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Preparing Your People for Transitioning to Industry 4.0

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Webinar Series

Speaker Bio

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Jack R Nicholas, Jr.

P.E., CMRP, CRL, IAMC, BS, MBA, CAPT USNR (Ret.)

- Graduate of the U.S. Naval Academy and the American University of Washington, D.C.
- Served as chief engineer of a surface warship and then in various positions on three nuclear powered submarines.
- Commanded five Navy Reserve support units at submarine tender, squadron, force and Chief of Naval Operations levels of the Navy over a period of ~9 years.
- Author, co-author, editor and major contributor to many books, professional papers and magazine articles on Reliability & Maintenance subjects since 1990.
- Over 30 years of international experience leading, teaching, training and consulting in government, military, utility and commercial venues.
- Recipient of two lifetime achievement awards for his civilian accomplishments as well as many military and civilian medals for support of nuclear submarines, surface warships and supporting commands.
- Photo appeared on the cover OCT/NOV 2019 Uptime magazine along with a tribute to him and his wife, a photo collage, and an article he authored, “Data Farming: A Way to Maximize Use of Data for Machinery Condition Monitoring”

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Introduction

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Big data and advanced analytics can have major impact on operations, maintenance and reliability (OM&R).

OM&R leaders should educate themselves on the results to be gained over their current approaches and begin planning to make the case for adding real benefits to their organizations.

Selective application of new capabilities on offer through use of the Internet of Things (IoT), Industrial Internet of Things (IIoT) big data management, cloud computing and advanced analytics can pay off handsomely for OM&R in almost any venue.

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What to do about the IIoT

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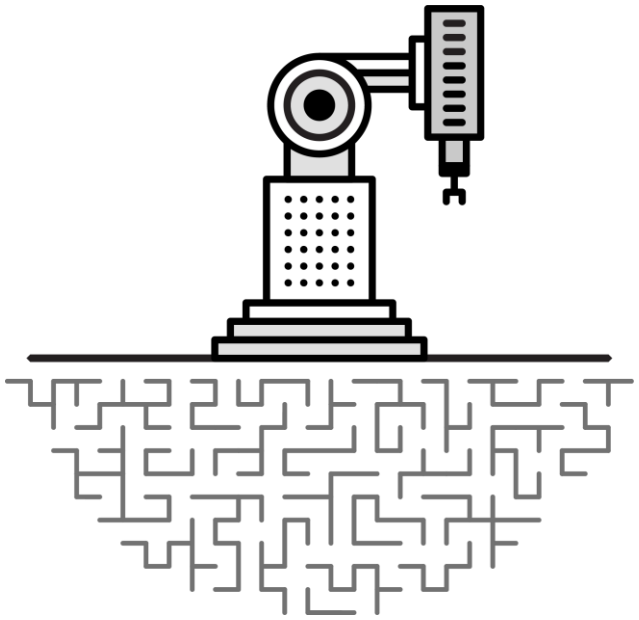
- Get the latest information
- Understand what's worked before and why
- Acquire the skills needed
- Revisit SCADA, RCM, TPM, RCA, CA, and DE to figure what to monitor and why
- Develop a plan that has a chance of success
- Sell & gain support and resources implement and monitor progress of the plan

Machinery Information

Machinery can provide a huge amount of data to assess health, performance, integrity and/or condition, **given the right sensors and capability to evaluate their outputs.**



Traditional methods of assessing these attributes were by:

- Operator or maintainer observation of installed meters and gauges
- Periodic recording of information in various forms such as handwritten log sheets for review looking for indications of problems

More recently aggregation and some fault diagnosis is being performed by electronic devices such as:

- Programmable logic controllers and tablet computers
- Use of condition monitoring technologies and analysis techniques
- Central analysis centers

Ice Breaker Question

POLL QUESTION No. 1

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Does your organization believe it will benefit from adopting Digital Transformation/IIoT Technology/Industry 4.0 capabilities for machinery monitoring?

(click only one answer)

- Yes
- No
- Don’t know/not sure

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1970s -1980s Multi-tiered CM & PM Program

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122 nuclear powered submarines

Up to 65 systems monitored up to 4 times/year

Analysis done on three levels

- At the machine being monitored
- Local for each plant
- At central analysis center(s) for all plants together

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Submarine Maintenance Monitoring & Support

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- 190 (mostly enlisted) at up to nine (9) operating ports
- 165 (mostly civilian) personnel in central analysis center
- Uncounted number of civilian contractors
- Civil servants in two vibration analysis centers

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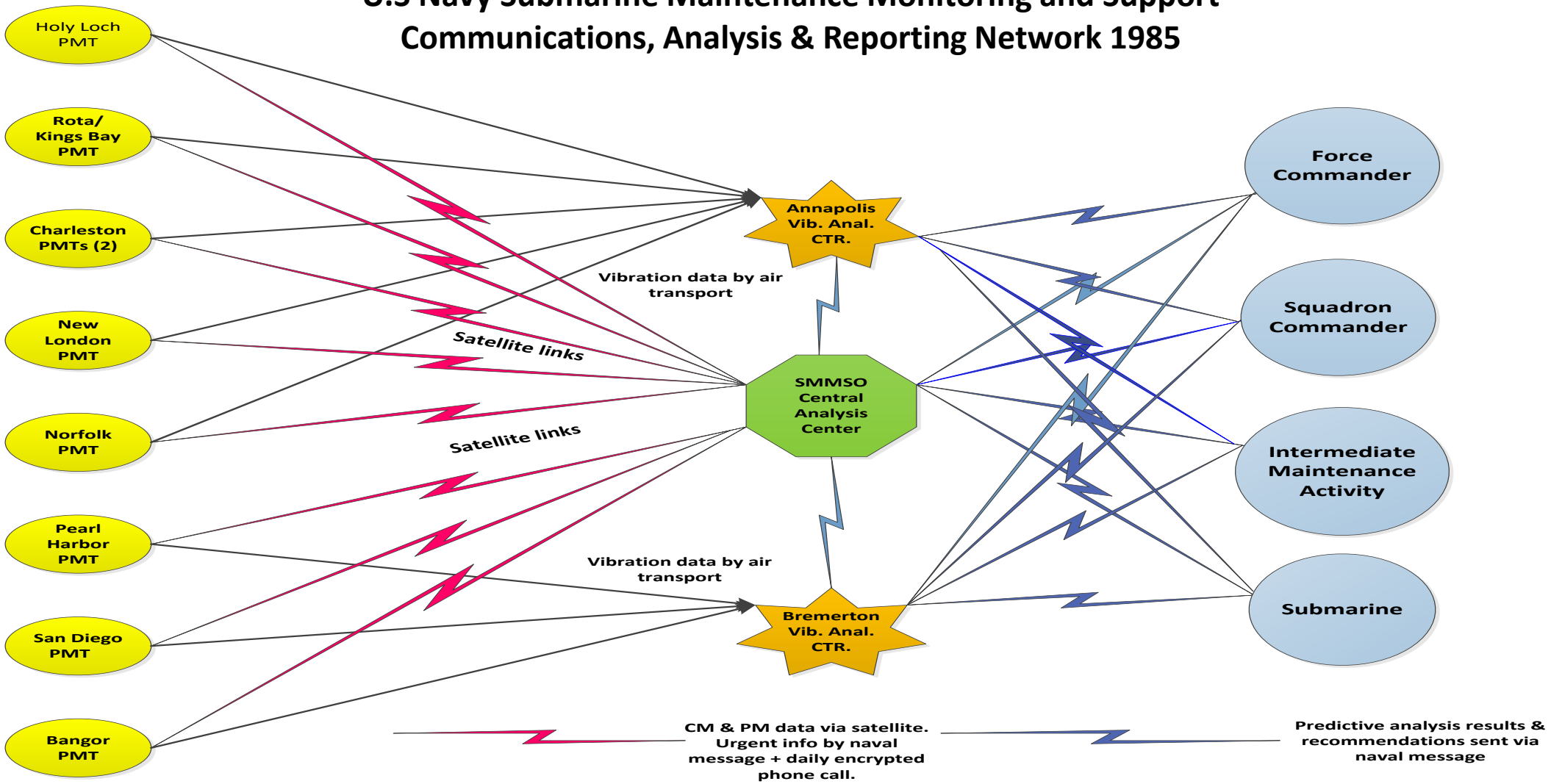
U.S Navy Submarine Maintenance Monitoring and Support Communications, Analysis & Reporting Network 1985



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Big Data & Predictive Analytics Payoffs

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- First 31 ships taken into the program 5 to 6 years into nominal 25-year life
  - 11% reduced life cycle maintenance cost (avoidance)
  - 17% increase in mission availability during the nominal 25-year ship life
  - In some cases (depending on reactor core life remaining) almost 50% increased operational life (36 vice 25 years)
  - Absolutely no reduction in ship reliability or mission readiness
- Reduced need for additional subs to meet defense commitments

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Big Data Payoffs Applicable to IIoT Big Data Management & Predictive Analytics

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- Having access to historical data on machinery performance and condition in the whole fleet collected using the same format that was quickly available for comparison with newly received information
- Being able more quickly to detect faulty replacement parts that had entered into the supply system resulting in earlier than expected failures
- Detecting the signs of aging of components or major systems so that resources to counter the effects could be developed and deployed to counter them
- More readily detect assets that were not performing as expected and that required alteration or replacement to meet mission or safety requirements

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Big Data Payoffs Applicable to IIoT Big Data Management & Predictive Analytics

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- Having a strong basis for changing criteria for performance and condition when required to meet safety, health, environmental or mission requirements and/or to drive criteria in desirable directions in order to enhance mission margins
- Being able to provide what is now called “prescriptive maintenance” recommendations and where appropriate, alert the logistics supply chain of need for support
- Being able to inform equipment suppliers quickly when their products were experiencing unexpected failures and operating difficulties in service

Advantages of Today's & Tomorrow's Capabilities

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- Connectivity can be established electronically from component being monitored to cloud-based data and analysis centers anywhere else.
- Locally the connectivity is made by WiFi, Ethernet and other protocols with LiFi coming into use in the near future.
- IoT & IIoT combined with 4G and in the near future 5G Long Term Evolution (LTE) communications links.
- All this means higher volumes can be transmitted at higher velocity to gain more value and variety - the 4Vs.

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Giving Your People the Big Picture

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To prepare personnel for Industry 4.0, **start with defining the ultimate goals** for converting to a digital future leading to higher level of reliability

- Fewer complete failures by providing early warning of the onset of degradation
- Concentration on preserving function over just restoring lost capability (Reduced Emergency Actions)
- Freeing personnel to apply other methodologies
    - Reliability Centered Maintenance
    - Root Cause Analysis
    - Defect Elimination
    - Process Improvement
    - Precision Maintenance
    - Analysis of data from hard to solve problems

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Sensors

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1. An increasing number are coming into the market, some “smart” and others simply providing raw data.

2. All should have digital output and wireless connectivity or be converted to provide it.

3. Energy to power the sensors and wireless links most often comes now from batteries.
   - Battery life dependent upon design technology, capacity and frequency of data transmission but still adds a new maintenance requirement
   - Longer life fuel cells are in the development pipeline.

4. Biggest advancement in sensor energy may be the development of ambient energy harvesting or scavenging methods to charge galvanic cell power circuits using sources of mechanical, thermal, natural, light, magnetic field and nuclear radiation energy.

Source: Asset Condition Monitoring Management Chapter 10 pp170-171 provides more detail on battery alternative power sources for sensors.

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Edge Computations

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1. Key principle of modern condition and performance monitoring is to conduct as much analysis as close to the “edge” of the network as feasible.

2. Each sensor point should be assessed for its ability to indicate an actual or likely failure mode standing alone or in combination with any other source(s) of data.

3. Intel announced a credit card-sized “Compute Card” that provides a modular approach to designing edge computing power and connectivity into consumer or industrial products.

   It’s a full computer with memory, storage, input/output options, WiFi and Bluetooth connectivity. Product availability was in mid-2017.

4. Google has introduced an AI chip (Edge TPU), a tiny machine learning accelerator that can be trained to perform “inference” analysis.

   Six of these chips can fit inside the perimeter of a US one-cent coin.

Source: De Leeuw, Valentijn https://industrial-iot.com/2017/01/intel-compute-card-iot-moduless-potential-impact-product-life-cycle- January 27, 2017

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Connectivity Options

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WiFi currently the most used wireless approach with protocols such as Zigbee.

- Bluetooth communications may also be employed for short range applications.

LiFi is a relatively new technology for data transfer that uses light emitting diodes (LEDs), increasingly used for area illumination because of lower energy requirements.

- It encodes messages in flashes of light.
- Light does not penetrate walls or other windowless containment boundaries making it more secure than WiFi.
- It does not interfere with radio, radar or other lower frequency electromagnetic signals It may be more easily installed, because the same cable supplying power to the LEDs can carry data.
- The iOS 9.1 operating system has buried in its iPhone the term “LiFiCapability.”

Source: Economist newspaper September 24, 2016, “In a Whole New Light” pp76-77

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Local Analysis Center Capabilities

- In the most advanced analysis centers a “virtual (digital) twin” plant is established that has all the characteristics of the real plant integral to it.
- The virtual twin contains all the information that describes “normal” safe operations for comparison with actual plant conditions from startup through full production to shutdown.
  - This requires constant attention to ensure accuracy of the “twin” as operating conditions change.
- Ideally, anything out of the ordinary comes to the attention of in-house analysts, along with what to do to correct any abnormal condition.

Remote Analysis

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- The final stage of analysis capability may be located hundreds or thousands of miles away from the plant being monitored with connection via the IIoT.
- Plant personnel must make decisions concerning what data are forwarded.
- Decisions should be based on expectations of both tangible and intangible returns on investment (ROI) and capabilities of the analytics employed by the services provider.
- The advantages of high capacity big data management and analysis centers exceed those of all but the most well equipped in-house analysis centers.

Today's Example CM & PM Analysis Network

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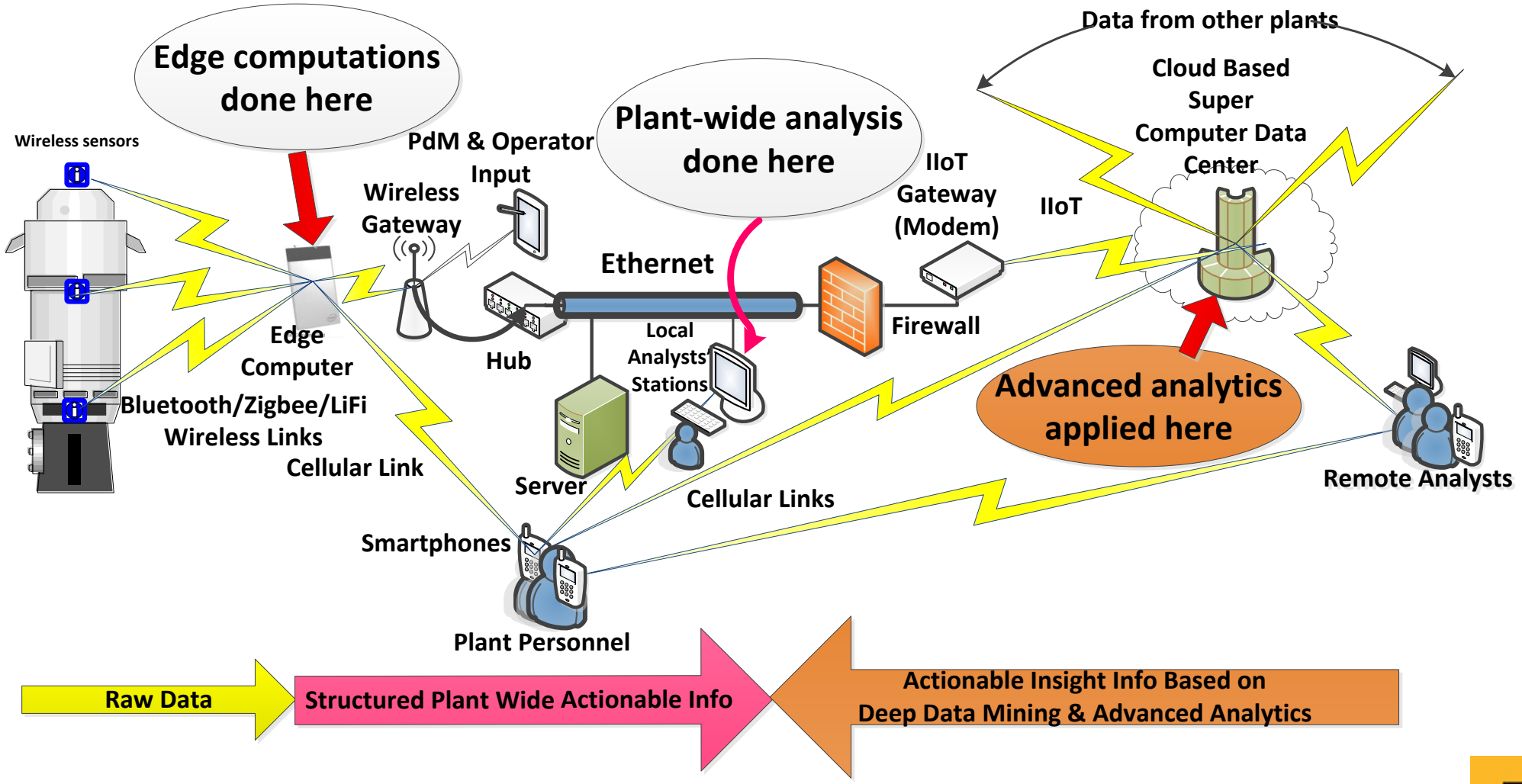
Example mid-2019 Machinery Monitoring Scheme Showing Levels of Analysis & Nature of Information



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Advanced Analytics (Examples)

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Analytical Method	Application
Association Rule (Apriori)	Exploratory Data Mining
Density-Based Spatial Clustering (DBScan)	Clustering Analysis
High-Dimensional Data Visualization by MDS	Visual Analysis
Regression (Principle Component, Partial Least Square, Multiple Linear) Analysis	Statistical Methods

Source: Pattern Discovery Technologies(PDT) Inc., website http://www.patterndiscovery.com/technology/discovere/

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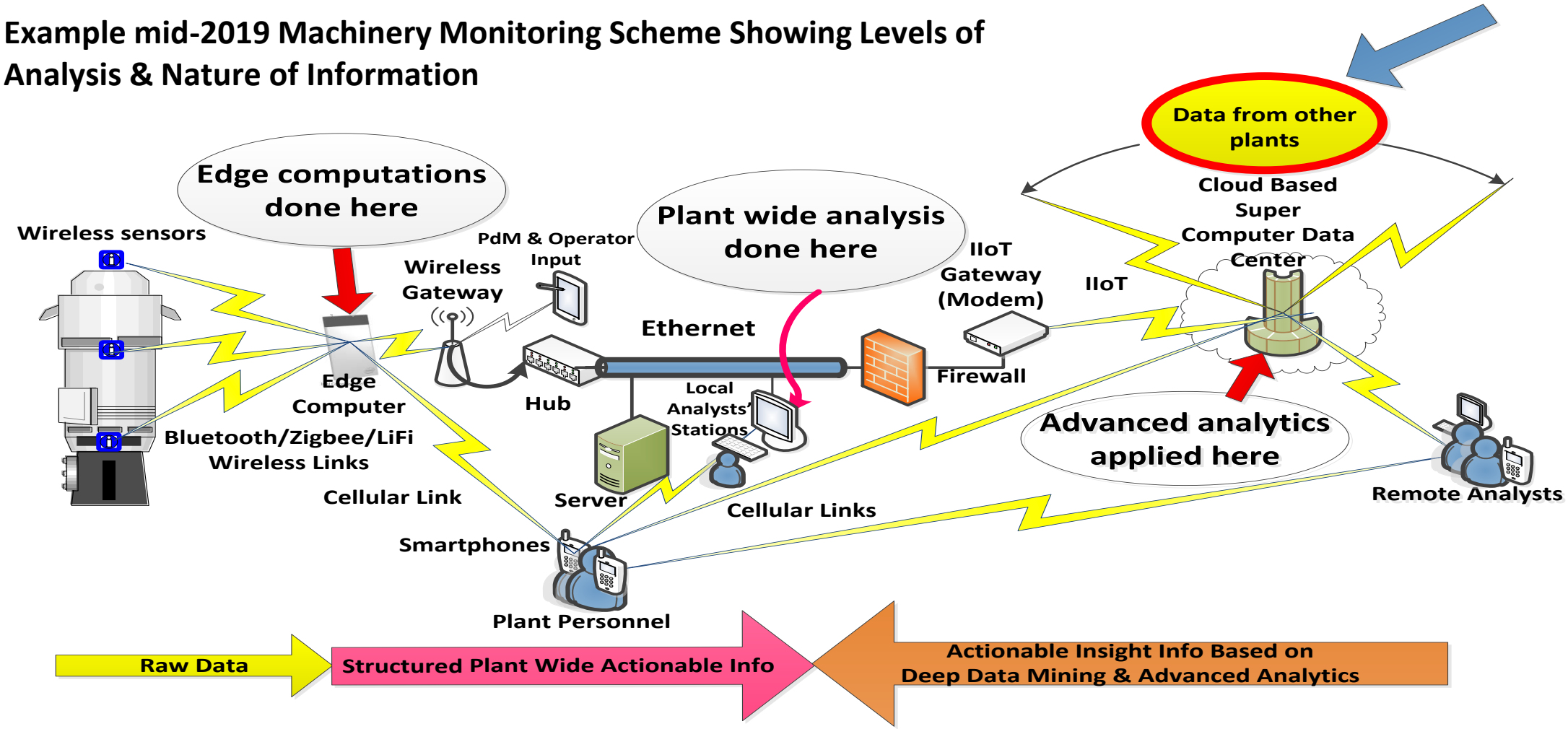
Example mid-2019 Machinery Monitoring Scheme Showing Levels of Analysis & Nature of Information



Comparable data from affiliated and unaffiliated plants that can be accumulated and used to hasten reaching conclusions about what is happening to equipment over time.

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Remote Analysis Advantages

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- Useful to equipment manufacturers desiring to keep ahead of clients that have purchased their products and want to design modifications that lessen their warranty costs and/or provide post-warranty solutions that will lead to additional sales.
- For those equipment suppliers that also provide contracted on-going lifecycle maintenance and logistics support under business models that sell things like engine hours or utilities such as high pressure air, big data and cloud based services make economic sense both for the supplier and all the clients served.
- An analytical method called time series analysis often takes substantial amounts of data and/or a large amount of time to accumulate sufficient information upon which to draw definitive conclusions.

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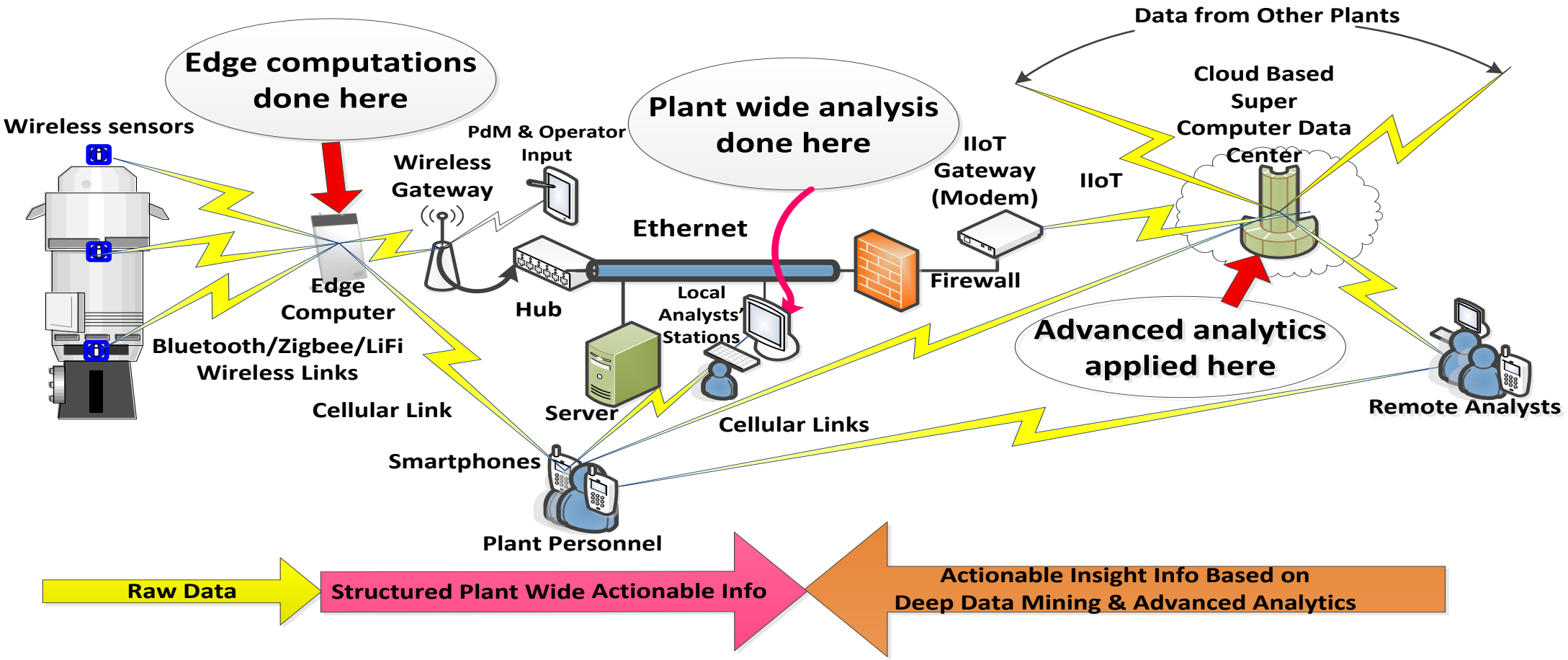
Example mid-2019 Machinery Monitoring Scheme Showing Levels of Analysis & Nature of Information



Unstated in the figure above is the possibility of moving beyond the actionable insight level possible with advanced analytics to wisdom about the plant being monitored.

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Wisdom Concerning Asset Condition & Performance defined as:

“Prescriptive advice and procedures to help achieve targets such as safety, health, environment, quality, schedule, throughput, efficiency, yields, and profits.”

Source: http://www.maintenancetechnology.com/2016/11/move-raw-data-smart-work/ (Poll Question #1)

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POLL QUESTION No. 2

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Where is your organization positioned relative to Digital Transformation/IIoT Technology/Industry 4.0 capabilities for machinery monitoring?

(click only one answer)

- Passed the pilot stage and heading to full implementation
- Pilot stage
- Planning stage
- No plans yet

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Local Analysis Center Capabilities

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- Integrated with the virtual twin plant in the most advanced internal analysis centers would be “object-oriented” supervisory control and data analysis (SCADA) software.
- From the inception of PC-based human-machine interface and supervisory systems, process data access, scripting, alarming and data analysis have been based on the concept of tags.
- Tag systems use a “flat” list of tags with built-in hierarchy, relationships or interdependencies.

Source: “The Benefits of Object-Based Architectures for SCADA and Supervisory Systems” white paper by Steven D. Garbrecht

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TAB-Based SCADA

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- The system creates common graphics containing scripts that switch the tags in run time.
- Because the application structure is flat, the user must then change each tag in the system and analyze how the change affects the rest of the application.
- Maintenance of tag-based applications typically involves tag-by-tag analysis and updates that can consume significant amounts of labor.

Object-based SCADA

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- The tag-based approach to SCADA is being overtaken by object-oriented methodology.
- In object-based SCADA, application objects contain aspects or parameters associated with the assets they represent.
- For example, a valve object can contain all the events, alarms, security, calculations, data collection, integrations, communications and scripting associated with the asset.

Object-based SCADA

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- Objects don’t just represent plant equipment.
- All of these objects can be standardized and used across all supervisory applications to drive consistency of system design and operation.

They can include:

Calculations, Database access methods

KPIs, Condition monitoring events,

Enterprise resource planning data transfer operations

Mobile operator procedures, Workflow activities

Manufacturing execution systems (MES) tasks

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Object-based SCADA

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- By moving to object-based SCADA, engineers will radically reduce the time spent maintaining and upgrading the capabilities.

- An object can be selected from an existing library and either used directly or, with slight modification, to add more knowledge sources for operators and asset condition monitoring specialists to use in gaining understanding of what is happening or not with the systems in their charge.

Source: "The Benefits of Object-Based Architectures for SCADA and Supervisory Systems" white paper by Steven D. Garbrecht

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Acquiring Skills for Big Data Management, Cloud Computing, Advanced Analytics, AI

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Specialists in Data and/or Analysis Centers include:

** = Systems Engineer in 1970s-1980s*

Big data engineer*	Database manager	Data modeler	Database administrator
Data architect	Business intelligence analyst*	Database developer	Data analyst/report writer*
Data warehouse manager	Data scientist*	Data warehouse analyst	Cybersecurity specialist

Other specialists include personnel for:

Computers and all peripheral equipment • Heating, ventilation and air conditioning systems

Physical security components • Protection against power outages every second of all years

Source: http://www.networkworld.com/article/3114754/careers/big-data-salaries-set-to-rise-in-2017.html article by Robert Half Technology associates (unnamed).

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Acquiring Skills for Big Data Management, Cloud Computing, Advanced Analytics, etc.,

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- It is unlikely that all but the largest industrial or utility organizations will employ all or even a large number of the specialists who carry the titles listed in an earlier slide for data center operations.
- For most organizations, a few specialists may be needed on a temporary basis from contractors offering their services (IIoT solutions providers).
- The most important of these are data scientists.

The (Citizen) Data Scientist

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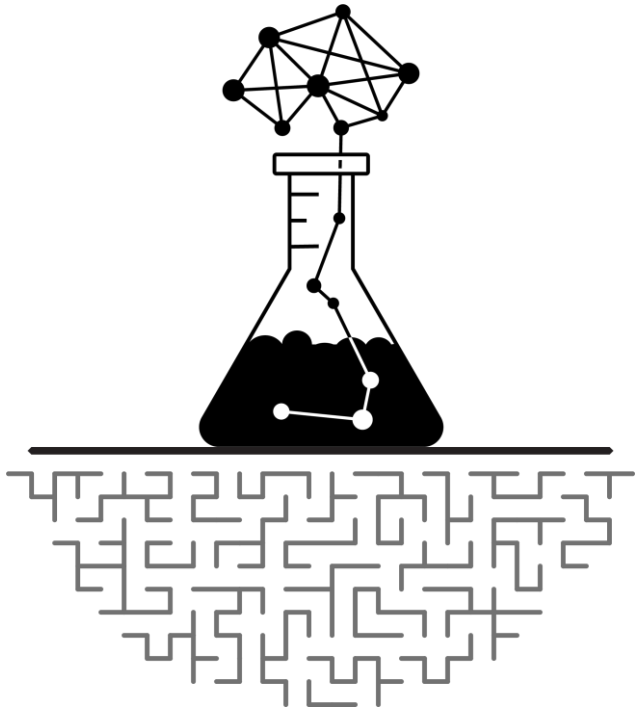

- Interface with in-house subject matter experts (SMEs) on systems and processes to understand what needs to be understood from data sources available.
- They select algorithms, build or apply already proven advanced data models and train and deploy them.
- They are responsible for the math, whether applied locally or at a remote data center.

Source: Guilfoyle, Mike "Data Scientist and Subject Matter Expert Roles in Predictive Analytics", 6 December 2016

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The (Citizen) Data Scientist

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- He or she creates and deploys additional basic models to gain added insight.
- As analytics initiatives move from pilot to become competencies within the enterprise, this role will increase in importance for the end-user organization.
- SMEs will take on the roles of citizen scientists for advanced analytics as core job responsibilities, supported by an analytics toolkit.
- Engineers can fill the role of citizen scientists, bringing to bear their background in math, statistics, and modeling.

Source: Guilfoyle, Mike "Data Scientist and Subject Matter Expert Roles in Predictive Analytics", 6 December 2016

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The (Citizen) Data Scientist (cont'd)

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- SMEs and engineers can use these skills to wring more value from the analytics solutions they are using, as well as dig more deeply and broadly into data made available to them.

- Analytics providers are moving quickly to build out tools to support the citizen scientist.
  - An example is rich data visualization, where data streams can be added, connected, and analyzed via drop and drag methods.
  - These tools are powered by an underlying analytics engine, so it is easy for the citizen scientist to create more "ah ha" moments using data, algorithms and models.

Source: Guilfoyle, Mike "Data Scientist and Subject Matter Expert Roles in Predictive Analytics", 6 December 2016

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Getting Smart about the IIoT

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- A good place to start is with the Industrial Internet Consortium (IIC) website http://www.iiconsortium.org/
- Free downloads of pubs that should be studied include:
  - Pub 1.8, The Industrial Internet of Things Volume G1 Reference Architecture issued 31 January 2017
  - The Industrial Internet, Volume G8: Vocabulary Technical Report, version 2.0 2016
- Almost all aspects of IIoT related matters are in a constant state of flux

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Developing a Plan

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This may involve the following steps:

1. Conversion of key monitoring points from analog to digital outputs,

2. Providing connectivity from key monitoring points to gateways for data transmission to edge analysis devices and/or for direct transmission to local and/or remote central analysis center(s). This may involve use of:
   - Wired connection via Ethernet, Modbus or other network protocol
   - WiFi, Bluetooth, LiFi and Zigbee or other connectivity protocol deployment and lifecycle maintenance requirements

3. Deciding and justifying what failure modes should be subject to analysis at the edge and at local and remote analysis centers

Developing a Plan (cont'd)

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- Providing connectivity for transmission of raw and edge calculated results from plant to remote analysis center(s) via IoT, IIoT, 4G/5G mobile network, etc.
- Ensuring cybersecurity along the transmission path(s)
- Establishing means of communications for actionable finds to plant personnel required to act on them
- Deciding how the current or changed organization and individuals within it or added to it can effectively manage the new order of business in order to gain the advantages inherent in modern technology

IIoT & Predictive Analytics Master Plan Outline

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A typical plan would have the following elements:

- Front pieces (e.g., title page, executive summary, table of contents, forward, preface and change pages)
- Master plan overview, goals and scope
- Team arrangements and the individuals and groups supporting them
- Roles and responsibilities
- Best practices to be adopted
- Processes and procedures already developed or needed
- Key performance indicators used to measure progress and ultimate success

- Safety and risk considerations including those related to cybersecurity
- Training and certification goals
- Management and communication methods and media employed
- Budgets and schedules
- Hardware and software tools to be employed
- Links to master plans for other key business practices of the organization that are engaged in using the IoT or IIoT

See: Asset Condition Monitoring Management, Chapter 7 by J. Nicholas for detailed explanation of each element in the context of an ACM Master plan

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IIoT & Predictive Analytics Master Plan

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- Should be a living document that grows with the program and links up with as many other IoT and IIoT initiatives undertaken by the organization as possible.
- OM&R leaders should make as many allies as possible with those whose support and knowledge may be able to help.
- This could include key members in departments such as information technology, human resources, marketing and sales, budget and finance, procurement and contracts.

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Understanding What to Continue In-house

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- RCM – IIoT & predictive analytics will not relieve in-house personnel of need to determine what maintenance to perform for best reliability.
- FMEA should be revisited for systems having it and perhaps be upgraded to FMECA to add estimates of failure mode severity and probability of occurrence to help prioritize what to monitor for failure mode detection and where (Edge, Local, Remote).
- Success will depend on having firm knowledge about failures historically experienced or likely in the future.

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Before Making Decision to Employ IIoT & Advanced Predictive Analytics

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- All current maintenance requirements should be reviewed to see if any time-based tasks (particularly those that which are intrusive) can be replaced with condition directed tasks triggered by predictive technology finds and/or analytics at any level of the total analysis hierarchy.
- Failure modes that are not easily identified may only become visible through use of data mining and application of advanced analytics.
- The methodology recommended for achieving the earliest return on investment (ROI) is Data Farming.

Getting the Maximum ROI From Data

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- A survey conducted by Cisco Systems Inc., results of which were presented at the May 2017 Internet of Things (IoT) World Forum in London, revealed that:
  - 60 percent of IoT initiatives stalled at the proof of concept stage
  - [Only] 26 percent of the surveyed companies considered their IoT deployments and initiatives as being successful
  - Overall nearly three-fourths of IoT initiatives were considered a failure, while a third of all projects being completed were not seen as a success
- In addition - with today's digital transformation – the fact is that only a small portion of the data (<5%) being accumulated is being analyzed in any meaningful way

https://www.i-scoop.eu/internet-of-things-guide/internet-things-project-failure-success /

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Getting the Maximum ROI From Data

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The number of personnel needed to carry out a modern predictive analysis program for hundreds of clients is becoming far less than before.

The variety of analytic methods available has grown significantly and become much more sophisticated.

With artificial intelligence (AI), human involvement is being reduced to only the most difficult analysis and interpretation tasks.

With shared computer resources in the Cloud, costs are dropping due to fewer people involved and seemingly continuous reduction in unit cost of data storage in digital form.

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Data Farming

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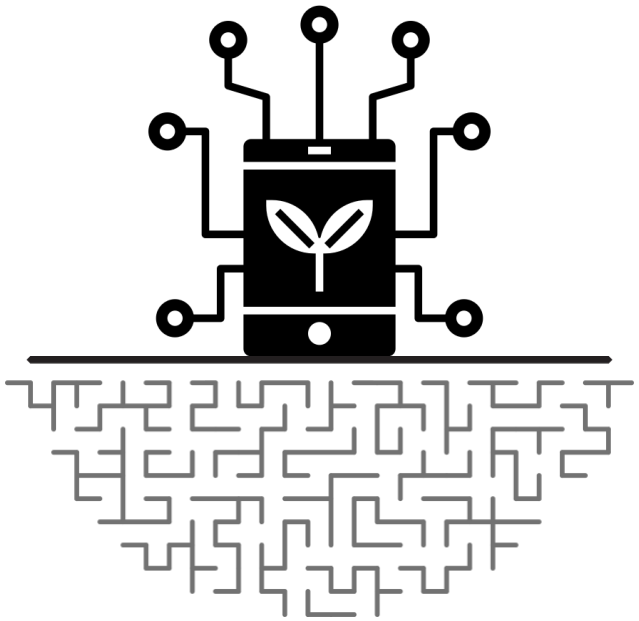

- Fertile fields for data farming are found in methodologies, such as RCM, RCA, and DE.
- Seeds to plant are the tasks derived from these proven schemes, especially if the tasks are nonintrusive and involve data collection and interpretation using mathematical algorithms and/or visual analysis.
- Once the tasks have been implemented, the data being collected have value, even if the value lies in assuring that everything is all right and no remedial action needs to be taken.
- This requires careful resource management (e.g., by filtering) in order to prevent the system collecting, aggregating and analyzing the data from becoming overwhelmed with repetitive and redundant information.

Valerio, Pablo. "Managing Resources on IoT and Edge Computing." *IoT Times* website, August 12, 2019: https://iot.eetimes.com/managing-resources-on-iot-and-edge-computing/.

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Overview of Data Farming Process

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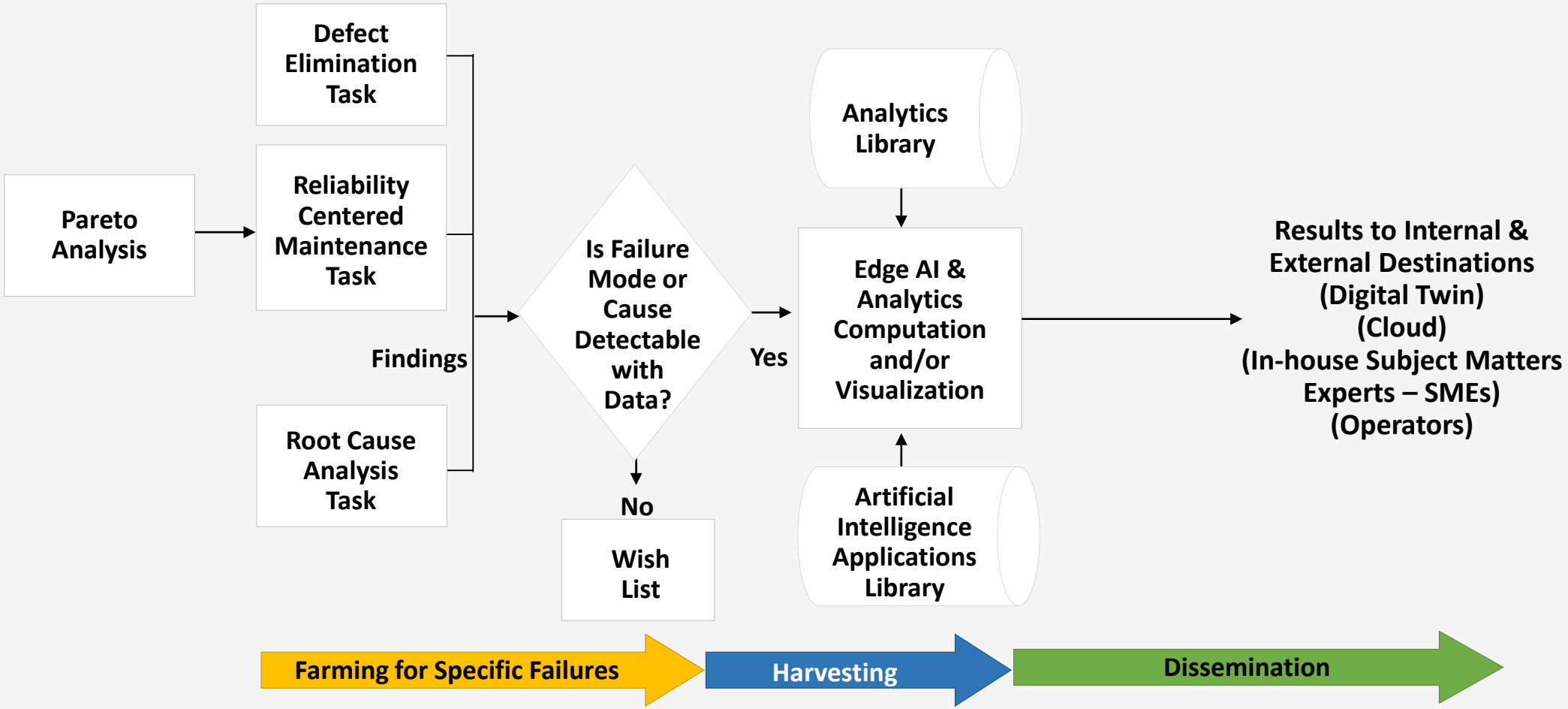
Data Farming Process in Support of Advanced Analytics



Source: Jack R Nicholas, Jr., All Rights Reserved

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POLL QUESTION No. 3

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Do you have a solid basis (such as Reliability Centered Maintenance, Root Cause Analysis, or Defect Elimination Findings) for determining what data to collect for machinery condition and performance monitoring?

(click only one answer)

- Yes, we do
- We have somewhat of a system or strategy
- No, we don’t
- Data farming makes no sense to me

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Getting Maximum ROI from Investment

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1 **Time series database management systems (DBMS) comprise the fastest growing and most popular database segment in Industry 4.0 circles from early 2016 into 2018.**

- In time series analysis, abnormal patterns, trends, or conditions relative to established ranges or limits are analyzed and reported for follow-up action by owners of the machines or processes being monitored.
- This is called data mining or exploratory data mining.
- Manufacturing leads by far in this regard.
- This implies where organizations are investing the most money in IIoT pursuits.

2 **The big question is**: Are they getting their money's worth from this investment?

3 **It can be very expensive in terms of data storage costs and searches for degraded conditions.**

- Often, it takes a long time for clusters or patterns to develop, even with the help of deep learning machine diagnostic or other AI programs.
- This may be useful if the conclusion is there are no problems or none being detected.

Risse, Michael. "The new rise of time-series databases." *Smart Industry* website, February, 26, 2018: https://www.smartindustry.com/blog/smart-industry-connect/the-new-rise-of-time-series-databases/

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Data Farming Versus Data Mining

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Data Farming

Planting known (via RCM, RCA, DE) seed stock for specific crop results - (Known Failures, Causes & Means of Detection by Analysis Tasks)

Data Mining

"Blind" analysis of comparable data for patterns, clusters, trends & early warning of deviation from the norm

Mostly in-house Limits Costs

Mostly in the Cloud Ongoing Expense

- The concept of **data farming** is to target the search for early warning when known causes and defects are recognized as probable.
- Blind searching or **data mining** can continue while targeted analysis based on data farming is being performed.

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The Overview Including Data Farming

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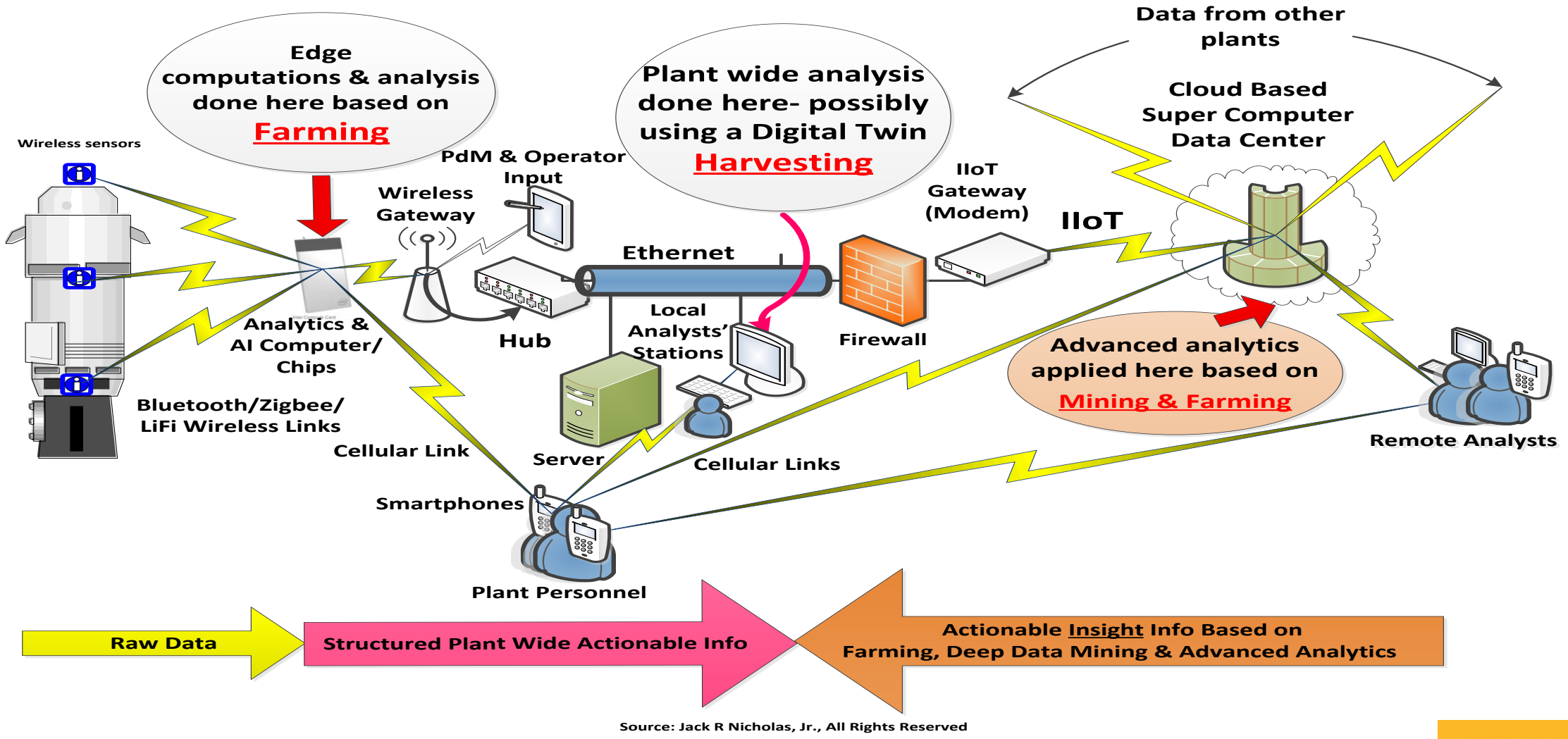
Example Future Machinery Monitoring Scheme Showing Levels of Analysis & Nature of Information



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Selling Decision-makers on the Plan

- Sales and marketing, customer service and other outward looking functions of a business are likely to get highest priority, at first.
- Those responsible for OM&R should campaign for their share of these capabilities using persuasive arguments that clearly state potential benefits in terms senior executives can understand.
- This means that like all such initiatives, the case should be made on the basis of monetary value to the organization or other intangibles such as customer satisfaction.

Comparing OM&R KPIs to Executive Metrics

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OM&R KPI	Executive Metric	Additional Benefit	Comment
Uptime	Increased Revenue	Better P & L and Balance Sheet	Larger Executive Bonuses
Asset Life Extension	Cash Conservation/Flow	Better Balance Sheet	Less Capital Investment
Cost Containment	Profit Margin	Competitive Advantage	Price Flexibility
Safety	Risk Mitigation	Enhanced Annual Report to Stakeholders	Affects Employees & Environment
Quality	Customer Satisfaction	Customer Retention	Market Advantage
Yield & Throughput	Capital Investment Deferral	Better P & L and Balance Sheet	Productivity Improvement

Sources: Rio, Ralph, ARC Research Industrial IoT/Industrie 4.0 Viewpoints, 3 February 2017 & 22 November 2016 & J. Nicholas

Conclusions

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- Get the latest Information - Get smart about the IoT/IIoT
- Understand what's worked before and why (or not)
- Acquire the skills needed (Citizen Data Scientist)
- Revisit SCADA, Pareto Analysis, RCM , TPM, RCA, CA, and DE - to figure what to monitor, why & how
- Develop a plan that has a chance of success - that avoids Pilot Purgatory, is geared for full expansion & gains allies
- Gain support & resources to implement & monitor progress of the plan - Sell it to C-level

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QUESTIONS?

Thank you!

Jack Nicholas

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