

Enabling Predictive and Preventive Maintenance using IoT and Big Data in the Telecom Sector

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Abstract: Telecom sector has always been working hard to improve network quality to satisfy end user services. Fixing telecom network errors (hardware and software) precisely and quickly is a main factor to improve quality of services. Telecom operators are spending a lot of budget on ad hoc maintenance to fix these errors. This paper presents a framework using internet of things (IoT) and big data to enable predictive and preventive maintenance, which have been applied in the telecom sector. A telecom network consists of radio nodes, transport network, switching centres and civil infrastructure; and in this paper, focus is on the maintenance of Radio Access Network (RAN). A challengeable task for telecom operators has been to maintain radio nodes as these are installed on different locations. This framework for predictive maintenance is modelled using active and historical data from telecom equipment as well as data collected from IoT devices and sensors. The major benefit of implementing this framework has been a control on the time and cost of the maintenance by pre-planning maintenance activities and related budget.

1. INTRODUCTION

Telecom industry is spending bulk part of their budget for the maintenance of their network. This maintenance cost is called operational expenditure (OPEX). Telecom operators are trying to increase their profit by reducing the OPEX cost of their network. Due to competition, technology change and productivity gains (Ciriani and Jeansjean, 2019), it is observed that there is variation in growth rate and profit in all industries related to technology. Also, telecom industry is becoming less profitable due to the competition between operators and technology variation, which is evolving day by day. There is another reason behind reduction of OPEX cost as it has no link with the output e.g., whatever telecom company will spend on maintenance, there is no guarantee that their sale or profit would increase. According to an earlier study (Takao and Ryoji, 2002) presented in the Telecommunication Development Plan, telecom companies should be trying to reduce the maintenance cost by re-organisation their field operation team's. We aimed to develop a predictive and preventive maintenance framework for telecom using IoT and big data. Using this framework telecom companies can re-design their network maintenance processes that will help to reduce their operational

cost and increase network stability. We have developed a list of descriptions related to telecom operation and maintenance activities and how these operation and maintenance can be transformed in a predictive maintenance model. Our work has evolved around following key aspects: (1) telecom base station equipment and infrastructure; (2) procedures to collect data of telecom equipment; (3) telecom network operation and maintenance departments and field engineer hierarchy; (4) telecom network errors, alarms triggering and collection; (5) transformation of telecom network active maintenance to predictive maintenance; (6) telecom maintenance engineer effort and time for telecom network maintenance; and (7) significant effects of predictive maintenance on telecom network performance.

2. SYSTEMS MAINTENANCE

Telecommunication is the transmission of voice and data over the wires and the wireless (radio layers) network (Gunawardena and Weihua, 2014). It is also known as the technology that enables one user to connect with other user for the exchange of voice and data. Base station sites consist of transmitter and receiver equipment, rectifier to covert AC power to

dc-48 volts, battery banks, air conditioner, RF cables, Oil storage (used for generators) and generators to generate electricity in case of commercial electric power failure. Table 1 shows the equipment which involves in the building of a base station.

Table 1: Base Station Site Equipment

<i>Item Name</i>	<i>Indoor/ Outdoor</i>	<i>Area</i>
Air Conditioner	Indoor	Civil Infrastructure
AC Power System	Indoor	Civil Infrastructure
Base Station	Indoor	Telecom Equipment
Battery Bank	Indoor	Civil Infrastructure
DC Power System	Indoor	Civil Infrastructure
Rectifier	Indoor	Civil Infrastructure
RF Cables	In/outdoor	Telecom Equipment
RF Combiners	Indoor	Telecom Equipment
RF Module	Indoor	Telecom Equipment
Tower	Outdoor	Civil Infrastructure
Tower Base	Outdoor	Civil Infrastructure

To control maintenance activities in telecom network, Hoang and Hai (2013) elaborated that every telecom operator has a structure of teams who are involved in telecom base station's maintenance, which include: network operation centre (NOC), NOC team to monitor alarms 24/7, field operation team for planned maintenance, field operation team for reactive maintenance, alarms from telecom equipment comes to NOC system via management link. This management link used to perform software upgrade and downgrade for telecom equipment in addition of alarms monitoring. Currently, telecom operators are doing planned and reactive maintenance of base stations. Current maintenance is carried out only when NOC team observed one of the following situations: equipment stops working, equipment starts to give critical/service effecting alarms, equipment starts to crash, Software starts to give alarms and software starts abnormal behaviour.

3. PREDICTIVE MAINTENANCE

Predictive maintenance means monitoring the equipment to avoid future failure and as soon as equipment performance is degrading then maintenance is scheduled to avoid down time. Yousef et al. (2017) proposed a methodology for building a *Node Failure Prediction Model*, which can help to implement node failures predications to take the precautionary measures. This node is called *optical switch* in telecom and used to transport voice and data traffic. In our work, data collection by real monitoring of optical switch is explored and then *three different models* of machine learning are implemented to

predict the optical switch maintenance. Using the decision tree, ensemble model and logistic regression, data is trained and then prediction for optical switch maintenance is triggered.

In order to build a telecom operator network there are three types of sections: *radio, transport and core sites*. Multiple devices are used to set up an end to end telecom operator network. However, in the existing work only one device of transport is considered to base prediction maintenance. From a telecom operator point of view, spending money only for one device maintenance solution is usually not worthy. Telecom operators are often looking to find a solution which can cover most part of their maintenance. Our work considers radio sites which covers most part of telecom network and optical switches are part of radio sites. Using the proposed framework, telecom operators can cover the optical switch maintenance as well, by adding the data from optical switch to the predictive model. Our predictive maintenance framework also has the flexibility to add data from different sources as well as from optical switch.

3.1. Predictive Maintenance in Power System

In (Sisman and Mihai, 2017). failure of power supply system is predicted using a statistical analysis of the power system. By using a statistical analysis method (*such as the Pareto analysis, etc.*) and failure risk assessment (*through the intelligent techniques e.g., fuzzy graphs, artificial intelligent, etc*) critical components can be identified and monitored. Our work covers power system as well as radio and transport equipment. The prediction maintenance for power supply system is not useable for telecom operators. This is because a framework for predictive maintenance in telecom, should have the capability to first merge different kind of data into predictive maintenance system to trigger maintenance flags.

3.2. Framework and Related Data Availability, Access, Exploration and Processing

Our framework (as shown in Figure 1) has four steps to deliver predictions i.e., (a) *access and explore data*; (b) *process data*; (c) *develop predictive framework*; and (d) *integrate analytics with system*. In this framework, both hardware and software related data is used for predictive analysis. As outcomes, notifications are triggered to declare areas needed maintenance. In terms of access to data, we

have found that it is possible to collect data about *hardware, alarms, key performance indicators (KPI), IoT (including CCTV, ultrasonic and temperature sensor)* from telecom network equipment and infrastructure. Moreover, data from maintenance servers, IoT devices, alarms, key performance indicators and equipment manufacturers are combined in the main data server. Processing included scattering or to rearrange to bring the data into standardise format, this standard data is then processed to bring in a meaningful form which can make sense from the maintenance point of view. In predictive analysis, data is processed, and prediction notification are generated based on the defined priority area(s) that require maintenance.

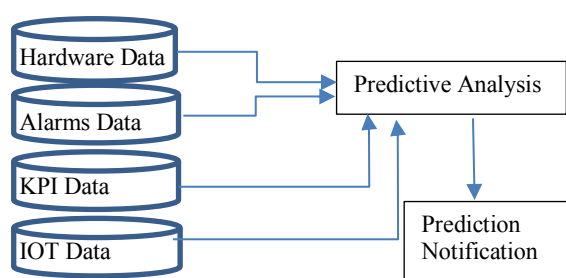


Figure 1: Overview of Predictive Maintenance Framework

This framework for enabling predictive maintenance suggests integration of the network alarms and IoT data to storage disks. These storage disks are integrated with both Hadoop/Hive and power business intelligence (BI) system. This Power BI system raises flags when a defined threshold is crossed. This flag then triggers task(s) for field engineers for maintenance.

4. METHODOLOGY

Due to the fact that it is impossible to self-raise faults in Telcom network as no Telecom operator will allow service suspensions, we have used simulations on the bases of our theoretical or visible values obtained from Telecom sector. However, we have collected original maintenance data from telecom industry equipment as well as their IoT data. Predictive maintenance default values are obtained and used as input. This maintenance input data is then processed i.e., either degraded or increase in quality, and then predictive maintenance results are observed. Our observations were based on varying the input data from the input sources to see the effects on the predictive maintenance outcomes. Moreover, data

generated by different resources is analysed. The margin of error in predicted results is covered by giving prediction using qualitative input data. These data sources include both hardware and software counters.

5. ENABLING PREDICTIVE MAINTENANCE

This section discusses the process adapted to enable predictive framework for the base station site.

5.1 Predictive Maintenance Framework Implementation for Base Station

In a telecom network all base stations are planned and installed in almost a similar model i.e., their operation and maintenance activities are similar. Therefore, evaluating predictive and preventive maintenance for one base station is largely applicable for all stations.

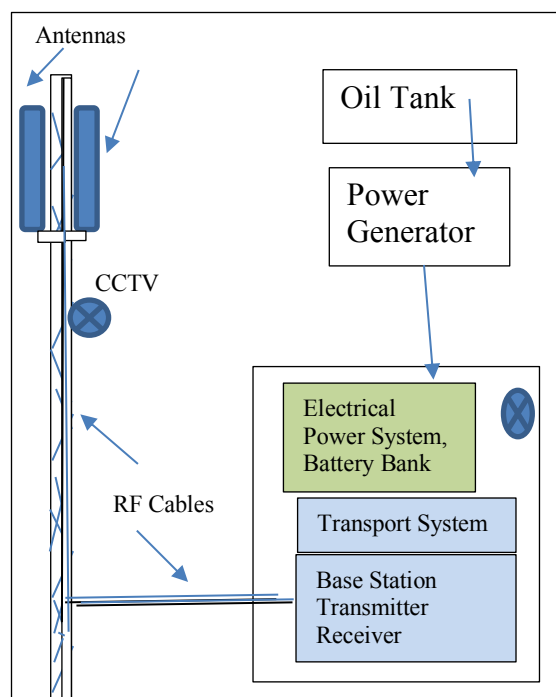


Figure 2: A typical Telecom Network Base Station Site

As shown in Figure 2, a base station consists of radio transmitter and receiver, transport system device (*optical switch or microwave link*) and electric power system. Base station transmitter and receiver are the main equipment responsible for receiving and transmitting the signals to end users. Electricity is fed by commercial sources as well generated by on-

site generator. Generator used for electricity production at site is dependant for oil stored in oil tank. Therefor maintenance and availability of oil tank is very important. This electricity is AC (alternating Current) which is converted to DC (direct current) by electrifier. This is because base station and transport system need -48v DC power as mentioned by Kasper, Bortis, Deboy and Kolar (2017). Base stations are also equipped with battery banks which are used to store DC power. In the next section each part of base station and prediction for maintenance is explored.

5.2 Base Station Transmitter and Receiver

Our requirements and design activities have established that prediction for radio hardware failure will be found by running diagnostic tests and then the results will be feed to the big data prediction system. Diagnostic test run through the hardware, check the health of the hardware and give immediate outputs. If a test case result is negative, then it means that the related hardware or part of that hardware is faulty. Radio equipment manufacturers have already added a default capability that when diagnostic test runs on a radio hardware, it checks the equipment stability and performance of each part of the radio module. The outcome of this test is either pass or fail.

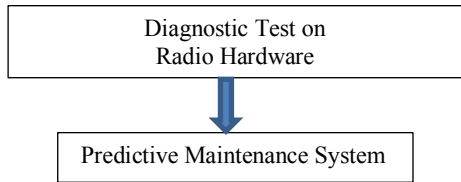


Figure 3: Prediction for a Radio Hardware Failure

Figure 3 shows the diagnostic test and result feed to predictive maintenance system. For diagnostic tests, a script is prepared which runs the diagnostic test on each radio module of the telecom base station and collect the results of these diagnostic tests. These results are in text format which are then transmitted to big data predictive maintenance system. These test results are in *pass* or *fail* format which reflects the hardware health status. The predictive maintenance system raises a flag for maintenance if the result is failed.

5.3 Base Station RF Cables

The RF cables data are collected from two resources. First from display sensor which shows the RF cable

and connector physical appearance. Human intervention is required to check the physical appearance and then to add this data in main database. Second data for RF cables and connectors are be collected from IoT devices. This data consists of actual RF measurements like voltage standing wave ration (VSWR), cable loss, return loss etc. These results are collected automatically from base station equipment and sent to main database. These results are precise, and each measurement reflect the status of the RF cable. Analysis triggers flags to predict if RF cable(s) situation is degrade and going to get worse if maintenance is not carried out.

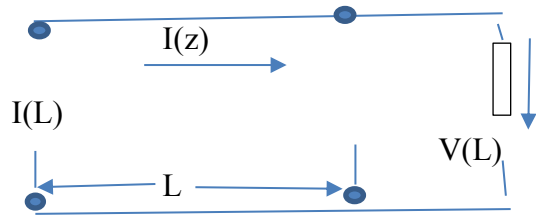


Figure 4: Transmission line terminated with load

In relation to the power transmission via RF cables, power is represented by voltage (V) and current (I). A Voltage V(z) and Current I(z) at any point z is shown in Figure 4 when it travels through the RF cables. Voltage and Current can be calculated in load condition and at any point where it needs to be measured. This RF power is travelled in sinusoidal form and can be expressed in phasor form in an equation 1 & 2 given below:

$$V(z)dz = - (R + j\omega L) I(z) \quad (1)$$

$$dI(z)dz = - (G + j\omega C) V(z) \quad (2)$$

Where R is series resistance expressed in (ohms/m) and L is inductance expressed in (henrys/m) for both conductors, and G (siemens/m) and C (farads/m) are shunt conductance and capacitance per unit length. When RF power is travelling via RF cable then this is given as follows:

$$V(z) = V^+ e^{-\gamma z} + V^- e^{\gamma z} \quad (3)$$

$$I(z) = I^+ e^{-\gamma z} + I^- e^{\gamma z} \quad (4)$$

$$\text{Where } \Gamma = \frac{Z - Z_0}{Z + Z_0} = \frac{(R + j\omega L) - (G + j\omega C)Z_0}{(R + j\omega L) + (G + j\omega C)Z_0} \quad (5)$$

above is a complex propagation constant, with α being the attenuation coefficient and $\beta = 2\pi/\lambda$ the wave number, V^+ and I^+ are the voltage and current amplitudes of the incident wave along +z direction, V^- and I^- are the voltage amplitude and current amplitudes of the reflected wave along -z direction, and Z_0 is the characteristic impedance of the transmission line and is defined by:

$$Z_0 = \sqrt{R + j\omega LG + j\omega C} \quad (6)$$

When Rf signals travel in RF cables then the output of power at exit end depends on the quality of the RF cable or the performance of the RF cable. This quality and performance of RF cables are measured in form of variable measurements. These measurements can be variable due to a fault or leakage in the RF cables. In case of faulty or leaked RF cable, the respective measurements will change which eventually will affect the output of RF signals. The measurements collected in this section for telecom RF cables health are in digits. These digits correspond the health of RF cable. High value of digit corresponds the bad health of RF cable and vice versa. These results which are in mathematical structure are feed to predictive maintenance system which analytical is applied to get prediction for RF cables maintenance.

5.4 Predictive Maintenance for Civil Structure

In telecom sector, an important part of base station is civil infrastructure. Civil infrastructure consists of cooling systems, electric power from commercial source, a rectifier to convert AC to DC power, system for electric power generation (*in case of commercial power failure*), battery bank (*used in case of commercial power failure*), and concrete base (*to install tower on this*). Figure 5 shows various sensors in our predictive maintenance model, which covers all areas of a civil infrastructure installed in a telecom base station. In order to predict maintenance for base station civil infrastructure, CCTV and sensors are used which are installed on battery banks and send live data to main database.

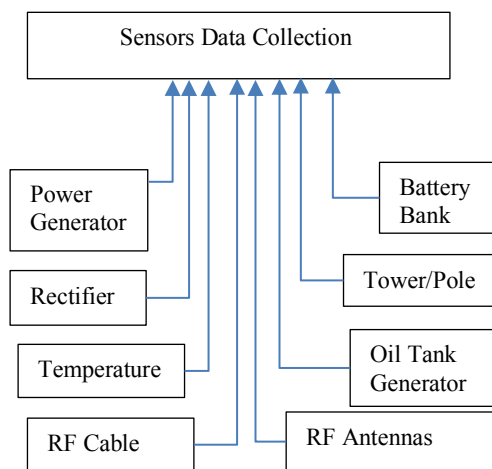


Figure 5: Prediction for base station infrastructure failure

Base station telecom equipment needs -48 dc voltage. The sensor on battery bank reads voltage of battery bank and send these measurements to main database on daily base. When this dc voltage data is processed, trends are sent to power BI tool. Power BI will raise flag if the voltage gets less than -48 volt. The telecom equipment is considered working fine if voltage is between the range of -48 to -53 dc volts. In case a flag is raised for low voltage, maintenance should be carried out as soon as possible to avoid outage in a base station service. Moreover, a sensor is also installed on oil tank to read the oil level. This reads the oil level and measurements are feed to the system which raises the flag for inappropriate oil levels.

5.5 Predict Maintenance for Telecom Network Failure

Most of the telecom equipment vendors have manufactured their own proprietary server to collect alarms and log data from their equipment. In these days major telecom vendors are Nokia, Ericsson and Huawei. Huawei has main network control system called U2000/U2020 and Nokia has Net-act. U2000 and net-act are providing statics of the network. These network statics are called key performance indicator (KPI). KPI's given by U2000 and net-act are in same format. Like both are giving data about calls and throughput. These data sets include:

- *Call attempted*
- *Call dropped*
- *Call successful*
- *Call failure*
- *Total Throughput*
- *Throughput in uplink*
- *Throughput in downlink*
- *Packet loss*
- *Packet dropped*

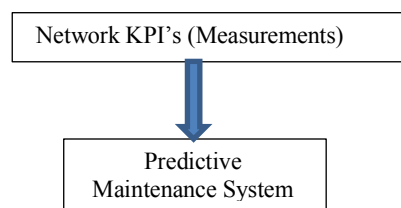


Figure 6. Network KPI's to Big Data Predictive System

It is important to note that the KPI's mentioned in this section are just example, there are a lot more KPI's who reflect the network performance. These KPI's are in text format which represent the stability and

performance of the telecom network. As shown in Figure 6, KPI's data generated from network management system is sent to the predictive maintenance system, where these data sets are processed, and flags are raised when performance is degraded by comparing it to the defined measures. Once flag is raised, a notification is sent to network operations team or network optimisation team for further diagnostics.

6 DISCUSSION, ANALYSIS AND LIMITATIONS

This section discusses our achievements, limitations, related issues and prioritise in using an automated telecom network predictive maintenance infrastructure.

6.1. Telecom Base Station Equipment and Infrastructure

In order to achieve predicative maintenance in telecom sector, equipment and infrastructure involved in building a telecom base station site is explored. Figure 2 gives an overview for the telecom base station equipment as well as civil infrastructure. The telecom base station outdoor view explains the tower at base station and antennas installed on tower. There is one generator installed at the base station site to generate electricity in case of outage in commercial electricity. Also, electricity received from commercial resources or from generator is alternate current (AC) but telecom equipment needs direct current (DC). For the purpose to convert AC to DC, rectifier is used. The base station transceiver system (BTS) is purely a telecom system, which is responsible for processing the signals, data and modulating the transmission and received signals. BTS is responsible for communication to end users as well as to the main control system (Mobile Switching System). The RF cables are used in base station site, which connect BTS and antennas. Maintenance of RF cables are also very important for the performance of the base station.

6.2. Procedure to Collect Data from Telecom Equipment

Section 2 presents telecom hardware data which telecom vendor can provide. This data has full

production history of the equipment manufacturing record, the batch (it belongs to) and related manufacturing issues (if faced during the manufacturing). Normally vendors don't (fully) share such information. Vendor usually only release information about the production data and expiry date of an equipment. This manufacturing data is stored in predictive maintenance database to verify the performance of the related equipment.

Table 2. Hardware Alarms

Location of Alarm	Alarm Type	Alarm raised by Equipment	Historical Alarm on this equipment
Site A	RF module	Major, minor, Critical	from one-month poor site performance
Site A	Main Processor	Major, minor, Critical	from one-month poor site performance

In Table 2, various types of alarms that a telecom equipment can raise are presented. These alarms feature is usually pre-added by telecom equipment vendor. Telecom equipment vendor can add and edit any alarm if necessary, by downloading software patches. These alarms are in status of minor, major or critical, depends on the effect of service it provides. The network stability is measured by various key performance indicator (KPI), and an example of is shown in Table 3.

Table 3. KPI's from base stations

Location	Call Attempted	Call drop Rate	Data Packet Loss	Call Failure	Call Successful Rate	Handover attempted	Handover failure rate	Call drops due to hardware failure
A	100	95 %	50 packets	95	5%	100	93	95
B	100	0	0	0	100 %	100	0	0

This KPI feature can be edited by a telecom equipment vendor. Normally every telecom vendor is following 3rd Generation Partnership Project (3GPP) aspects for network performance (Release 15, 2018). But some KPI's can be proprietary to a vendor, which they add to optimise network or these propriety KPI's help vendor to improve the network performance.

6.3. Telecom Network Operation and Maintenance Departments and Field Engineer Hierarchy

We have explored telecom current maintenance design and it was found that telecom operators perform maintenance activities both in planned and reactive arrangements. Telecom vendor usually spend a lot of money for their daily operational tasks. There are usually two teams involved in daily maintenance task. One does the planned maintenance activities, who are not responsible to immediate alarms and only visit the site according to planned date and observe if there is any maintenance required. The other team is the one which attend the base station for priority maintenance e.g., if there is a service failure alarm triggered by the base station site.

6.4. Telecom Network Errors, Alarms Triggering and Maintenance

In telecom sector, usually maintenance is carried out when there is fault in network. Li, Lansburg and Cocciantelli (2001) have explored the maintenance and operations characteristics in telecom application. It is found that two kinds of maintenance are adopted i.e., planned and proactive maintenance. Many telecom operators have outsourced their operation and maintenance activities. Takada, Tanji, Seki, Yamagoe, Soejima and Tahara (2019) has explored the operation and optimising based on SLA. To avoid the SLA, a maintenance engineer visits the site according to the maintenance plan which has been drafted for the site maintenance, regardless the planned site required maintenance or not. For proactive maintenance, maintenance engineer receives the task from the NOC team that a site raised alarms and needs to be fixed, usually as soon as possible. Mostly these alarms are about service failures, which means operator is losing money due to outage in network. In order to overcome the outage in the network services and to save the maintenance engineer time, predictive maintenance can help these maintenance engineers in upholding the telecom network.

The key idea behind the predictive maintenance is to get all possible alarms and historical data from telecom equipment, including technical and non-technical areas and make use of all these data sets. Big data analytics can help getting accurate predictions for needed maintenance. Data from civil infrastructure (se discussed in Section 4) need to be collected via IoT devices, which involved;

for example, sensors and CCTV monitoring. Moreover, sensors can be used to detect the oil level in oil storage tank and to send the measurements back to the system.

6.5. Issues and Limitations in Enabling Predictive Maintenance on Telecom Network

Enabling predictive maintenance could be expensive in the start, but in the long run telecom operators can increase their income by reducing the network issues as well as by decreasing the time and cost for maintenance. Challenges also arise in testing the system as it may not be possible to test all live failures until a failure occurs automatically. Moreover, in order to enable this framework in telecom industry, telecom operators need to plan implementation in various small steps. Moreover, they will need to keep running their manual (existing) maintenance operations and structure. Even after enabling an automated framework for predictive maintenance, telecom operators will need to optimise this framework to get accurate and quick predictions for future maintenance. We cannot ignore the chances of wrong of misleading predications made by the automated system at-least in the initial period. Therefore, there will still be a need to verify the performance of the base station site when predictive maintenance system triggers a required maintenance. This usually done by verifying the counters and KPI's of the site, and manual verification is performed for the civil infrastructure installed at a telecom site.

6.6. Verifications from Telecom Experts

We conducted a survey from senior telecom professional engineers to get their opinion about the need of predictive maintenance and its possible effects on telecom network. Here is a partial snapshot of the key results obtained from our survey:

- 72% (21 out of 29) telecom field engineers agree that predictive maintenance is better option for telecom industry
- 97% (28 out of 29) telecom field engineers has agreed that predictive maintenance can bring benefit for telecom industry.

- 93% (27 out of 29) telecom field engineers has recommended that predictive maintenance can improve the stability in telecom network.
- 97% (28 out of 29) telecom field engineers has idea that predictive maintenance can reduce time and cost for telecom network maintenance.
- 100% (29 out of 29) telecom field engineers agree that historical alarms are beneficial for future planning in telecom network.
- 97% (28 out of 29) telecom field engineers agree that KPI (voice and data measurements) are helpful for future planning in telecom network
- 100% (29 out of 29) telecom field engineers has recommended that enabling predictive maintenance system for power infrastructure can improve the outage in telecom network.
- 100% (29 out of 29) telecom field engineers that combining network alarms, KPI and environment data are helpful for predictive maintenance in telecom network.
- 97% (28 out of 29) telecom field engineers agree that predictive maintenance is helpful in generating more revenue for telecom industry.

8 CONCLUSIONS

Predictive maintenance in telecom can bring stability in the network and increase in revenue. For the purpose of incorporating predictive maintenance in telecom network, research is carried out about active maintenance structure and network entities which require maintenance. Research is also carried to find different sensors / IoT devices to monitor the telecom network base station temperature, power system, generator and oil. This framework for predictive maintenance is modelled using active and historical data from telecom equipment as well as data collected from IoT devices and sensors. A survey is also carried out to confirm that senior professional engineers working in telecom network agree with the benefits obtained through predictive maintenance in telecom network. Results also show that enabling this predictive maintenance framework in telecom network can increase the stability and performance of network which can lead to decrease in maintenance cost and increase profit.

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