

**Internet  
Architecture  
Board**

# **Next Era of Network Management Operations (NEMOPS)**

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# IAB

## Internet Architecture Board



- The IAB provides **long-range technical direction** for Internet development, ensuring the Internet continues to grow and evolve as a platform for global communication and innovation.
- Provides **Architectural oversight**
- Runs **workshops** to:
  - address current challenges
  - explore emerging technologies
  - **create input for future work within the Internet Engineering Task Force (IETF) and Internet Research Task Force (IETF)**
- Runs **programs** to address long term perspectives/issues
- Manages liaison relationships with organizations outside the IETF (such as other SDOs)

# First IAB Workshop on Network Management

- **1990-2000**
  - IETF OPS area has been collecting **network management requirements**
    - Configuration, Monitoring & Security requirements
- **April 2001~ May 2002**
  - OPS-NW **Roadshow** visited Operators at RIPE, NANOG, and LISA\* conferences
    - Unusable configuration management
    - Network monitoring is complex with so many alternative protocols and tools
- **June 2002**
  - 3-day **IAB workshop** on Network Management in Reston, Virginia, USA

\* USENIX Large Installation System Administration



# 2002 IAB Workshop

## Key Outcome



- Importantly, all IETF WGs work together to develop a cohesive collection of YANG data models, at both the element and service levels

# **IAB / IETF NM Workshop 2024**

## **Next Era of Network Management Operations (NEMOPS)**

**December 3-5**  
**Virtual Online**



# NEMOPS Workshop

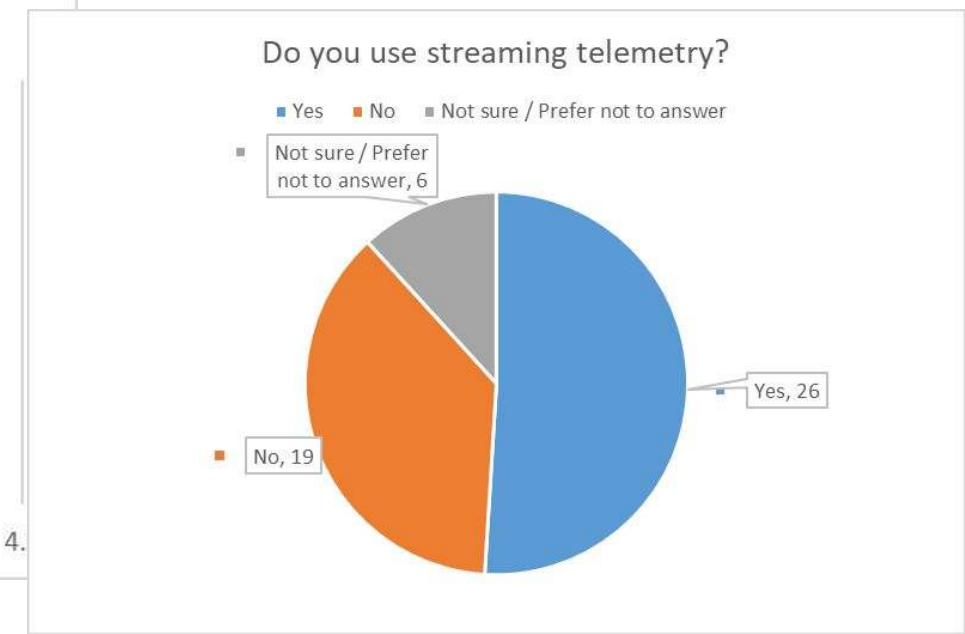
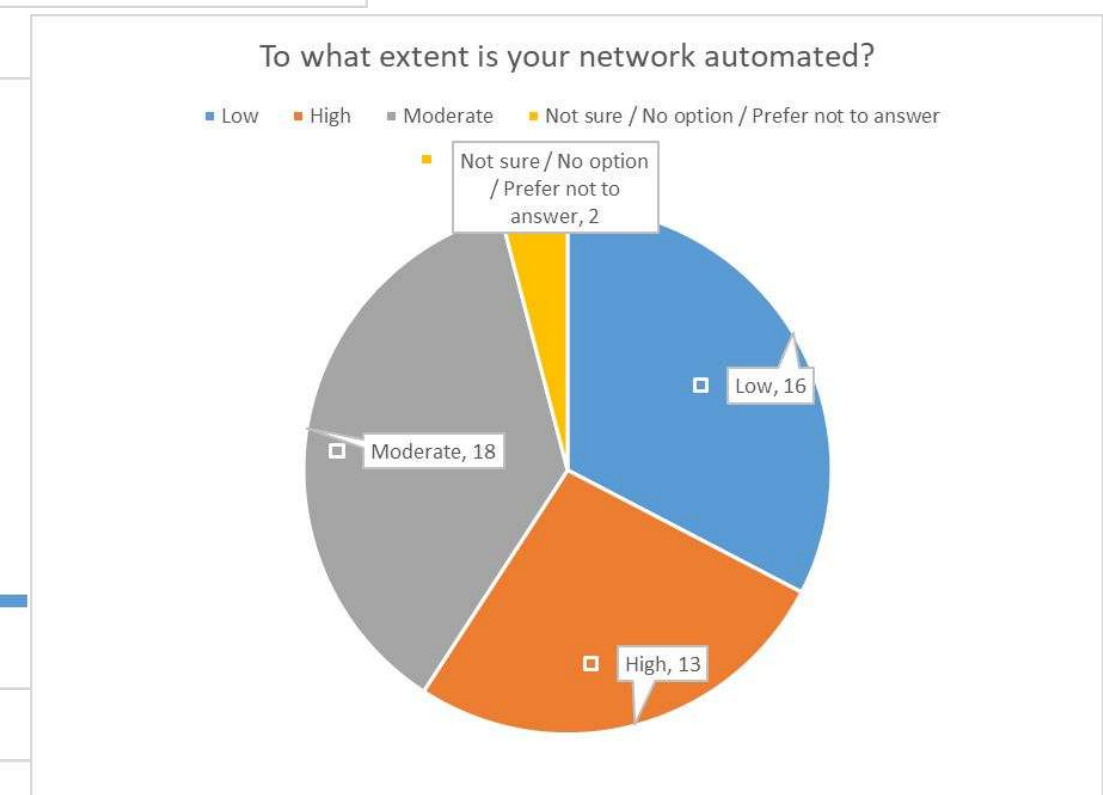
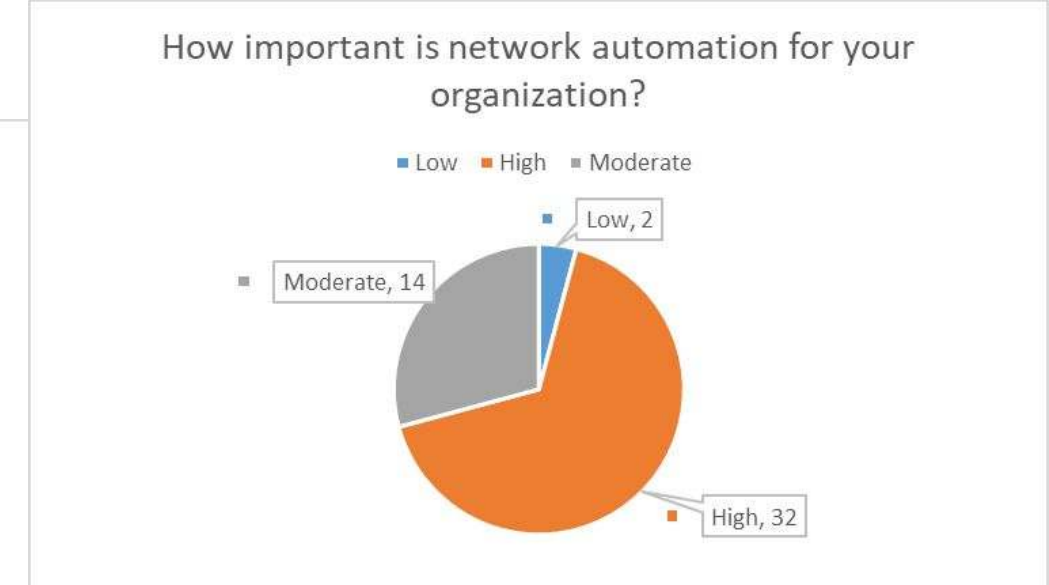
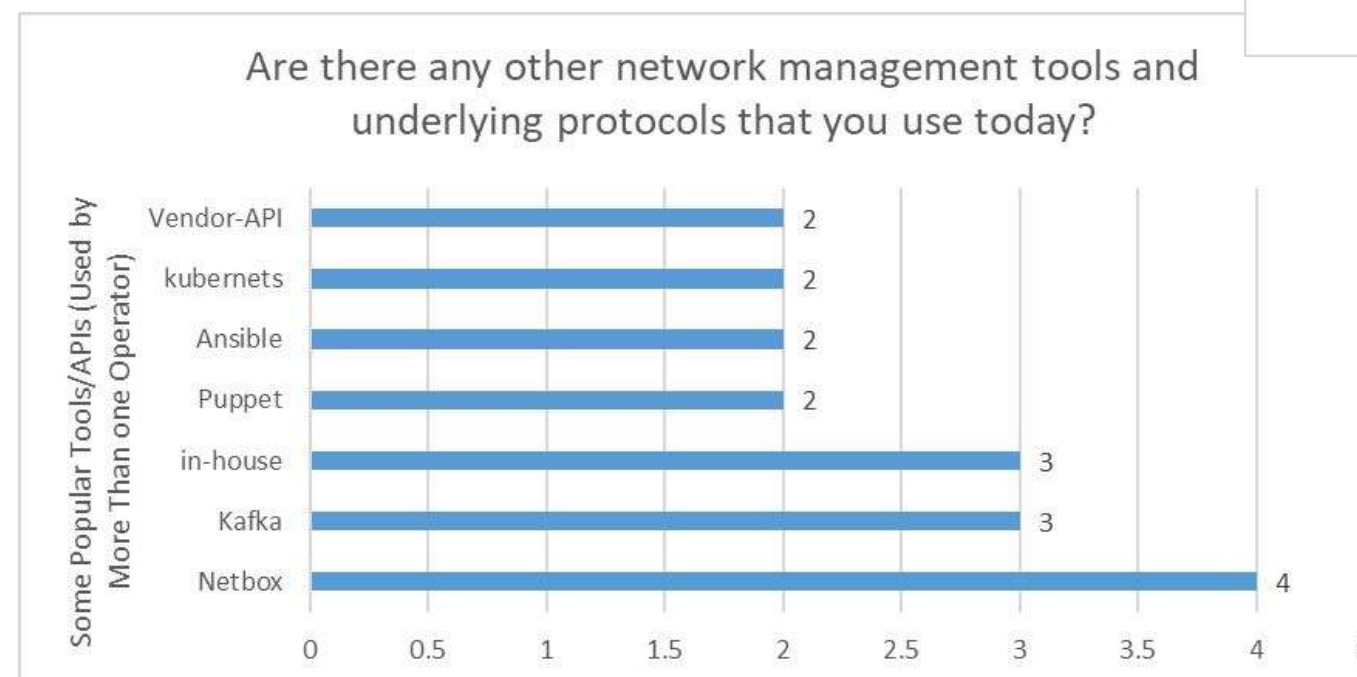
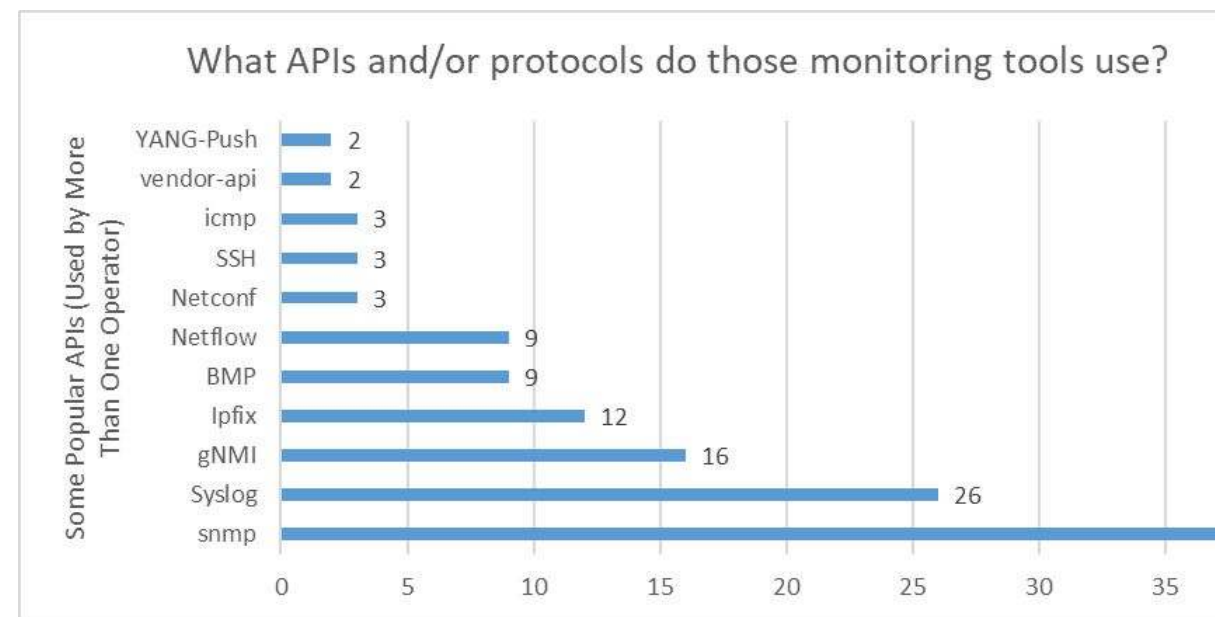
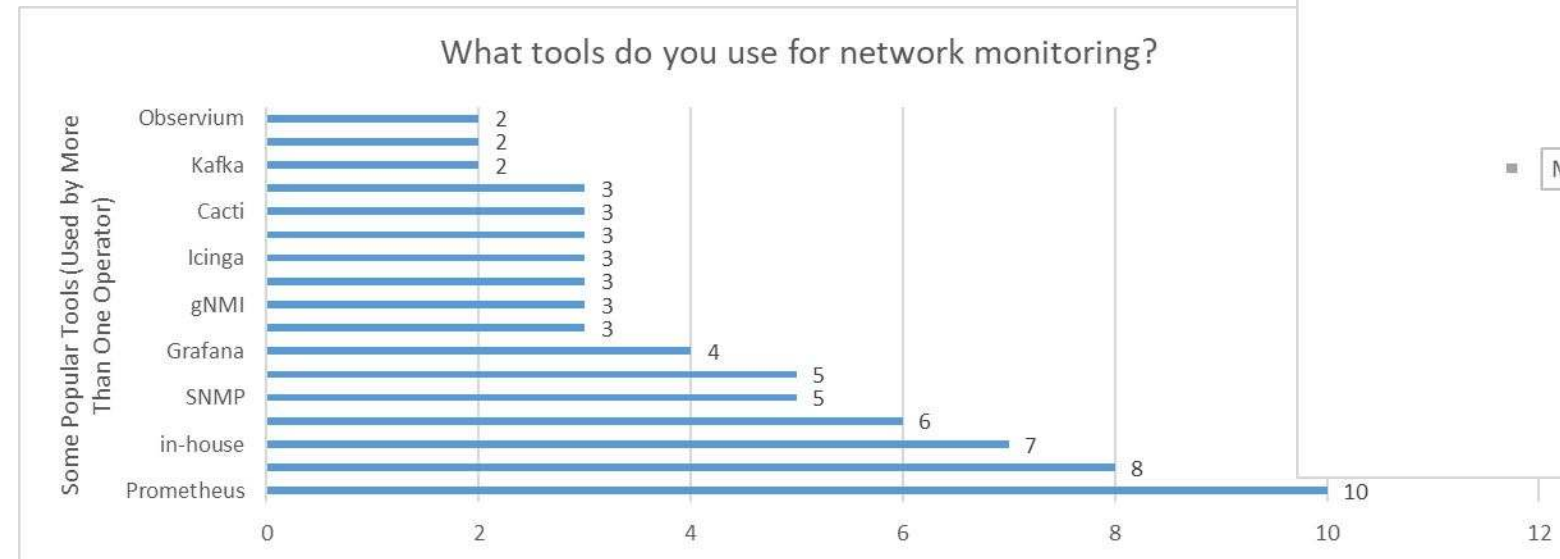
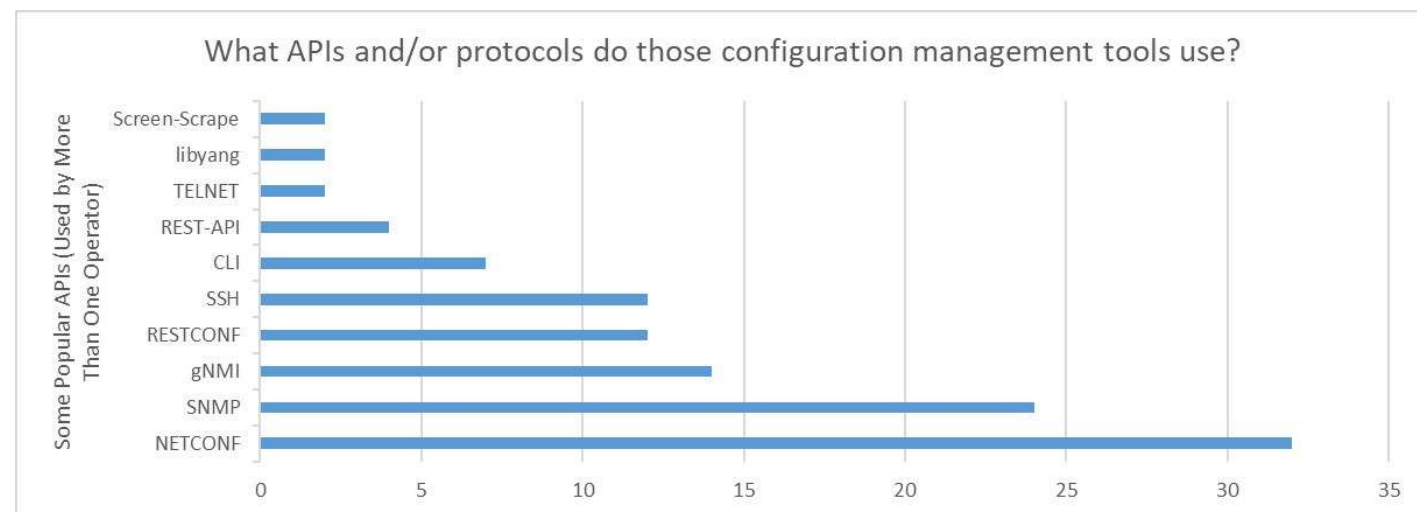
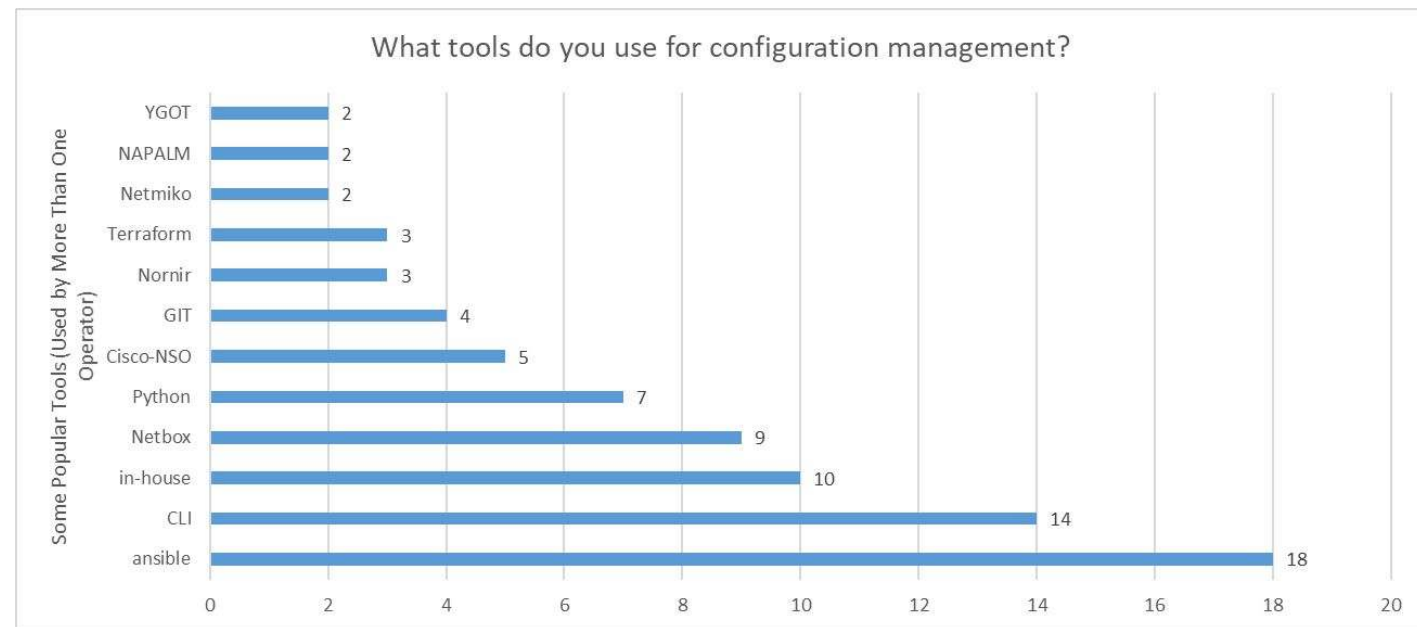
## Objectives



- **Review the outcomes** and results of the 2002 workshop (e.g., current deployments, state of the art) and **identify any operational barriers** that prevent these technologies from being widely implemented (limitations, hurdles).
- **Explore new requirements** for future network management operations in a collaborative manner with the industry, network operators, and protocol engineers.
- Develop a **plan of action and recommendations** for the IETF.
- More details at <https://datatracker.ietf.org/group/nemopsws/about/>

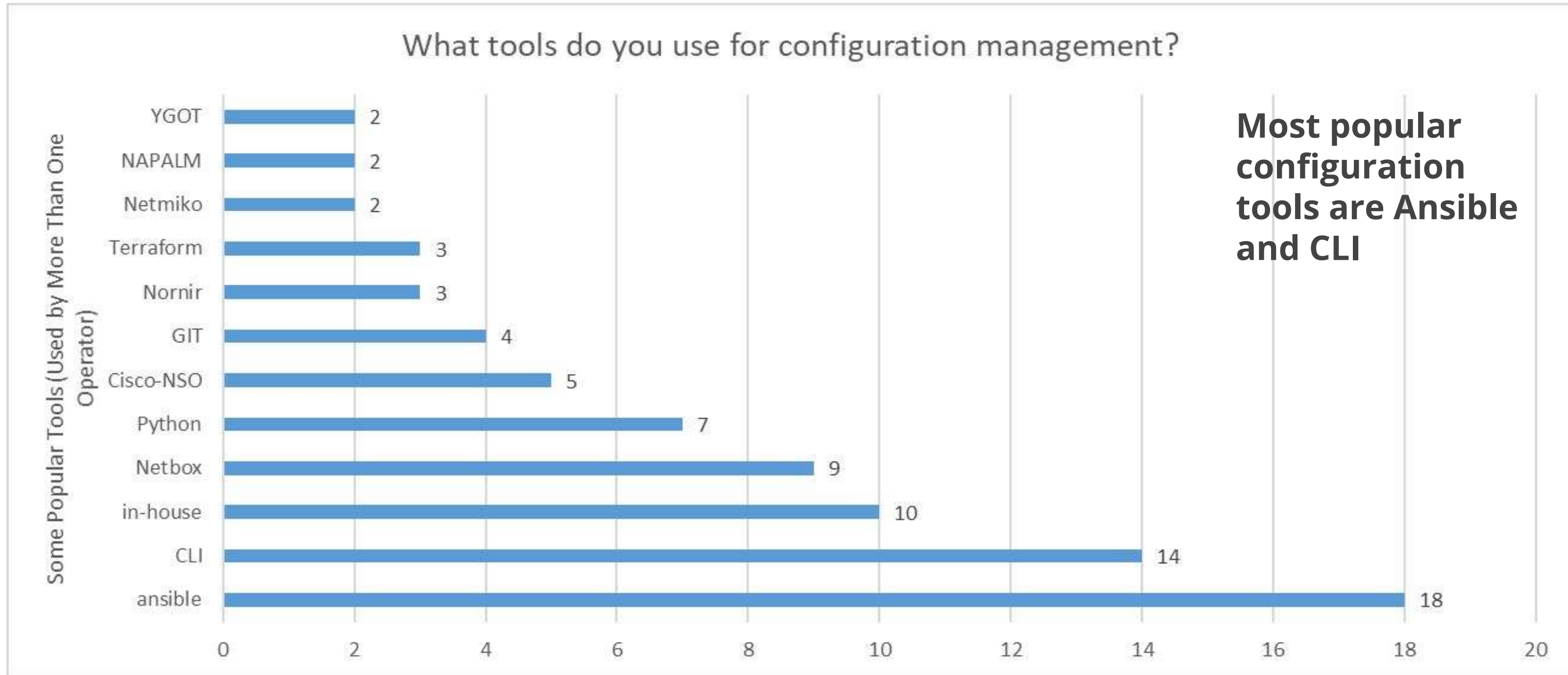
# NEMOPS Workshop

## Operator Survey



# NEMOPS Workshop

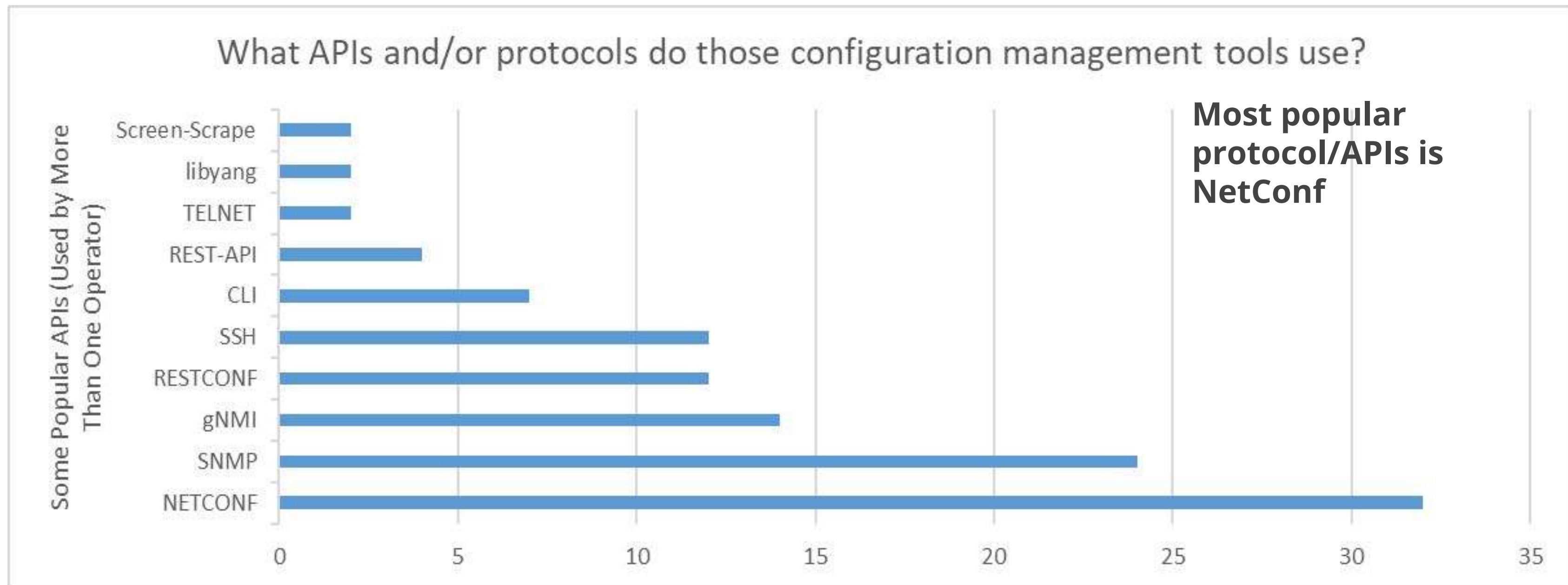
## Operator Survey





# NEMOPS Workshop

## Operator Survey



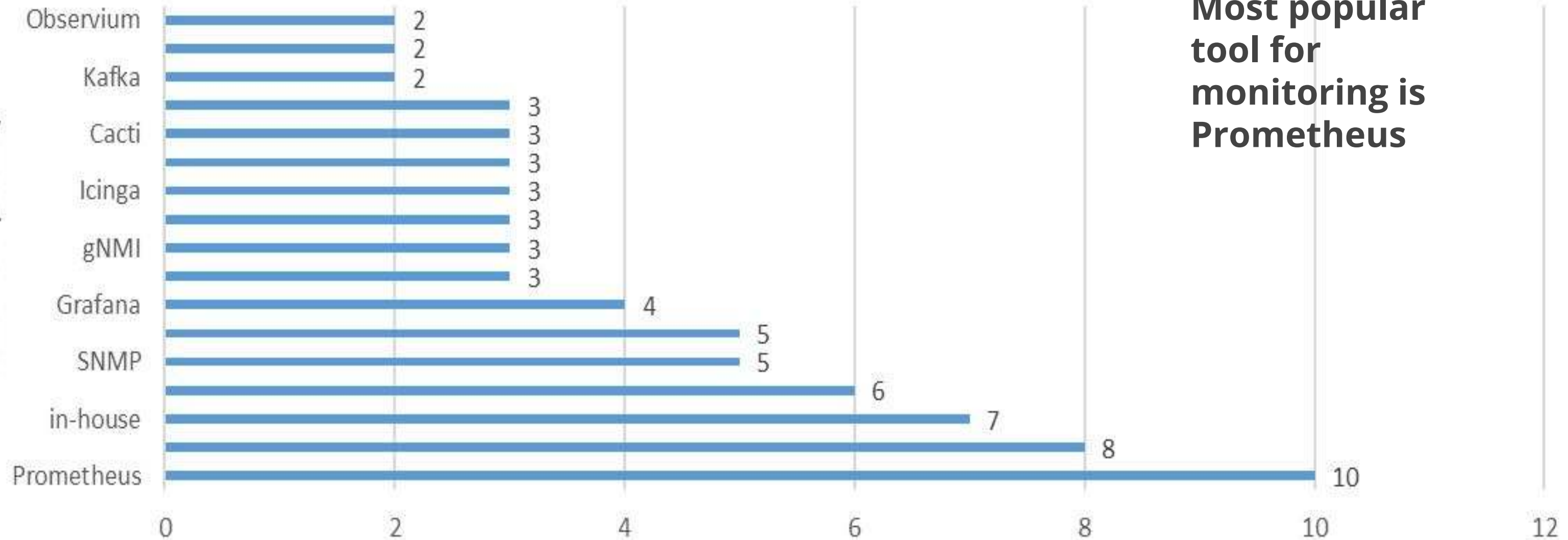
# NEMOPS Workshop

## Operator Survey



What tools do you use for network monitoring?

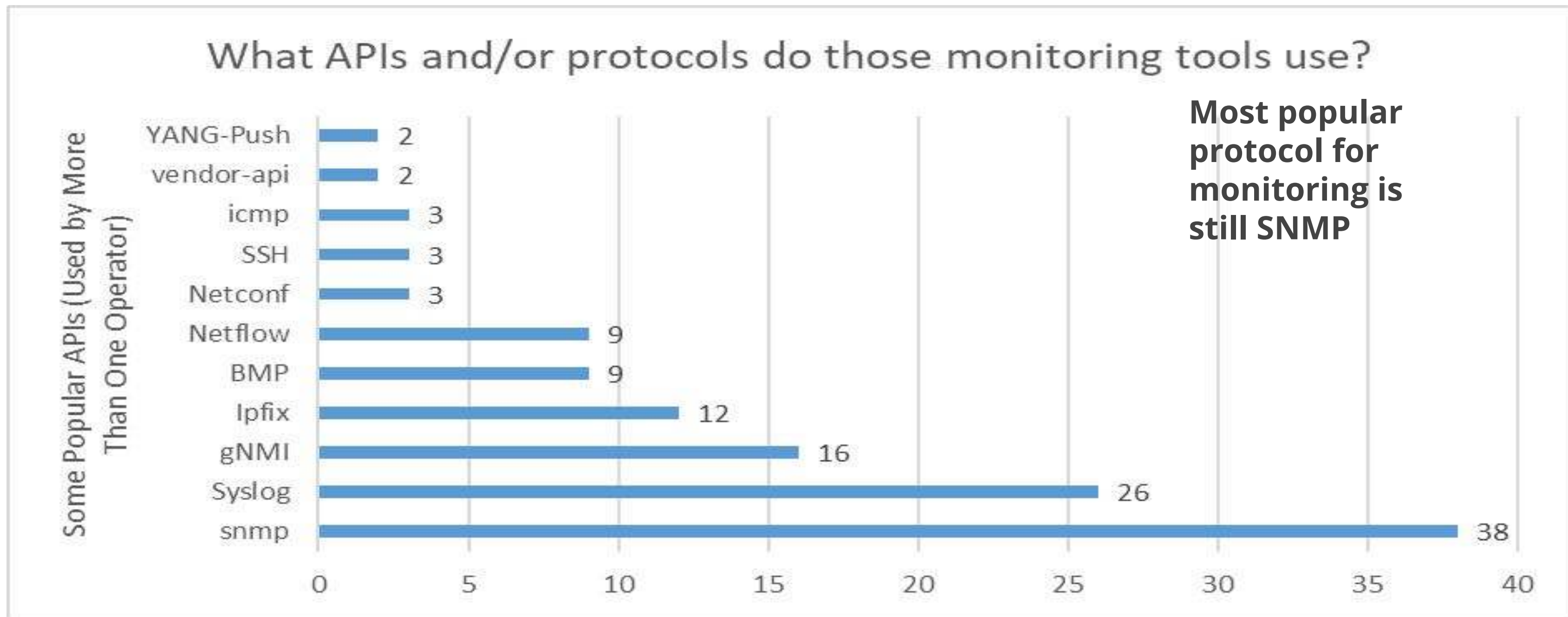
Some Popular Tools (Used by More Than One Operator)



**Most popular tool for monitoring is Prometheus**

# NEMOPS Workshop

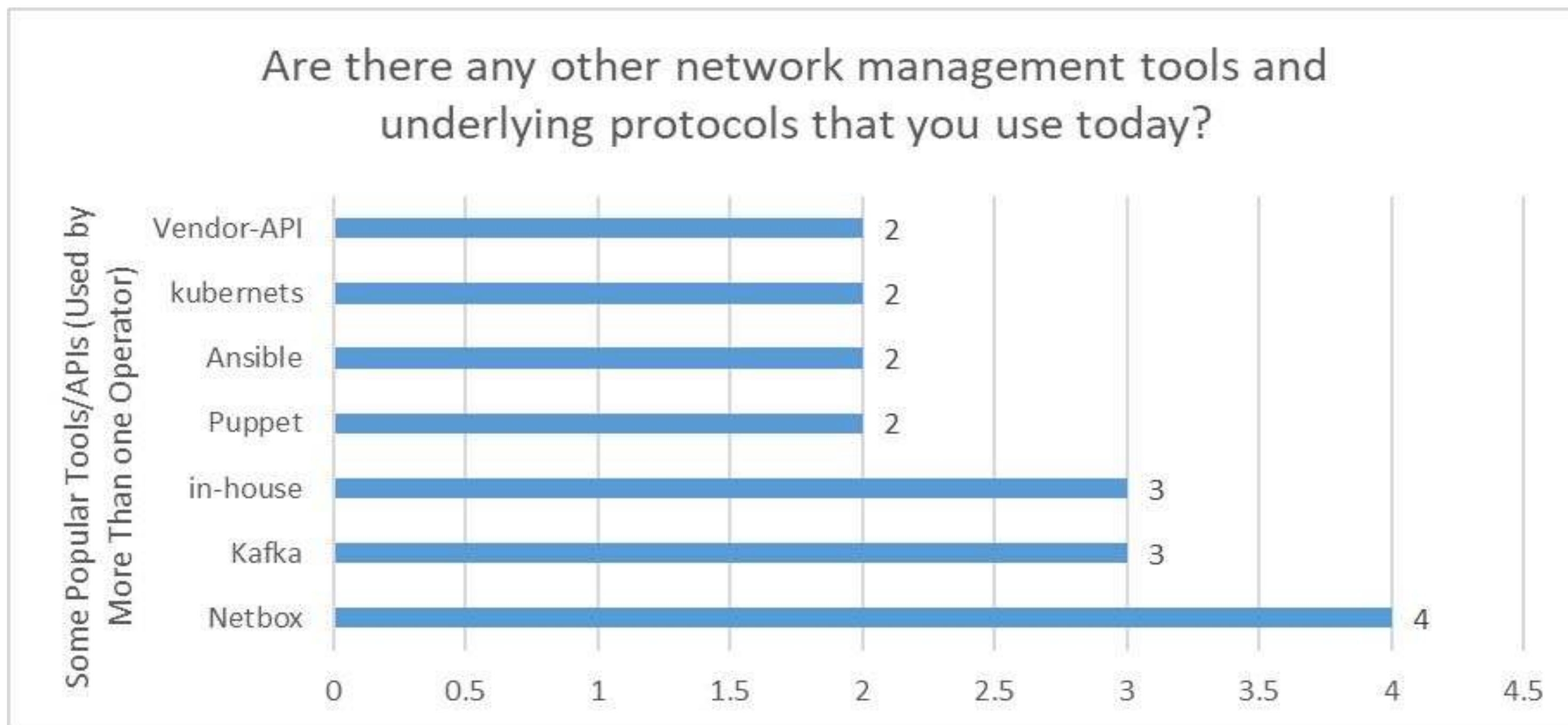
## Operator Survey





# NEMOPS Workshop

## Operator Survey

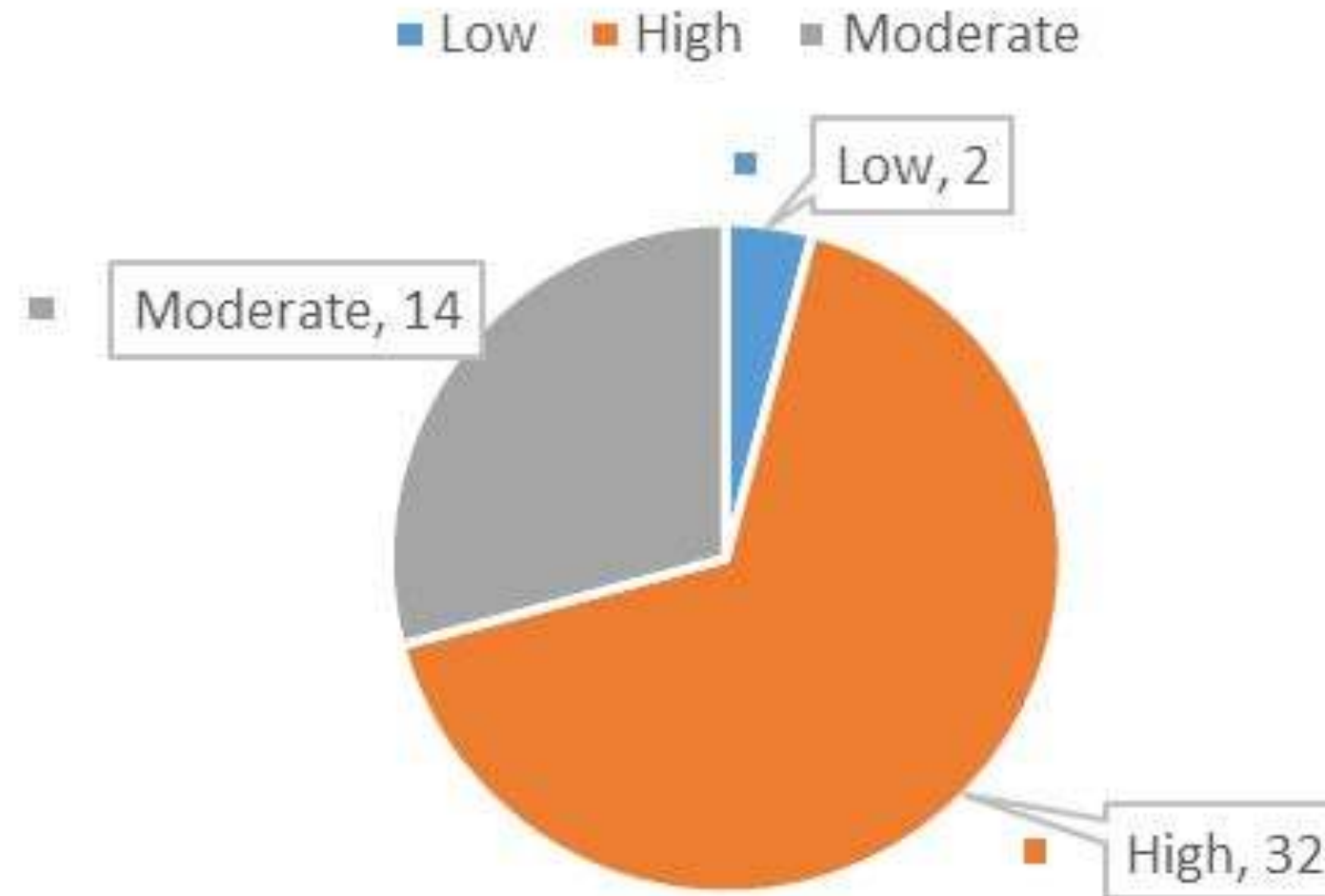


# NEMOPS Workshop

## Operator Survey



How important is network automation for your organization?



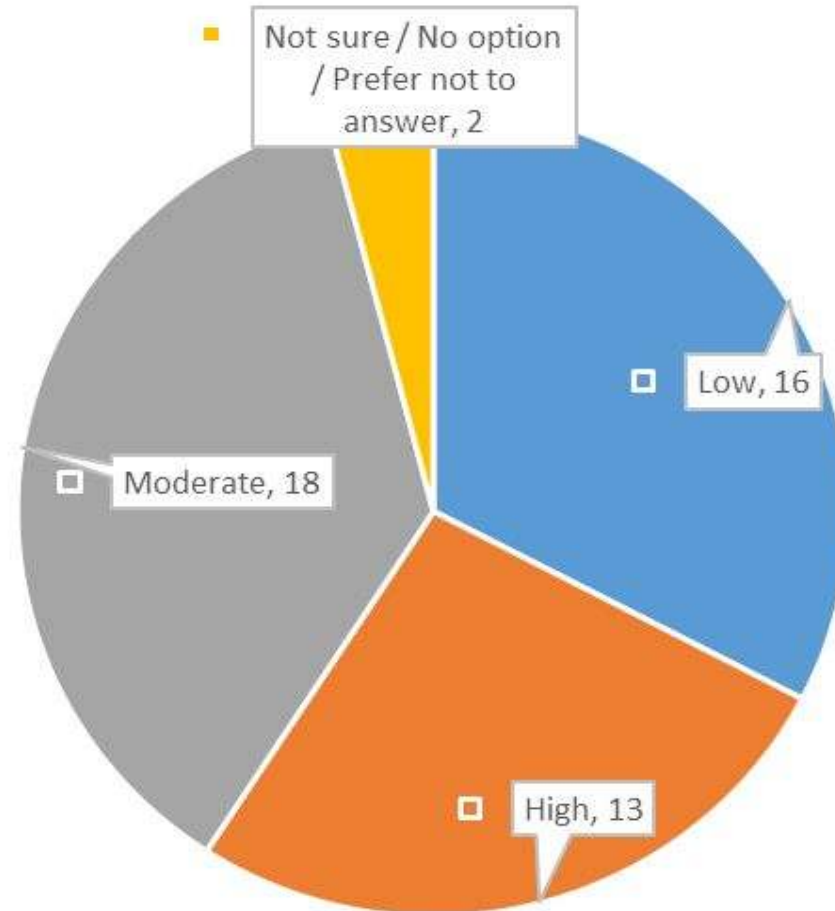
# NEMOPS Workshop

## Operator Survey



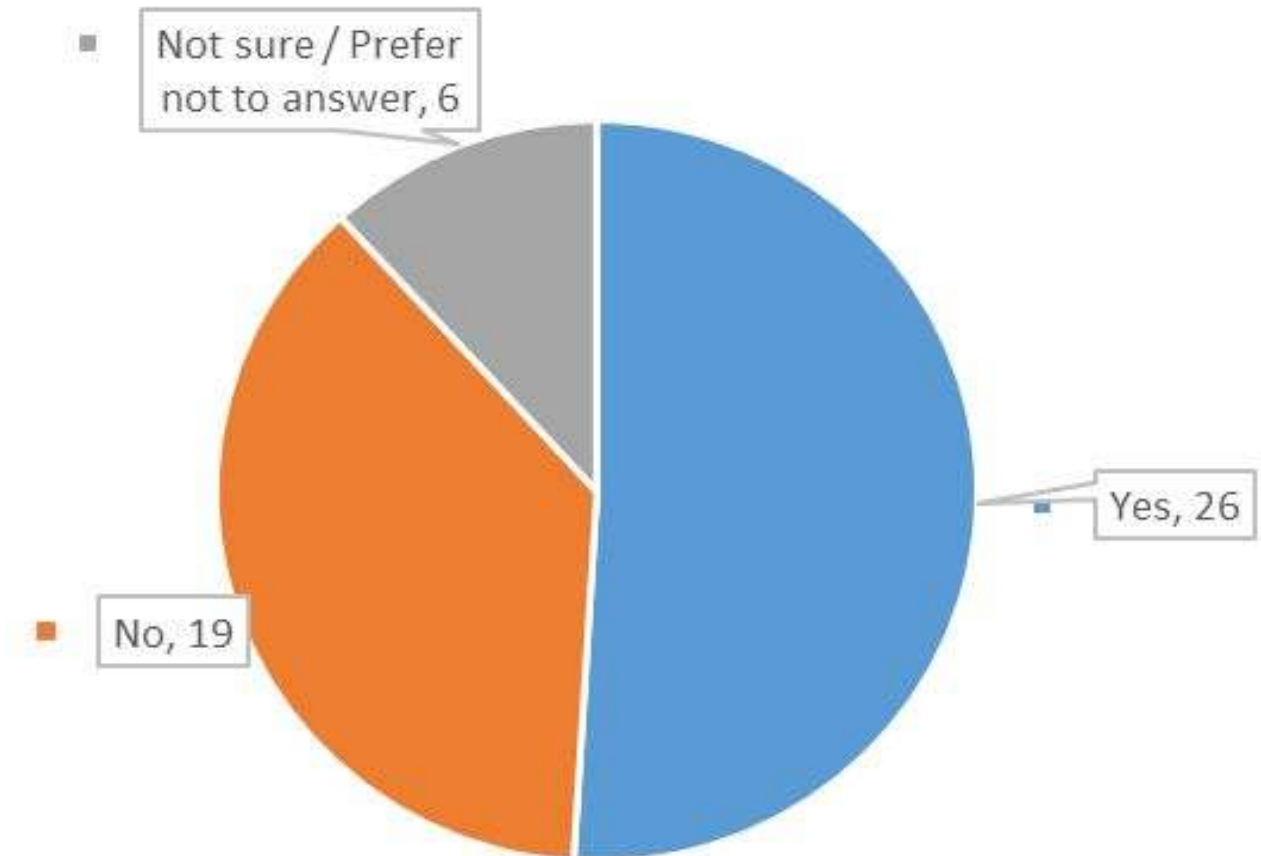
To what extent is your network automated?

■ Low ■ High ■ Moderate ■ Not sure / No option / Prefer not to answer



Do you use streaming telemetry?

■ Yes ■ No ■ Not sure / Prefer not to answer





# NEMOPS Workshop

## Agenda



- Papers: <https://datatracker.ietf.org/group/nemopsws/materials/>
  - 20 position papers from 53 authors
- 16 expressions of interest to join the workshop
- The workshop agenda was divided into:
  - Session I: Past (**lookback, analysis**)
  - Session II: Present (**identified problems & requirements**)
  - Session III: Future (**possible solutions, recommendations and next steps**)

# NEMOPS Workshop

## Agenda



- At the conclusion of the workshop, the Workshop Program Committee collected:
  - **Key takeaways,**
  - **Requirements,**
  - **Recommendations,** and
  - **Potential next steps.**

# NEMOPS Workshop

## Past (1/3)



- Jürgen Schönwälder (author of RFC 3535) went over the **experience from past** IAB workshop and laid out a direction for Network management to be - **Declarative, Composable, Reproducible, Verifiable!**
- Ian Farrer (DT) provided an operator perspective on how YANG has been successful but there are **challenges in mapping** it to higher level orchestration systems and **lack of open source** NMS and IETF device model implementations.
- Wes Hardaker (Net-SNMP) highlighted the need for **simplicity** and how we have largely failed the operator requirement #1 (Ease of use) of RFC 3535!
- Carsten Bormann gave an overview on how YANG ecosystem has been adapted for **managing IoT** Devices via CoAP, CBOR, & CORECONF.



# NEMOPS Workshop

## Past (2/3)



- Rob Shakir (google, openconfig) made a plea to **rethink** how we do standardization in network management space - the need to iterate faster, focus on systems and business outcomes, quickly integrate lessons from large-scale deployments!
- **Lack of full converge** via YANG models (and thus going back to CLI, screen-scraping)
- Incorporating **fast iteration** within the IETF process remains a challenge
- Lack of **tooling** continues to be a major barrier to effective network management and automation.
- **Performance** issues at scale limit the adoption of YANG-based solutions in large networks.
- The steep **learning curve** for network management protocols and models makes adoption difficult.

# NEMOPS Workshop

## Past (3/3)



- Operators struggle to move away from CLI, as it remains deeply ingrained in operational workflows.
- Backward compatibility and **versioning** challenges create uncertainty when updating YANG models.
- **System-level APIs** could help address specific operational issues more effectively than low-level models.
- The proliferation of protocols and languages raises concerns about complexity and adoption barriers.
- A mechanism to harmonize multiple schemas and protocols (NETCONF, BMP, IPFIX) is needed to provide a cohesive view of network data.

# NEMOPS Workshop

## Present (1/3)



- Holger Keller (DT) highlighted how configuration is working well but needs **monitoring** support to be able to **validate** them. There is a need to focus on enhancing observability!
- Jaime Jiménez talked about challenges and **complexity** in managing legacy and multi-vendor networks within SDN platform.
- Luis M. Contreras (Telefonica) went over some of the collected **new requirements**
- Thomas Graf (Swisscom) highlighted YANG-Push as an example of standards misalignment with operators, vendors, and integration needs, advocating for an **agile, iterative** approach with **minimal viable products**.



# NEMOPS Workshop

## Present (2/3)



- **Transitioning** to YANG is challenging, particularly due to difficulties in mapping standard models to vendor-specific implementations.
- **Divergence** in vendor implementations creates complexity, requiring workarounds and adding operational burden.
- Supporting both standard and **native vendor models** increases complexity and can lead to confusion in implementation.
- **Mapping** standard models to internal device models and legacy hardware is difficult, and in some cases, not feasible due to device-specific configurations.
- **Open-source reference implementations** are crucial for improving adoption and ensuring consistency.

# NEMOPS Workshop

## Present (3/3)



- **Compliance and interoperability testing** are needed to improve vendor implementation quality and ensure better documentation.
- **Multiple models** (IETF, OpenConfig, native vendor models) must coexist, as they are an unavoidable reality in network management.
- Operators' service offerings vary widely, making it difficult to achieve consensus on a single IETF service model.
- IETF should expedite standards publication while ensuring practical implementation feasibility.
- Standards should be gated by multiple interoperable implementations to ensure real-world viability before finalization.

# NEMOPS Workshop

## Future (1/3)



- Benoit Claise shared the **Knowledge graph** framework via the Resource Description Framework (RDF) used by Semantic Web and it can be used to describe the YANG models via a basic ontology for the networking domain
- Kent Watsen highlighted that the data model driven management is a success but recommended focusing on **RESTCONF**, JSON, YANG-Push-Lite, NMDA, **off-box data model and protocol adapters**.
- Rob Wilton stressed on minimizing unnecessary complexity, timely solutions, open collaboration, simplicity, and aim to converge to a single model/protocol.

# NEMOPS Workshop

## Future (2/3)



- The **absence of NMDA in OpenConfig** was discussed, questioning whether the resulting complexity is necessary. The history of introducing gNMI in the IETF was revisited, with a debate on whether RESTCONF provides any significant advantages over it.
- **Building consensus takes time**, and while efficiency is needed, it should not come at the cost of bypassing the consensus-building process.
- The practicality of converging on a **single protocol** was examined, with discussions on whether this is achievable or even necessary.
- **Off-box adapters** were emphasized as a way to allow vendors to continue innovating while maintaining compatibility with native models. A proposed standard model mapping to native models received significant attention, with the idea of maintaining it in a common repository to assess coverage and alignment across vendors.



# NEMOPS Workshop

## Future (3/3)



- **Alternative approaches to YANG model development were explored**, including using GitHub for faster iteration, living documents within WG charters, and open-source efforts through academia for developing device adapters. Process experimentation at the WG or area level was suggested, allowing iteration within YANG/OPS working groups without requiring IETF-wide changes, while ensuring operator involvement.
- Some critical topics were absent from the discussion, including tooling gaps, funding and maintenance for tool development, and other network management protocols beyond YANG and NETCONF/RESTCONF. The focus remained on improving existing solutions rather than introducing entirely new approaches.



1. The current network management protocols, models and tools still **fail the 'ease of use'** requirement. Participants noted that the tools almost matter more than the protocols.
2. The overall ecosystem is still **fragmented** for both protocols and data models. SNMP is still used extensively for monitoring, and the CLI is still heavily relied on in many networks. Popular protocols include SNMP, CLI, NETCONF, RESTCONF, gNMI, etc.
3. **Documentation** about the architecture and usage of the network management ecosystem is lacking. More work is needed to create general architecture documentation, deployment guides, tutorials, training material, and getting-started guides.
4. **Transitioning** between network management frameworks is challenging, just like it is for transitioning between other protocols like IPv4 to IPv6.
5. Model-driven network management is generally a success where it has been implemented and is possible to use.
6. More easily usable network management **tools** for the operators are needed. The lack of open-source tools is seen as a barrier to adoption. Tools need good use cases, example flows and better analysis of when and how they work and have been successful.



1. Netconf and YANG are not used much for **monitoring** tasks.
2. Netconf and YANG do not have **full coverage** on many devices.
3. **Polling**-based solutions are still frequently deployed. **Push**-based solutions are often desired but are not yet widely available.

### More Work Needed:

- NETCONF has been successful in some large-scale deployments, but many operators still rely on CLIs, scripts, and other protocols, highlighting the need for further work to improve NETCONF adoption, with some participants viewing RESTCONF as a potential solution.



1. Some YANG models can become **too complex**, though not as a fault of the language itself.
2. Multi-vendor **compatibility** support is required.
3. Even **vendor-specific features**, not just standardized protocol features, need to be exposed through network management models and protocols for a network management ecosystem to be viable.
4. Greater support for **service-level modeling** is needed. Device level modeling can be a building block to achieve a sufficient service-level model, but is not a complete solution by itself.
5. Network configuration needs to be **verifiable** to ensure any potential changes can be accepted by devices. Model translation adapters (likely performed on the management station, not the end device) may be the best path forward to simultaneously achieve this and the goal of supporting one configuration set across a diversity of devices with different internal models.





1. A methodology of **rapid model development** procedures is needed to ensure model deployment can keep pace with new feature deployment. We need a solution that significantly increases the speed and predictable timeline for developing and publishing models within the IETF. New approaches and methods to make models live outside of published RFCs should be explored. An experiment should be started to test a new rapid development approach.
2. Protocol and model complexity should be reduced to keep additions and changes to a **minimal set of agreed-upon core features**.
3. More standardization focus is needed on the **scalability** of the different roles of network management: monitoring, configuration, notifications.
4. Enhancements to network management protocols and models need to be backed by real-world operator use cases and expected adoption by vendors. Vendors and operators will need to work together to ensure these goals are appropriately met.

# NEMOPS Workshop

## Whats Next



- IAB Workshop acts as a **spark for in-depth discussions** and engagement that might otherwise be missing.
  - Designed to improve the overall understanding of technical challenges in network management.
- An initial **workshop draft report** at:  
<https://datatracker.ietf.org/doc/draft-iab-nemops-workshop-report/>
- **Workshops are Not the Final Destination**: Workshops initiate conversations rather than conclude them
  - Particularly impactful in advancing discussions within the Network Management Operations (NMOP) Working Group at the IETF
  - Encouraging participation in NMOP WG to collaboratively shape the future of network management and Internet architecture

- Feedback on the outcome of the workshop at [nemops-interest@iab.org](mailto:nemops-interest@iab.org)
- The Program Committee is working on the workshop reports:  
<https://datatracker.ietf.org/doc/draft-iab-nemops-workshop-report/>
  - Send feedback or GitHub PR:  
<https://github.com/intarchboard/draft-iab-nemops-workshop-report>
- Reminder: workshop is not the end, it is just a trigger for further discussion!
- New requirements being finalized in NMOPS WG
- IETF 122 Bangkok meeting on 15-21 March 2025
  - Participate in-person or online (remote-fee waivers available).

「thank you.」



「Backup」

# References



- CoAP: <https://datatracker.ietf.org/doc/rfc7252/>
- CBOR: <https://datatracker.ietf.org/doc/rfc8949/>
- CORECONF: <https://datatracker.ietf.org/doc/draft-ietf-core-comi/>
- gNMI: <https://openconfig.net/docs/gnmi/gnmi-specification/>
- NETCONF: <https://datatracker.ietf.org/doc/rfc6241/>
- NMDA: <https://datatracker.ietf.org/doc/rfc8342/>
- YANG: <https://datatracker.ietf.org/doc/rfc7950>
- RESTCONF: <https://datatracker.ietf.org/doc/rfc8040/>

## Overview of the 2002 IAB Network Management Workshop



### 3. Operator Requirements

During the breakout session, the operators were asked to identify needs that have not been sufficiently addressed. The results produced during the breakout session were later discussed and resulted in the following list of operator requirements.

1. Ease of use is a key requirement for any network management technology from the operators point of view.
2. It is necessary to make a clear distinction between configuration data, data that describes operational state and statistics. Some devices make it very hard to determine which parameters were administratively configured and which were obtained via other mechanisms such as routing protocols.
3. It is required to be able to fetch separately configuration data, operational state data, and statistics from devices, and to be able to compare these between devices.
4. It is necessary to enable operators to concentrate on the configuration of the network as a whole rather than individual devices.
5. Support for configuration transactions across a number of devices would significantly simplify network configuration management.

*From RFC 3535*

### 6. Recommendations

1. The workshop recommends that the IETF stop forcing working groups to provide writable MIB modules. It should be the decision of the working group whether they want to provide writable objects or not.
2. The workshop recommends that a group be formed to investigate why current MIB modules do not contain all the objects needed by operators to monitor their networks.
3. The workshop recommends that a group be formed to investigate why the current SNMP protocol does not satisfy all the monitoring requirements of operators.
4. The workshop recommends, with strong consensus from both protocol developers and operators, that the IETF focus resources on the standardization of configuration management mechanisms.
5. The workshop recommends, with strong consensus from the operators and rough consensus from the protocol developers, that the IETF/IRTF should spend resources on the development and standardization of XML-based device configuration and management technologies (such as common XML configuration schemas, exchange protocols and so on).

*From RFC 3535*



## Overview of the 2002 IAB Network Management Workshop



Three (out of fourteen) “**Operator Requirements**” from RFC 3535:

1. Ease of use is a key requirement for any network management technology from the operators point of view.
2. It is necessary to make a clear distinction between configuration data, data that describes operational state and statistics.
4. It is necessary to enable operators to concentrate on the configuration of the network as a whole rather than individual devices.



## Overview of the 2002 IAB Network Management Workshop



Two (out of eight) “**Recommendations**” from RFC 3535:

1. The workshop recommends that the IETF stop forcing working groups to provide writable MIB modules. It should be the decision of the working group whether they want to provide writable objects or not.
4. The workshop recommends, with strong consensus from both protocol developers and operators, that the IETF focus resources on the standardization of configuration management mechanisms.

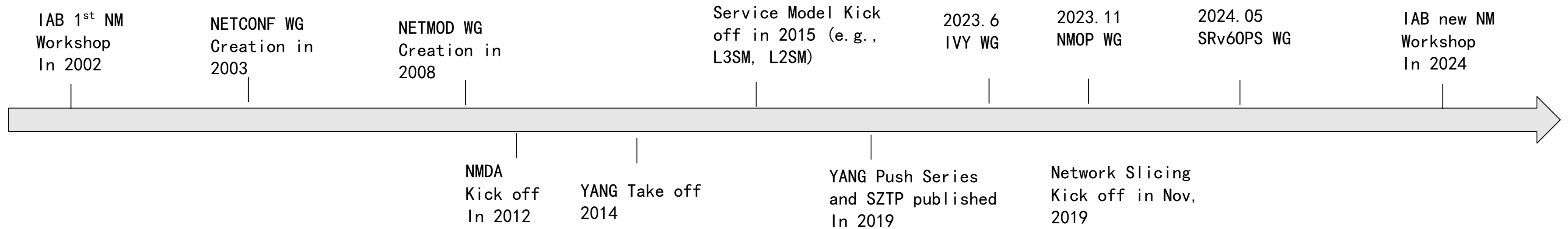
# Some Current Network Management Topics



- **NETCONF** WG
  - NETCONF-next, RESTCONF-next, list pagination, transaction correlation, transports for telemetry data, models for the configuration of clients and servers (Protocols and YANG models)
- **NETMOD** WG
  - YANG-next, YANG versioning, system datastore, data immutability flag (Language and YANG models)
- **IVY** WG
  - Models for inventory management, topology correlation (YANG models)
- **NMOP** WG
  - YANG-push integration, anomaly detection, and incident management (YANG models)
- **"Green"** WG
  - Service-level models for energy use and efficiency related metrics (YANG models)

# NEMOPS Workshop

## 22 years later



- L3SM: L3VPN Service Model
  - YANG Data model for L3VPN Service.
- L2SM: L2VPN Service Model
  - YANG Data model for L2VPN Service

- NMOP: Network Management Operations
  - Network Management problem faced by operators such as YANG Push integration with Kafka, Anomaly detection and incident management
  - updating RFC 3535-bis (collecting updated operator requirements for IETF network management solutions)

- SRv6OPS: SRv6 Operations
  - operational aspects of deploying and managing SRv6 networks.
- [IVY](#): Network Inventory YANG
  - Core model for Inventory of network equipment including correlation with existing IETF models