2ND QUARTER PROGRESS REPORT OF IGNITE FUNDED PROJECT

Prediction of Remaining Useful Life (RUL) of Aerial Bundled Cables (ABC) in Coastal Areas

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1 Introduction

The Ignite funded project, **"Prediction of Remaining Useful Life (RUL) of Aerial Bundled Cables (ABC) in Coastal"** started on December 1st, 2017. This document describes the project progress, activities and milestones that have been performed at the NDT Centre during the second quarter of the project.

The activities for this quarter included diagnostic algorithm development on lab acquired data, formulation of NDT test procedures, fabrication of solar powered and Bluetooth enabled data logger followed by its installation at first test site, thermal imaging and ultrasonic testing of the first test site, design of nomenclature for creating the NDT database of data acquired from field testing and lastly development of prognostics framework.

The details are discussed in the subsequent sections.

2 Principal project progress/Milestones

Following were the milestones achieved in the second quarter as per the approved proposal:

- Formulation of NDT procedures
- Fabrication and installation of first data logger
- Initiation of field testing as per the formulated procedures
- NDT database
- Diagnostic algorithm development and application on lab acquired data
- Development of prognostics framework

2.1 Formulation of NDT Procedures

Project members met with K-Electric team on 15th March to present the testing model. In this presentation, project progress of first quarter was discussed followed by the NDT procedures to be implemented. These included:

- ***Installation of temperature and humidity data logger*** – Initially at first test site for two weeks to check/validate performance and results of the installed equipment. For remaining 02, locations are yet to be finalized by K-Electric. Currently the logger will log data every three hours

- ***Thermal Imaging & Ultrasonic Testing*** – These would be done every two months using the test equipment procured earlier.

  Details of equipment are also appended below in table 1.

Table 1. NDT Equipment

S. No.	Equipment	To test	Model
1	Ultrasonic Testing Probe	Cable and connectors	UE - 9000
2	Thermal Imaging Camera	Cable and connectors	FLIR E40

- ***Database Management*** – Specific nomenclature to be used for saving the acquired field testing data and create the NDT database

2.2 Fabrication & Installation of first Data Logger

Commercial prototype of the Temperature and Humidity Data Logger has been successfully developed with a sturdy mechanical casing. Features and installation details are provided in sub sections.

2.2.1 Finalized Data Logger

Few alterations have been made in the design of the data logger. For longer operation of the system, power parameters were changed due to which size of solar panel and battery had to be increased. Mechanical housing was then designed accordingly and revised look is shown in figure 1.

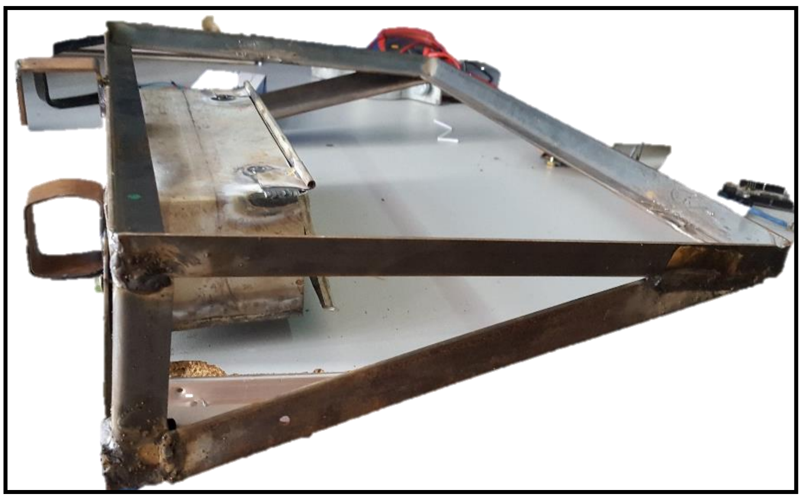


Figure 1. Updated Mechanical casing

The finalized equipment, as shown in figure 3 and 4, houses the following:

- ***Solar circuitry***
  - 15W Solar panel
  - Charge controller
  - 7A/12V Battery

- ***Instrumentation circuitry***

- Temperature & Humidity logger PCB

Figure 2. Mechanical housing with Panel

Figure 3. Complete redesigned Data Logger equipment

The features include:

- ***Detection of temperature & humidity of the surroundings*** – logs data in real time every 03 hours
- ***Solar powered*** – 15W solar panel is used at an angle of 73º for optimum capture of the solar energy
- ***Bluetooth enabled*** – logger is capable of sending data to mobile and laptop via Bluetooth
- ***Real-time data saving*** – 16 GB SD card used on the board for saving all the data
- ***Password protection***
- ***Starts sending data when an action key is pressed after logging in***
- ***Data is deleted from SD card after being retrieved on PC on auto***

2.2.2 First Field Installation

The designed temperature and humidity data logger was successfully installed on 3rd April 2018 at the first test site (i.e. Clifton) with support from K-Electric team. It is mounted via 02 clamps on the KE pole where the ABCs are installed.

Figure 4. Data Logger installed at Clifton

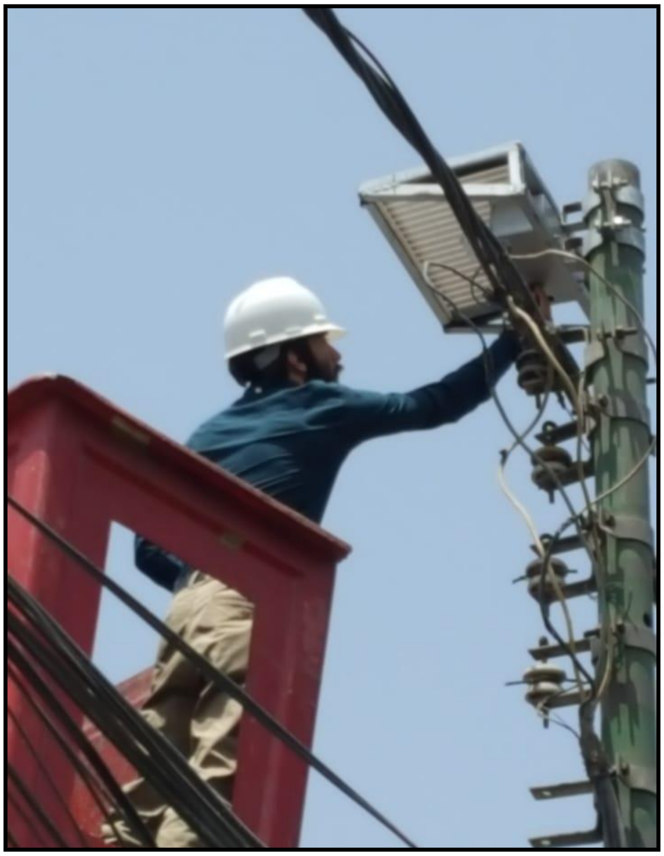


Figure 5. RA of ABC Team installing the Data Logger

Real-time data of 02 weeks has also been retrieved. Both temperature and humidity data is precise. Snapshot of a portion of the data acquired is shown in figure 2.

```
Tuesday 03.04.2018 -- 16:00:00   Temperature = 30.00   Humidity = 41.00
Tuesday 03.04.2018 -- 18:59:57   Temperature = 30.00   Humidity = 41.00
Tuesday 03.04.2018 -- 21:59:55   Temperature = 29.00   Humidity = 95.00
Wednesday 04.04.2018 -- 00:59:53   Temperature = 28.00   Humidity = 95.00
Wednesday 04.04.2018 -- 03:59:51   Temperature = 27.00   Humidity = 95.00
Wednesday 04.04.2018 -- 06:59:48   Temperature = 27.00   Humidity = 95.00
Wednesday 04.04.2018 -- 09:59:46   Temperature = 27.00   Humidity = 95.00
Wednesday 04.04.2018 -- 12:59:44   Temperature = 30.00   Humidity = 95.00
Wednesday 04.04.2018 -- 15:59:41   Temperature = 31.00   Humidity = 95.00
Wednesday 04.04.2018 -- 18:59:39   Temperature = 32.00   Humidity = 95.00
Wednesday 04.04.2018 -- 21:59:37   Temperature = 30.00   Humidity = 95.00
```

Figure 6. Real time data acquired from Data Logger

For remaining two data loggers, proposed locations are Saddar area and DHA. Same are however to be confirmed by K-Electric. Installations will then be done accordingly.

2.3 Initiation of Field Testing

After formulating the NDT procedures for the field testing of Aerial Bundled Cables (ABCs) and its connectors, team has successfully initiated the field testing at the first test site. The testing details are provided below in table 2.

Table 2. Purpose of NDT Techniques

S. No.	NDT Technique	Purpose
1	Ultrasonic Testing	Testing the insulation
2	Thermal Imaging	Thermal profile graphical form

First field test was completed on 27th April 2018 in which major part of the ABC team participated. Some snaps of the same are attached below.

Figure 7. Thermal Imaging & Ultrasonic Testing by ABC Team

Figure 8. Group photo with KE Team

To ensure consistency in the field database, points of test have been marked and data will be acquired from the same points every two months. Similarly, both ultrasonic and thermal images have been captured from the same test points. This methodology will help in the development of a more accurate prediction software.

2.4 NDT Database

For creating an effective NDT database, a nomenclature has been designed by the team. It incorporates all relevant parameters required for description and understanding of the acquired field data.

2.4.1 Format

Type of test, date, location, reference point, track, equipment, pole, cable segment, connector

2.4.2 Legends

For each element in the format, legends have been specified as shown in tables 3 – 14.

- Type of Test

Table 3. Code for Type of Test

S. No.	Type of Non-destructive test	Code (Combination of 02 capital alphabets)
1	Ultrasonic Testing	UL
2	Thermal Imaging	TI

- Date

Table 4. Code for Date

Description	Code (6 digits separated by hyphen)
Date-month-year	dd-mm-yy

- Location

Table 5. Code for location

S. No.	Location	Code (Combination of 03 capital alphabets)
1	Clifton	CLF
2	DHA	DHA
3	Saddar	SDR

- Reference point

Table 6. Code for Reference Point

S. No.	Location	Code
1	Data Logger	dl

- Track

Table 7. Code for Track

S. No.	Track	Code
1	Left	Lt
2	Right	rt
3	Center	ct

- Equipment

Table 8. Code for Equipment

S. No.	Equipment under test	Code (02 digits)
1	PMT	01
2	Connectors	02
3	Poles	03
4	Cables	04

- Connectors

Table 9. Code for connector

S. No.	Connectors	Code (C + Double Numeric)
1	No connector	C00
2	Connectors on pole 1 towards pole 2	C12
3	Connectors on pole 2 towards pole 1	C21
4	Connectors on pole 2 towards pole 3	C23
5	Connectors on pole 3 towards pole 2	C32

6	Connectors on pole 3 towards pole 4	C34
7	Connectors on pole 4 towards pole 3	C43

- Poles

Table 10. Code for Pole

S. No.	Pole	Code (P + Single Numeric)
1	No pole	P0
2	Pole1	P1
3	Pole2	P2
4	Pole3	P3
5	Pole4	P4

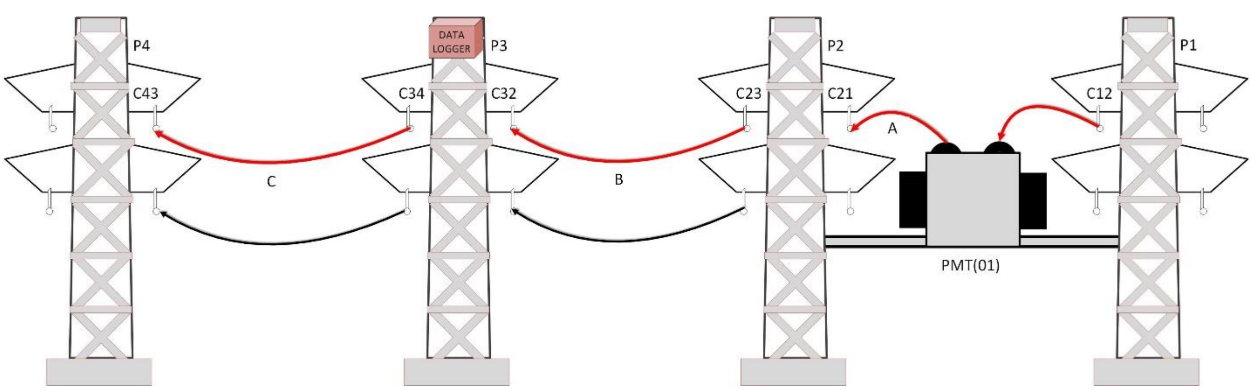
- Cable Segment

Table 11. Code for Cable Segment

S. No.	Cable Segment	Code (single alphabet)
1	No cable	0
2	Between pole 1 and 2	A
3	Between pole 2 and 3	B
4	Between pole 3 and 4	C

2.4.3 System Schematic

Schematic shown in figure depicts all the components involved in the nomenclature.



2.4.4 Examples

Some examples of nomenclature are given below. These are in reference to the acquired thermal imaging and ultrasonic data of different components.

- ***PMT***
  TI, 27-04-18, CLF, dl, rt, 01, P1, 0, C00

- ***Cable***
  UL, 27-04-18, CLF, dl, rt, 04, P0, A, C00

- ***Connector***
  TI, 27-04-18, CLF, dl, ct, 02, P2, 0, C21

- ***Pole***
  TI, 27-04-18, CLF, dl, lt, 03, P4, 0, C00

2.5 Diagnostic Software development & Application on Lab Data

Diagnostic algorithm has been developed. For application, below laboratory acquired thermal images have been selected.

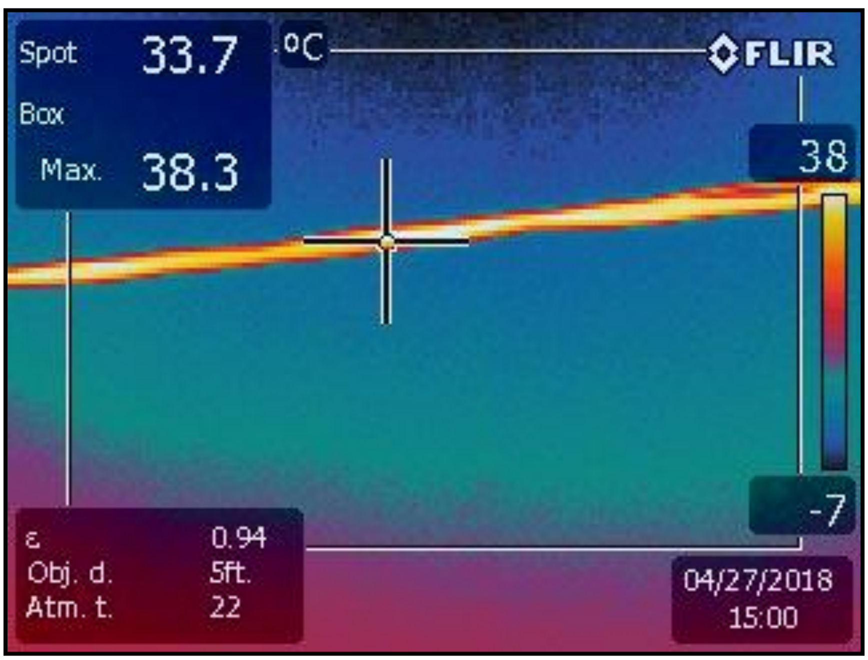


Figure 9. Thermal Image of ABC (Segment 1)

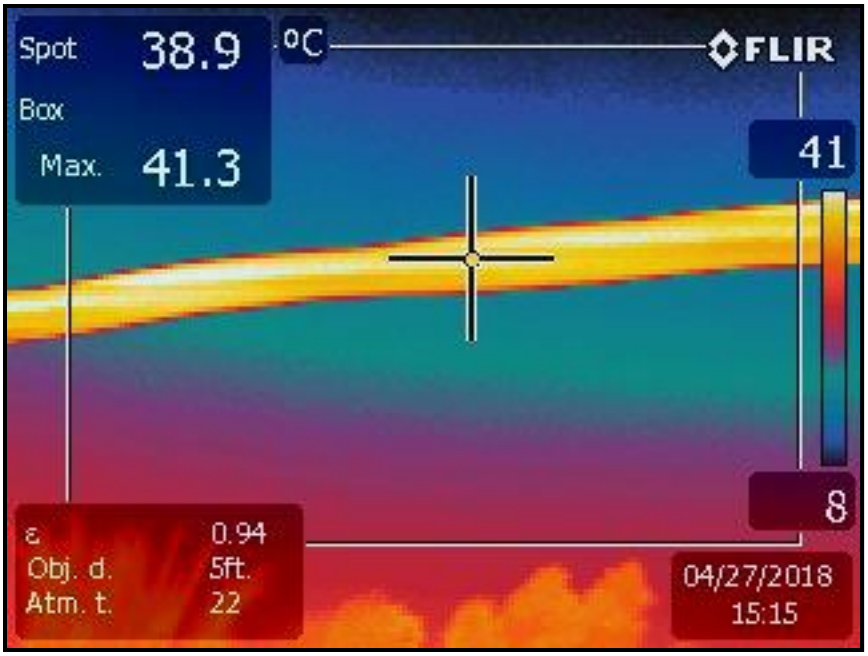


Figure 10. Thermal Image of ABC (Segment 2)

However due to insufficient information in these images, results have not yet been received. With periodic testing of the cables, historical database is being developed that will allow development of efficient algorithm.

2.6 Prognostics Framework

2.6.1 Prognostics

Diagnostics involves identifying and quantifying the damage that has occurred, while prognostics concerns with predicting the damage that is yet to occur. Prognostics algorithms are designed for the prediction of future health states and failure modes based on current health assessment, historical trends and projected usage loads on the equipment. This leads to predictive diagnostics, which includes determining the Remaining Useful Life (RUL) or time span of proper operation of a component, and consequently a system.

Engineering prognostics is used by industry to manage business risks that result from equipment failing unexpectedly. In the previous days, the deterioration in the Electric cables were analyzed manually by the humans and based on their analysis; they would predict the remaining useful life of these cables. However, human decision making is not always sufficiently reliable or accurate. Therefore, over recent years a significant amount of research has been undertaken to develop prognostic models that can be used to predict the remaining useful life of engineering assets.

2.6.2 Remaining Useful life Prediction

Remaining Useful Life (RUL) of a component identifies lead time to failure. It is also known as Estimated Time To Failure (ETTF). It is formally defined as the time span from the occurrence of a failure event to functional failure, for a given failure mode. In context of our project, it is the desired output, which will represent the useful life left on an asset at a particular time of operation. Thus, RUL estimation shall play an important role in scheduling maintenance and replacement of degraded component before functional failure. The RUL of an asset is clearly a random variable and it depends on the current age of the component, the operating environment, and the observed condition monitoring (CM) or health measurements.

2.6.2.1 Estimating RUL from Degradation History:

Data analysis of the material undergoing degradation is of primary importance. It plays a vital role in various RUL prediction techniques and methodologies. Conclusively, deep and thorough understanding of degradation is essential for any material being tested for RUL prediction. An understanding of the degradation of the material under study can lead us to successful prognostics. According to literature [2], the degradation types which affect the system are:

- Corrosion
- Deformation
- Fracture
- Wear

2.6.2.2 RUL Prediction Models

There are many types of prediction models used in the literature. Those prediction models are divided in two categories: 1) Stochastic Models 2) Statistical Models. Within stochastic models, we selected the *Bayesian techniques* with *particle filters*.

2.6.3 Bayesian Techniques

Classical Bayes theorem enables a recursive algorithm to be implemented in computer efficient manner to determine *posterior probability*, given a *prior probability* and an *update* or *likelihood function*. Posterior probability is the conditional probability of a state given previous measurements. Prior probability is determined by the *state-transition equation* and expresses the uncertainty of a state before any new measurements. This is a function of uncertainty of previous states. The update or likelihood function is determined by the *measurement equation*, which gives the current measurement given previous states. A typical flow of Bayesian model is shown in figure (11) as:

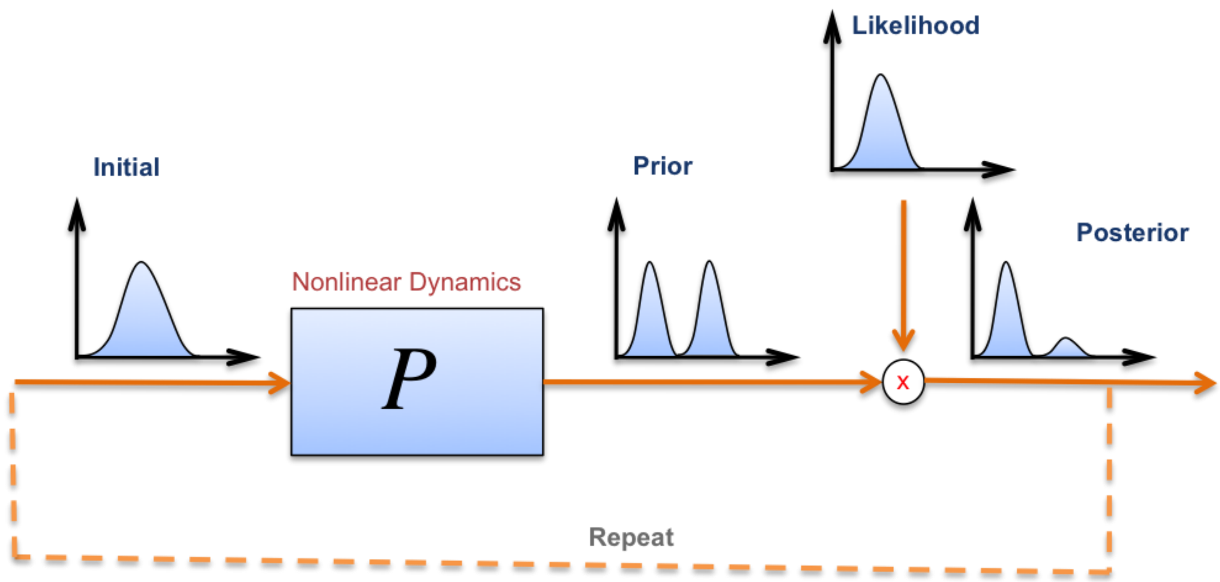


Figure 11. Bayesian Model

2.6.4 Particle Filters

Particle filters uses real-time on-line Monte Carlo simulations to model the decrease of uncertainty due to sensor measurements and the increase of uncertainty as time evolves in the physical system of interest. This is a very direct approach to modeling uncertainty, facilitated by the availability of fast, low-cost modern computers with large memories.

Particle filters can be used to model multivariate, dynamic processes with multi-modal noise / non-Gaussian noise profiles. Particle filters use Sequential Importance Sampling (SIS) to simulate the entire next state in each iteration of the filter. They do this by drawing a set of random samples, termed particles, from a theoretical density function and then adjusting the associated set of particle weights on each iteration. Adjusting the weights with the actual data values is known as the update process. The update and propagate steps are shown in figure (12) as:

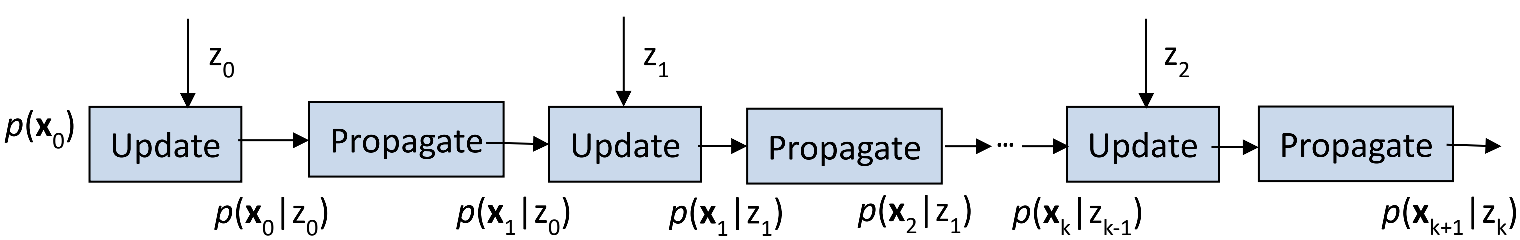


Figure 12. Particle filter flow diagram

Now we have tried to develop a framework to implement this technique onto the degradation problem of ABC cables. The aim is to find out the degradation trend or how much degradation is occurring in the cable after installation.

As discussed in the previous section, we have two types of measurement data:

1) Thermal Imaging data
2) Ultrasonic Probe data (Corona measurement)

These two measurements offer a room for data fusion as well. We will collect these measurements after every two (2) months. The frequency of measurement can also be modified depending upon what we are getting after every two months. If there is a big variation in the measurement data, then we will take the measurements after every month or after every week. If there is less variation in the measurement data, then we may decrease the frequency of data acquisition to three (3) months. Once we have data at different time instants at different significant locations then we will divide some data into training and validation data. From the training data, we will predict the data using the discussed prognosis framework. Using the validation data, we will also try to reduce the error in order to capture the degradation trend.

After finalizing the activities of the 2nd quarter, we are all set to collect field testing data for algorithm development and achieve the milestones of upcoming quarter.