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Inventory of the Future: Flexible, Scalable, and Highly Dynamic

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Summary

Inventory solutions are the linchpin of a network operator's operational support system (OSS), facilitating many different work and data flows. They help manage product, service, and resource inventory, such as outside plant (OSP). But inventory systems often have poor data integrity. For example, the state of passive OSP infrastructure cannot be polled directly from the network via APIs. Manual records are required, which are subject to error on data entry and error because changes might not be recorded.

Another challenge for inventory systems has been the move to network function virtualization (NFV). This has changed inventory from a static system of record to a dynamic, real-time platform. As a result, some of the largest OSS vendors have focused their efforts on this logical network inventory (LNI) of virtualized resources and left the physical network inventory (PNI) to OSP specialists.

Vendors have been grappling with LNI for several years, but in Omdia's view, most existing inventory systems do not adequately support dynamic, virtualized networking or indeed the massive scale required for 5G IoT (Internet of Things) services (massive machine-type communication). To enhance their solutions, vendors should consider using graph and time series databases, a microservices architecture, standardized open APIs, artificial intelligence and machine learning (AI/ML), and augmented reality and virtual reality (AR/VR).

Vendor solutions should also evolve to integrate seamlessly with fulfillment/orchestration and closed-loop assurance/observability systems. Ciena Blue Planet's purchase of Don River in 2018 and Oracle's acquisition of Federos in 2021 exemplify the strengthening ties between orchestration, assurance, and inventory.

The inventory of the future should enable

- Better resource allocation and utilization
- Faster operational insights and increased operational automation, productivity, and cost-effectiveness
- Improved situational awareness and observability of networks and services
- More reliable networks and services and better integrity of the data underpinning them
- Improved customer experience
- Increased adaptability to changes in networks and market conditions, such as new product offerings
- Greater security of data to protect private/confidential information

Introduction

Communications networks connect and underpin the modern global economy. Inventory is a key management function for these networks, supporting key activities associated with operational and business support systems (OSS/BSS) such as assurance and fulfillment.

But network inventory tools are often maligned. When discussions turn to inventory, you can almost sense the collective groan. As the chief technology officer of an Asia & Oceania enterprise communications service provider (CSP) told us recently: “Some of our automation projects have been derailed because the inventory data had errors. Reliable data is the main challenge.”

For most, inventory is just not sexy, especially in comparison with other elements of network management such as orchestration, automation, and virtualization. It is like comparing James Bond with Q. Bond is the suave, sophisticated man of action. But behind the scenes it is Q and his inventory, including a stable of Aston Martins, that provide the tools for Bond to execute his barely plausible assignments. Inventory is a similarly valuable linchpin in the OSS/BSS stack.

Telecom networks are undergoing significant change, becoming virtualized, cloudified, and highly dynamic. The decades-old inventory solutions many telcos use cannot cope with this complexity. Omdia believes the industry is at an inflection point. Recent technical advances provide compelling reasons to upgrade inventory. By doing so, CSPs can transform their operational effectiveness.

This report considers the changes in networks and services that are managed with inventory systems. It also considers advances in non-inventory-specific tools that support monitoring and management.

Often do the spirits of great events stride on before the events, and in today already walks tomorrow.
Friedrich Schiller (1759–1805)

Omdia does not prescribe a singular future state for inventory. Rather, channeling the thoughts of the playwright and philosopher Schiller, we look for the indicators today in which the future of inventory will walk tomorrow. This report considers recent technology advances, emergent strategies, and transformation factors that will influence the inventories of tomorrow.

Inventory 101

Inventory solutions are essential for fulfillment and orchestration workflows such as order to activate (O2A) or order to cash (O2C). Inventory has an awareness of network connectivity and topology to facilitate assurance and observability flows such as trouble to resolve (T2R), service impact analysis (SIA), and root cause analysis (RCA). Inventory also aids the many resource deployment, asset management, and workforce management functions, including plan to deliver (P2D), that are performed by network operators daily.

Inventory covers more than just resource management. TM Forum groups inventory into four main categories:

- **Product inventory** (defined by TMF637 in the Open API specs and the Product ABE of SID) captures attributes such as the place the product is used, its configuration characteristics, and the services and resources that the product comprises.
- **Service inventory** (TMF638 and Service ABE) captures service definitions (customer-facing services and resource-facing services), their attributes, and mappings such as orchestration plans.
- **Resource inventory** (TMF639 and Resource ABE) is what most people know network inventory to be; it captures resources such as servers, routers, cables, and connectivity. It often also includes spares and warehouse management. Resource inventory includes PNI, such as outside plant (OSP), and LNI.
- **Entity inventory** (TMF703) allows for the capture of “things” that are not addressed by product, service, or resource inventories. An example could be a cohort of IoT sensors.

Despite these definitions, as with much of telecom IT, *inventory* means different things to different people. There are also overlaps between inventory and configuration management databases (CMDB, Passionate About OSS, 2020). Inventory solutions are constantly evolving to cater to the changes occurring in the networks and services they manage. Inventory tools have always managed inside plant (e.g., routers, switches, multiplexers), outside plant (e.g., cables, pits, ducts, splices, towers), and their connectivity. However, they are now adapting to manage virtualized infrastructure, logical connectivity, and new topology models.

The future environment

To provide a perspective on the inventory of the future, we first need to consider the likely future environment in which it will operate. There have been recent changes that stimulate the need to reevaluate the role of inventory. However, the fundamental objectives of network inventory have not changed much. It is still expected to do the following:

- Model any type of network, service, or topology, flexibly coping with any changes.
- Capture all relevant network and service data and reconcile with other sources to ensure data integrity is maintained.
- Handle almost unlimited growth in volume, scope, and type of network or service under management. This is particularly embodied by increased device counts in virtualized and sensor/IoT networks.
- Collect and correlate masses of network and service data to provide operational insights quickly and then make those insights actionable.
- Ensure the security and privacy of all the privileged data collected.
- Leverage the collected data and the power of machines and algorithms to improve operational efficiency via better user interfaces, integrations, and automation.
- Optimize use of scarce or valuable resources.

The environment that inventory tools operate within is changing, providing opportunities to better meet the objectives above. The changing dynamics include the following:

- **Databases.** Inventory tools were traditionally built using relational database management system (RDBMS) technologies such as Oracle and PostgreSQL, which use Structured Query Language (SQL) to interact with the data. RDBMS are still likely to be used but can be complemented by newer data management technologies:
  - *Graph databases* such as Neo4J, JanusGraph, and TigerGraph are based on graph theory, employing concepts such as nodes, edges, and properties, which makes them well suited to the connected nature of inventory data, traversing associations between inventory objects. Data queries such as network, path, or circuit trace (pathfinding) are often many times faster using graph databases than traditional data models.
  - *Time series databases* such as KX's KDB+ and InfluxDB are optimized for storing temporal (time-stamped) data. Traditional inventory tools provided a "nailed up," that is, static view of networks, services, and circuits as they exist now. However, conditions within packet-switched and virtualized networks are constantly changing. Traditional

inventory tools did not attempt to model the evolving models of the network, in part because the data management solutions were unable to keep up. Time series databases better facilitate the tracking of changes over time in inventory stores, joining it with high-velocity metrics associated with the infrastructure.
KX is unique in that it is also a relational database, allowing network configuration and topology data to enrich the event data. This is particularly important in modern virtualized networks where the network topology and configuration can change significantly in a relatively short space of time. It also integrates with graph databases such as Neo4J and JanusGraph for a visual representation of network relationships, providing a powerful combination of inventory, spatial and temporal data.

  - Other models such as *NoSQL* (e.g., MongoDB), of which graph databases are a subset; *cloud* (e.g., Amazon RDS); *columnar* (e.g., Apache Cassandra); and *key-value* (e.g., Redis) databases enable other targeted inventory use cases. Vendors may even use a combination of different data platforms on a fit-for-purpose basis. For example, Ericsson Adaptive Inventory uses RDBMS (typically Oracle or PostgreSQL) for data persistence, but graph for cached presentation.

- **Network and infrastructure virtualization.** Virtual machines (VMs) and virtual network functions (VNFs) offer several operational benefits for network operators. These benefits include greater scaling, flexing, and availability of infrastructure to support demand in near-real time. However, this flexibility means the network and infrastructure under management are increasingly transient. To cope, inventory tools need to be able to flex and track the changing infrastructure to assist with fulfillment scenarios (such as resource allocation) and assurance scenarios (such as service impacts).
Virtualization has facilitated network slicing, allowing separate virtual networks to be built from the same network resources. Network slice inventory management will be key to efficient slice deployment, management, and monitoring.
- **Network scaling.** With network virtualization, sensor networks, and network slicing the number of objects under management will increase significantly. Intent and cohort management strategies and automations will be required to handle the increased scale.
- **Other platforms.** These are not specifically designed with inventory in mind, but can improve inventory solutions:
  - Artificial intelligence and machine learning
  - Augmented reality and virtual reality / digital twin platforms
  - Self-organizing networks (SON) and programmable networks
  - Network automations
  - Design automations
  - Cloud data engineering / integration / extract, transform, load (ETL)
  - Cloud hosting

Visions of a future state

The future state of inventory solutions must consider

- The need for improved operational efficiency
- Problems and challenges with current inventory solutions
- Indicators of change and/or innovation within current inventory solutions
- Indicators of changes in environment and ecosystems

Inventory platforms

Inventory solutions are the great connectors, supporting many of the other human- and machine-based workflows within telecom networks. Operators need fast, accurate, intuitive, and flexible inventory solutions.

New architectural paradigms

The monolithic solutions of the past have long been supplanted by modular designs that facilitate the use of the following:

- **Microservices:** small functional components, simplifying design, build, release, and test cycles
- **Layering:** enabling a separation of concerns such as
  - Three-tiered architectures: client/business/application layer, logic/control/processing layer, and data layers
  - Speed-based layers: fast (Agile), mid (waterfall / scope of work), and low development (network change) speeds
- **Dynamic programmability:** supported by standardized application programming interfaces (APIs) such as TM Forum's open APIs
- **Catalog-driven models:** including catalogs of products and services that also help realize design and runtime functionality; these catalogs may also facilitate software and services marketplace capabilities for network operators
- **Standards-driven frameworks:** including OASIS TOSCA, IETF YANG, TM Forum's Open Digital Framework (ODF), Open Digital Architecture, and open APIs

Innovative service provider examples

BT

BT's SRIMS (Service Resource Inventory Management System) was built using open source software and based on standards such as TM Forum (SID and open APIs), YANG, TOSCA, and a graph database. SRIMS is a scalable, intent-based inventory solution capable of managing BT's hybrid network. SRIMS provides a unified view across physical, logical, virtual, and service entities. It also incorporates a low-code platform to support DevOps within its support team. This team plans, designs, and deploys network infrastructure in an automated, self-service manner, all aided by remote situational awareness via its 3D visualization and digital twin capabilities.

Vocus

The principal IT architect of Australian telecom operator Vocus presented the company's digital transformation (Passionate About OSS, 2021) at a TM Forum event last year. He explained how Vocus has transformed its OSS/BSS, including inventory, by applying modern architectural principles.

Innovative vendor examples

GE Digital

GE Digital's Smallworld Physical Network Inventory is a geospatial inventory solution. The user interface is laid out so that operators can intuitively follow each of their primary workflows from left to right across the screen.

Synchronoss

Synchronoss has created a mobility-centric inventory solution that allows field workers to better interact with inventory data while they build and maintain the network. Synchronoss's spatialSUITE leverages a modern web services framework (spatialSTORM) and graph data technologies to achieve significant performance improvements in queries and transactions. Optimized path-tracing is highly relevant to OSP inventory management solutions.

VETRO

VETRO FiberMap has taken the traditionally complex OSP plan, design, and build interface and applied design innovation to make its application more intuitive. The user interface is designed around projects, plans, and layers, with end-to-end workflows in mind rather than the support of isolated features and functions.

Data models

The database management solutions (DBMS) used in next-generation inventory tools are only as good as the data models and data that reside within them. This data is fundamental to achieving the fast, accurate, intuitive, and flexible inventory solutions that operators need.

Operators can find it infuriating when the inventory solution they have invested so much time and resource into are unable to cope with updates to the network under management. Rather than having to wait for new modules or feature requests to be released, operators want inventory tools that adapt, without any code updates, to the following changes:

- New network technologies such as dense wavelength-division multiplexing (DWDM), including modern flex-grid optical networks; xDSL; SD-WAN; and secure access service edge (SASE)
- New device types (e.g., next generation of switch/router from their chosen network supplier or VNF updates)
- New topologies (e.g., mesh, ring, star) or protocols
- New features and attributes (e.g., extensible attribute lists or picklists)
- New service types (e.g., non-telco, enterprise offerings)
- New cohorts and templates (e.g., IoT device types/groupings, wholesale compute)
- Multi-tenancy (e.g., neutral hosting and network slices)
- Ad hoc user-defined queries and insight generation

This flexibility can only be achieved through adaptable data models, where the inventory taxonomies and schema must be suitable for

- Classifying resources/inventory/assets (of any type of network, product, service, topology, etc.)
- Sharing information via APIs
- Easily querying and cross-linking data points
- Incorporation into any database (e.g., relational or graph)
- Providing a pattern that allows limitless flexibility and extensibility
- “Design-time” versus “runtime” datasets
- Intent-based or policy-driven applications
- Data lineage for consistent naming, policy enforcement, and traceability to support decentralized data ETL pipelines and governance

When it comes to data, architects must consider data flows and which sources will master each data point. This introduces architectural decisions around which model of inventory federation (e.g., centralization, decentralization) is the best fit for each situation. There may be ideal approaches for these decisions (e.g., consolidation to eliminate fragmented inventories, simplifying management, and streamlining automations), but it is rarely simple. A pragmatic approach considers existing investments, available budget, in-flight projects, transformation complexity, and other factors, especially when multiple inventory sources exist after mergers and acquisitions.

Data mesh approaches may contrast data products being generated closer to raw sources (more distributed) with derived and aggregated insights being generated further from the source (more centralized). It is debatable whether there is a one-size-fits-all design to recommend for a model for the inventory of the future.

Security

Inventory data is often confidential or privileged in nature, so data protection expectations and regulations such as the General Data Protection Regulation (GDPR) require robust data security. Architects need to consider granular security and privacy of data at rest (e.g., in inventory databases), in motion (e.g., when traversing system interfaces), and during utilization (e.g., access control within inventory applications).

Inventory solutions are the repository of devices, applications, and services that require monitoring. Unchecked network access or device configurations represent a gap in security observability. With their far-reaching awareness of devices, configurations, access controls, and connectivity topologies, inventory solutions offer an additional tool in the arsenal of security operatives that is arguably underutilized today. Flexible inventory solutions can also incorporate physical security and surveillance network solutions that include building management, CCTV, and ACS.

Discovery and reconciliation

Discovery and reconciliation used to be performed on a daily or weekly cycle when inventory changes were relatively static. However, in a virtualized environment the changes are more frequent, and inventory needs to be updated at the same cadence. For the inventory of the future, this can be considered in the following tiers:

- **Fast discovery and reconciliation** (also known as dynamic or active inventory) captures the changes in inventory and configuration (e.g., logical and virtualized network resources) in close to real time to support fulfillment and assurance use cases.
- **Mid-speed** captures changes that occur less frequently, such as physical device details, which are suited to the traditional daily poll cycle.
- **Planning speed** captures changes that occur over longer timeframes but also primarily relate to passive devices, such as OSP (cables, splices, pits, poles), that cannot be polled for information. Creation of this data normally comes about during the design and planning process. Subsequent updates to this data occur via field-worker touchpoints and physical audits.

Capacity prediction

Clearly, it takes longer to bring on new physical capacity such as cable routes than to spin up new virtual capacity. However, because of cost and security attack surface implications, some carriers prefer to bring up capacity on a just-in-time basis. With the hierarchy of Layer 1/2/3 networks, it often takes inventory's awareness of layer topologies to properly coordinate capacity availability. Similarly, network slicing and bandwidth on demand are examples of dynamic utilization of network resources. Scenarios like these are driving vendors such as Ciena Blue Planet to prioritize the development of capacity prediction functionality.

Amdocs is also looking at capacity prediction, but with an additional lens. Rather than just predicting capacity from a resource shortage perspective, Amdocs is looking for windows of time when there is an abundance of resource, where surge pricing can incentivize greater utilization of capacity.

Innovative vendor examples

CROSS Network Intelligence

CROSS Network Intelligence is an inventory federation platform that consolidates multiple OSS/BSS data sources into a homogenized and integrated database. Its strength is that it has a relatively simple underlying data model but extensive visualization and data connectivity tools to interact with the data. CROSS offers not just resource and service inventory but can also present and cross-link inventory with assurance data. CROSS has clever mechanisms built in for improving and assuring data integrity that come to the fore during the homogenization and integration process.

HPE Trueview

HPE Trueview offers customized service stitching to construct multilayer topology graphs, flexibly adapting to changes in the underlying networks. Trueview has been designed acknowledging that automation ambitions can only be achieved if there are accurate inventory records. It uses near-real-time discovery and reconciliation of configuration data from the network to support active inventory.

Kuwaiba

The Kuwaiba open source inventory solution provides an exemplar for this type of flexible data taxonomy. Built on the Neo4J graph DBMS, Kuwaiba's data model is designed around object-oriented concepts of classes, attributes, hierarchies, and templates. The Kuwaiba solution accommodates physical, logical, virtual, entity, and service inventory. It can handle power, water, gas, smart city/IoT, and security networks in addition to communications networks. In theory, it can facilitate any type of network that can be modeled as a series of nodes, connections, and services. Many network outages are caused by interrupted power supply. Being able to relate power infrastructure to communications infrastructure allows an operator to perform power impact analysis (i.e., if a power outage notification is received from an energy supplier, a list of affected equipment and customer services can be calculated, and diagnostic truck rolls halted). It can also perform blast-radius analysis, where a cluster of device outages can be correlated with a power supplier (one which has not provided any outage notifications).

Nokia

Nokia Unified Inventory, a component of Nokia's Digital Operations Center solution, has been designed with high-velocity, closed-loop orchestration and assurance operations in mind. It has been built to store information to support these two use cases that might not otherwise be stored by traditional inventory products.

SunVizion

The SunVizion Network Inventory solution uses an object-oriented model of class, inheritance, and attributes to provide data model flexibility. While many inventory solutions are built around geographical information systems (GIS) and provide a 2D map view of inventory (e.g., devices and connectivity), SunVizion's is one of the first to add a third dimension to its data model, height, which is relevant for multistory buildings, riser cables (in buildings, towers, poles), and subterranean infrastructure such as ducts and pits. Most inventory solutions only cater for latitudinal/longitudinal coordinate systems and use workarounds to handle height. This third dimension will become increasingly relevant as AR/VR tools allow operators to interact with inventory (devices, connectivity, and associations) in an immersive 3D environment.

Auxiliary systems

There are many opportunities to leverage non-inventory-specific platforms to better facilitate inventory-related use cases or overcome inventory-centric problems. The following solutions are relatively nascent in their application for inventory purposes:

- **AI/ML.** Platforms such as Anodot are assisting with advanced, autonomous network forecasting. Nokia is using AI techniques for scope discoveries to understand patterns of change in the inventory database to better understand how and where the network is evolving.
  As a part of Bentley's core functional capabilities, AI tools are used on 3D photogrammetric mesh models of communications towers to infer the total structure of the tower. Full structural and geometric digital twin models of the tower can be generated automatically. AI tools are also used to identify defects such as corrosion, missing nuts and bolts, and obstacles such as vegetation. APIs are being developed to enable external software applications to integrate with the Bentley OpenTower iQ platform.
- **Situation enrichment.** AR/VR and digital twin platforms such as Trendspek are allowing for immersive interactions with photorealistic models of inventory without site visits. These platforms allow for a two-way situation enrichment when paired with OSS (Passionate About OSS, 2022). They allow the field worker to access back-office/OSS data that enriches decision-making at site. They also allow remote workers (e.g., designers, NOC operators, etc.) to have greater situational awareness of sites and resources that better inform decision-making remotely.
  Another benefit of the Trendspek platform is the ability to accurately measure dimensions of objects (e.g., towers, concrete plinths, antennas, fences, areas, etc.) that are on site. This means contractors can "visit" the site without ever setting foot there.
  Appearition provides an AR/VR platform that combines 3D photogrammetry models with live data overlays that include inventory, alarms, performance and more. These solutions allow

greater situational awareness for remote operators such as designers, NOC (network operations center) operators, contractors, and other personas.

- **Radio frequency (RF) coverage mapping.** While not typically considered network inventory, RF coverage maps provide a useful adjunct capability for inventory tools that support service qualification requests. Note that coverage maps might not typically be considered inventory, but spectrum is definitely an important asset on many CSPs' balance sheets. Allocation of spectrum is an important resource management consideration, much like allocation of IP addresses and subnets, so radio frequencies themselves could be considered an inventory-managed resource. With increased emergence of radio-based networks such as 5G, Low Earth Orbit satellites, and IoT networks such as LoRaWAN, RF coverage awareness is expected to become increasingly important for inventory solutions. Kuwaiba and Twinkler have already demonstrated the integration of coverage mapping into inventory.
  The Appearition AR/VR solution has also been integrated with Twinkler to provide an immersive in-building coverage planner to optimize the placement of radio infrastructure within a building or campus.
  The Trendspek AR/VR solution allows for antenna attributes such as height, tilt, and azimuth to be calculated from the 3D photogrammetry models it stores. Using the Trendspek API, these attributes can be passed to tools such as Twinkler to generate RF coverage maps.
- **Self-organizing networks.** These facilitate dynamic network and service configuration, healing, and optimization as demonstrated by solutions from vendors such as Celona and KX RAN Optimization. More broadly, inventory solutions are primed for greater integration with programmable networks.
- **Network automation.** Inventory solutions were originally designed to aid human interactions with inventory data and workflows. Next-generation inventory solutions will be designed for greater machine-to-machine interaction first and human-machine interactions only where necessary. Itential is one example that provides network automation that aims to reduce human involvement in network and cloud management.
- **Design and rollout automation.** These tools allow operators to aid the design of greenfield and brownfield/infill networks. These algorithmic approaches help to optimize the use of resources, materials, and labor, providing an initial install cost reduction but also lower ongoing costs thanks to reductions in the number of installed resources that must be managed and maintained.
  Automated planning and design tools are sometimes provided as part of a vendor's inventory offering; an example is the SunVizion Network Planning module. Others are available as standalone solutions, for example, those provided by Biarri.
  Amdocs has introduced its Plan Management solution to optimize the allocation of design and field resources, not just for planned network changes but also for interleaving emergency-fix changes into job lists. Amdocs expects that ML will be added to enhance these allocations imminently.
- **Cloud data engineering / integration / ETL.** These platforms are proliferating and making it easier to collect data, move it around, and synchronize it with other sources. In the past, inventory vendors had large libraries of data collectors to source information from hundreds of different devices and element management systems (EMS). These collectors were often expensive to develop and maintain, especially when they might not be used by all of a vendor's clients and therefore could not be easily amortized. It appears that modern data architectures

are allowing intermediaries such as Splunk and AWS to collect the data from many sources. This means OSS solutions then only need to collect the aggregated data (thus reducing the number of collectors required). Modern ETL pipeline tools are being leveraged to minimize the expensive mediation layer maintained for inventory solutions of the past.
Distributed event streaming platforms such as Apache Kafka are gaining widespread use for data pipelines, streaming analytics, and data integration.

- **Cloud hosting.** Like many other workloads across all industries, inventory solutions are increasingly becoming cloud native, ready for cloud hosting. They are being designed as microservices and managed with orchestration tools such as Kubernetes, allowing inventory solutions to scale up and down as necessary.
  Not only do inventory solutions reside on cloud hosting, they also manage cloud resources. Operators have the potential to offer wholesale compute-based services, particularly edge compute, in addition to their more traditional network access services. This means inventory needs to track these resources to support their service orchestration and assurance. Ericsson inventory and orchestration solutions use smart workload allocation for VNFs, CNFs, and vApps to optimize for availability, cost, region, and so on.

Standards

Several standards bodies have existing and in-flight initiatives underway that may have an impact on the inventory systems of the future. These include (but are not limited to)

- **TM Forum**
  - Open APIs such as Product Inventory (TMF637), Service Inventory (TMF638), Resource Inventory (TMF639), Entity Inventory (TMF703), Topology Discovery Service Management (TMF920A), and Service Qualification (TMF645)
  - Inventory Framework (SID) (GB922)
  - Business Requirements for a Multi-layer Topology Discovery Service (TR283)
  - Resource Inventory of 3GPP NRM for Service Assurance (IG1217)
  - Inventory Transformation Guide (IG1263, under development)
- **MEF**
  - MEF 55: Lifecycle Service Orchestration (LSO), including Legato (service management), Presto (network management), Adagio (resource management), and Sonata (for service provider to partner interactions)
  - MEF 81 (Product Inventory Management)
- **ETSI/3GPP**
  - TS 32.692: Telecommunication management; Inventory Management (IM) network resources Integration Reference Point (IRP); Network Resource Model (NRM)
  - TS 32.612: Telecommunication management; Configuration Management (CM); Bulk CM Integration Reference Point (IRP): Information Service (IS)
  - TS 32.615: Telecommunication management; Configuration Management (CM); Bulk CM Integration Reference Point (IRP): eXtensible Markup Language (XML) file format definition

- **ANSI/TIA/EIA**
  - 606-B: Administration Standard for the Telecommunications Infrastructure
- **ITU-T**
  - M.1400: Designations for interconnections among operators' networks
  - G.805: Generic functional architecture of transport networks
- **Modeling and templating languages**
  - OASIS TOSCA Simple Profile in YAML
  - IETF YANG – RFC 7950
  - IETF NETCONF – RFC 6241

Transformation considerations

There is no single target-state architecture for an inventory of the future. Modular architectures, standardized interfaces, and ETL pipelines have reduced integration complexity. But inventory solutions still have many dependencies, which makes their transformation a challenge. Below we discuss key considerations of a pragmatic inventory of the future.

Service provider transformation

CSPs face an even harder challenge to transform than vendors do. Transformation projects are complex, lengthy, resource hungry, and risky. They often require a leap of faith because there may not be a clear path between current and desired future states. CSP transformations need pragmatic compromises because of wide-ranging complexity:

- The technology stack (old platforms, new platforms, data flows, federation, system dependencies, incorporating inventory into workflows, architecture, etc.)
- Customizations made by the CSP to its current off-the-shelf (OTS) inventory tools that often need to be unpicked and reengineered to migrate to the new solution
- Evolving the solution and work practices while running the existing business, operations, and network

One of the reasons inventory transformation projects are seen to be risky stems from the fact that they have tended to be handed over as "big bang" deliverables. Under a big-bang approach, significant time and resource is consumed before the release of business value. The Agile delivery methodology and a more dexterous breakdown of work can lead to faster but more incremental delivery of business value. A modular and decoupled architecture can assist with this delta migration approach.

Further to the network changes described in the ***Data models*** section, CSPs can face challenges onboarding new inventory. This could take the form of new devices, network vendors, VNFs, and so on. BT's SRIMS project has tackled this challenge by instigating a standardized data exchange format. Each of its vendors is asked to create network inventory templates in this common format, which has drastically improved the certification and onboarding process for new inventory models.

Process transformation

Digital transformations may require business process reengineering (BPR). The inventory of the future model described above provides opportunities for new activity sequences. For example, increases in automation, cohort or policy management of inventory, and remote situational awareness using AR/VR capabilities introduce entirely new ways of working. These new inventory platforms, tools, and processes can affect many personas across a CSP, including designers, NOC operators, field workers, and capacity planners.

Perhaps the fiercest challenge to overcome is resistance to change. New ways of working force people out of their comfort zones. Automation introduces the threat of job cuts. Maximizing the opportunities from an inventory of the future depends on an effective workforce and organizational change management.

Vendor product transformation

There has been a long-standing trend for network operators, particularly Tier 1 service providers, to insource development of their OSS/BSS solutions. Despite this, inventories are one of the functionalities that remains largely built around OTS components. Even operators that opt for heavy customizations will still tend to start from an OTS inventory baseline.

Many of the product transformation opportunities described in this report will require significant refactoring by inventory vendors. For example, transforming from a solution underpinned by a relational database to one based on a graph database is likely to take significant time, effort, and resources. This is often a drastic business decision to make: it may require thousands of developer days of effort to replicate functionality that already exists.

However, this type of transformative overhaul provides the opportunity to modernize or even to revolutionize architectures, interfaces, workflows, and performance. It provides the platform for radical rather than incremental innovation.

If a complete overhaul is not viable for your inventory of the future, increased modularity still provides opportunities to innovate and transform. Modularity allows vendors to embark on a phased product transformation. Similarly, standardized interfaces allow for vendors to partner with and build upon existing solutions.

Inventory vendor capabilities

Table 1 and **Table 2** provide information about the key inventory solution providers mentioned in this report. Note there are other specialist inventory solution providers that we have not covered. For further details of these see the Passionate About OSS vendor directory.

The following legend is provided for use with the tables:

- **Physical network inventory / outside plant (PNI/OSP).** Generally, passive components such as racks, panels, server bays, patch-panels/leads, and tray ways are modeled in PNI/OSP inventory tools.
- **Logical network inventory / inside plant (LNI/ISP).** These tools model components (and connectivity) that can be polled via API (e.g., active devices such as DSLAMs, routers).

- **Virtual network inventory (VNI).** Some modern inventory solutions can support virtualized networks (e.g., VMs, VNFs, SDN, VIMs).
- **Product inventory.** Defined by TMF637 in the Open API specs and the Product ABE of SID, this captures attributes such as the place the product is used, its configuration characteristics, and the services and resources that the product comprises.
- **Service inventory.** This, defined by TMF638 and Service ABE, captures service definitions (CFS, customer-facing services; and RFS, resource-facing services), their attributes, and mappings such as orchestration plans.

The table indicates which vendors use partners for some aspects of their inventory solution (e.g., HPE for PNI) and the name of the partner solution if the vendor has expressed a preference (e.g., GE Digital with CROSS Network Intelligence).

Table 1: Telecom inventory solution description

Company	Product names	Description
Amdocs	Amdocs Network Inventory	Built to accelerate and automate service provider operations by providing northbound applications and end users with an accurate, real-time, end-to-end view of network resources and services. Includes an advanced user interface and advanced process engine for orchestration and automation of inventory operations, fast onboarding of new network functions and service types, and advanced resource planning. It is highly scalable and can be run on cloud or on premises. Supports TM Forum open APIs and advanced federation of third-party inventory systems.
Bentley	Bentley ISP, Bentley Comms. GIS, Bentley Fiber	Helps to model all equipment, connections, and signal performance from the physical fiber port at the headend to the access port at the subscriber. It offers precision layout tools, a rich GIS environment, and real-time design verification.
Ciena Blue Planet	Blue Planet Inventory	Blue Planet Inventory (BPI) is a telco-grade, cloud-deployable inventory that fuses graph and table data-modeling approaches. BPI can blend data into the daily operations of a CSP, allowing context-driven decision-making. It can ingest data from systems that can then be retired. Operations can be user based or fully automated, spanning 5G RAN, SD-WAN, Ethernet, and optical transport network (OTN) service planning and design. Network discovery and event-based integration to other systems keeps BPI data fresh and accurate.
Comarch	Comarch Network Inventory Management	A common, unified inventory (PNI, LNI, VNI), Comarch Network Inventory facilitates network resource catalog management for multi-vendor, multidomain networks. It manages RAN, transmission/transport, core and fixed-access networks, IT infrastructure, and data center inventory tasks for SDN/NFV and hybrid networks. It handles ISP and OSP operations for planning and provisioning and allows easy onboarding of new technologies.
CROSS Network Intelligence	CROSS	A modular web application capable of linking to specialist GIS and planning systems and merging that content with network-derived logical information. It provides a single source of network truth that integrates with BSS functions such as product and service inventory and provides service check, service impact, and fault analysis. Enables automation and workflow integration, with open APIs and optional modules for tracing, link schematics, and RCA.
Ericsson	Ericsson Adaptive	Uses a single interface to view all network inventory data (PNI, LNI, and VNI). Expedites new service introduction and fulfillment,

	Inventory	with fast provisioning and high flow through. Saves time and money by automating network lifecycle management processes. Increases inventory data accuracy to reduce order fallout and fault resolution. Provides an SDK with which customers can configure automation themselves.
GE Digital	Smallworld	Smallworld Network Inventory is a GIS-based PNI solution used by more than 160 telecom operators and utilities globally. It provides a scalable multitechnology, multi-vendor platform suitable for the largest telecom operators. It integrates network design with OSP inventory in a database that allows operators to support the entire plan, design, build, and operate network lifecycle. Close coupling with LNI provides a 360° view of the entire network. It has a mobile-first approach and supports deployment in major cloud providers.

HPE	Trueview	A hybrid network inventory solution that extends over physical and virtual network functions, and their elements, networks, and infrastructure management systems down to individual network elements to enrich, collect, and reconcile dynamic network configuration and topology data. It provides accurate network data to support business process automation, ranging from order management to assurance correlation and intent-based orchestration.
Kuwaiba	Kuwaiba	An open source, enterprise-grade network inventory system for telecom and IT. It supports asset, change, and facility management processes and is a key element in the implementation of ITIL and COBIT components.
Netcracker	Netcracker Hybrid Resource Management	A unified, cross-domain approach for managing physical and virtual resources across hybrid network and IT resources to optimize network performance, reduce costs, and enable on-demand services. Based on a cloud-native architecture, its components are deployed as a set of reusable microservices with open APIs to deliver a centralized, real-time view of networks and devices, providing zero-touch provisioning of network elements.
Nokia	Nokia Unified Inventory	A cloud-native application that can be used with other Nokia OSS such as Assurance Center, Orchestration Center, Digital Operations Center, and FlowOne. It supports virtualized and cloudified 5G networks, extreme automation, and large numbers of logical resources. It provides a single source of truth in near-real time, with an end-to-end service and resource topology view across multidomain and multi-vendor networks. Nokia's fulfillment and assurance can use Unified Inventory for service lifecycle management (design, deploy, and assure) including closed-loop automation, intent-based operations, and automated network discovery and reconciliation.
Oracle	Unified Inventory Manager, Network Integrity	An open standards-based, cloud-native application for PNI, LNI, and VNI that clearly distinguishes network and resource from service inventory. It has a modular, flexible, and extensible architecture. It addresses wholesale and discrete inventory needs through its inventory federation framework and prebuilt support for multiple service and technology domains. It supports service fulfillment and orchestration; customer order capture; network planning, design and build; network asset lifecycle management; and network automation and operations across multiple technology domains.
SunVizion	SunVizion Network	A multimodule, multitechnology solution for LNI and PNI with intelligent discovery and reconciliation to improve network data

	Inventory (and others)	accuracy. PNI integrates inside and outside plant data. LNI manages information about connections and relationships between connection types. LNI records the resource's functionality, bandwidth, and relationships with other physical and logical resources. The solution can also document the bandwidth allocation in a network and track relations between logical and physical elements.
Synchronoss	spatialSUITE	Tracks asset information including physical location, attributes, connectivity, and capacity for every inside and outside plant asset. Information can be distributed as a seamless, connected network with none of the breaks at the edges of drawings found in file-based systems. A single database repository allows any network device to be found by searching for name, number, or location. Network maps give an overview of the entire system as well as detailed views. The flexible, open data model facilitates the integration of network asset data with systems designed for ERP, financial, project management, and other OSS/BSS.
VETRO FiberMap	VETRO FiberMap	A cloud-native fiber management GIS platform for complex OSP plan, design, and build. The user interface is designed around projects, plans, and layers with end-to-end workflows in mind. VETRO is a platform offering with an open architecture and an API suite powering a data pipeline and integrations with adjacent OSS/BSS.

Source: Omdia

Table 2: Telecom inventory solution functionality overview

Company	PNI/OSP	LNI/ISP	VNI	Database
Amdocs	✓	✓	✓	RDBMS and GraphDB
Bentley	✓	✓	×	RDBMS
Ciena Blue Planet	✓	✓	✓	Graph, SQL
Comarch	✓	✓	✓	RDBMS and GraphDB
CROSS Network Intelligence	✓	✓	✓	RDBMS in core with GraphDB in optional modules for tracing, schematics, etc.
Ericsson	✓	✓	✓	Oracle or Jboss; Service Design component uses graph
GE Digital	✓	Partner	Partner	RDBMS
HPE	Partners	✓	✓	RDBMS
Kuwaiba	✓	✓	✓	Graph DB
Netcracker	✓	✓	✓	RDBMS and GraphDB
Nokia	×	✓	✓	Graph DB based on NEO4J plus open source databases such as MariaDB and Casandra
Oracle	✓	✓	✓	RDBMS. Moving Topology & Path analysis engine to Oracle Graph DB
SunVizion	✓	✓	✓	RDBMS
Synchronoss	✓	✓	×	RDBMS, Graph DB
VETRO FiberMap	✓	×	×	RDBMS, Graph, Network
Note: GE Digital partners with CROSS NI for parts of its solution.				

Source: Omdia

Appendix

Companies mentioned and acronyms used in this report

Table 3: Companies mentioned

Amazon (AWS)	JanusGraph
Amdocs	Kuwaiba
Anodot	KX
Apache	MEF
Appearition	MongoDB
Bentley	Neo4J
Biarri	Netcracker
BT	Nokia
Camunda	OASIS
Celona	OpenConfig
Ciena Blue Planet	Oracle
Comarch	PostgreSQL
CommScope	Redis
CROSS Network Intelligence	Splunk
Ericsson	SunVizion
ETSI/3GPP	Synchronoss
GE	TigerGraph
HPE	TM Forum
IETF	Trendspek
InfluxDB	Twinkler
Itential	VETRO FiberMap
ITU-T	Vocus

Source: Omdia

Table 4: Acronyms used in this report

Acronym	Full term	Acronym	Full term
ABE	Aggregate business entities: from TM Forum's standard information and data model (SID)	ODF	Open Digital Framework, by TM Forum
AI	Artificial intelligence	OSP	Outside plant
API	Application programming interface	OSS	Operational support system
AR	Augmented reality	OTS	Off-the-shelf (software)
BPR	Business process reengineering	RAN	Radio access network
BSS	Business support system	RCA	Root cause analysis
CFS	Customer-facing service	RDBMS	Relational database management system
CMDB	Configuration management database	RFS	Resource-facing service
CSP	Communications service provider	SASE	Secure access service edge
DBMS	Database management system	SDN	Software-defined network
DWDM	Dense wavelength-division multiplexing	SD-WAN	Software-defined wide area network
EMS	Element management system	SIA	Service impact analysis
ETL	Extract, transform, load (of data)	SID	TM Forum's shared information / data model
IoT	Internet of Things	SON	Self-organizing network
ISP	Inside plant	SQL	Structured Query Language
IT	Information technology	T2R	Trouble to resolve
LSO	Lifecycle service orchestration (MEF standard)	UI/UX	User interface / user experience
MEF	Metro Ethernet Forum	VM	Virtual machine
ML	Machine learning	VNF	Virtual network function

NFV	Network function virtualization	VR	Virtual reality
NOC	Network operations center	xDSL	Describes the family of digital subscriber line technologies (e.g., ADSL, VDSL, etc.)
O2A	Order to activate	XML	Extensible Markup Language

Source: Omdia

Methodology

This report is based on the authors' ongoing work in the field of telecom inventory systems and on a series of interviews with technology vendors during January 2022. In addition it draws on feedback from telecom operators about the challenges they face in network automation; one of the principal pain points is incorrect inventory data.

Further reading

Network and service assurance—market trends, taxonomy, and outlook (October 2021)

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