product failure rate of all sold products in the market. Warranty data since 2006-2013 has been recorded and calculated monthly reliability as subgroup pafter warranty data validation/approval process. The assumption of part production date was using the same production month that has been recorded in warranty report from customer. The result of calculation is presented in the table below.

The analysis of product reliability can be calculated by the general expression for the Weibull F(t) distribution as the following [3].

$$F(t) = 1 - e^{-\left[\frac{(t-\gamma)}{\eta}\right]^{\beta}} \quad (4.2)$$

where

β : shape parameter

η : scale parameter or characteristic life

γ : location parameter or minimum life

Table 4.2 Result of monthly product reliability

Value	**Average**	**STD**	**Median**	**Max**	**Min**
Beta (β)	3.847449	3.60565	2.893618	19.49752	0.919628
Reliability Probability	0.998879	0.003067	1	1	**0.983471**
Reliability Life (Mileage)	33144.35	19761.25	35286.76	83897.30025	975.1136
B10 Life (Mileage)	29628.29	19124.57	31971.54	82052.93856	632.1631

Minimum β is the shape parameter (slope)which is used to calculate failure rate prediction of a future year. The lowest value will be chosen for calculation of reliability, which can convert to a failure rate and also will be used to forecast the warranty in the next year. In this case, the calculation is separated into 4 groups which are;

1. sold product in the market from 2006 to 2013
2. sold product in the market for 7 years period
3. sold product in the market for 6 years period
4. sold product in the market for 5 years period

Table 4.3 Result of monthly product reliability

Condition of Warranty Period	Forecast (Case)	Population (Unit)	Warranty Reserve (THB)
Warranty Forecast for all Population	842	1,011,956	THB 3,817,291
Warranty Forecast for 7 Years Period	741	890,570	THB 3,359,400
Warranty Forecast for 6 Years Period	614	737,606	THB 2,782,391
Warranty Forecast for 5 Years Period	534	640,892	THB 2,417,567

Calculation results are computed by the lowest product reliability. The result was 0.983471 coming from production month of September 2014 and used for calculation for various conditions of product population as shown in Table 4.2. The result of warranty reserve forecast from this method is higher than the use of percentage product failure rate in fixed value, result is shown in Table 4.3.

4.3 Traditional Method by Using Failure Rate of Testing Data to Calculate Warranty Reserve in the Same Method with Traditional Method

Based on fatigue testing results of sample parts that have been tested in certified laboratory which is able to identify life time of a new product. The testing methodology varied in usage condition that can be represented and simulated actual usage condition on the road while customers are using.

Regarding individual fatigue, failures are impossible to predict. Failures from a given set of test conditions are distributed randomly within a fairly predictable distribution function. The most familiar type of distribution function is the normal or Gaussian distribution. Unfortunately, fatigue failures do not usually follow this type of distribution. Consequently, proper analysis requires more sophisticated statistical techniques. A normal distribution can be fully characterized with two parameters: mean and standard deviation. A more generic method of describing distributions is through the Weibull function. A Weibull distribution can also usually be characterized by two parameters.

First is the shape parameter (β). As its name implies, this parameter describes the shape of the distribution. The second parameter is the characteristic life (η). From -∞ to this value, the area under the normalized probability distribution function is 0.632. In certain cases, a third parameter is necessary to identify the minimum expected life (x0). In evaluating spring fatigue life, the third parameter is generally accepted to be zero and, therefore, will not be discussed further here. [10]

Obtaining the distribution parameters from a set of data can be somewhat involved. Historically, the shape parameter was determined graphically. The following steps are simplified.

Constructing a Weibull Plot

(1) The data is ordered from shortest life to longest.

(2) A regression analysis is conducted to calculate the median rank for each life value. (The regression technique may vary based on sample size, type of data, etc.) The median rank is a value between zero and one and approximately represents the fraction of the distribution expected to exist below the specific life value.

(3) The double logarithm 1/(1-median rank) is plotted vs. the logarithm of the actual life data. The data points typically fall very near a straight line.

(4) A best-fit line is drawn through the data points.

(5) The shape parameter is the slope of the best-fit line.

(6) A horizontal line is constructed at a y value of 0.632.

(7) The characteristic life is the x value at the intersection of the horizontal line and the best-fit line through the data points.

Many software packages are available which automate the calculations. The software typically also calculates the Weibull parameters rather than determine them graphically. A Weibull plot is shown in Figure 4.1 for failures occurring in Table 4.4 following intervals (32405; 35994; 77080; 78245; 79442; 95875; 189083; 198820; 243962; 360792; 386825; 390339; 581909; 689314; 726652; 818681; 855650; 1342075). Note that the shape parameter and characteristic life have been calculated and are shown on the plot (β=1.049088, η=403775.1782).

Table 4.4 Testing result of Bi-directional fatigue test

Result (Cycle)	Testing Condition
78245	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
35994	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
32405	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
386825	-506 to 844 Nm, 3Hz, 1:0.6 ratio
189083	-506 to 844 Nm, 3Hz, 1:0.6 ratio
360792	-506 to 844 Nm, 3Hz, 1:0.6 ratio
581909	-398 to 664 Nm, 3Hz, 1:0.6 ratio
818681	-398 to 664 Nm, 3Hz, 1:0.6 ratio
689314	-398 to 664 Nm, 3Hz, 1:0.6 ratio
95875	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
77080	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
79442	-606 to 1010 Nm, 3Hz, 1:0.6 ratio
243962	-506 to 844 Nm, 3Hz, 1:0.6 ratio
198820	-506 to 844 Nm, 3Hz, 1:0.6 ratio
390339	-506 to 844 Nm, 3Hz, 1:0.6 ratio
726652	-398 to 664 Nm, 3Hz, 1:0.6 ratio
1342075	-398 to 664 Nm, 3Hz, 1:0.6 ratio
855650	-398 to 664 Nm, 3Hz, 1:0.6 ratio

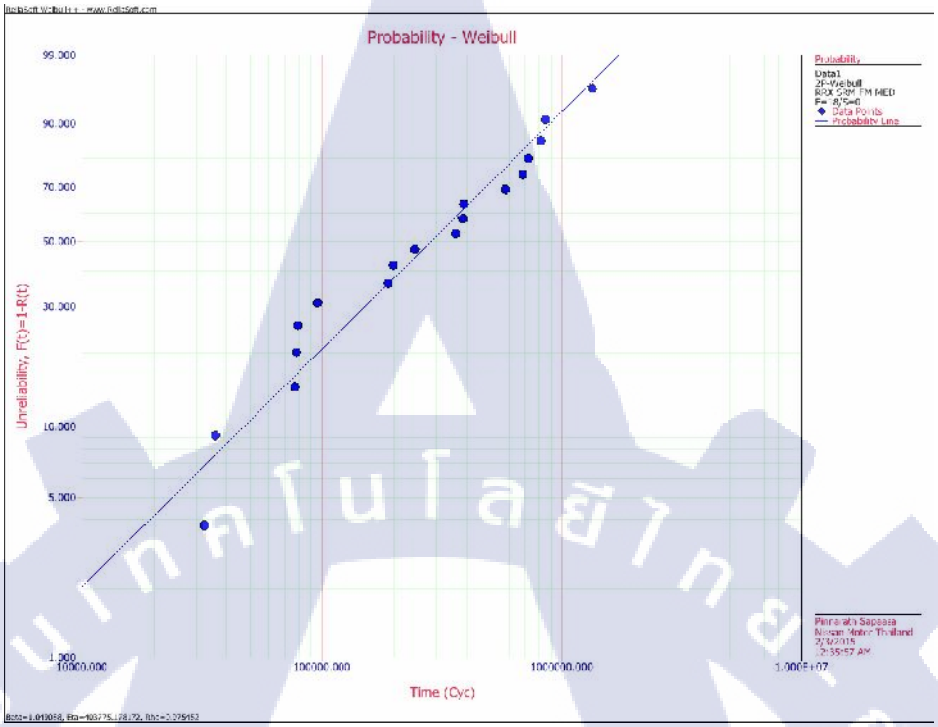


Figure 4.1 Weibull probability plot of faitigue testing result

Based on the different conditions, Beta and Eta (β=1.049088, η=403775.1782) value are used to calculate product reliability and failure rate forecast of product in order to use that information to predict the failure rate for warranty reserve prediction. For prediction follow testing criteria that required maximum 2,000,000 cycles to meet performance level car manufacturer expectation.

The result is 0.004710 showing the reliability (Figure 4.2, Figure 4.3, Figure 4.4) This value is closed to traditional method that presented in previous method. Therefore, we assume that using method for comparison warranty reserve in the future would be considered to use traditional method versus Nevada chart format of Weibull++ method to be a sample of this studying.

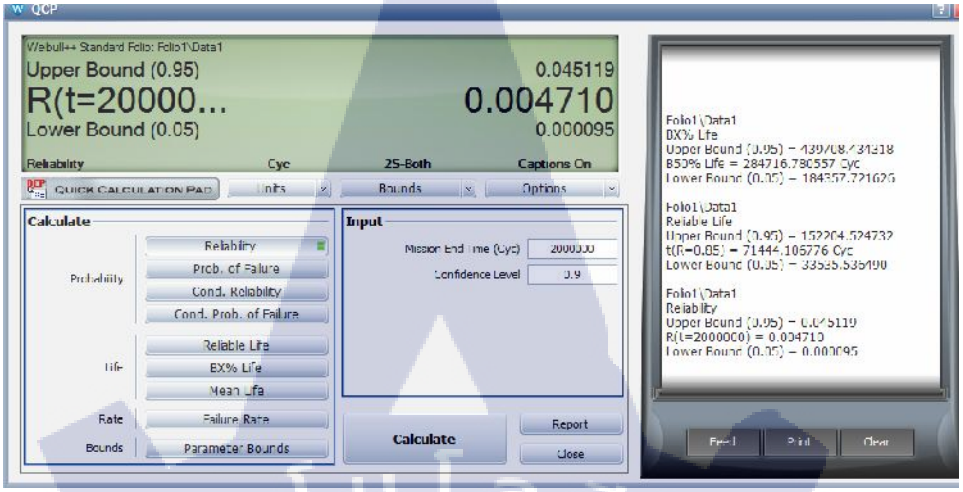


Figure 4.2 Weibull probability plot of faitigue testing result

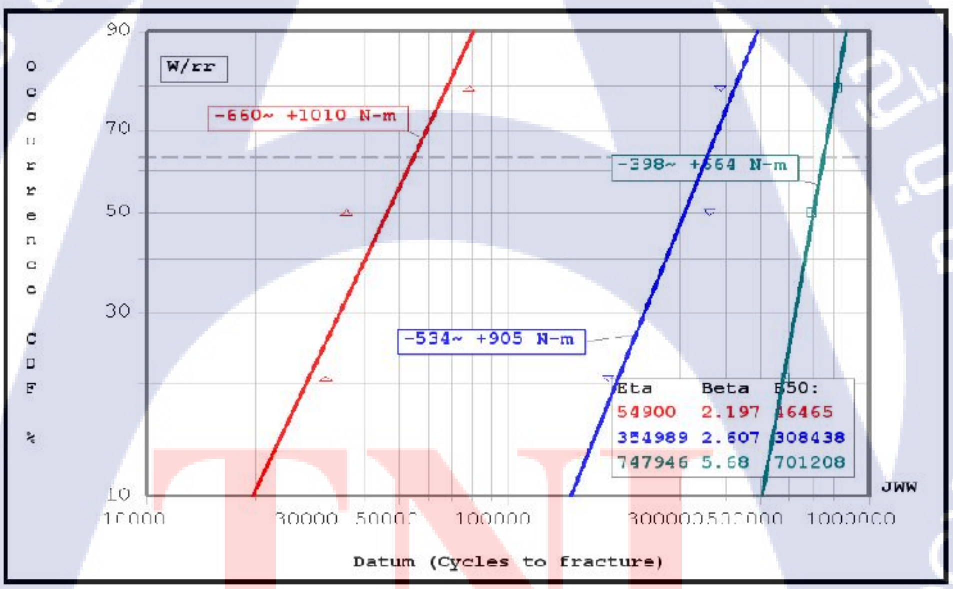


Figure 4.3 Weibull plot for fatigue result of 1st sample set

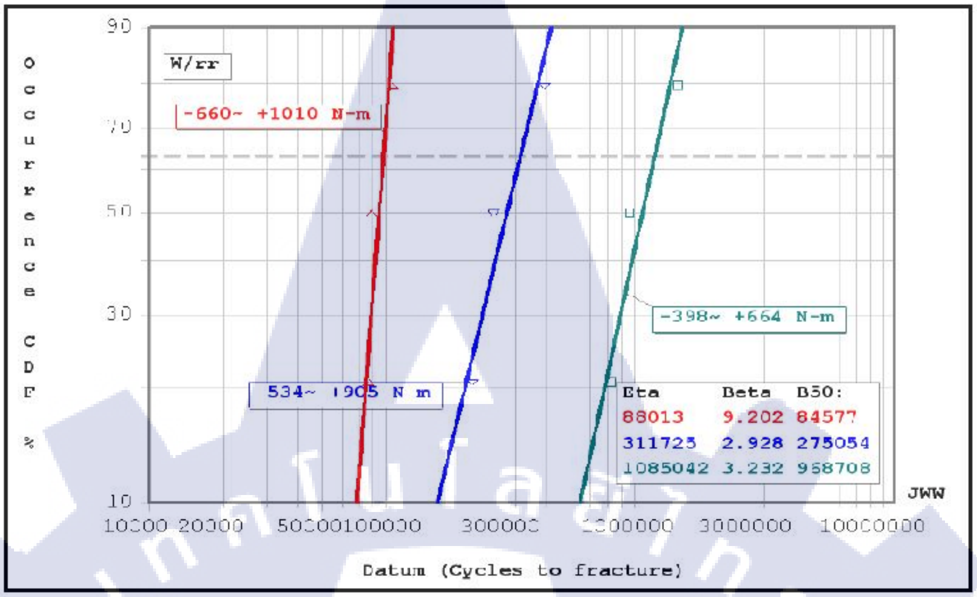


Figure 4.4 Weibull plot for fatigue result of 2nd sample set

4.4 Using Nevada Chart of Weibull++ Software to Calculate Warranty Reserve

Warranty claims data typically consists of quantities of units sold and quantities returned within a specified warranty period. Performing reliability calculations on this type of raw data can be tedious and time-consuming. To speed up calculations, the warranty analysis folio (Nevada chart format) is designed to convert existing warranty claims datasets into failure/suspension data sets so that it can be easily analyzed with traditional life data analysis methods. In addition, the folio can predict future warranty returns which can detect and correct potential product quality problems in the field and plan for warranty fulfillment needs such as warranty reserve cost including repair costs and the number of spares to stock. If you keep track of the period in which each returned unit was sold and the period in which it was returned, using the Nevada chart format to convert warranty claims data into failure/suspension data. [12]

Optimization of warranty period is the target of automotive part supplier in order to minimize warranty reserve cost. Normally, 60 months period is set in original contract with customer. However, the additional coverage time period during transportation and storage before end customer has brought car from dealer. Probably, 3 months is minimum period that we should add for varying to find the optimum period. This paper is varying from 60 months until 72 months warranty period is shown in Table 4.5 and Figure 4.5.

Table 4.5 Warranty claim forecast result of Y2014 by Weibull analysis

Study Period	Warranty Period								
	60M	**61M**	**62M**	**63M**	**64M**	**65M**	**66M**	**69M**	**72M**
Jan 14	12	12	12	12	13	13	13	14	15
Feb 14	13	12	12	12	13	13	13	14	15
Mar 14	13	13	12	12	12	13	13	14	15
Apr 14	13	13	13	13	12	13	13	14	14
May 14	13	13	13	13	13	12	13	13	14
Jun 14	13	13	13	13	13	13	13	13	14
Jul 14	13	13	13	13	13	13	13	13	14
Aug 14	13	13	13	13	13	13	13	13	14
Sep 14	13	13	13	13	13	13	13	13	13
Oct 14	13	13	13	13	13	13	13	13	13
Nov 14	13	13	13	13	13	13	13	13	13
Dec 14	13	12	13	13	13	13	13	13	13
Total	155	153	153	153	154	155	156	160	167

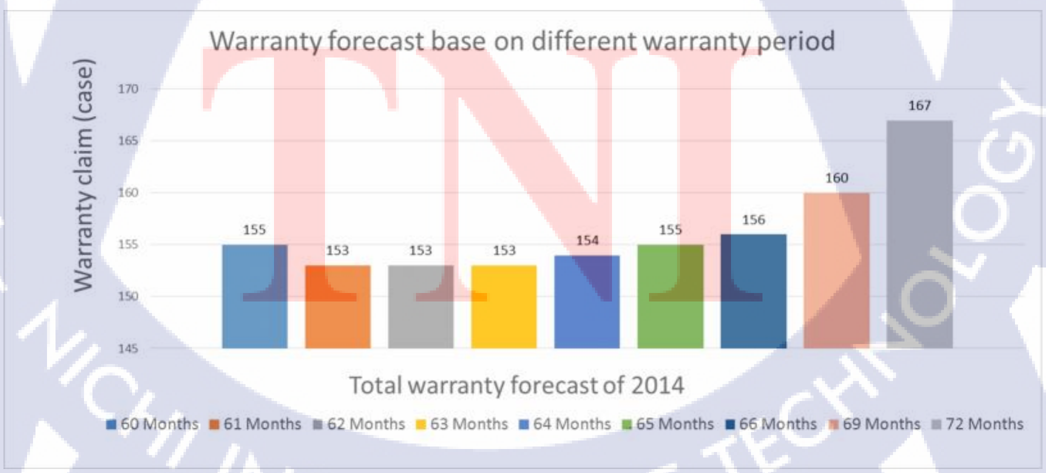


Figure 4.5 Warranty claim forecast result of Y2014 by Weibull analysis

Supplier warranty period is varying in 9 steps: 60 months, 61 months, 62 months, 63 months, 64 months, 65 months, 66 months, 69 months, and 72 months to monitor the trend line of the claimed cases and warranty reserve. The optimum warranty period will be chosen and based on the shortest warranty period that has the stable percentage error of the past year forecast. Data analysis is computed from Weibull++ software in Nevada chart format using database for 5 years period to predict warranty forecast in next 12 months. By starting with October 2006-September 2011 warranty data in order to forecast warranty occurrence in period of October 2011-September 2012. Then, continue using warranty data of March 2007-February 2012 to calculate future warranty in period of March 2012-February 2013, October 2007-September 2012 for October 2012-September 2013, March 2008-February 2013 for March 2013-Feb.2014, and October 2008-September 2013 for March 2013-February 2014until completion of 6 sets of database till September 2014. All results are shown in Figure 4.6 to Figure 4.14.

Once information of warranty forecast is completed by this methodology, optimization of warranty period is reviewed by using the comparison between calculation from Weibull++ and actual claim information from customer that we recorded. After calculations are completed, outcome of this comparison can suggest the percentage error of Weibull++ methodology in order to choose the warranty periods that have lowest percentage error of forecast in 3 different indicators are MAD (Mean Absolute Deviation), MSE (Mean Squared Error) and MAPE (Mean Absolute Percentage Error) are able to evaluate and recommend lowest percentage error of data set to become useful for warranty policy management in the future.

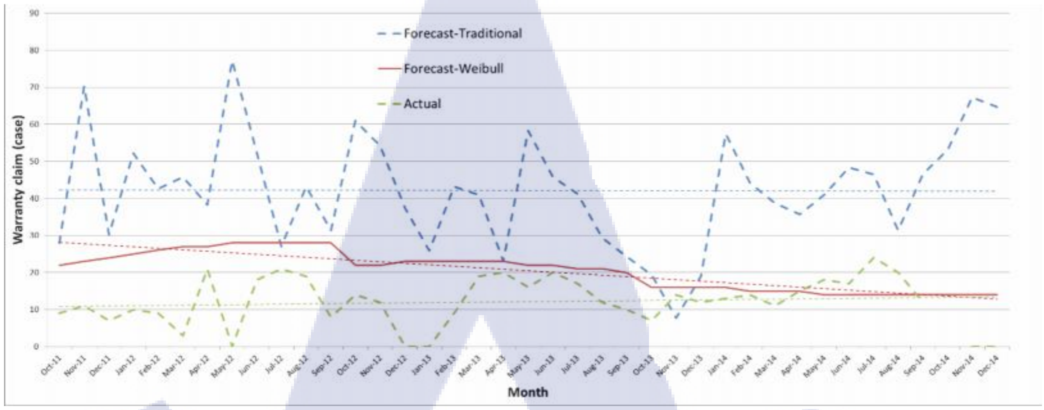


Figure 4.6 Warranty claim forecast comparison by supplier 60-month warranty period

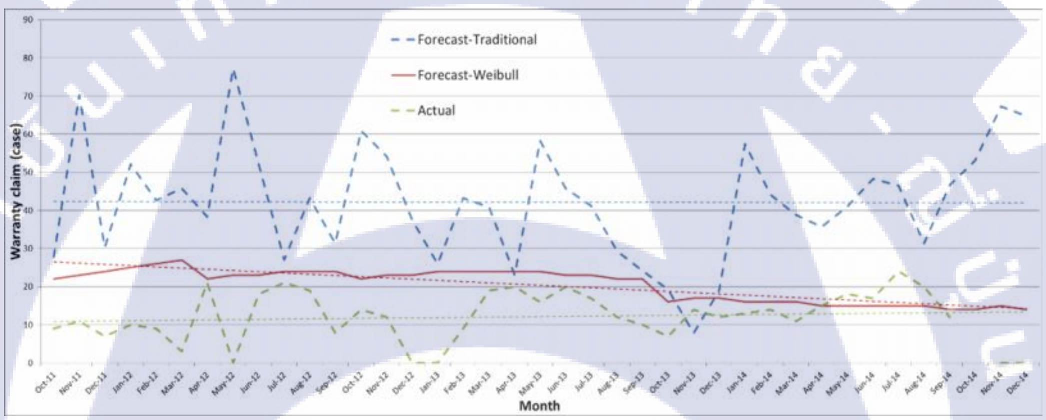


Figure 4.7 Warranty claim forecast comparison by supplier 61-month warranty period

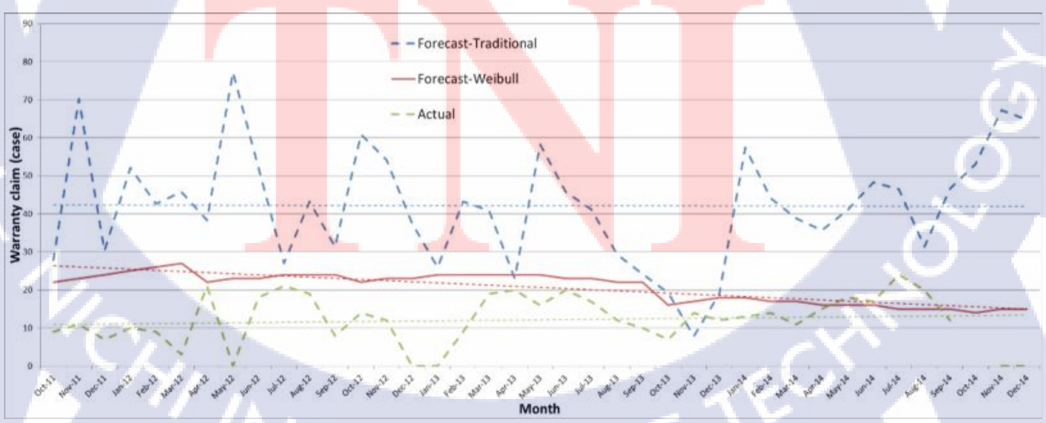


Figure 4.8 Warranty claim forecast comparison by supplier 62-month warranty period

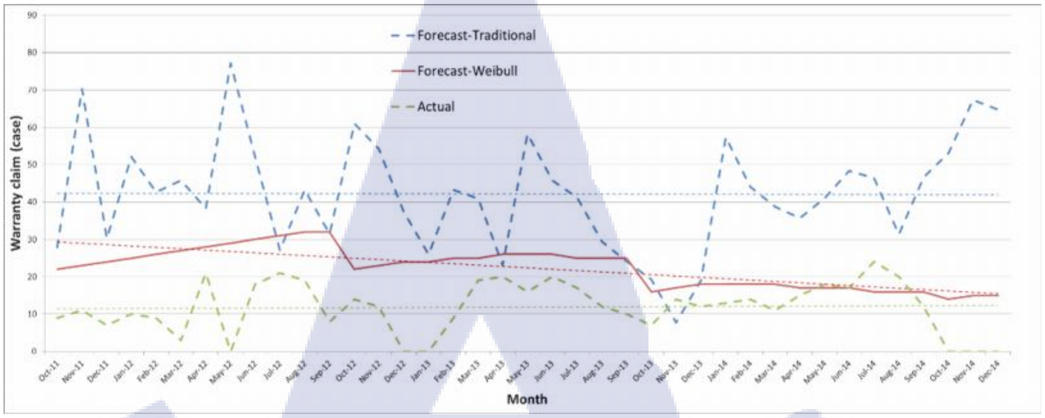


Figure 4.9 Warranty claim forecast comparison by supplier 63-month warranty period

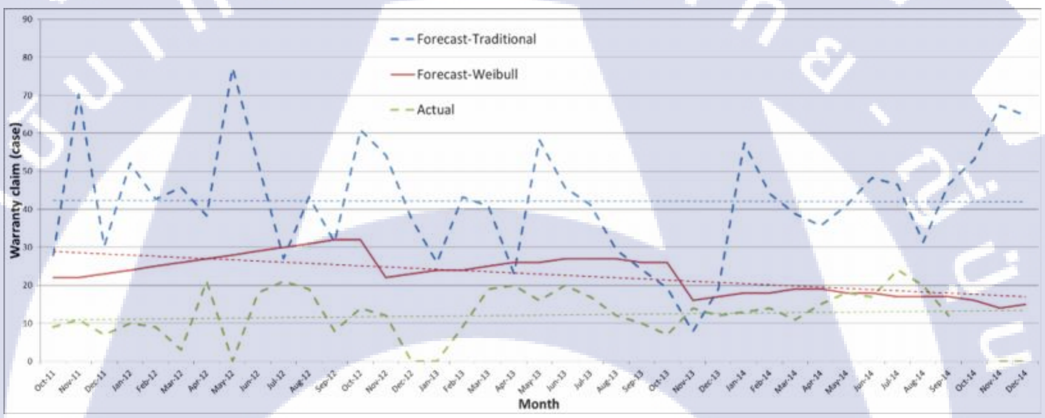


Figure 4.10 Warranty claim forecast comparison by supplier 64-month warranty period

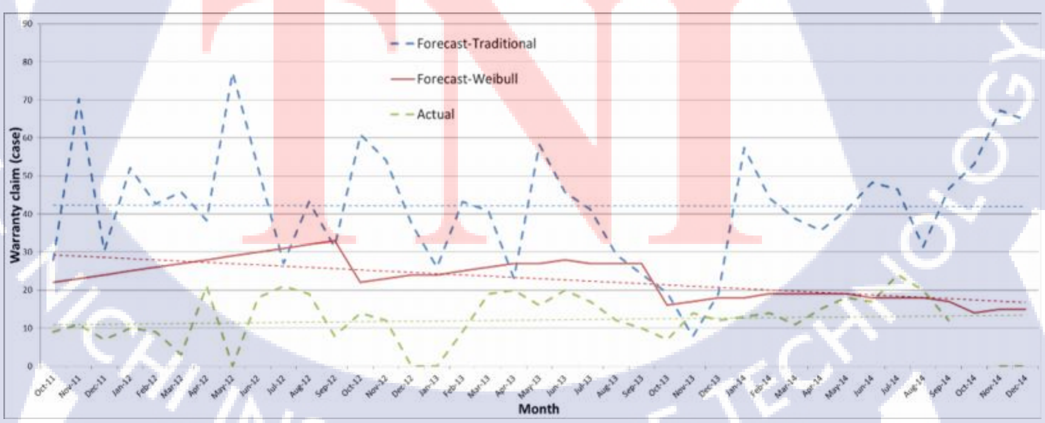


Figure 4.11 Warranty claim forecast comparison by supplier 65-month warranty period

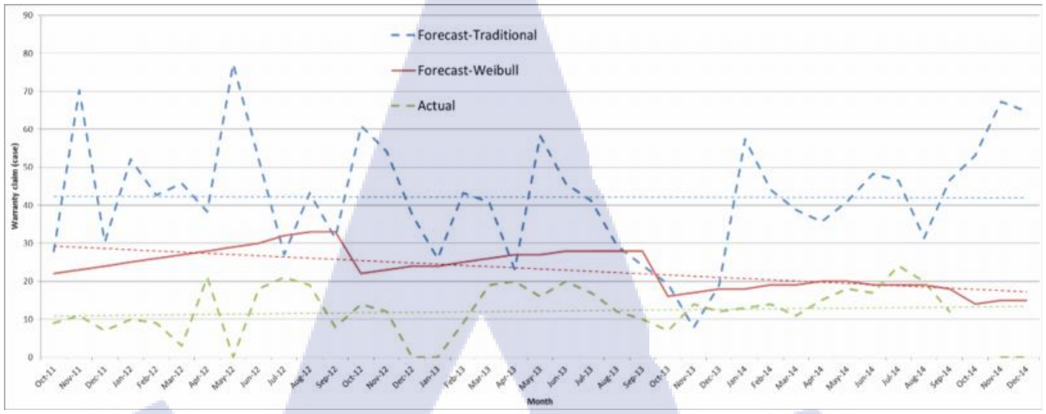


Figure 4.12 Warranty claim forecast comparison by supplier 66-month warranty period

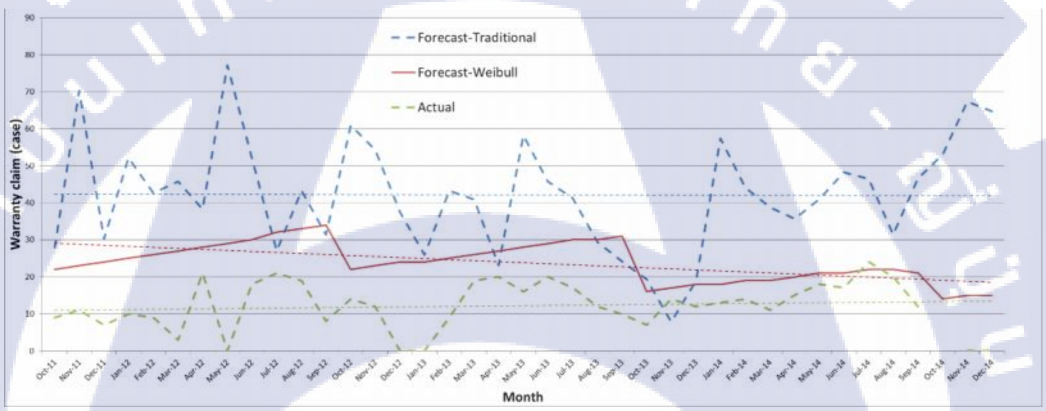


Figure 4.13 Warranty claim forecast comparison by supplier 69-month warranty period

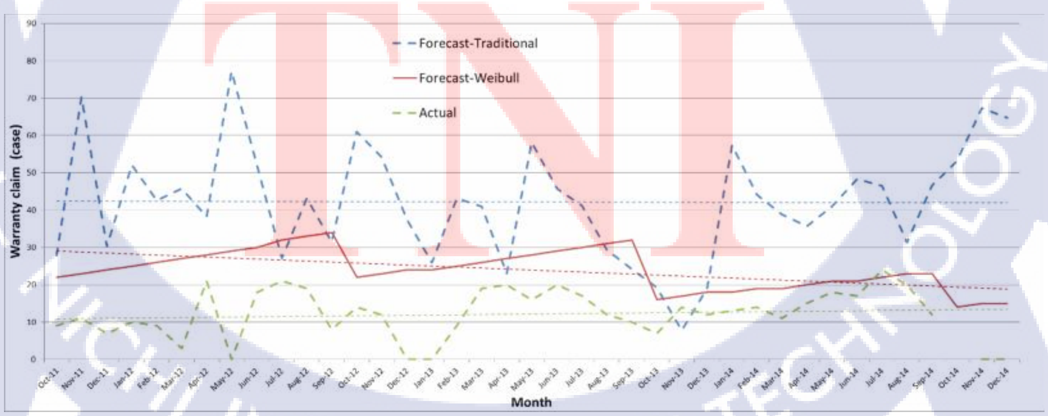


Figure 4.14 Warranty claim forecast comparison by supplier 72-month warranty period

From Figure 4.11, it can be seen that the warranty claim forecasted by trend line of Weibull analysis is converging to the trend line of actual claim data. In addition, the warranty claim of the traditional method seems unchanged overtime. However, the optimum warranty period is chosen and based on the unchanged percentage error of forecast with the shortest warranty period. Therefore, this case study result of 65 months warranty period is chosen and considered optimum as shown in Table 4.6.Because the result has shown in trend line between Weibull Nevada chart and actual claim, it has not intersected each other. The gap between two lines is able to explain the optimum of warranty forecast but will not lower than the actual result which is possible to cause of budget shortfall problem in automotive part supplier.

Table 4.6 Percentage Error of Forecast by Varying Supplier Warranty Period

Measuring Forecast Error	**60 Month**	**61 Month**	**62 Month**	**63 Month**	**64 Month**	**65 Month**	**66 Month**	**69 Month**	**72 Month**
MAD (Mean Absolute Deviation)	7.47	7.58	7.67	7.67	7.78	7.83	7.83	7.83	7.83
MSE (Mean Squared Error)	97.75	100.25	103.33	104.56	106.78	107.22	107.22	107.22	107.22
MAPE (Mean Absolute Percentage Error)	44.96	45.64	46.01	46.04	47.29	47.82	47.82	47.82	47.82

Warranty reserve level has been verified and recommended warranty period at 65 months which considers after customers assembled vehicle in assembly plan. Trendline graph can explain the warranty reserve level of Weibull method. It is little higher than actual claim cases that occurred during study period which is able to recommend this methodology for using in real business case of automotive business. Graph is shown in Figure 4.12.

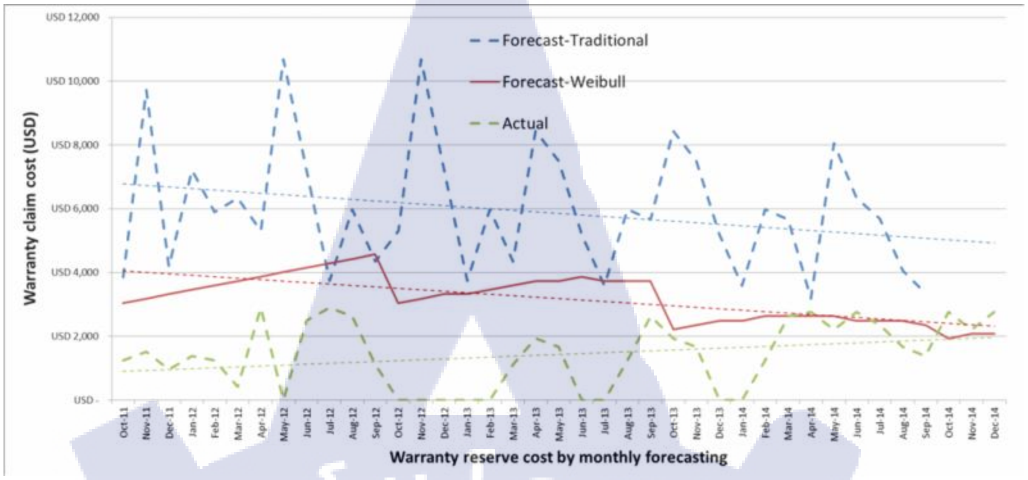


Figure 4.15 Warranty claim cost reserve by monthly forecasting of 65-month warranty period

Moreover, the result of this study comparing percentage error of forecast between Weibull Nevada chart format method and traditional method to present performance and accuracy of warranty forecasting of these 2 methods is shown in Table 4.7.

Table 4.7 Comparison of percentage error of forecast between Weibull Nevada chart format method and traditional method

Measuring Forecast Error	**Weibull Nevada Chart Format at 65 Months Period**	**Traditional Method**	**Comparison Result**
MAD (Mean Absolute Deviation)	7.83	27.64	Nevada Chart Method Better Than Traditional Method
MSE (Mean Squared Error)	107.22	991.19	Nevada Chart Method Better Than Traditional Method
MAPE (Mean Absolute Percentage Error)	47.82	166.94	Nevada Chart Method Better Than Traditional Method

Table 4.8 Result of warranty reserve analysis

Method	Claim Case Forecast (Y2006-2013)	Warranty Reserve Cost in USD (Y2014)	Claim Case Forecast (Y2014)
Traditional	3170	57,241	575
Weibull_Nevada Chart for 65 Months Warranty Period	N/A	21,443	155
Difference		35,797	420
Percentage		63%	73%

Based on historical warranty data between 2006 and 2013, company was claimed by the end users in the total of 817 cases. The comparison of percentage error (MAPE) from traditional method is much higher than Weibull method, approximately 250% when comparing with the actual claimed cases is shown in Table 4.7.

However, traditional method calculates warranty reserve cost by accumulating warranty reserve cost for every part that have been sold to market in percentage of selling price (Example : 0.4% of selling price). Normally, traditional method has to continue accumulating reserve cost of this percentage for at least 6 years until overdue the warranty period of vehicle. For Weibull forecast with Nevada chart warranty tracking method, it is possible to reduce warranty reserve cost is shown in Table 4.8 approximately 63% in comparison with the traditional method because this method calculates product reliability from all history data and tracks status of every single production months and also monitors until each production lot has been passed warranty period prior elimination of the overdue warranty period lot from tracking system with the specific confident level that can be specified by automotive part supplier. This method uses a chi-squared test to detect unusual high or low return rates for any given period, alerting any possible deviations in manufacturing, quality control or any other factors that may adversely affect the reliability of the product in the field. This enables supplier to intervene immediately and avoid increasing warranty costs or more serious repercussions. The Nevada chart can also solve the difference in warranty period problem of car manufacturer and part automotive supplier because this method calculates and is based on actual claim data from car manufacture by monitoring all product population. They are in warranty and are not counted out of warranty. This is useful when planning for warranty costs, spare parts and other fulfillment needs and forecast warranty claim in specified period that can manage warranty reserve cost year per year.

Analysis of extended warranty is demonstrated in Table 4.9 by calculating extended warranty from 60 months (5 years) period to 72 months (6 years) and 84 months (years) which included additional optimum period by plus additional 5 months for optimized warranty and considering additional cost of warranty reserve for supporting extended warranty and calculating additional cost amortization to 1,000 units.

Table 4.9 Proposed option to sell extended warranty

	Additional Warranty Reserve Cost in 2014 (THB)	**Additional Claim Case Forecast in 2014 (THB)**	**Extened Warranty Sell in THB/Unit***	**Add 25% of Profit in Selling Price (THB)**	**Proposal for Extended Warranty by% of Increase for Selling Price**
Weibull Nevada Chart for 72 Months Warranty Period	208,426	46	208.43	908.43	26%
Weibull Nevada Chart for 84 Months Warranty Period	403,259	89	403.26	1,117.92	31%

*Minimum Order of this Calculation is 1000 Units

Regrading result of feasibility study to sell extended warranty of 72 months warranty period. Additional 46 cases of warranty claim may occur and require to reserve additional warranty budget approximately 27% from original warranty reserve budget. When comparing with the additional possibility of automotive part supplier to sell the extended warranty by increasing the sale price to 26% of original price of normal product which included 20% of additional profit in that portion. It seems reasonable for automotive part supplier to sell this extended warranty option to the end user who requires longer period of product warranty than normal warranty term/condition. The extended warranty is able to improve sale revenue for supplier by increasing the sale price with product realibility analysis and management, It is possible to make profit if the company can sell the extended warranty more than its cost.

On other hand, the result of extended warranty study for 84 months period would require approximately 53% increasing of warranty reserve cost but automotive part supplier is going to receive additional income of extended warranty about 31% of original selling price which is not a good deal for the company for selling extended warranty in 84 months period because possibility of product failure in this period is very high. And it is quite risky to do so.

Chapter 5
Conclusion and Recommendation

This research focuses on studying product reliability of propeller shaft model P32 by analyzing result of testing, product life of warranty return in order to calculated product reliability by applying Weibull++ which using Weibull distribution to analyze product reliability.

This research is also presented the methodology to reduce idle capital by using Weibull Nevada chart format to predict warranty claim case. Including able to identified the current status of product reliability which higher than customer original contract agreement.

This research has presented the opportunity to selling extended warranty for customer who required to extended warranty period longer than normal usage period in warranty contract. However, the additional opportunity is to minimize or reduce material grade and re-grade of design application which is not in the scope of this research. This item could be an interesting topic for future research study.

The traditional method of warranty reserve is set as a reference point in order to compare performance of new proposed methodology. Result of calculation is shown 444 cases of warranty prediction based on forecast sale volume at 143,697 units and 0.4% of warranty return for one year period 2014.

The product reliability prediction by each production month of product is used for estimation based on product reliability of warranty return population. The lowest reliability is used to calculate product reliability of returned cases and forecasting warranty return cases base on forecast volume of product which were sold in market for 5 years, 6 years and 7 years period. The result was presenting the estimated warranty return are 534 cases for 5 years, 614 cases for 6 years and 741 cases for 7 years of warranty reserve period. The outcome of warranty prediction from this method is higher than traditional method. The traditional method is better than using lowest reliability by production month of product. By comparison result of failure rate prediction.

The predicted reliability result of fatigue testing at requirement of testing criteria of maximum 2,000,000 cycles is 0.004710. This reliability result is lower than failure rate of traditional method. Then, testing result could not be a representative of product reliability prediction.

The warranty prediction by Weibull distribution in Nevada chart format is presented the best result of warranty return forecasting because all warranty data have included in the calculation with all population of sold product that currently using on road. Including specified warranty period to cover gap of coverage period of car manufacturers and part automotive suppliers. The result of comparison of percentage error of each warranty period is presented that warranty period at 65 months is the optimum warranty period for cover the gap and minimize warranty reserve cost for the company as well.

Accuracy of warranty prediction is verified by comparing warranty prediction from Weibull distribution in Nevada chart format versus actual warranty claim result of year 2012, 2013 and 2014. The comparison result of year 2014 is 6.9% and year 2013 is 13.5% that much better than other method. Anyhow, comparison result of year 2012 was a bit high because of this research has used actual data since year 2006 to 2011 equal to 60 months period in order to forecast warranty result in year 2012. The number of history warranty return information could be key item to improve accuracy of warranty prediction that have been shown in result of year 2013 and year 2014 which presented in figure 5.1.

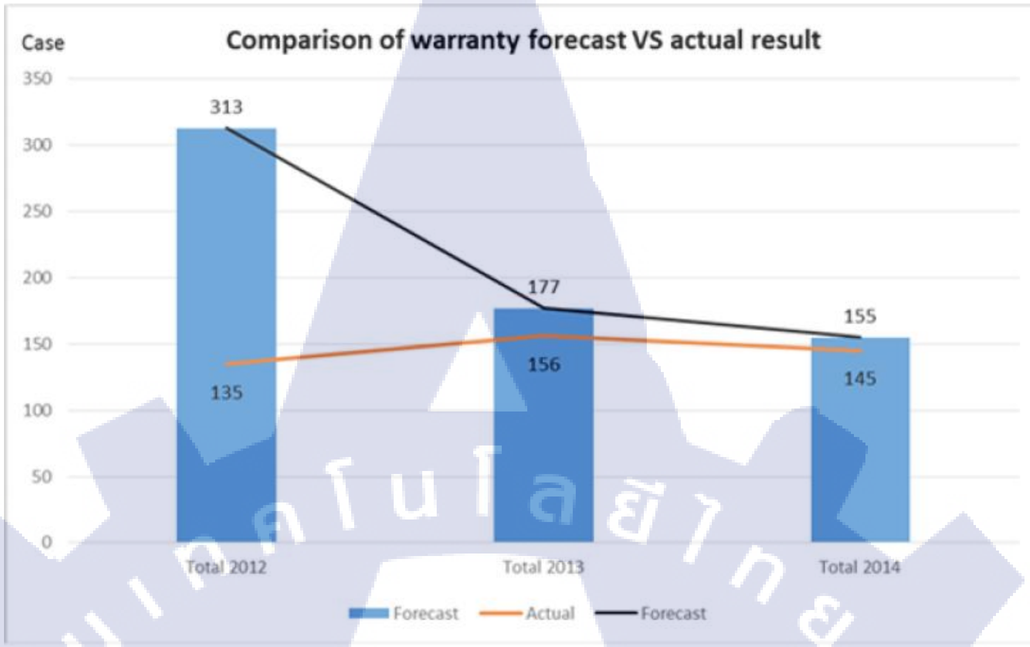


Figure 5.1 Comparison result of warranty forecast by using Weibull Nevada chart VS actual result of year 2012, 2013 and 2014

Warranty prediction result of Nevada chart is 155 cases which is 65% improvement when comparing with traditional method. Company is able to minimize warranty reserve by 1 of 3 of traditional method by using Nevada chart format.

The recommendation method of warranty reserve cost is Nevada chart format of Weibull distribution analysis that can yield various benefits such as minimize warranty reserve cost, minimize risk of too small reserve cost (hamper customer service and hence customer satisfaction), using real warranty data and know exactly number of potential product that under supplier coverage of warranty claim including quality alert for manufacturing process improvement to avoid surprise of increased warranty cost and serious quality problem issue and ability to solve different warranty period of car manufacturer and automotive part supplier.

Also feasibility study result of extended warranty has been calculated and result was presented that supplier can extend warranty period by add another 12 months or 24 months to be 6 year warranty or 7 year warranty by set selling price in market at least 26% higher than normal price for additional 1 year warranty and 31% price increase for additional 2 years warranty period. This is an opportunity to make additional profit and can be presented to customer who willing to use product in longer period than normal use. The estimate additional profit approximately 25% increasing from original with the condition of extended warranty selling unit more than 1,000 units as target. In case of the number of customer who required longer warranty period is higher than this target, company could made additional profit easily without any additional investment rather than additional warranty reserve cost 27 % for 6 years warranty and 53% of 7 years warranty that calculated based on the minimized warranty reserve cost from Nevada chart format. The additional warranty reserve for opportunity to sell extended warranty is lower than currently condition of warranty reserve cost of traditional method. This is the great opportunity for part automotive suppliers to change idle capital in our warranty reserve fund to make additional profit by selling extended warranty without additional investment.

Regarding this result is able to explain current product reliability level of this product which is higher level of product reliability than customer expectation. Also, this can be opportunity for company to minimize product design and process design such as re-grade of material, re-design to lower application, eliminate some expensive process inspection, reduce inspection frequency and eliminate functional periodic testing.

This methodology has proposed a tool for automotive part supplier to understand level of their product reliability, to know risk level of current warranty reserve cost in organization and benefit to review the appropriate warranty period of new project with similar product and process design for optimize warranty period target setting in order to use in new contract agreement with OEM car manufacture including consideration to propose extended warranty option to customer with their confidence in product quality level since new project bidding process that can be a strong point of organization to increase competiveness with competitor.

The results of this research have identified opportunity for part automotive supplier for consider for choosing the right direction to tradeoff between opportunity to minimize warranty reserve cost including additional opportunity to increase profit by selling extended warranty versus the additional incomes from minimize design of product, process and inspection frequency. This topic is interesting for future research study.

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