

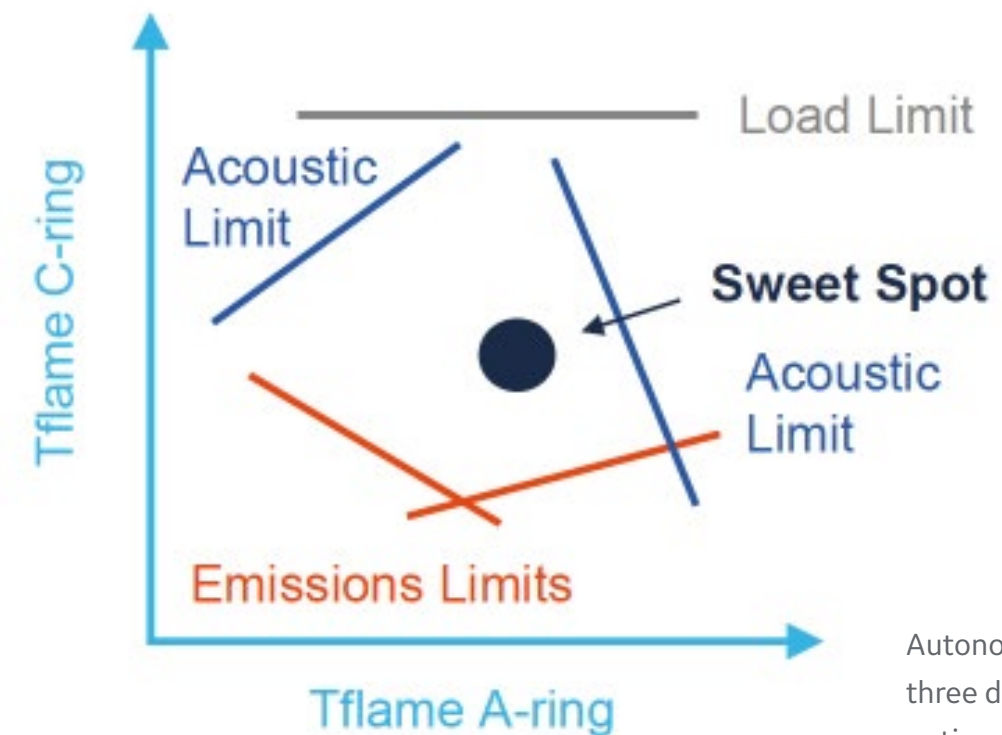
# Autonomous Tuning for Aeroderivative Turbines from GE Digital



Reduce CO & NOx emissions while improving fuel efficiency

GE Digital's Autonomous Tuning software automatically tunes for emissions compliance and ideal performance based upon changes in ambient temperature, fuel properties and degradation.

The AI-powered product automatically explores the space of operation of gas turbines, builds a machine learning model, and continuously finds the optimal flame temperatures and fuel splits to minimize emissions and acoustics... every 2 seconds.



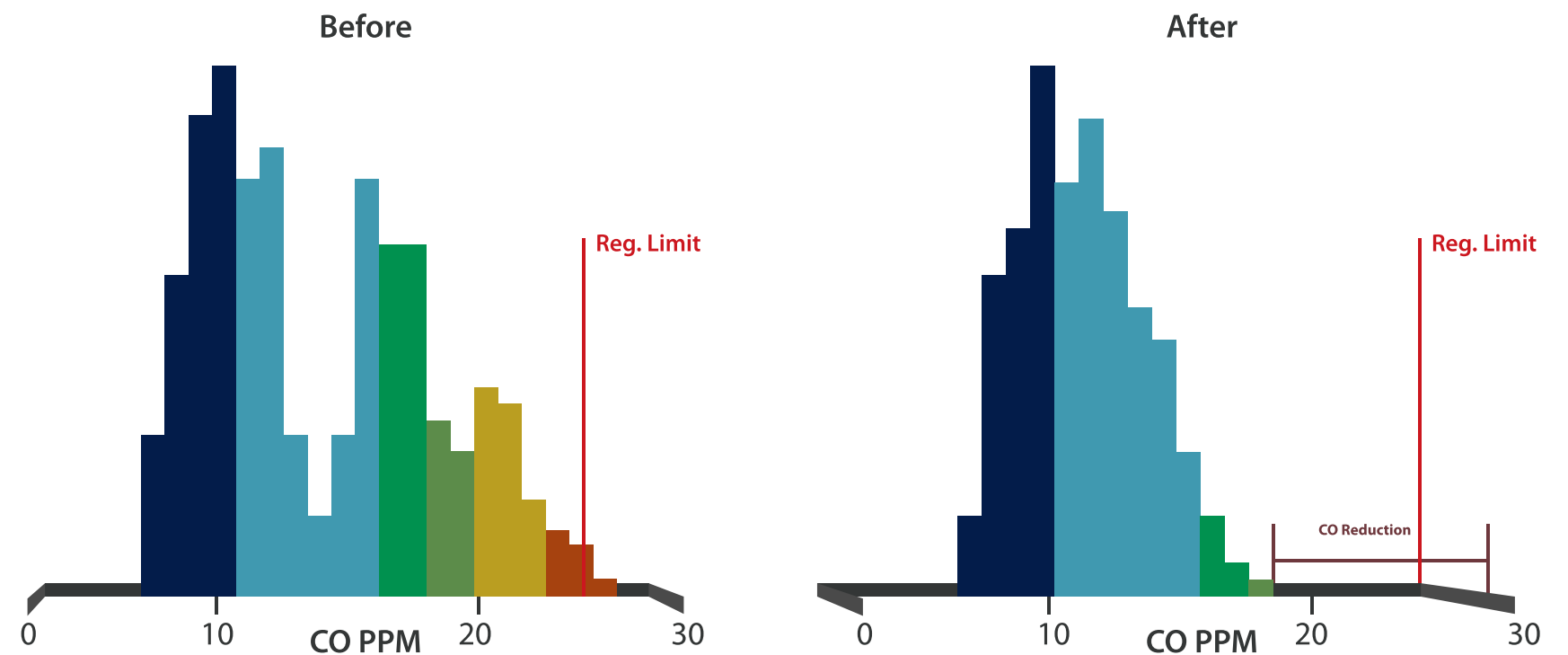
Autonomous Tuning uses three dimensions to calculate optimal combustion, narrowing performance to the 'sweet spot.'

## Benefits

- 0.5% to 1% reduction in fuel consumption
- Up to 14% reduction in CO emissions
- Up to 12% reduction in NOx emissions
- 0 manual tuning or associated downtime

## Frame Applications - any OEM

- LM2500 Base, Plus, +G4, +G5
- LM6000 PD
- LM6000 PF/PF+



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## Standard Scope

The key components of the on-premise software and hardware solution include the following:

### L1 Turbine Control

Level 1 (L1) Primary Control package software, including HMI, is configured to handle NGAT features and communicate to ProcessLink Edge Control Server without impacting qualified core software. This architecture enables upgrades to either legacy systems (already installed) or new systems (installed in parallel).

### L2 Digital Twin Model & Supervisory Control

Level 2 (L2) provides supervisory combustion control utilizing NGAT turbine-specific models and ProcessLink software. For L2 and gas turbine controller (L1) communications EGD protocol is preferred, however, NGAT will work with any communication protocol supported by "ControlST".

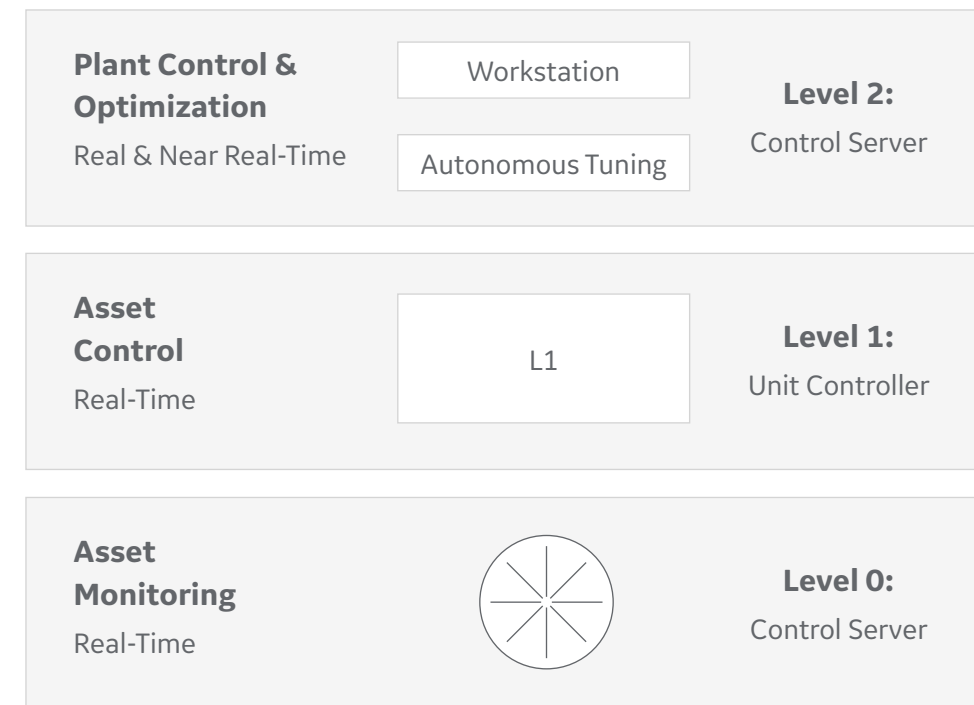
Communication speed does not have a "minimum speed" requirement; typical speed is 100 ms. Software solves a nonlinear optimization problem to find optimal adjustments every 2 seconds subjected to constraints in manipulated variables.

Manipulated Variables (MVs): Inner Ring Flame Temperature, Outer Ring Flame Temperature, Bulk Flame Temperature, Pilot Split, ELBO

Controlled Variables (CVs): PX36 Acoustics, NOX Emissions, CO Emissions; priorities can be adjusted to meet customer requirements. (e.g. European customers are more interested in emissions)

- Level 2 control: NGAT acts only on biases
- Biases ramp back to base schedule when deactivated
- Deactivated by manual operator action or automatically in case of unsafe conditions (e.g., loss of communication, high dynamics, fluctuations)
- Remote access for supervision
- ProcessLink Edge Control Server: See Appendix A for hardware specification

Priority	Variable	Objective
1	Acoustics	Below 2.5psi
2	T48Error	Above 50 °F
2	N25HError	Above 120 RPM
3	CO	Minimize
3	NOX	Minimize





# Modes of Operation

Autonomous Tuning has two automated modes of operation – Learning Mode and Control Mode – that are linked by a pervised model building step.



Autonomous Tuning modes of operation are sequential. Learning Mode must be executed first to map the space of operation of the turbine. Data collected in Learning Mode is subsequently used to build a neural network model of the turbine’s behavior. Once the models have passed quality checks, they are used in closed loop to adjust the turbine’s flame temperatures to ensure optimal behavior.

The software is allowed to operate (in Learning or Control Mode) if the following conditions are true:

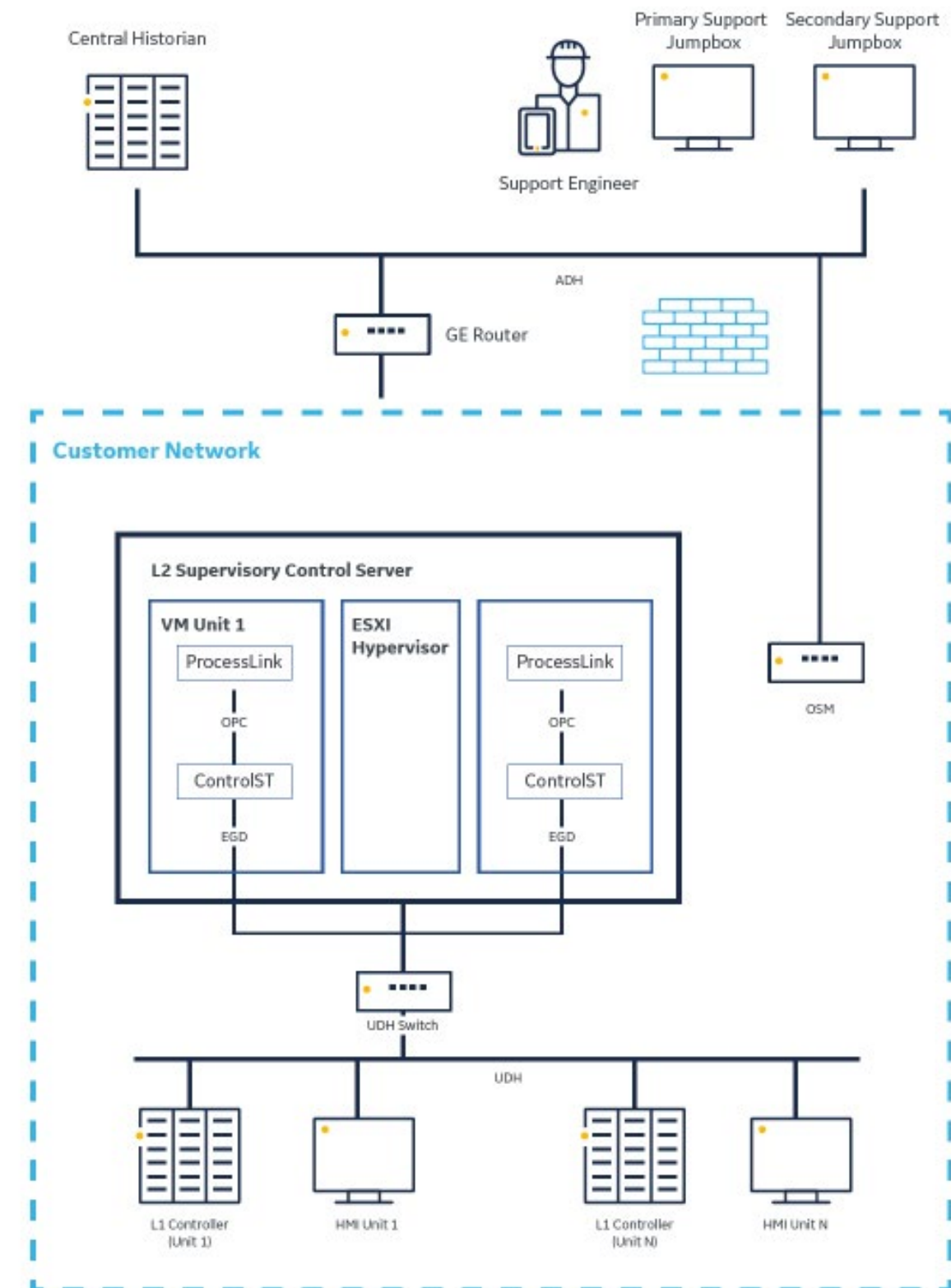
- DLE unit must be in ABC mode, i.e., NGAT will not run during transition modes
- Shutdown must not be in progress
- Software must have been enabled on the operator’s HMI
- The unit’s load must be in a MW control mode
- Gas turbine is not going through transients (abrupt load changes, grid fluctuations)

The goal is to allow for tracking of the turbine’s sweet spot (operational conditions with low acoustics and low emissions) in response to changes in environmental conditions, fuel properties, or physical degradation, and reduce the need for seasonal remapping.

### Optional scope:

- ProcessLink software upgrades
- Model tuning in the event of a major mechanical or controls modification (limited to one event per year, additional coverage available at time and materials rates)

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## Prerequisites

Remote access is required for implementation and support on an as-needed basis.

There are two options available.

### Standard – Lock Box:

- Lockbox is part of the Electronic Security Perimeter
- The Lockbox allows the customer to control GE Wan access to PDH via an On/Off Air Gap Switch
- Access is enabled by the customer to the GE Digital Services Team only during set and mutually agreed upon periods of time

### Optional scope:

- Required: Minimum of one NOx emissions sensors located in engine exhaust upstream of any duct burners, CO catalysts or NOx reduction SCRs with ammonia injection. Must be connected to turbine control system with NGAT
- Required: Minimum of one O2 sensor for emissions corrections to 15% O2
- Optional: CO sensor in engine exhaust upstream of any duct burners, CO catalysts or NOx reduction SCRs with ammonia injection if to be part of NGAT limits imposed. Not part of Base NGAT offering, but must be connected to turbine control system with NGAT under such conditions
- Optional: Ambient Pressure (Pamb) and Ambient Temperature (Tamb) outside of the turbine inlet of one package or site measurement available to turbine control system with NGAT
- Optional: Humidity Sensor located downstream of inlet conditioning inside inlet filter house connected to turbine control system. Site measurement acceptable if no inlet conditioning present and humidity input is available to turbine control system with NGAT

### Premium - Remote

#### Connection Broker:

- Zero-trust security backbone t-less browser (HTML5), virtual, safe access
- Multi-factor authentication
- Centralized User Management
- Custom permitting (unit, application, time-frame customization)
- User monitoring & recording (Forensics)

For sites that may not have the required sensors or wish to include optional sensors these can be sold and implemented by GE Gas Power. Emissions measurements (CO, NOx, O2) must be routed (analog wiring) to the unit controller and made available as tags, hence, it is required to have field services personnel at site to perform standard communication and connection checks, other activities are performed remotely by the GE Digital team.

### Additionally, the following controls system pre-reqs need to be met:

- Human Machine Interfaces (GE and non-GE) that are Windows XP or newer that can have Remote Desktop Protocol or Virtual Network Computing enabled
- 1Mbps network connection (symmetric upload and download speed) for control per network connected. This number has a 6x safety factor applied – the solution may work at lower bandwidth in contingency operations. Note: the network connection is to be supplied by Owner
- Ethernet connection to the internet that is within 20 feet of where the included firewall will be installed.
- Minimum two (2) units of rack space

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## Implementation Services

Project implementation, starting after receipt of order, typically consists of:

- |  |   |
|--|---|
| <ol style="list-style-type: none"> <li>1. Project Initiation (1 week) – GE Digital &amp; GE Gas Power             <ol style="list-style-type: none"> <li>1. R3 Handover</li> <li>2. Pre-kick off preparation</li> <li>3. Kick-off meeting with customer</li> </ol> </li> <li>2. Server/Hardware Prep and Installation* (6 weeks) – GE Digital Services via Supplier             <ol style="list-style-type: none"> <li>1. Configuration</li> <li>2. Shipment</li> <li>3. Installation</li> </ol> </li> </ol> | <ol style="list-style-type: none"> <li>3. L1/L2 Updates (2 weeks) – GE Digital Services - L2, Gas Power - L1             <ol style="list-style-type: none"> <li>1. Configure Software</li> <li>2. Deploy Software</li> <li>3. Validate Software</li> </ol> </li> <li>4. Unit Start, Manual Mapping &amp; Communication checks (1 week) - Gas Power leads with GE Digital Services support</li> <li>5. Learning Mode &amp; model training (1 week) - GE Digital Services</li> <li>6. Control Mode validation and UAT (1 week) - GE Digital Services</li> </ol> |
|--|---|

**Emissions measurements (CO, NOx, O2) must be routed (analog wiring) to the unit controller and made available as tags, hence, it is required to have field services personnel at site to perform standard communication and connection checks, other activities are performed remotely by the GE Digital team.**

### Support (Acceleration Plans)

GE provides an option for Acceleration Plan support services. If included, GE will provide on-going support during the term of the agreement to implement software updates, bug fixes, (collectively “Updates”) and engineering support to ensure proper functionality.

The following describes GE’s processes and approach to working with our Customers on technical support issues and inquiries for the solution.

### Software Updates

Periodically, GE will remotely review the models and perform updates to the software solution as need to maintain functionality, in accordance to your product license entitlement.

### Proactive Software Monitoring

GE Support Services continuously monitors your software solutions to ensure that they are running reliably and that issues are identified and resolved quickly.

### Case Management and product assistance

GE offers multiple channels to contact your support agent, report any problems with your GE Software products, and find answers to your questions about our software products.

### Web Self-Service: available 24/7

Support ticket creation and management can be performed on our Customer Center Support Portal at [digitalsupport.ge.com](https://digitalsupport.ge.com).

Customers have access to our knowledge base and search for answers to questions about our software products. We are constantly updating and improving our knowledge base to provide the most up to date and comprehensive information.

### Phone Support for Critical “System Unavailable” issues: available 24/7

**US** 1-800-433-2682

**Europe, Middle-East, & Africa**

+ 800-1-433-2682 / + 420 239015850

**Asia, India, Indonesia, & Pakistan**

+ 86-400-820-8208 / + 86-21-3877-7006

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The models and versions are representative. Computing technology, operating systems and software versions have a relatively short life cycle making it difficult to guarantee specific models/versions. Any deviations from these specs will be discussed in detail during the kickoff meeting. The capacity of the server is determined by the number of units and the size of the models required for the optimization solution at GE's discretion.

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## Hardware

### Hardware for 1 to 4 Unit(s) Quantity

GE Digital ProcessLink Server – **Low to Medium Capacity Applications**  
Provides 16-Cores/32-Threads, 128 GB memory and 1.92 TB Unformatted disk space (RAID 1+0).

- Dell R440 19" Rackmount Server System - (Including the Following Items) (1)
- Intel® Xeon® Silver 4216 2.1 GHz 16-Core (32-Thread) Processor - 22 MB Cache (1)
- 32 GB DDR4-2666 Dual Rank ECC Registered DIMM - (128 GB Total System Memory) (4)
- Dell PERC H730P PCI-Express 12 Gb/s SAS Hardware RAID Controller - 2GB NV Cache (1)
- Dell 240 GB 2.5" Hot-Pluggable 6 Gb/s SATA Intel S4610 Mixed Use Solid State Drive (1)
- Dell 960 GB 2.5" Hot-Pluggable 6 Gb/s SATA Intel S4610 Mixed Use Solid State Drive (4)
- Dell IDSDM and Combo Card Reader (1)
- Dell 16GB microSDHC/SDXC Card (2)
- Dell Slim-Line SATA DVD-ROM Drive (1)
- Broadcom 5720 LOM 10BaseT/100BaseTX/1000BaseT Dual Port Gigabit Ethernet Adapter - (Dual RJ-45 Interfaces) (1)
- Broadcom 5720 Mezzanine Card 10BaseT/100BaseTX/1000BaseT Dual Port Gigabit Ethernet Adapter - (Dual RJ-45 Interfaces) (1)
- Dell Trusted Platform Module 2.0 (1)
- Dell iDRAC 9 Embedded Systems Management - Basic with Factory Generated Password Configuration (1)
- Dell 550 Watt High-Efficiency 1+1 Hot-Pluggable AC Power Supply Module (2)
- Dell 1U ReadyRails Tool-Less Slide Rail Kit (1)
- Dell 1U Cable Management Arm (1)
- Dell 1U Locking Front Security Bezel (1)
- Dell ProSupport 39-Month Hardware Warranty & Support with NBD On-Site Service (1)
- DB-9 Serial Port Blocker (Black) (1)
- USB Micro B Port Blocker (Black) (1)
- USB Type A Port Blocker (Black) (3)
- RJ-45 Network Port Blocker (Black) (5)
- 14' CAT6 Ethernet Cable - Gray with Sentinel Clear Connectors (5)
- 10' Standard U.S. Power Cable - NEMA 5-15P to IEC-60320-C13 - (Black) (2)
- 10' International Power Jumper Cable - IEC-60320-C13 to IEC-60320-C14 - (Black) (2)
- VMware vSphere Standard 6.x – Per Processor - Perpetual License - (Includes 1-Year Software Maintenance) (1)
- Microsoft Windows Server 2019 Standard - 16 Core - (OEM Edition) - Base License - Includes Downgrade Rights to Server 2016 / 2012 R2 (1)
- Microsoft SQL Server 2014 Standard - Perpetual Embedded Server License - Includes 5 Client (1)
- Intel® Xeon® Silver 4216 2.1 GHz 16 - Core Processor - 2 MB Cache (2)

### Hardware for 4+ Units Quantity

GE Digital ProcessLink Server – **Medium to High-Capacity Applications**  
Provides 32-Cores/64-Threads, 256 GB memory and 1.92 TB Unformatted disk space (RAID 1+0). **In addition to previously listed features:**

- 32 GB DDR4-2666 Dual Rank ECC Registered DIMM - (256 GB Total System Memory) (8)
- Microsoft SQL Server Device Client Access License - Includes 5 Client Access Licenses (1)
- Microsoft Office Professional Plus 2016 - Perpetual ISV License (1)
- AVG Antivirus Business Edition - 1 User - 3 Years (1)
- Intel® Xeon® Silver 4216 2.1 GHz 16 -Core Processor - 22 MB Cache (2)

If you want to find out how much Autonomous Tuning can cut your emissions and improve your fuel efficiency, get in touch today.

REQUEST A QUOTE

LEARN MORE