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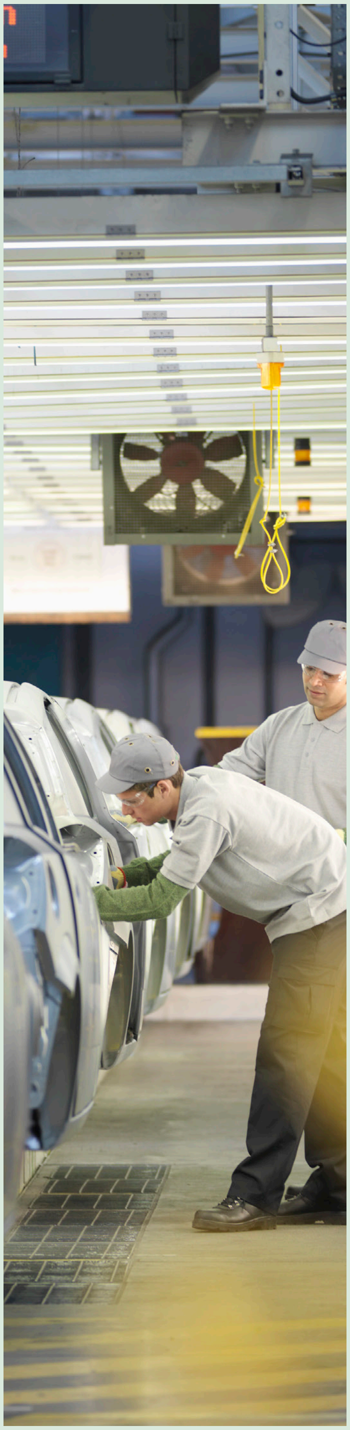

DRIVING ENERGY EFFICIENCY THROUGH THE INDUSTRY 4.0 MATURITY INDEX

Abstract

Energy is a precious resource for a manufacturing plant; consequently, it is essential to push for energy efficiency to reduce the costs of operations. The Industry 4.0 Maturity Index provides a structured framework to implement and realize efficiencies in a manufacturing plant. In addition, it is essential to identify the key performance indicators to drive efficiencies.

This paper presents an approach to drive and implement energy efficiency through the Industry 4.0 Maturity Index. Further, it presents key performance indicators to capture, assess and optimize energy consumption in order to drive and realize energy efficiency on the shop floor. The paper considers an automotive shop floor to demonstrate the approach.

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1.0 Introduction

Industry 4.0 helps organizations improve their topline with new and innovative products and services, and reduce their bottom line through improved efficiencies. The main factors encouraging the adoption and implementation of Industry 4.0 technologies are the value and return on investment realized. These efficiencies can be achieved across the value chain of the asset lifecycle, from engineering, manufacturing, operations to maintenance. In manufacturing, these efficiencies can be broadly classified into operations, maintenance, information and energy. The energy efficiency, which includes sustainability aspects as well, is a low hanging fruit.

Both legacy and modern plants have significant opportunities to reduce energy demand through better energy management by using Industry 4.0 technologies. Energy efficiency can deliver substantial benefits:

- **Lower or avoid capital investment** - Energy efficiency can reduce capital expenditure through improved efficiency of existing equipment or reduced capacity requirements.
- **Improve productivity** - A higher production output with lesser energy consumption has the potential to reduce operational costs. Further, reduced downtime will increase productivity and quality.
- **Reduce maintenance costs** - Often, energy waste is a sign of other problems. Hence, energy-efficiency initiatives can reduce maintenance costs and downtime.
- **Reduce greenhouse gas emission** – The energy-efficiency improvements help avoid the use of fossil fuels or electricity generated from fossil fuels and will contribute to reduced greenhouse gas emissions.
- **Work health and safety** – Analysis of energy patterns at the workplace can highlight work health and safety risks related to factors such as temperature, humidity and fire hazard.
- **Culture of continuous improvement** - The energy efficiency initiatives motivate employees to identify and implement business improvement opportunities.

The paper illustrates the challenges in an automotive manufacturing plant and provides a systematic approach to improve energy efficiency through the Industry 4.0 Maturity Index. However, the approach is generic and can be applied to other similar industries.

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2.0 Industry 4.0 Maturity Index

The Industry 4.0 maturity of an organization is assessed on a six-stage scale. The first two stages (computerization and connectivity) are characteristics of previous industrial revolutions driven by an exponential growth in computing power. The next four stages, defined as visibility, transparency, predictability, and adaptability, are shown in Figure 1. Figure 1 (Infosys Limited, 2018) shows the capabilities required to attain each stage.

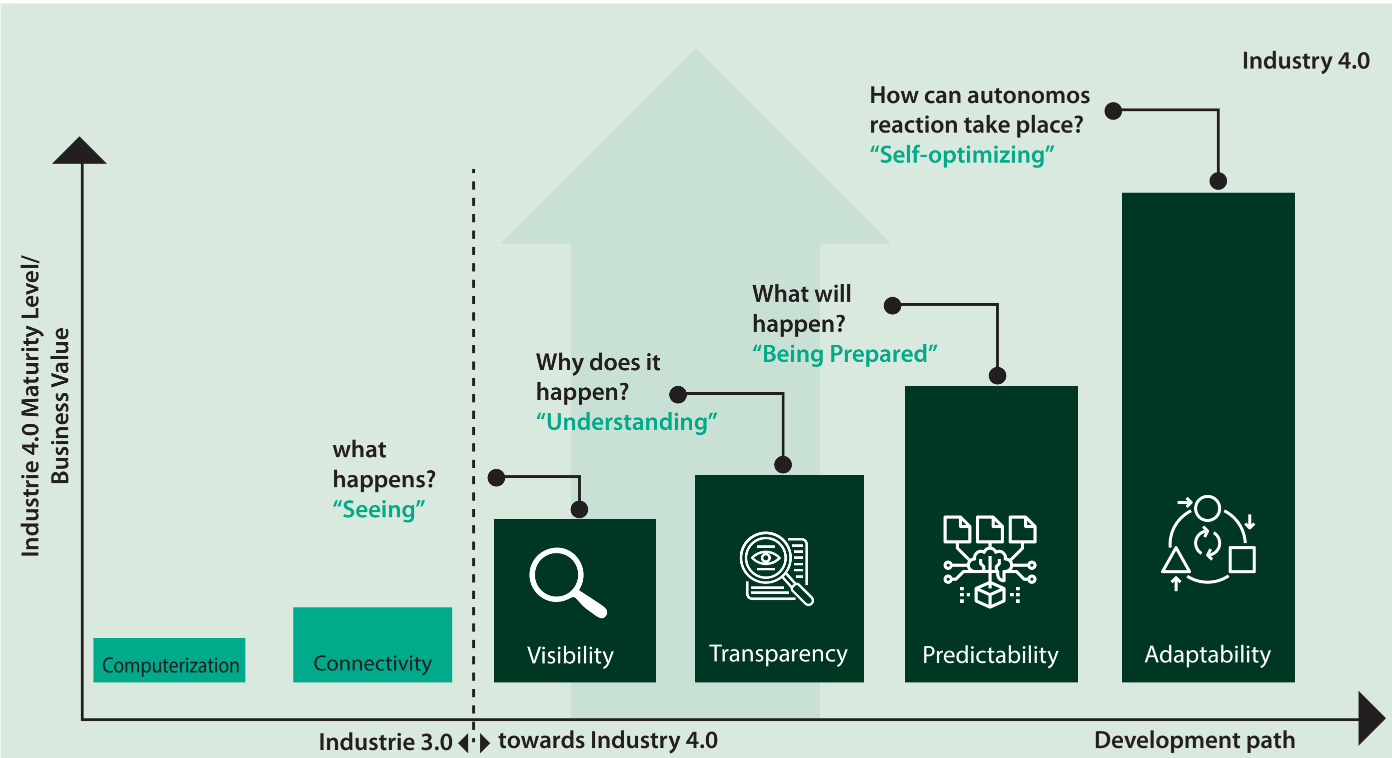

Figure 1: Industry 4.0 Maturity Stages

Table 1: Capabilities of Industry 4.0 maturity stages

1	Computerization	Computerized control and data processing systems supported tasks. Employees are relieved of repetitive manual tasks.
2	Connectivity	Data processing systems are structured and linked. Core business processes are reflected in IT systems.
3	Visibility	Companies have a digital shadow (real-time data); management can make data-based decisions.
4	Transparency	Companies understand why events happen; knowledge is discovered through recognition.
5	Predictability	Companies know what will happen; decisions are made based on predicted scenarios
6	Adaptability	Companies react autonomously on conditions. The system controls itself autonomously and is entirely viable.

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2.1 Visibility

An organization with access to real-time data can gain complete visibility of its operational parameters. Energy meters or sensors help the plant to capture data from all assets, equipment, systems. The acquired process data is processed onto a common platform to establish a single source of truth. A 'digital twin' is implemented at this stage, that has relevant information with adequate quality and in real-time for decision-making purposes. However, processing such massive volumes of data on a common platform is a significant challenge, since data is often held in decentralized silos. The captured data must be aggregated and analyzed by applying engineering knowledge to produce complex events reflecting the condition of the system or equipment. Only such an approach can generate useful insights from the data and provides relevant operational data across the plant.

The following sections explain some of the common challenges and approaches deployed to address the issues.

2.1.1 Current Challenges

In a typical automotive plant, about 60% of the energy consumed is used for painting, compressed air requirements, lighting, HVAC in office spaces, material handling, welding, robotic arms and machining. Figures 2 shows the basic process flow of an automobile manufacturing unit.

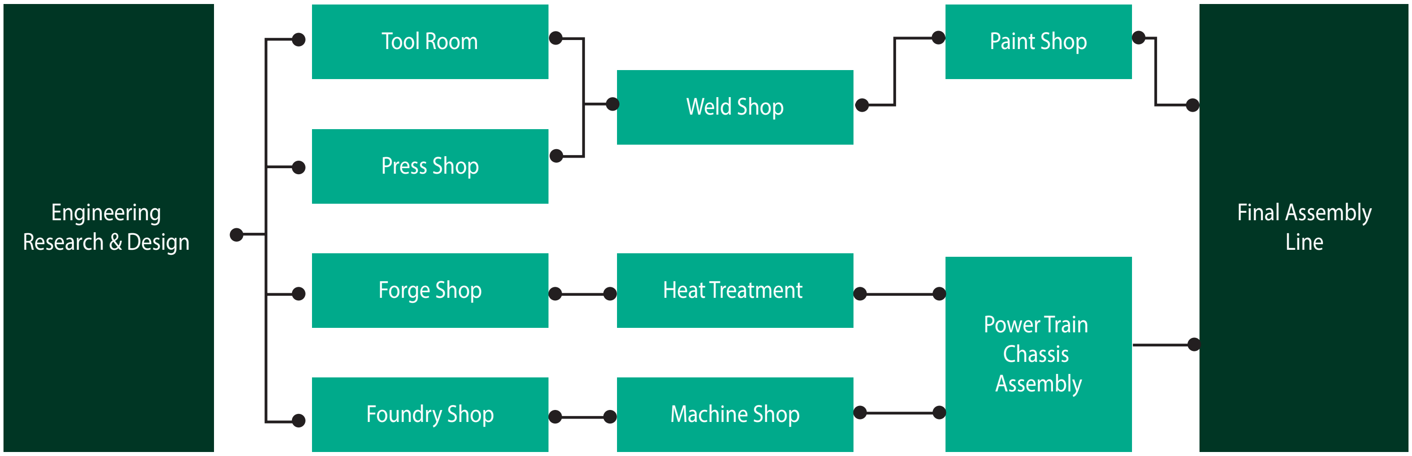

Figure 2: Basic process flow

Figure 3 shows the typical energy consumption (press, body, paint, assembly shop alone) of about 500–700 kWh per vehicle and its costs constituting about 9-12% of the total manufacturing cost.

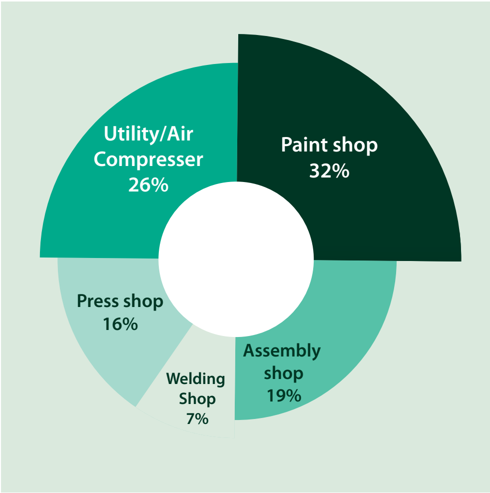

Figure 3: Energy consumption pattern

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Some typical issues faced are:

- **Energy supply and demand balancing issues** – Mismatch between energy supply and demand occurs due to inadequate metering or unaccounted energy within the plant and leads to transmission losses. Installation of additional sensors or energy meters in critical equipment prevents such a mismatch, and helps to understand the energy supply and demand gap.
- **Metering of mixed loads (production & non-production loads)** – A mix of production and non-production electrical loads will always cause issues when a plant tries to establish energy accountability to the end users.
- **Establishing accountability for plant consumers** – Plants are constrained by their inability to establish actual energy usage department-wise or process-wise to track energy performance and costs.
- **People dependency** – Here, the plant relies excessively on a single energy champion. Consequently, it is a challenging situation for an organization to capture process, plant and location data on to a common platform.
- **Independent SCADA system** – Today, many facilities deploy a variety of monitoring systems such as Distributed Control System (DCS) and Supervisory Control and Data Acquisition (SCADA). However, these may not function at an enterprise level with complete data aggregation.
- **Energy meter connectivity issues** - Most energy meters were initially used as a stand-alone. However, these should be integrated with a complete plant or facility-wide system for monitoring and control through a common communication link.

2.1.2 Approach to Address Challenges

A systematic approach to measure, monitor, and manage energy is essential to minimize the energy consumption necessary to meet business objectives. The first step in the process is to perform a thorough assessment of the current state of the production plant. It includes to:

- A preliminary study to investigate and analyze the current state of the plant. Responses to these questions will help ascertain the maturity of existing operations
- Which system or assets are currently managed?
- How are these systems or assets connected?
- How is the data collected and stored?
- What are the challenges faced in data collection?
- How do various stakeholders use the data?
- Does the collected data produce useful insights for the operational team?

Also, it is essential to collect secondary data to establish the design condition of the plant such as to:

- Electrical distribution diagrams
- List of energy meters for the entire plant or facility
- Daily, monthly, yearly sample energy reports
- Calibration report for energy meters
- Wiring technical specification

Data reporting structure

The next step is an analysis of the energy supply and demand balance. For example, the review of an electrical single line diagram to ascertain whether the current configuration of the energy distribution and metering is adequate for monitoring energy usage and whether it captures the entire energy usage within the facility. A typical electrical single line diagram is shown in Figure 4. The electrical supply and demand balance analysis can be carried out across four levels of the electrical distribution system with the energy usage data from existing energy reporting in the plant.

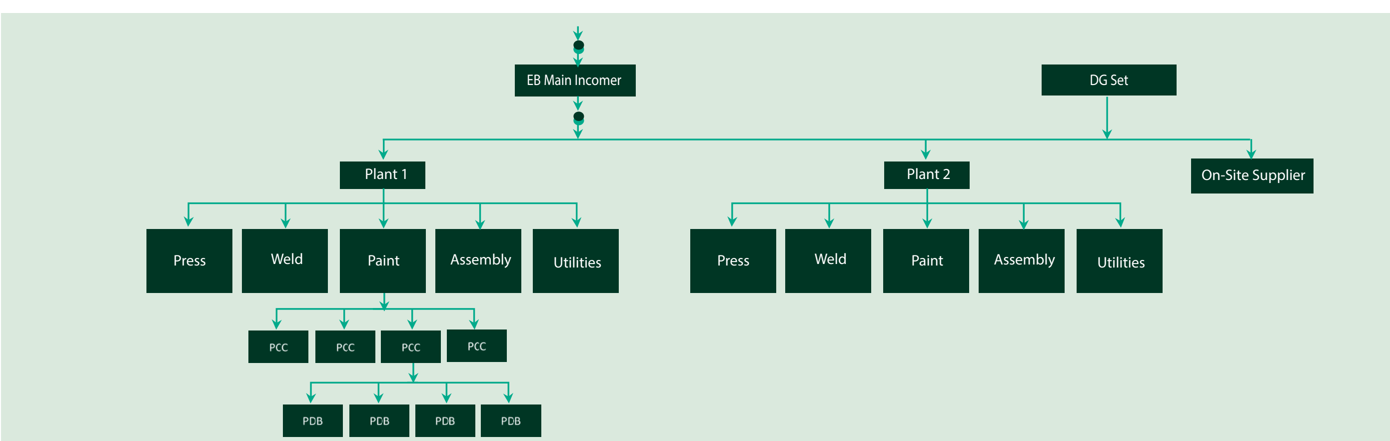

Figure 4: Sample Electrical Distribution Line Diagram

Level 1: Overall consumption = Total supply from the main feeders + power supply from DG generators

Level 2: Total power supply from main feeders = Total HT level feeders supply

Level 3: Total HT level feeders supply = Total LT feeder power control center (PCC) level consumption

Level 4: Total LT level feeders supply = Total sub-feeder power distribution board (PDB) level consumption

- Address the deficiencies in terms of inadequate sensors or energy meters, connectivity and so on, observed in the assessment study
- Ensure all edge devices are on secured network connectivity that supports new architecture, including intranets, extranets for utility and supplier connections and links to the Internet

2.2 Transparency

With the relevant information, the organization is equipped to reach the next stage to - transparency, which helps derive more insights from the data. Enriched data with system and process information along with historical data insights on "why does it happen" is easily inferred, which is then integrated with the operations process for automation and notification for initiating the right intervention. At this level, it is no longer about measuring specific operating parameters. Instead, it is about estimating actual key performance indicators (KPIs) from captured data and comparing it with design KPI in real-time across plant operations.

For an automobile plant, individual departments like press shop, welding shop, assembly shop and painting shop comprise work centers, machines, material handling devices and various automation. Hence, KPIs can be broken at the plant, shop, line and equipment levels, which will provide an operational view of performance measure and monitoring as given in Table 2.

Table 2: Hierarchical structure of KPIs

1	**Plant level KPIs**	• Overall specific energy consumption - SEC (kWh/Vehicle) • Shift-wise energy consumption • Percentage of energy source used • Percentage of energy usage break up (shop-wise) • Carbon footprint (tones CO2/vehicle) • YoY energy reduction % • Percentage of error (energy balance gap)
2	**Shop level KPIs** (Example: press, weld, paint, assembly, utility, non production area ,etc.)	• Shop-wise specific energy consumption - SEC (kWh/vehicle) • Shift-wise energy consumption • Percentage of energy usage break up (shop-wise) • YoY energy reduction % • Percentage of error (energy balance gap)
3	**Utility level KPIs** (Example: Compressed air system, HVAC, plant lighting system material handling, etc.)	• Utility-wise specific energy consumption - SEC (kWh/Vehicle) • Shift-wise energy consumption • Percentage of energy usage break up (utility-wise) • Ideal running hours
4	**Equipment level KPIs** (Example: Chillers, air compressors, heat treatment furnace, lighting system, pumps, fans, cooling tower etc.)	• Air compressor system efficiency (kWh/CFM) • Compressed air leakage rate (%) • Chiller plant efficiency (kW/TR) • AHUs efficiency (kW/ft3) • Cooling tower effectiveness (%) • Heat treatment furnace efficacy (%) • Lighting system efficiency (LPD –W/ft2)

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Performance metrics can also be categorized as Key Management Indicators (KMI), Key Performance Indicators (KPI) and Key Action indicators (KAI). Key personnel such as the plant head, plant operational manager, instrumentation and automation engineer and operators track and evaluate these performance metrics.

KMIs are metrics tracked at a leadership level and provide an overview of the health of the global portfolio. The success of KMI metrics is tied to KPI performance. The KPIs track the health at a plant and function level and are usually visible to the plant head and plant manager. KAIs are activity indicators, tracked at an operational level by duty managers and automation engineers. Some of the metrics as given in Table 3 to.

Table 3: Key management, performance and action indicators

	Key Management Indicators (KMI)	• Plant performance rating ("under" and "good" performance) - against international industry standards • Carbon footprint performance versus standard benchmarks • % of energy source used (electricity, gas, renewable, diesel etc.) • Energy and production forecasting for next month
	Key Performance Indicators (KPI)	• Plant energy performance index (kWh/ unit of production output) • Process wise energy performance (kWh/unit of production output) • Production quality rate • Utility equipment level efficiency (kWh/ CFM, kW/TR, boiler thermal efficiency (%), etc.
	Key Action Indicators (KAI)	• Meantime before failure (MTBF) • Meantime to repair (MTTR) • Top ten alarm contributions (process section-wise) • Power density (peak load / ft2) – section-wise

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2.3 Predictability

Data collected from key performance indicators set by organizations, help in understanding their energy systems. Abnormal patterns in the historical data are stored and categorized systematically for further analysis. Big data is not precise enough, since only filtered, combined and enriched information is useful. The result is smart data and in comparison to big data, enriched and context-sensitive to gain knowledge about future events. Predictive asset analysis can be supported by artificial intelligence or machine learning algorithms. A step-by-step workflow process often followed during predictability analysis-based implementation is illustrated in Figure 5.

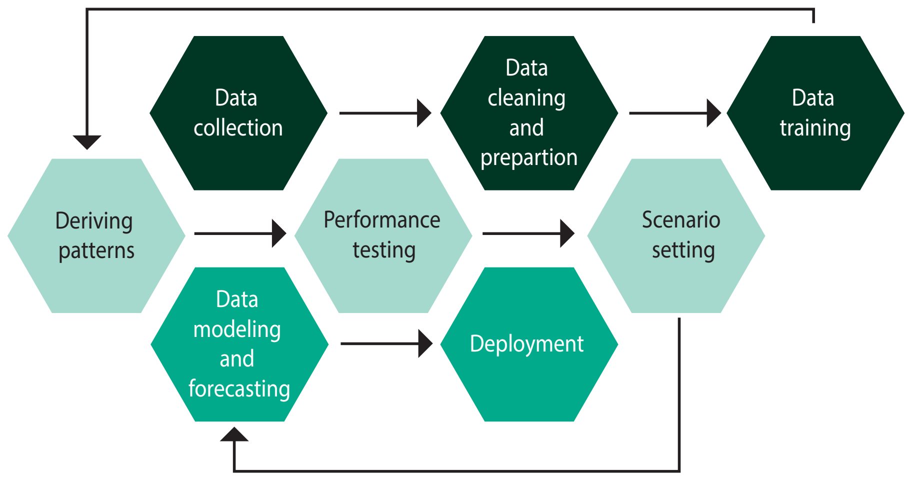

Figure 5: Predictive analysis-based workflow process

Access to asset data enables centralized data analysis and decision-making. It is made possible by including data from different systems and using machine learning to make better decisions for each asset based on the collective knowledge gained from the network.

For example, predictive analysis can be implemented in four use cases in an automotive plant and offer long-term benefits in the areas of energy reduction, equipment life, quality and cost as given in Table 4.

Table 4: Typical use cases to implement energy efficiency

Root cause analysis	During the manufacturing phase, the root-cause analysis uses massive amounts of testing data, sensor measurements, manufacturer parameters and more. The use of historical data as an input for root cause analysis helps organizations correlate failure modes and identify energy inefficiencies in the underlying manufacturing procedures.
Energy demand response management	Energy prediction is a promising approach which studies the trends and patterns of energy consumption to make predictions based on the time-series data. With the help of accurate demand forecasting, manufacturing plants can efficiently operate on-site energy supply systems and ensure the energy supply and demand balance to bring stability in the energy supply system.
Renewable energy generation forecasting	Advanced forecasting models predict renewable energy generation by correlating multiple weather measurement parameters to ensure reliable information for better energy management and operation strategies. The same approach can be used by any manufacturing plant, utility company and energy service provider.
Dynamic energy management	The system uses big data analytics to make performance estimation and provide smart recommendations for energy management.

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2.4 Adaptability

The final step on the path to digital energy management is "adaptability." It is an extreme level of connectivity and automation of the system to react automatically to changing environmental conditions and manage energy within the plant. The changes in the environmental conditions need not have occurred in the past, as the system is trained to adapt and adjust to new circumstances. Therefore, a deep understanding of all interdependencies within the system and its influences is critical.

Conversion of a monitoring and supervision system into a smart system that detects, localizes and diagnoses failures is made possible. A smart system can take the most appropriate action to eliminate failures and understand their causes to avoid them and improve the efficiency of production systems. Sensors must be installed in the fundamental equipment of production systems, structuring a reliable two-way communication system with comprehensive coverage encompassing the various devices and automation of the physical assets, as illustrated in Figure 6.

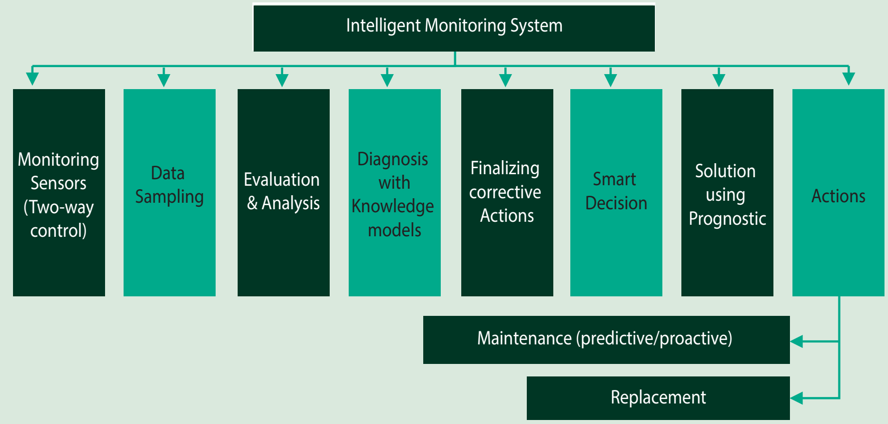

Figure 6: A sequential structure of an adaptable monitoring system

The smart monitoring system becomes autonomous, and decides and indicates the appropriate corrective action necessary for any unusual event. The intervention must be in real-time, online mode and show the type of corrective action that will be performed, the point where the intervention will be made, the components that will be reached and their intervention time. For example, this means changing the sequence of a planned schedule of the equipment to avoid peak electrical usage at the plant or to avert expected machine failures.

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3.0 Conclusion

Industry 4.0 helps improve the energy efficiency of production plant operations, optimize the maintenance process by maximizing the convergence of IT and OT technologies. By implementing this systematic approach, the expected energy reduction will be in the range of 10-20% of overall energy consumption. A high-level implementation program for an automotive manufacturing plant is given in Figure 7.

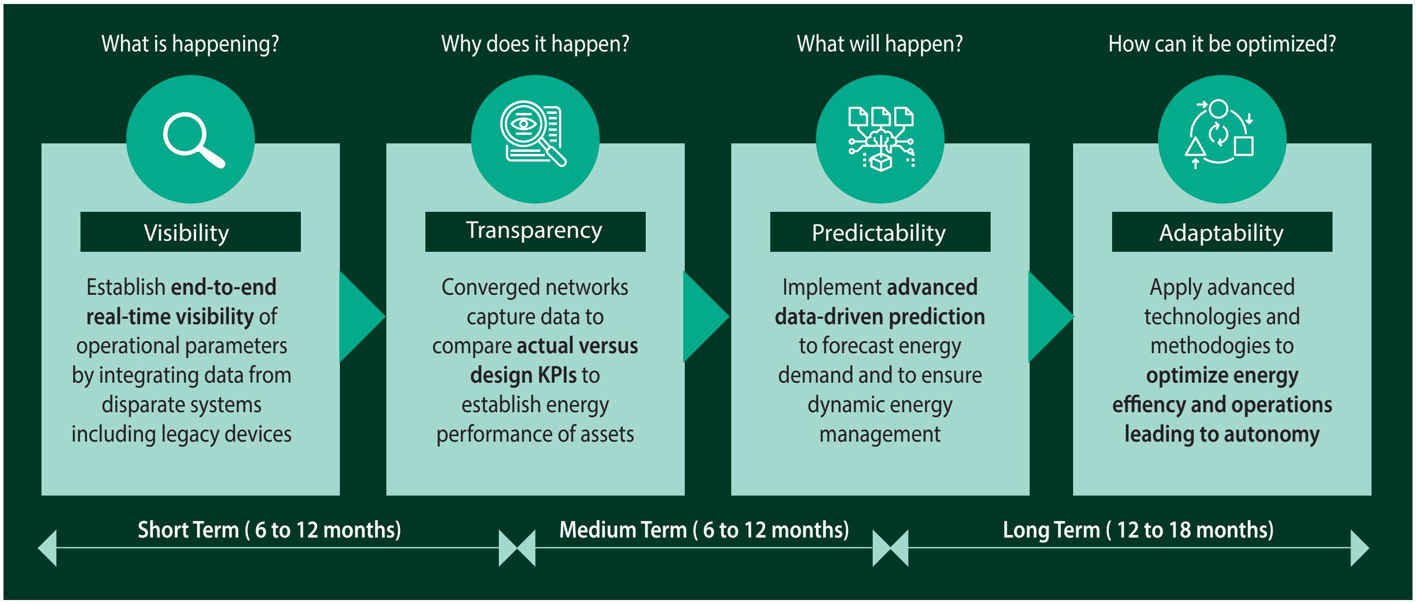

Figure 7: Typical roadmap for digital energy management

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Sridhar Chidambaram is from the Advanced Engineering Group (AEG) of Engineering Services. He brings rich expertise in consulting, implementation of energy management programs and adoption of renewable or clean energy technologies using IoT and autonomous technologies. Having 18 years of experience in the energy management and environment sustainability fields, he has managed energy efficiency projects in various sectors such as commercial buildings, manufacturing industries, power plants, textile, oil and gas industries. He led a team of a central command center in Infosys, which is a unique set up to monitor and control remotely over 45 million square feet of smart buildings across India. He is also an Accredited Energy Auditor (AEA: 0012) by Bureau of Energy Efficiency (BEE), Ministry of Power, Govt. of India. He has published over five journals / white papers and co-authored the book "Handbook on energy audit and environment management." He holds M. Tech in Energy Conservation and Management from School of Energy, Bharathidasan University and bachelor's degree in mechanical engineering from Anna University, Tamil Nadu, India.

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