Human Error Zero

The path to reliable data center networks

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Networks that just work

Modern organizations rely on data centers for practically every key facet of their operations. To compete and succeed, they need data center networks that are reliable and easy to manage. In other words, they need data center networks that just work.

Nokia is addressing this need with a new mission for data center networks: Human Error Zero.

There are two main sources of human error in networks:

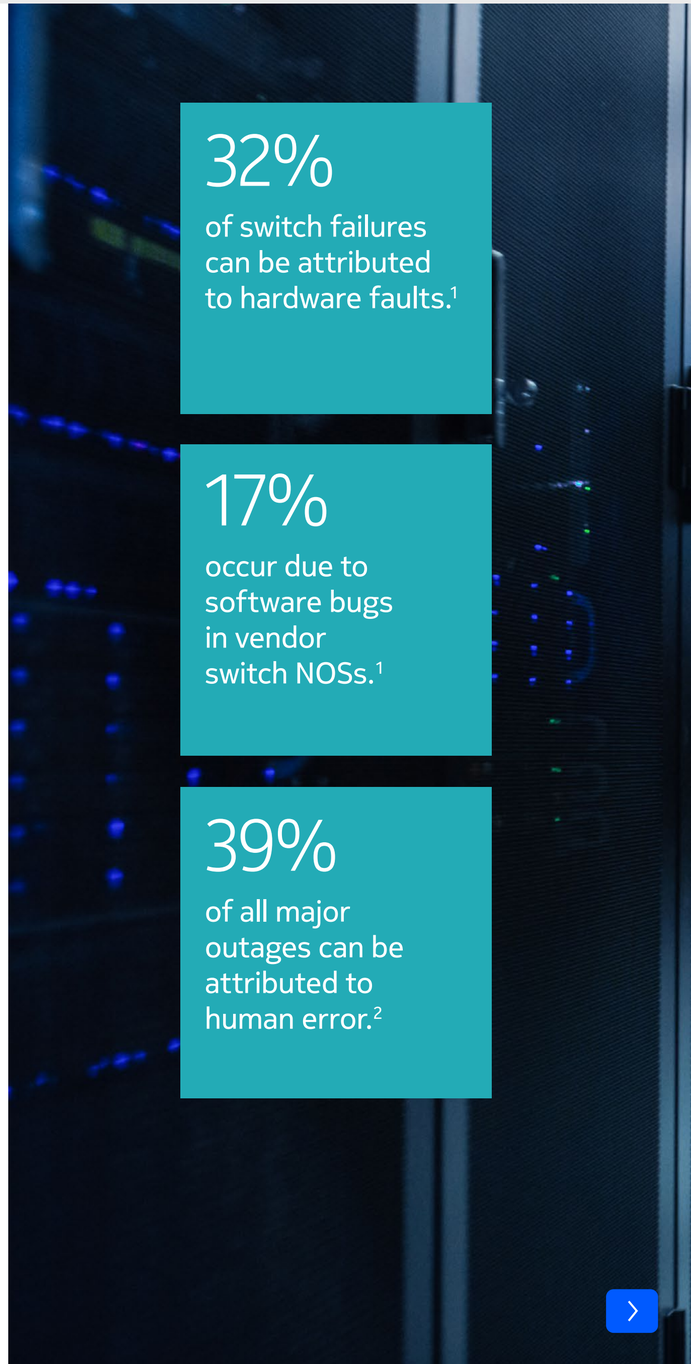
- Mistakes made by vendors, such as software bugs and hardware issues
- Mistakes made by users, such as provisioning errors and operational miscues.

Human error plays a role in two-thirds to four-fifths of all outages[2]. The rest can be traced to planned events such as maintenance windows and unplanned incidents such as power outages.

The mistakes made by network operators are further exacerbated by changes in the network and applications. In today's dynamic data center environments, these changes happen often.

Our aim is to drive human errors to zero in data center networks. We're making it happen with the market's highest-quality and most highly available data center hardware and software, along with an operations platform expressly designed to eradicate mistakes.

Imagine a world where your IT operations teams are not always reacting to issues but are instead free to innovate and spend their time on creative endeavors that help to drive your business. With our solutions, you can make this world a reality.



[1] Surviving switch failures in cloud datacenters, Rachee Singh, Muqeet Mukhtar, Ashay Krishna, Aniruddha Parkhi,,itendra Padhye, David Maltz, https://www.racheesingh.com/papers/sigcomm-ccr-final465-with-open-review.pdf

[2] Annual outage analysis 2023, The Uptime Institute, https://uptimeinstitute.com/uptime_assets/5f40588be8d57272f91e4526dc8f821521950b7bec7148f815b6612651d5a9b3-annual-outages-analysis-2023.pdf

Why everyone needs reliable data center networks

The demand for data center computing is at an all-time high, with artificial intelligence (AI) emerging as a catalyst for the disruption of data center fabric architectures across the world.

Enterprises and consumers are demanding more and more from data center applications. These applications are no longer best effort and low bandwidth. We are beginning a new era of data center networking that demands higher performance and greater scalability to meet higher service expectations.

An ultra-reliable data center network is essential for delivering on the promise of these applications. However, one size does not fit all, and modern data center networks must cater to organizations in all segments, from cloud hosting players to enterprise verticals, communications service providers (CSPs) and hyperscalers. These networks must also be able to adapt to any environment and play well with technologies from multiple vendors, including hardware, software, management and automation platforms, DIY platforms and open-source projects.

Reliability is often discussed but seldom realized in practice because it is difficult to achieve. To meet the demands of both AI and general purpose data-intensive applications with your data centers, you need to focus on delivering reliability in three key areas: **architecture**, **quality** and **operations**.

[3] "Gartner Says More Than 80% of Enterprises Will Have Used Generative AI APIs or Deployed Generative AI-Enabled Applications by 2026," Gartner, Oct. 11, 2023. https://www.gartner.com/en/newsroom/press-releases/2023-10-11-gartner-says-more-than-80-percent-of-enterprises-will-have-used-generative-ai-apis-or-deployed-generative-ai-enabled-applications-by-2026

Building reliable data center fabric architectures

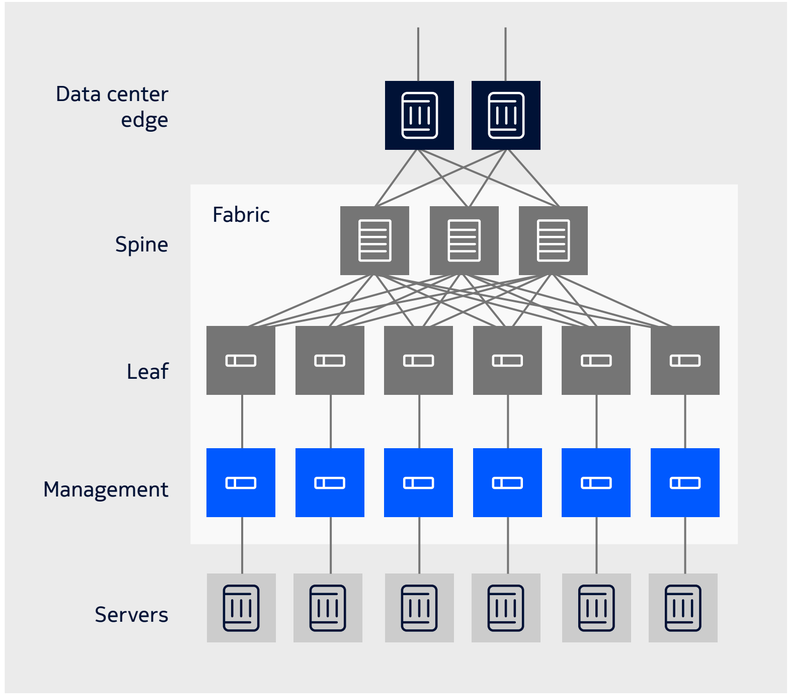
The dominant architecture in data centers today features non-blocking Clos fabrics.

A Clos architecture is implemented in a leaf-spine layout in which the spine layer represents the switches in the middle stage and the leaf layer represents the switches in the ingress and egress stages. It is highly reliable and works exceptionally well for east–west communications.

This architecture uses IP or Ethernet Virtual Private Network (EVPN) technology, depending on the requirements of the applications it will support. Both approaches offer super-reliable switching of packets across the fabric and between data centers.

The industry has settled on merchant silicon as the hardware building blocks for data center networks. Broadcom silicon is the de facto standard.

At Nokia, we started with highly scalable and reliable hardware based primarily on Broadcom merchant silicon and built a comprehensive family of data center platforms that are right-sized for any data center size, segment and application. The controlling software that manages these platforms is our SR Linux network operating system (NOS). SR Linux is based on our proven Service Router Operating System (SR OS), and replatformed on Linux.



Non-blocking fabrics

- IP and EVPN fabrics
- DC gateway or border leaf derivatives
- Collapsed core for edge DC
- Scale via super spines / pods

Merchant silicon (Broadcom)

- Tomahawk for shallow buffer IP fabrics
- Trident for shallow buffer EVPN fabrics
- Jericho for deep buffer requirements

Out of band management

- Merchant silicon
- 1G/10G port speeds

Data center fabric architecture is one of the key aspects of reliability. The industry has solved the problem of architecting data centers, and there is consensus on what a data center ought to look like. But not all implementations are the same.

SR Linux is built around a core premise: getting network information into and out of the box with super efficiency. Everything in SR Linux is model driven. We use YANG for data modeling into every application that runs on SR Linux. Each application across the entire system has its own independent YANG data model, which enables SR Linux to provide industry-leading telemetry capabilities. These capabilities include per-application subscriptions to "on change" streaming telemetry that allows for automated updates on system configuration or state changes for each application.

SR Linux provides the market's most automation-forward software. It also offers the most robust implementation of automation tools and interfaces, including gNMI, gRPC and OpenConfig.

In addition to these capabilities, SR Linux offers the industry's most proven implementations of IP and EVPN fabrics. For EVPN fabrics, we have led the standardization of its feature set by working directly with customers catering to their specific needs.

For IP fabrics, you need look no further than our SR OS routing stack, which provides the foundation for SR Linux and our data center portfolio. SR OS has been deployed in the most demanding routing environments worldwide, and we have led in this space for more than two decades.

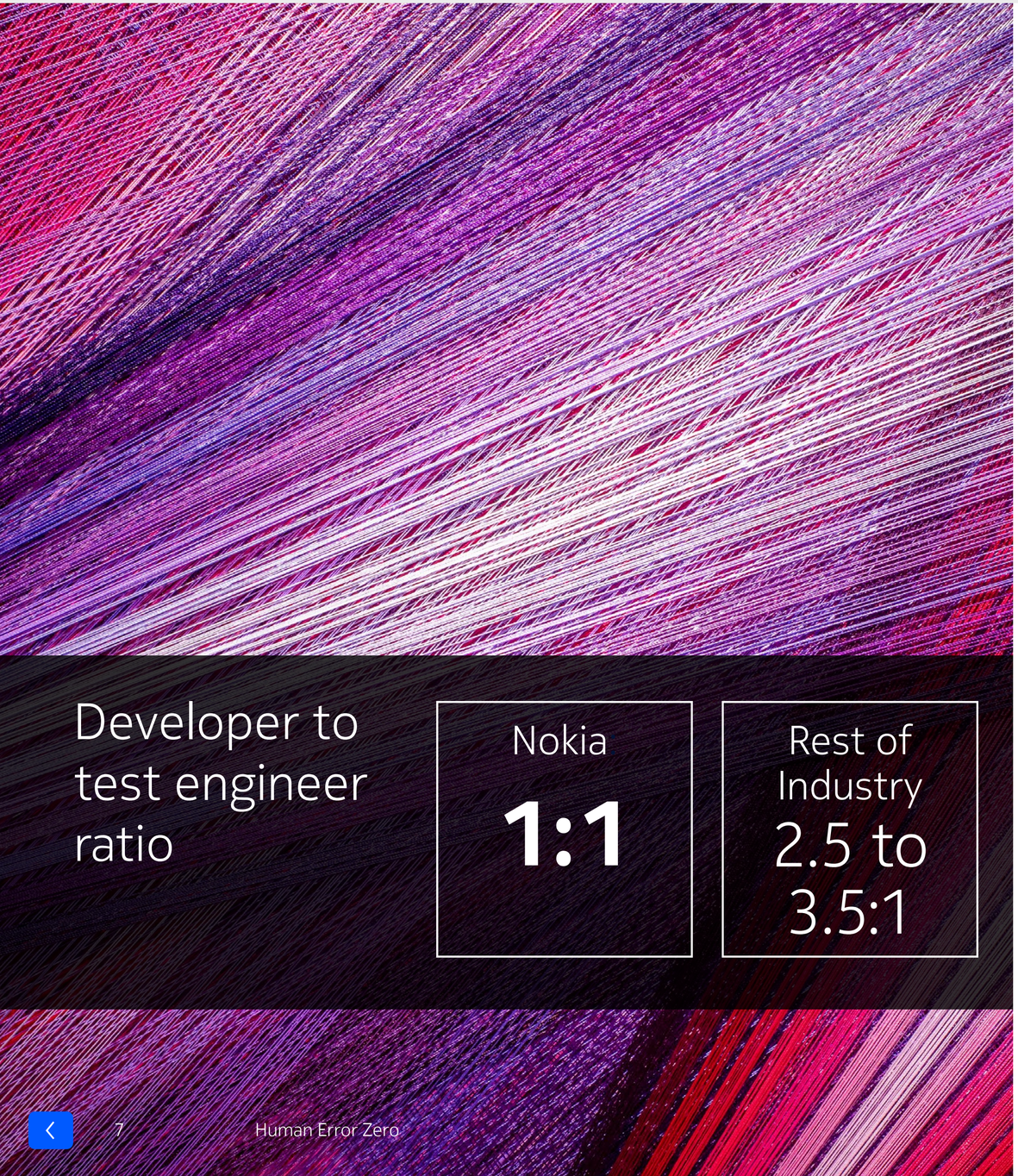
SR Linux builds on SR OS, the industry's leading routing stack for IP fabrics:

- Deployed by more than **1,700** CSP and cloud provider customers
- Deployed by more than **1,300** enterprise customers
- **1.9** million routers shipped
- **#1** in IP edge routers: global[4]

SR Linux provides the industry's leading EVPN implementation, featuring:

- **10+** years of EVPN feature development
- **30+** EVPN IETF standards co-authored by Nokia
- Market's most complete EVPN feature set

[4] Source: Dell'Oro 3Q24 Service Provider Routing Report



A quality-first approach to reliability

Network architectures are ultimately built with products, and their success in supporting demanding applications depends on the quality of the underlying components. Quality is a function of three things: **culture**, **innovation** and **perseverance**.

Our culture of quality

Nokia has a decades-long heritage of quality established in delivering solutions for mission-critical applications. When you build a business on keeping people safe, quality just means more.

There is no quality if accountability is not shared. Having a quality czar or someone who owns a quality initiative is a sign that quality is not embedded into everything you do. At Nokia, quality is a team sport, and everyone has a role to play.

Every Nokia test engineer is an automation engineer. Testing something once is useful; testing it every time is a difference maker. To maintain a high fidelity of results, the people automating must be the same as the people testing. This leaves no room for mistakes, and no gaps through which things can slip.

If quality doesn't change how you allocate resources, is it really a focus? At Nokia we ensure that we invest in quality testing and ensure that developer-to-test ratio is 1:1.

We embrace continuous learning from our customers as a key imperative. Learning from customer-found defects is a critical part of our organization. To ensure that this happens, we conduct weekly reviews of customer issues. The support team reports directly to research and development and has access to all the resources it needs to resolve issues.

> "...SR Linux in our data center network fabric allowed us to move control directly into our hands so we can operate exactly the way we want."
>
> **Scott Brookshire**, CTO, OpenColo

Our innovative approach to network operating systems

In creating the SR Linux NOS, we brought decades of experience in the routing world together with the most modern software tooling and techniques available today.

SR Linux is built on top of a Linux foundation, so everything we run on the NOS is basically an independent process with an independent data model. For example, the SR Linux routing stack is represented by separate processes. This modular structure breaks the monolithic NOS architectures of the past. It unlocks capabilities such as ensuring efficient and fast access to system data, creating and running new processes or agents natively, and being able to maintain and operate the system more simply and with modularity.

For example, we have built an askAI agent, called SR Linux GPT, using our NetOps Development Kit (NDK). The NDK allowed us to build a lightweight application outside of the operating system so that we could get the benefits of a large language model (LLM) on SR Linux without having to modify source code. This demonstrates the capabilities you can add with AI and the extensibility of SR Linux.

In addition we have added the ability to create your own CLI that suits your own personal operational environment showcasing another example of customization and flexibility built into the system.

Much of what needs to happen in today's data centers is operational. So we built SR Linux to get information into and out of the box quickly and efficiently—a central requirement for any automation ambition. Since each process is model-driven, with its own data model for all processes across the entire system, SR Linux provides the most sophisticated and ganular telemetry in the industry and is the market's most automation-forward software.

SR Linux also has the most robust implementation of northbound interfaces such as gNMI, gRPC ad OpenConfig.

All of this innovation is designed to deliver reliability. It's at the core of our quality-first approach.

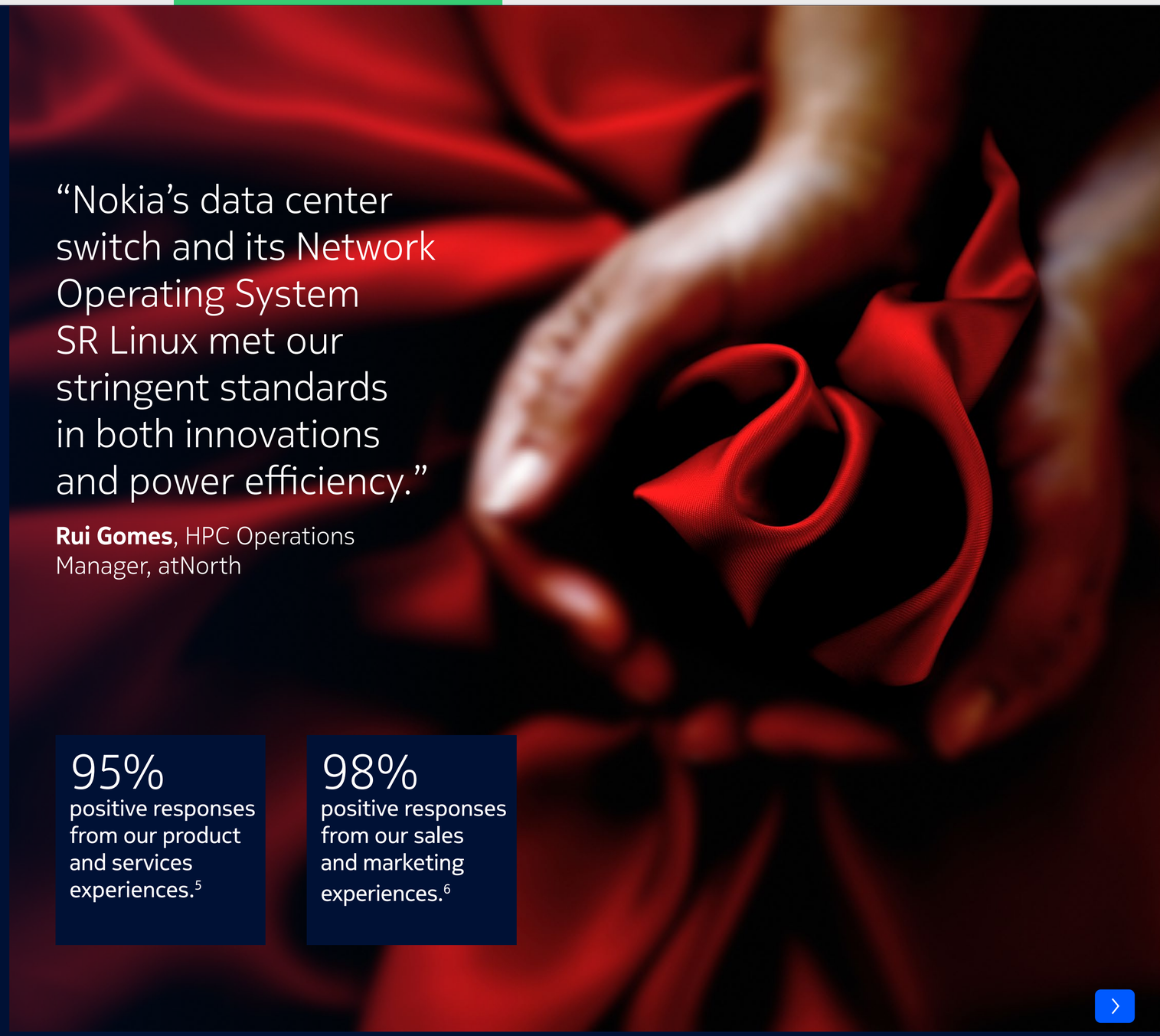
Our commitment to quality through perseverance

We are committed to maintaining a quality-first approach to data center networking regardless of what obstacles or distractions might arise. We won't trade off quality measures to meet the demands of individual customers because we know everyone else will feel the impact.

When a hot new technology comes along, we'll stay focused on quality instead of rushing it to market. This perseverance ensures that you can safely deploy our solutions and get the most from any new innovation without concerns of breaking other features.

Culture is critical because it determines how an organization acts when no one is looking. If your culture is truly based on quality, good decisions are almost assured. With a culture that prioritizes quality over chasing business, we aim to help you build more quality into every facet of data center network operations.

As a testament to our commitment to quality, we are frequently collecting customers feedback. Two key metrics are the percentage of positive responses across products and services, and sales and marketing. In this case we have achieved 95% and 98% respectively.



"Nokia's data center switch and its Network Operating System SR Linux met our stringent standards in both innovations and power efficiency."

Rui Gomes, HPC Operations Manager, atNorth

95%
positive responses from our product and services experiences.[5]

98%
positive responses from our sales and marketing experiences.[6]

[5] Source: IP Networks - survey results overview, report window, June 2nd to June 1st, 172 respondents
[6] Source: NI sales and marketing - survey results overview, report window, June 2nd to June 1st, 146 respondents

Making reliability the cornerstone of data center operations

While the industry has reached consensus on what a data center fabric should look like, there are widely varying views on how a fabric should be managed. And most of the conventional wisdom is wrong.

For many in data center operations, the primary objective is speed. When you hear people talking about agility or "moving at the speed of business," they are saying that going fast is the goal. The core belief that underpins the pursuit of speed is that building a bigger engine is the key to unlocking speed. But what if the thing preventing us from going faster wasn't the engine at all?

Today, we drive much faster than we used to. But if the key to speed is a bigger engine, why are we not all driving jet-powered cars? Speed that is lethal is not functional.

To unlock practical speed that everyone could use, we needed to make it safe. This analogy also applies to network automation: technology for faster and more scalable network automation exists, so the question is whether we have the necessary safety measures to execute at scale.

Consider the land speed tests in the 1960s and 1970s:

- Drivers with helmets and strapped into safety harnesses
- Cars that looked like jets with massive engines
- Record speeds achieved, but also danger and death.

Lessons on reliability from the aviation industry

There's no safer way to travel than by air. Measured by incidents per mile, aviation sets the global standard for safety.

Behind every flight is a rigorous process: detailed checklists, precise procedures and a cockpit packed with instrumentation. Nearly every process in an airplane is automated, and there is an enormous amount of telemetry fed in to support this automation. It's a closed-loop system that allows the aircraft to maintain a desired state of operation without constant human intervention.

This is exactly how we want data center network operations to function—with high levels of precision, reliability and predictability.

Network automation is a top priority. But too often, it feels risky. Data center networks are complex and fragile. The fear is that automation could amplify problems instead of solving them.

To eliminate this fear, we need to make automation more resilient, more transparent—and above all, more trustworthy.

What can we learn from the aviation industry's approach to automation? And what practices can we adopt to make data center network automation just as dependable?

1

We need full visibility through real-time, fine-grained telemetry and diagnostics.

2

Using this level of visibility, every network operation should begin a comprehensive set of automated checks similar to the pre-flight checks.

3

If changes are needed before automation, they must be tested through a network digital twin prior to pushing live.

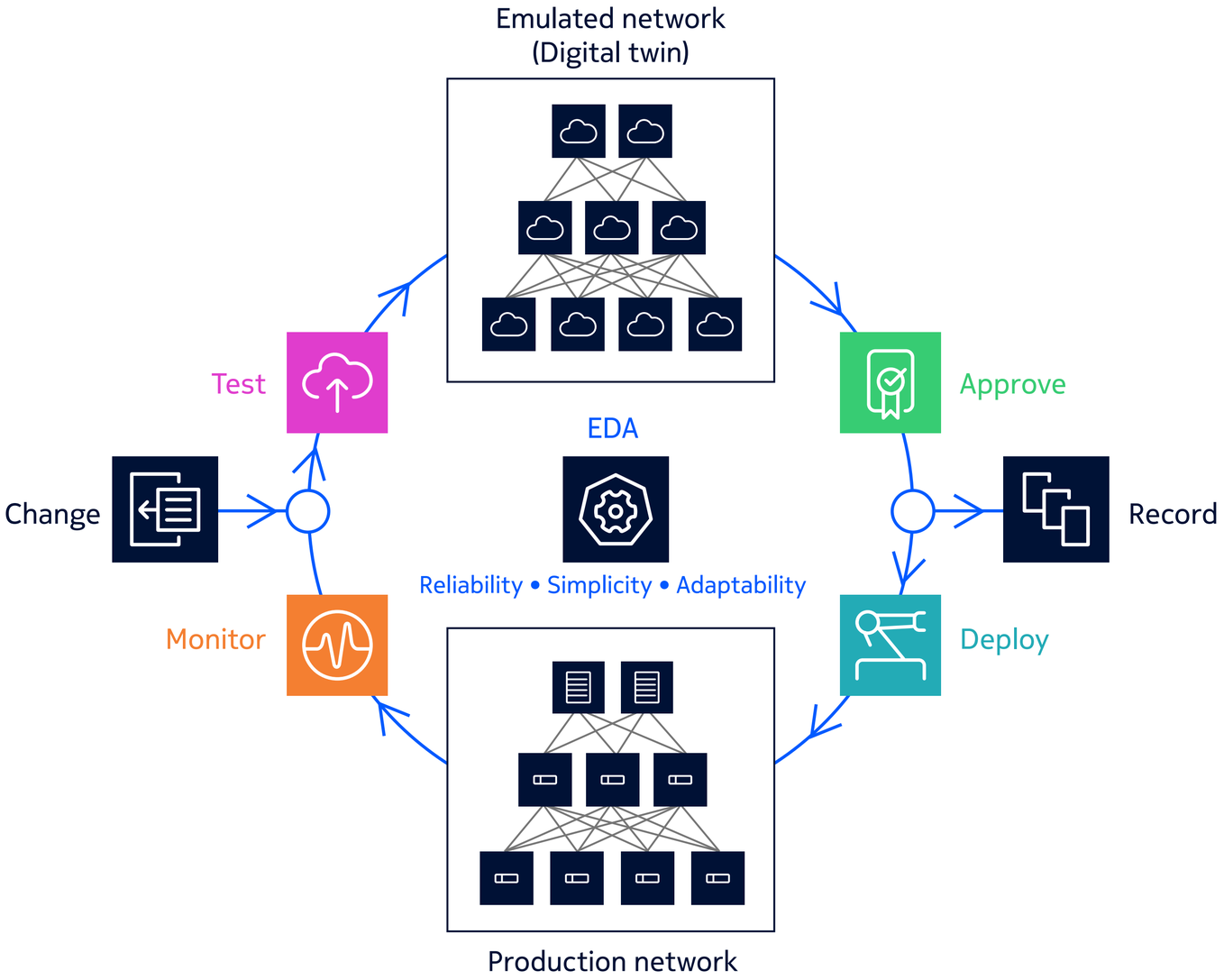
Making reliability the cornerstone

Nokia Event-Driven Automation (EDA) enables network teams to operate more like flight crews: calm, confident and in control. Like aviation systems, EDA is reliable, simple and adaptable. Offering comprehensive instrumentation and automated network checks, it delivers the safety, speed and trust you need for automated data center network operations.

EDA is a modern infrastructure automation platform that combines speed with reliability and simplicity. It makes data center network automation more trustable and easier to use, from small edge clouds to the largest AI fabrics.

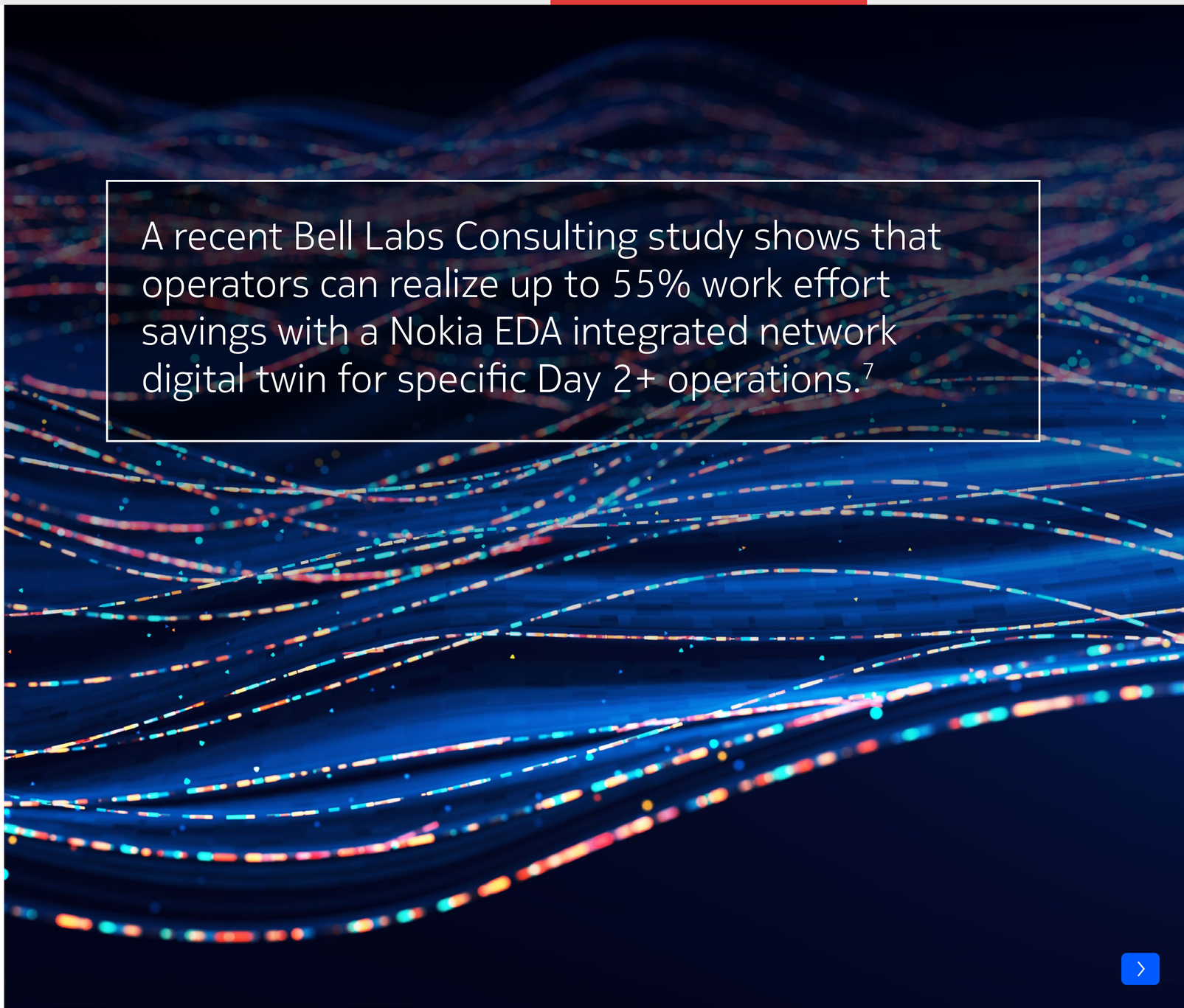
With EDA, you can automate the entire data center network lifecycle from Day 0 design, Day 1 deployment to Day 2+ daily operations. The platform abstracts the complexity of multivendor networks, which helps you provision and monitor your network in real time and make sure it always operates as expected.

EDA builds on the proven Kubernetes platform and taps into its vast open-source ecosystem. This reduces your risks and lowers barriers to entry for users.



As a key component of our Data Center Fabric solution, EDA complements and extends our SR Linux NOS, which features the industry's most complete set of programmatic and telemetry interfaces. While EDA is a vendor-agnostic platform, it provides exceptional insight into how the network is operating when it is combined with SR Linux.

With EDA, you can create a closed-loop automation environment where each network change is first tested in an emulated network environment using a network digital twin. Once the change is validated and approved, you can then schedule it for deployment into your live production environment, which further reduces risk. The network will always be monitored, and EDA will constantly receive telemetry information from the network to ensure that all systems and processes are working as expected. If EDA finds an issue or deviation, it will rerun the validation process on the network remedies or solution, will go through the process again starting with testing and validation through the network digital twin.



[7] DC Fabric TCO Calculator

Human Error Zero

Modern cloud organizations needs data centers that just work. Networking is a key part of enabling this and driving business continuity for their clients. To compete and succeed, they need to focus on reliability which is an outcome based upon three key pillars: the right data center network architectures, product quality, and the operational environment.

Human Error Zero recipe

	Ingredient	Why choose Nokia?	Proof points
Reliable architecture 	**Architecture**	We bring proven hardware design expertise to the data center switching space with superior platforms featuring exceptional resiliency and efficiency. SR Linux network operating system (NOS) uses proven IP/Ethernet protocol stacks from our SR OS to ensure interoperability and accelerate feature development.	• Our superior hardware design helped us win business with a leading hyperscaler. • Flexible NOS and hardware that integrates into new and existing networking infrastructure. • IP routing stack **deployed in more than 1.9 million routers across 3000+ mission-critical networks**. • **#1 in IP edge routing globally** and in EMEA and North America according to Dell'Oro (Q3 2024).
	Routing protocols	We deliver proven IP and EVPN fabrics while leading standards development for EVPN capabilities.	SR Linux uses the industry's leading EVPN implementation, which incorporates: • 10+ years of EVPN feature development • 30+ EVPN IETF standards (co-)authored by Nokia • The market's most complete EVPN feature set
Reliable quality 	**Culture**	Decades of delivering our routing solutions to the most demanding and largest companies in the world. Our engineers ensure quality through automation and consistent testing.	• **Industry-leading 1:1 developer-to-test ratio** (vs industry benchmark of 2.5 to 3.5:1) • IP networks **customer positivity rating 95%** • IP sales and marketing **customer positivity rating 97.9%**
	Innovation	SR Linux NOS unites our decades of routing experience with modern software tooling and techniques.	• Cloud-native design ensures superior programmability, unrivaled flexibility and resilient IP routing. • Unmodified UNIX kernel for modular applications with isolated failure domains. • Modular model-driven management design delivers complete openness. • State sharing with a pub/sub architecture provides reliable, scalable and secure communication channels. • IP stacks from SR OS support a feature-rich, secure NOS. • Microservices-based design enables hitless per-application upgrades and resilient networking.
	Perseverance	We maintain a quality-first approach even when obstacles, distractions or next-big-thing opportunities arise.	Our quality-first approach extends consistently from SR OS to SR Linux across all use cases.
Reliable operations 	**Operations**	EDA: Modern platform for reliable data center automation with pre-checks, post-checks, Git versioning, atomic updates and digital twin. EDA simplifies operations with intent-based automation, an intuitive UI, and flexible deployment options. It supports multi-vendor environments and integrates with IT and cloud management systems. EDA complements and extends our SR Linux NOS, providing exceptional network operation insights.	Bell Labs research shows operators using SR Linux and EDA can realize: • **Up to 43% effort savings** by using SR Linux alone for specific operations tasks • **Up to 60% effort savings** by using SR Linux with EDA for specific operations tasks • **Up to 40% cumulative effort savings** over four years for all operational tasks

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About Nokia

At Nokia, we create technology that helps the world act together.

As a B2B technology innovation leader, we are pioneering networks that sense, think and act by leveraging our work across mobile, fixed and cloud networks. In addition, we create value with intellectual property and long-term research, led by the award-winning Nokia Bell Labs.

Service providers, enterprises and partners worldwide trust Nokia to deliver secure, reliable and sustainable networks today – and work with us to create the digital services and applications of the future.