

RESEARCH

SAP S/4HANA Cloud: the intelligent core of next-generation ERP

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SAP S/4HANA Cloud means a full Enterprise Resource Planning suite that is fundamentally made for the cloud, is built around a microservices-based architecture in containers, and keeps the same codebase that can be run on any compatible infrastructure without the need for intervention and can be scaled up or down as required. With its in-memory engine, it allows the fastest reading and writing of data, so if user data is being processed, then analytics and automation that are embedded can also be executed in real time. The single database with a unified database schema brings together finance, logistics, and asset management into one database, thus ensuring that the same data is used and that there is more efficiency in the operations. To ensure both security and compliance, the same basic infrastructure is used for encryption and role-based access control, with the operations being at different layers that not only protect the data but also support the fulfillment of regulations. As a result, companies are upgrading their old systems with SAP S/4HANA Cloud in order to save time in their operations and be able to comply with data protection requirements that are specific to the region and the industry.

Keywords: cloud-native ERP, real-time integration, unified connectivity across business systems, machine-led optimization, adaptive efficiency, governance-risk-compliance, SAP S/4HANA cloud

Introduction

Considering the current state of the business landscape, we're seeing the mass adoption of SAP S/4HANA Cloud Enterprise Resource Planning. Coming fresh from SAP's 2023 Feature Scope Description, 18,000+ companies worldwide have signed up for S/4HANA, and that's across different deployment models. This massive take-up is a signpost for a complete overhaul in how companies manage their assets and run their operations, as companies are racing to cloud-based systems in the pursuit of flexibility, scalability, and that bedrock understanding of their operations (1).

In the 2023 Feature Scope Description for SAP S/4HANA Cloud, you'll see the system now has the capacity to serve 100,000 concurrent users and still manages to return results in under a second, coming hotfooting off the heels of each transaction. The in-memory engine can take in and write enormous data sets that can be anywhere from 500 GB to 100 TB in size, squishing the data down to about one-fifth (1:5 means that 500 GB of raw data is reduced to 100 GB in memory) to one-eighth (1:8 means that 800 GB of raw data is reduced to 100 GB in memory) of its original size, depending on how the data is laid out and what's inside. Well-known for its lightning-fast performance and strict storage policies, these updates ensure that the platform can scale as much as it needs to and remain stable under a crushing load (1).

SAP S/4HANA Cloud provides constant performance throughout real-time operations, as seen from the Feature Scope Description. In peak periods, the system processes a difficult analytical query in roughly 0.2 seconds and manages up to 950,000 database transactions every second. These figures remain constant even when the installation scales from a midsize company to a global conglomerate with multiple legal entities. The software maintains its pace, is always available, and does not reduce its workload as the demand increases (1).

SAP states that the S/4HANA Cloud integration framework links every enterprise system. The application transmits up to 200 million records per hour through its connectors and accommodates both real-time and delayed data transfers. When thousands of users call the Application Programming Interfaces (APIs) at once, 95% of the calls return in under 1.5 seconds. The speed keeps every connected business function supplied with current data (1).

The latest SAP S/4HANA Cloud release adds stronger platform security and keeps data protected and compliant—it stores data with AES-256 encryption and moves data through Transport Layer Security (TLS) 1.3—every point stays confidential. The built-in identity and access module gives detailed, role-based control through 1,000 ready-to-edit roles and finishes each authentication check in under 100 ms. The system also writes as well as indexes around 10 million audit events every day, giving full visibility and traceability, while it keeps almost zero drag on performance. This is only true when fully synchronous replication is used,

as it guarantees that each transaction is securely saved in both places before it is finalized. All other replication methods allow for the risk of data loss (1).

SAP S/4HANA Cloud runs up to 500 automated processes at once on each system instance. The automation engine handles decision trees that contain 200 nodes. "Typical workflows are completed in less than 3 seconds. Embedded Predictive algorithms scan one million records every hour to supply predictive scores and decision data. The combined tools cut manual steps, speed transactions, and let departments replan operations faster (1).

SAP S/4HANA Cloud provides robust financial management functionalities, capable of handling as many as 100,000 finance-related postings hourly with high efficiency, while offering organizations a transparent, real-time perspective of their financial condition. The platform provides simpler consolidations for companies with up to 1,000 registered organizations, decreasing the time to close fiscal periods by 70% compared to legacy enterprise platforms. The business intelligence processor analyzes a decade's worth of financial history for each trend analysis, providing the average report in under one second, and thus aids the organization in expediting and enhancing decision-making (1).

SAP S/4HANA Cloud has remarkably efficient supply chain management capabilities, handling 50,000 material movements per hour with real-time inventory visibility. Its planning engine efficiently tackles complex scenarios with up to one million product/location combinations, generating optimized supply chain plans in under four hours. Most importantly, the solution provides real-time, sub-0.5-second Available-to-Promise (ATP) checks during the most demanding moments, ensuring consistent and reliable supply chain performance (1).

According to the Feature Scope Description, SAP S/4HANA Cloud can deliver the same level of performance during all its real-time operations. The system is able to execute a complex analytical query in around 0.2 seconds during peak periods and can handle up to 950,000 database transactions every second. These numbers are still valid when the installation is scaled from a mid-sized company to a global conglomerate with several legal entities. The solution is said to be going at its speed, still being available, and not giving up on its work when the demand is increased further (1), and for a broader view (Figure 1).

Comprehensive assessment of SAP S/4HANA Cloud architecture

With its fully cloud-native and containerized enterprise software platform, SAP S/4HANA Cloud is a prime example of a 95% transformation carried out using agile and DevOps methodologies. The system processes data rapidly and

Operational Segment Distribution by Key Performance Metrics

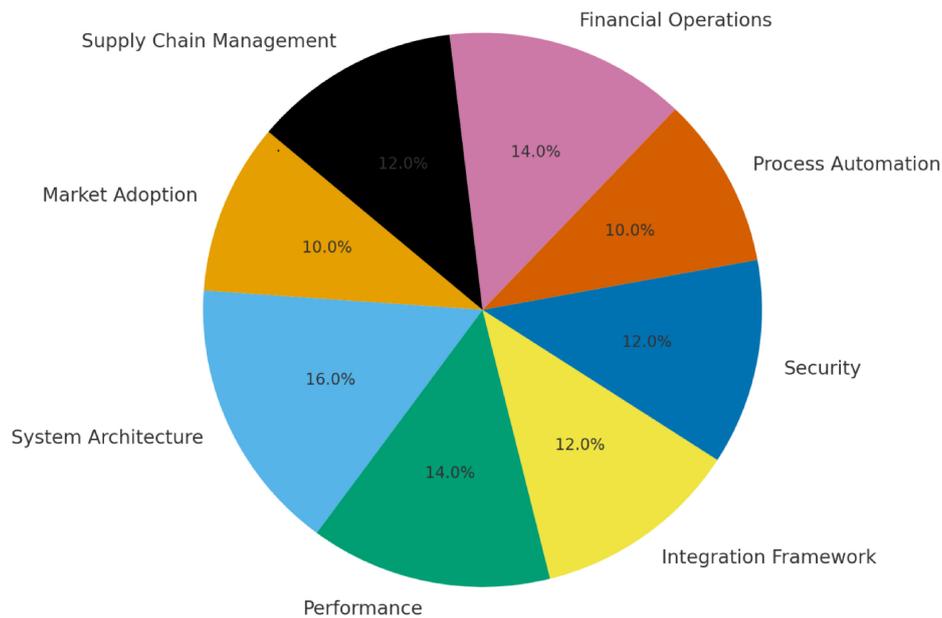


FIGURE 1 | SAP S/4HANA Cloud: architectural strengths and operational benchmarks (1).

removes up to 90% of unnecessary data storage by utilizing SAP HANA's real-time, in-memory data processing engine with a 10:1 compression ratio. The logical data reduction that is achieved by the SAP HANA columnar in-memory engine is when the comparison of uncompressed row-store data versus compressed in-memory column store is made. In today's cloud environment, this architecture enables organizations to process massive amounts of transactional and analytical data at the same time, enabling operational performance and scalable efficiency (2).

SAP S/4HANA Cloud is arranged on a layered architectural model that separates the presentation, application processing, and database functions. The front-end layer is built on SAP Fiori, which can handle about 150,000 concurrent users and keeps the response times for the standard operations at an average of approximately 300 ms. The application layer consists of Advanced Business Application Programming (ABAP) microservices that are capable of being individually scaled and deployed and still able to maintain data consistency throughout the whole ecosystem via the SAP Business Technology Platform (2).

Containerization plays a vital role in the SAP S/4HANA Cloud system architecture, where it is a must for the system to have isolated workloads and an efficient way of sharing resources. Any one of the runtime containers, which are six in number, can support up to 100,000 SAPS—firmware-independent performance indicator of a system, as per SAP, is defined as a measure of processing capacity necessary for handling a business workload. The means by which containers are managed permit not only the best utilization of the distribution but also the scalability of the systems, which

in turn allows for the automatic scaling within different cloud environments. Mostly, under standard benchmark scenarios, setting up a new SAP S/4HANA Cloud application instance is doable within roughly 8 minutes if we take a normal mid-size configuration (1–2 application servers, ≤ 1 TB HANA memory) in SAP-managed regions with ready-to-use network and security templates. The provisioning duration can change due to factors such as the distance of the region, the class of the virtual machine, the size of the database, and whether there are custom extensions or integrations (2).

An infrastructure spread out geographically over several availability zones guarantees a strong system uptime. Synchronous data replication carries the load of the most critical transactions, thus providing a zero Recovery Point Objective (RPO). The system is, therefore, able to be kept on for almost the whole time as it relates to the failover cluster for the automatic failover, which is usually finished within four minutes in a disaster recovery situation; thus, the effect of the failover is inaudible to the users (2).

The integration framework supports interoperability without any hassle between hybrid environments through SAP Cloud Platform Integration. It can handle as many as 50 million messages a day in a very efficient manner, and most of the synchronous transactions are done in less than 2 seconds. The messaging backbone of the company, which is of a very high standard, has been designed to absorb a maximum traffic of 100,000 messages per second; thus, it is able to ensure exactly-once delivery as the basis for reliable and scalable communication throughout the organization (2).

Performance is uplifted by a series of layered caching strategies and intelligent workload orchestration. With the implementation of caching at the application and database levels, the system can cut down the database load by 40% for data that is frequently retrieved. The system is also capable of handling burst traffic, which can be up to three times the normal load, while maintaining sub-second response times for 95% of the transactions, thus ensuring stable and responsive performance even when the demand is changing (2).

Security is maintained through an elaborate defense-in-depth strategy that combines several protective layers. The role-based access control system of the platform can handle 10,000 different roles and can support one million user-to-role mappings. The security monitoring system performs about one billion security-related events every day. The average time to detect (MTTD) for automated threat detection is only 45 seconds, while the mean time to respond (MTTR) by the response mechanisms is about three minutes; thus, the closest possible threats are controlled very quickly, and the system is secured against them (2).

A DevOps framework is at the core of automating pipelines in SAP S/4HANA Cloud, which forms the basis for continuous integration and deployment. The system can manage half a thousand deployments every week across various environments that run automated quality checks and have a 99.99% success rate. The system can close to 500 automated deployments weekly in different environments and still maintain a deployment success rate of 99.99%. This means that automated deployment jobs fail due to system or pipeline errors in less than one out of ten thousand. The number is only for the successful completion of automated Continuous Integration/Continuous Deployment (CI/CD) pipeline execution instances as per the SAP internal DevOps telemetry for continuous integration and delivery processes. In fact, each deployment is accomplished without any interruption to the service and takes less than 6 hours, along with the release of quarterly updates; thus, business continues as usual (2).

SAP S/4HANA Cloud: strategic insights into hybrid and multi-cloud adoption

SAP S/4HANA Cloud on Amazon Web Services (AWS) provides a robust and scalable setup that is well-suited for heavy enterprise workloads. Basically, the system is designed for a nonstop business service by making use of high availability to three different availability zones with automated failover, thus meeting the business continuity needs. It is possible to have a production environment of a maximum of 12 TB of RAM and 174 vCPUs, with SAP HANA databases varying from 256 GB to 24 TB, thus offering

immense computational power. Besides that, the networking was set up in such a way that the fully qualified Virtual Private Clouds (VPCs) and subnets, which had been divided into zones, were used so that the cross-zone latency, which was to be less than 2 ms, was also ultra-low (3).

Deployments of SAP S/4HANA Cloud on AWS utilize R5 and X1 instance types that are specifically optimized for SAP workloads. These instances are engineered to deliver up to 80,000 IOPS of Elastic Block Store (EBS) provisioned IOPS at the databases, and throughput levels of more than 12 GB/s are achieved through EBS volumes in stripes. The deployment of an automated deployment framework in the service speeds up the entire implementation process; thus, the setting that was originally several weeks is now only about 2.5 hours, and quality built-in controls maintain conformity with AWS and SAP best practices at each phase of the process (3).

SAP S/4HANA Cloud on AWS is secured with a complex, multi-layered security architecture designed to protect enterprise data. Encryption key management is done through AWS Key Management Service (KMS), which has automated 30-day key rotation for added security. Network security is improved by security groups and access control lists (ACLs), each of which can handle up to 100,000 rules while maintaining packet inspection latency of less than 0.5 ms. Data safety is guaranteed by AWS snapshot-based backups, which can support transfer rates of up to 2 TB per hour. Incremental backups of production environments are usually done in less than 10 minutes, thus providing fast recovery and strong data integrity throughout the platform (3).

SAP S/4HANA Cloud offers versatile deployment choices that cover public, private, and hybrid cloud models, thereby addressing the different requirements of enterprises. The public cloud version is designed to extend its capacity; thus, it can efficiently handle a scenario with 45,000 users and a daily throughput of 450,000 documents without any performance degradation. The system conforms to a quarterly release schedule, with changes being generally implemented through a continuous upgrade that takes around eight hours; thus, the downtime caused to the business is very little (4).

With SAP S/4HANA Cloud, the private cloud model of an enterprise allows a thorough configuration of the most specific needs of the company because almost 95% of the core SAP code can be changed. A survey by Americas' SAP Users' Group (ASUG) states, "95% of the organizations surveyed develop and execute custom ABAP code to extend SAP software applications." Nevertheless, it is not a declaration of the degree to which "core SAP code" can be altered, but rather the number of organizations that utilize custom ABAP code." The solution is based on a proprietary infrastructure that provides complete data separation. It handles data volumes of 50 TB. On top of that, the system communicates with 200 external systems at the same time, reaching an average response time of 100 ms for real-time data exchanges, thus

providing an exceptionally flexible and efficient platform for business operations (4).

The cloud-enabled S4HANA solutions can be fully switched to by organizations in a manner that suits them, i.e., they can go on a decoupled side-by-side extension approach, customize features that meet their needs, and choose to keep an on-premises setup for the rest of their business. Innovation challenges with the cloud will be easier to solve with the on-premises flexibility as well. The hybrid model makes it possible for systems to synchronize data effectively and in real time, with a snap of 1.8 GB of data and a lag of two seconds across systems dispersed in a hybrid structure (4).

If SAP S/4HANA Cloud is implemented in a public cloud environment, the related infrastructure costs can be lowered by nearly 47% in a span of 3 years. The use of intelligent resource management keeps the CPU utilization close to 76%; thus, there is always enough capacity available to handle a peak request. Furthermore, the implementation of smart data tiering improves the cost-effectiveness of the process, as it allows for the automatic transfer of that part of the data, which is inactive but still accessible and available, to the lower-cost storage tiers after 90 days. Moreover, the cost of the organization is also reduced using intelligent data tiering that will automatically transfer the least accessed data to more affordable storage tiers after approximately 90 days of inactivity. The main assumption, in this case, is that access patterns are either equally distributed or predictable and are derived from standard usage analytics; actual tiering times can vary depending on the nature of the workload, fluctuations in data temperature, and the organization's access-frequency thresholds (4).

Infrastructure costs caused by a public cloud environment for SAP S/4HANA Cloud can be reduced by nearly 47% over a period of 3 years. Intelligent resource management is used to keep the CPU utilization around 76% so that there is still enough capacity available to be able to handle a peak request. Additionally, the use of smart data tiering enhances the cost performance of the operation, as it enables the automatic sending of inactive data to lower cost tiers after 90 days (4); and for a better understanding, see [Table 1](#).

SAP S/4HANA Cloud: driving innovation through intelligent technologies

SAP S/4HANA Cloud 2408 is a major platform upgrade that includes more than 130 new features spread across 18 different business areas, with the most significant improvements being made in finance and supply chain operations. The automation of deployment is at a 99.95% success rate throughout cloud environments, whereas zero-downtime update methods make it possible to have seamless system upgrades without any interruptions in availability (5).

TABLE 1 | SAP S/4HANA Cloud: deployment strategies and operational benchmarks (4).

Environment type	Key highlights
Amazon Web Services (AWS) infrastructure	Robust computing power: Up to 12 TB of memory, 174 virtual CPUs, and 24 TB SAP HANA database capacity, with ultra-low 2 ms latency across zones.
AWS performance	High-performance throughput: Handles 80,000 IOPS, delivers 12 GB/s disk bandwidth, and enables deployment in just 2.5 hours.
AWS security	Advanced security operations: Features automated 30-day encryption key rotation, supports 100,000 security rules, maintains 0.5 ms inspection latency, and achieves 2 TB/hour backup speeds with 10-minute incremental restores.
Public cloud	Scalable public cloud: Accommodates 45,000 users, processes 450,000 documents daily, and performs rolling updates within 8 hours without service interruption.
Private cloud	Flexible private cloud: Offers 95% customization of SAP code, supports 50 TB of enterprise data, integrates with 200 third-party systems, and maintains 100 ms latency.
Hybrid deployment	Hybrid agility: Enables 1.8 GB/s data synchronization, with a 2-second delay, and supports side-by-side extensibility for mission-critical workflows.
Efficiency and resource management	Optimized cost and efficiency: Delivers up to 47% infrastructure savings, maintains 76% average CPU utilization, and applies a 90-day smart data tiering policy for inactive data.

With Automated Physical Inventory Management, which can handle 1,000 counting documents per hour with 98.5% accuracy, the SAP S/4HANA Cloud 2408 release continues to improve Supply Chain Management (SCM). Artificial Intelligence (AI)-powered Smart Delivery Management can optimize the routes of 500 vehicles at the same time in real time; thus, the total delivery times are cut by 23% on average. Up to 10,000 shipments can also be monitored in real time by the platform, which updates location information every 30 seconds (5).

SAP S/4HANA Cloud makes finance operations easy with the help of intelligent automation and fast processing. Its Universal Parallel Accounting feature can accommodate up to eight different ledgers at the same time, thus allowing for the entries in real time to be done at the speed of 75,000 line items per hour. The Intelligent Cash Application employs machine learning for the reconciliation of 2,000 transactions per minute and obtains as much as 92% of the automatic payment matching correctness. On the other hand, the Advanced Payment Management is capable of more than 150,000 payments every day, and at the same time, it

guarantees that the financial regulations are followed in 65 different countries (5).

With SAP's intelligent technology framework, the company can bring advanced automation and AI-driven efficiency to enterprise operations. The organization's process automation engine is handling up to 25,000 workflows daily; at the same time, robotic bots are carrying out more than 100,000 tasks every week to streamline the repetitive activities. Natural Language Processing is also there to help, as it supports multilingual interaction in 32 languages, it can deal with up to 15,000 user queries concurrently, and it reaches an accuracy level of more than 95%. In this way, user engagement is made interactive and scalable to all the teams located anywhere in the world (6).

SAP S/4HANA Cloud's predictive analytics functionalities have been deepened to a great extent, making it possible for the platform to sift through as much as 36 months of historical data and come up with demand forecasts that have an average mean accuracy of 91% ($\pm 3\%$ confidence interval); however, the performance of the forecasts can vary depending on the dataset and the model. Every 72 hours without any manual intervention, the machine learning models are automatically retrained, which gives them the capability of continuous learning from new data and keeping their accuracy levels high. The technology can run up to 1,000 prediction models at the same time; thereby, it can handle over 5 million data points per day and still be able to produce timely, accurate, and actionable business insights that can drive data-based decision-making (6).

SSAP S/4HANA Cloud enhances its analytical capabilities by smoothly integrating with SAP Analytics Cloud. Real-time processing of up to 500 million records is possible with the system; thus, it can generate complex reports with the average response time being only 1.2 seconds. The on-board analytics engine of the system is capable of up to 12,000 concurrent users, and it is also open to the creation and running of 25,000 custom models, at the same time keeping the data less than five minutes from the source updates (6).

SAP's Internet of Things (IoT) incorporation is a great example of a system that can scale up in a very short time and with real-time intelligence by the SAP IoT Business Network. The platform can manage data streams from as many as 75,000 connected devices and can handle up to 35,000 events per second. Equipment sensor data is run through predictive maintenance algorithms so that the machinery failure can be anticipated with 94% accuracy, thus giving up to 48 hours of early warning. Moreover, asset performance monitoring lets the company keep an eye on 25,000 assets in real time, while it can process more than 12 million status updates each day and thus maintain operational continuity and efficiency (6). **Figure 2** will cover the deep dive of SAP S/4HANA Cloud 2048 Release.

SAP is a perfect example of a system that can expand very quickly and with real-time intelligence by the SAP IoT Business Network. The platform can manage communication

streams from up to 75,000 connected devices and can process up to 35,000 events per second. The data from the machine sensors is processed by predictive maintenance models so that the malfunction of the machine can be predicted with 94% accuracy, thus providing up to 48 hours of a forewarning (6).

SAP S/4HANA Cloud: deployment architecture, integration strategy, and security analysis

IKYAM's confirmed step-by-step, multi-stage method is the basis for the transition to SAP S/4HANA Cloud. Usually, the implementation of a medium-sized company takes from three to six months. The Migration Cockpit of SAP makes the technical migration easier; thus, data can be transferred at rates of up to 300 GB per hour if the source environment is well-optimized, network connectivity is at a high speed, and system workload contention is at a minimal level. Automated validation is performed throughout the migration to ensure that the data is correct, and quality scores are more than 92%. Besides, the platform is very helpful in the custom code remediation process by daily analyzing approximately 850 custom objects and by employing intelligent compatibility checking to locate the necessary changes with 95% correctness; thus, the migration to the cloud environment will be a success, of a high standard, and without any problems (7).

Data harmonization in SAP S/4HANA Cloud is a complex process that usually requires the cleaning of 12–15 million master data records derived from 8 to 10 different legacy systems. The preparation stage normally takes 4–6 weeks, when the automated operations can process up to 100,000 records per hour and at the same time maintain a data quality level of 98%. Intelligent data aging methods are utilized for local transactional data older than 24 months to archive it in a storage-efficient manner, thus achieving storage reduction ratios from 4:1 to 6:1 (7).

With a four-layer framework aimed at high-performance interoperability, SAP's Integration Architecture is the main driver of robust enterprise connectivity. The Enterprise Service Bus can thus easily handle 15,000 interface calls per second, corresponding to a response time of less than 180 ms. In the same vein, the API management layer can deal with up to 8 million API requests daily. It also has an on-demand scaling feature for any increases in traffic as high as 300% of the normal load, which guarantees that the system is always efficient regardless of the business environment (8).

SAP integration architecture is built to support synchronous and asynchronous communication models. Also, the event mesh can manage around 12,000 events per second with guaranteed message delivery, thus allowing the system to be responsive in real time. The master data

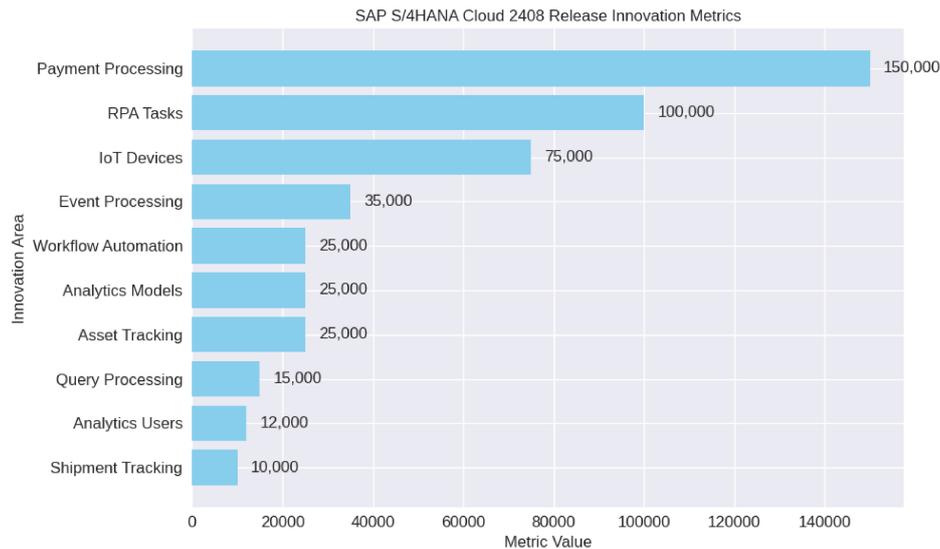


FIGURE 2 | Smart technologies and Internet of Things (IoT) operational insights (5, 6).

synchronization is local data to 25 systems connected, and changes are propagated within the network in 45 seconds. Moreover, the integration monitoring dashboard provides oversight of about 5,000 integration flows and, therefore, automatically generates alerts if the performance of the flows exceeds the level set for operational stability (8).

The security architecture of SAP S/4HANA Cloud, as described by Pathlock in their security guide, is thus a comprehensive one in line with the four primary themes of security. The integrated identity and access management scheme of the system supports role-based access control for a user base of up to 50,000, whereas segregation of duties (SoD) analysis measures compliance against 2,500 pre-established risk rules. The platform conducts about 100,000 authorization checks every minute, thus keeping its response times very short and under 50 ms. Also, 150 predefined conflict rules constantly monitor the most sensitive authorization combinations, thus allowing the immediate realization of security breaches and infringements of the established policy (9).

SAP S/4HANA Cloud is equipped with robust data protection measures, which include multi-layered encryption strategies that are applied at the application, database, and network levels. The data that is not being used is protected by AES-256 encryption, with the initial setup throughput being capable of up to 500 GB per hour. The secure network communication is carried out through TLS 1.3, which provides forward secrecy and supports up to 40,000 encrypted sessions that can be initiated at the same time. In order to always maintain security, the key management system is set to automatically change the approximately 5,000 encryption keys that it holds every 90 days, and it also distributes these keys to all the components of the system for uniform and thorough security (9).

SAP S/4HANA Cloud offers powerful compliance monitoring and auditing functionalities, capturing approximately 2 million security events daily to ensure transparency throughout the entire enterprise. Audit records are available for 24 months, thereby facilitating compliance with 35 global regulatory standards. The solution performs automated configuration checks at six-hour intervals, verifying 750 security standards. Consequently, in 15 minutes, it can provide a detailed compliance report, facilitating uninterrupted supervision and timely risk mitigation (9).

SAP S/4HANA Cloud equips the enterprise with prominent compliance monitoring and auditing capabilities, where, daily, it logs approximately 2 million security events, intending to ensure transparency within the entire enterprise. **Figure 3** will be a broader view of SAP S/4HANA Cloud: Integration Strategy, Data Security, and Migration Framework. The audit records can be accessed for a period of 24 months, and thus, they serve as a tool for compliance with 35 global regulatory standards (9).

SAP S/4HANA Cloud: system optimization and diagnostic analysis

With an eye to massive enterprise workloads, SAP S/4HANA's in-memory computing architecture is a sleek, high-performance setup. As per SCM Champs, the HANA database is quite a sight for sore eyes when it comes to data compression, as it achieves very high compression ratios—usually 5:1 for transactional data and even up to 8:1 for analytical data—thus leading to a significantly reduced memory footprint while still enabling the queries to be executed in less than a millisecond.

SAP S/4HANA Cloud Migration, Security, Compliance, Integration, Performance and Data Management Metrics Value

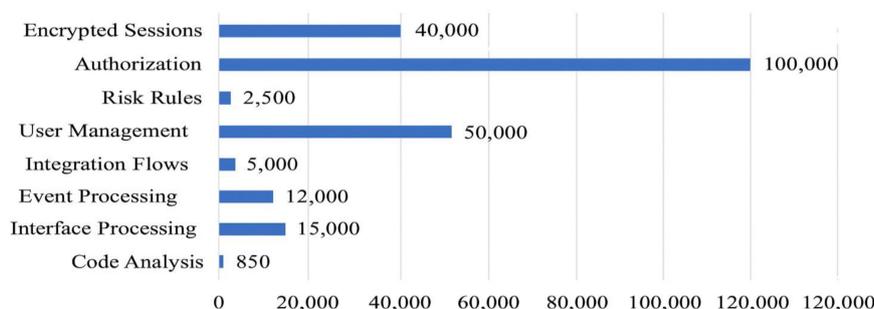


FIGURE 3 | SAP S/4HANA cloud: integration strategy, data security, and migration framework (7–9).

Additionally, the implementation of the code-to-data model has contributed substantially to the system's speed and efficiency by lessening the data movement between the application and database layers by 78%, thereby making the system capable of handling up to 1.5 million business transaction records per second with the average response time being less than 150 ms.

In essence, by performing the logic closest to the data in the in-memory model of SAP S/4HANA Cloud, the architecture can reduce the number of network roundtrips and the volume of intermediate data transfers across tiers, thus enabling faster and more efficient data processing as well as the possibility of real-time analytics (10).

SAP S/4HANA Cloud improves memory efficiency with its columnar data storage format, which splits tables with more than 2 billion records automatically to ensure performance at a high level. The system has a delta-main merge operation that can handle up to 250,000 records per second, while smart algorithms control delta storage to be within 10% of the main store's size, thus guaranteeing stable response and resource usage. The memory consumed is also optimized by the dynamic threshold management through about 850,000 optimization actions being performed on the fly each day; thus, the size of partitions is changed depending on the workload patterns. Also, SAP HANA is always checking the relationship between the delta and main stores, and a delta merge is initiated when the delta is around 10%. At this point, the uncompressed delta data is combined with the read-optimized main store, and the 10% threshold controlled dynamically by the Delta Merge Manager can be adjusted in real time to keep efficient memory use and steady query performance (10).

SAP S/4HANA Cloud presents top-tier workload management capabilities that allow for smart request handling and resource distribution that is adaptive. The workload classifier of its system effectively recognizes the 10,000 requests that come in per second and divides them into 24 different workload classes; thus, it can apply automated prioritization to optimize throughput. At a high

point in the activity, the system is said to move around 85% of the CPU cores to the execution threads that are running simultaneously, while the process of automated workload balancing keeps CPU utilization at an even 72%; thus, there is no resource contention, and the operations run at a high level of performance and are consistent (10).

Through intelligent execution planning and automated management of column statistics, SAP S/4HANA Cloud significantly improves query performance. It is tracking about 1,800 statistics to assist the optimizer in finding the most efficient way for complex queries. By this method, the system speeds up the data retrieval process, limits resource consumption, and keeps the system responsiveness at a high level during both analytical and transactional workloads. Execution paths are being updated constantly, with query optimizations happening every eight hours to provide maximum efficiency. The Structured Query Language (SQL) optimizer is capable of very complicated joins with 15 tables, and the execution time is less than two seconds. At the same time, the execution plan stability feature of the optimizer keeps the performance variation between different runs below 5%, which means that the business processes are predictable and reliable. This “<5% execution variance” is derived from stable workload conditions, and, however, it can be somewhat higher under mixed or highly concurrent workloads where query patterns and resource contention cause more variability (10).

SAP S/4HANA Cloud employs data aging based on storage tiers defined by temperature. Daily, the system classifies the data and distributes 100 GB of it among high-performance, mid-tier, and archival storage layers. It also migrates 2.5 TB each week. By cutting down on active storage through data aging, the system achieves 65% of the storage being released without compromising the performance, and the system can provide active records on demand within 500 ms through efficient management of buffer pools (10).

SAP S/4HANA Cloud uses the Database Maintenance Planner from the Maintenance Planner for automated database management, which makes database management

more efficient. Around 1,200 maintenance activities, like updating statistics, memory reorganizing, and cache optimization, are performed every day by the automated system. Backups for the database are done via parallel processing, resulting in a 4:1 compression ratio and 1 TB per hour transfer speeds, and thus, very reliable database management is guaranteed. The processing speeds, backup speeds, and compression ratios are the factors that attest to the reliability of SAP S/4HANA Cloud database management (10).

The advanced analytics system evaluates close to 15 million performance metrics on a daily basis. It also maintains a second-by-second 7-day rolling history for essential metrics, which enables root cause analysis for performance incidents to be accurate to 92%. The automated alert generation identifies a deviation and initiates the action within 30 seconds, and the correlation engines have the capacity to handle 50,000 events per minute for cause determination (10).

Furthermore, the deployment of the code-to-data model has been a major factor in the system's speed and turnaround time by significantly reducing the data movement between the application and database layers by 78%, so the system can process up to 1.5 million business transaction records per second (7). **Table 2** covers more details of the Operational Performance Review 2023.

SAP S/4HANA Cloud: strategic impact and return on investment

The International Data Corporations (IDCs) detailed study of large-scale enterprise implementation revealed that the use of SAP S/4HANA Cloud on AWS brings about very good financial results. Companies disclose an average Return on Investment (ROI) of 357% within 5 years and a payback period of only 11 months. The total expense framework is very much simplified, as companies can make close to \$36.1 million of annual profit. The savings come from a variety of sources, such as \$11.4 million from business efficiency improvements, \$14.2 million from Information Technology (IT) workforce productivity enhancements, and \$10.5 million from reduced infrastructure costs (11).

Cloud-based deployment models have been a major factor in the reduction of infrastructure costs that businesses have had to bear. Companies disclose a 54% reduction in costs associated with infrastructure, resulting in a decrease in operational costs over 5 years from \$46.5 million to \$21.4 million. Moving to consumption-based pricing has caused the amount of unforeseen infrastructure expenses to drop by 71%; at the same time, storage costs have been reduced by 62% through resource optimization carried out by smart data handling and automation (11).

Organizations are significantly improving their operational efficiency across their major business functions.

TABLE 2 | Operational performance review 2023 (10).

Optimization domain	Key metrics and functional highlights
Real-time data processing	<ul style="list-style-type: none"> - 5:1 compression for transactional workloads - 8:1 compression for analytical datasets - 78% reduction in data shuffling - Handles 1.5 million records per second - Average latency of 150 ms
Memory resource handling	<ul style="list-style-type: none"> - Partitioning for tables with up to 2 billion entries - Merge throughput of 250,000 records/seconds - Delta storage capped at 10% - 850,000 optimization decisions made daily
Task and load distribution	<ul style="list-style-type: none"> - Classifies 10,000 incoming requests per second - Supports 24 distinct workload categories - CPU thread usage capped at 85% - Peaks at 72% CPU utilization
Query performance tuning	<ul style="list-style-type: none"> - Maintains 1,800 column-level statistics - Refreshes stats every 8 hours - Supports complex joins across 15 tables - Executes queries in 2 seconds - 5% variance in execution time
Data lifecycle strategy	<ul style="list-style-type: none"> - Categorizes 100 GB of data daily - Migrates up to 2.5 TB weekly - Reduces active data footprint by 65% - Hot data accessible in 500 ms - Utilizes a three-tier storage model
Database operations	<ul style="list-style-type: none"> - Performs 1,200 maintenance routines per day - Achieves 4:1 compression for backups - Backup speed of 1 TB/hour - Executes backups in parallel
System health monitoring	<ul style="list-style-type: none"> - Tracks 15 million performance indicators daily - Retains 7-day historical data - Captures metrics every second - 92% accuracy in root cause detection - Alerts triggered within 30 seconds - Correlates 50,000 events per minute

The implementation of automated workflows and process simplification has increased staff productivity by 37%, whereas IT teams are able to save around 6,275 hours annually through automated system maintenance and updates. Moreover, business process automation has reduced the volume of manual tasks by 52%, thus facilitating a 41% increase in the speed of new application deployment and a 56% decrease in occurrences of business disruptions (11).

Improved system management and maintenance capabilities have led organizations to experience significant positive changes in IT operations. Some of the efficiency gains are a 47% enhancement of the IT infrastructure team performance, a 32% rise in the application development productivity, and a 25% growth of the IT security operations. Moreover, the platform is speeding up the provisioning of computing resources by 66% and reducing the occurrences of unplanned downtime by 71%, which is resulting in an average yearly saving of \$3.2 million in IT workforce productivity (11).

Through improved business productivity, organizations are achieving notable operational gains. User efficiency increases by 25%, whereas time-to-market for new offerings gets faster by 32%. Business operations teams have a 37% higher performance level, and the speed of application development and deployment increases by 41%. All these improvements lead to an average annual productivity gain of \$11.4 million, which is mainly the result of streamlined processes and better execution (11).

Cloud-enabled application development and deployment have been a major factor in the quickening of innovation cycles for organizations. As a result, development timelines are 33% shorter, which makes it possible to have a 41% higher number of new applications and features released per year. The platform is also instrumental in speeding up business applications' production by 56% and cutting the need for development staff by 32%. On top of that, security and compliance oversight have been improved by 25%, which is one of the reasons for the average saving of 2,000 hours per year in security-related operations (11).

Cloud infrastructure agility and performance improvements are the main factors behind significant operational changes in organizations. As a result, deployment of new compute resources has become 66% faster, the time for unplanned downtime has been reduced by 71%, and disruptions to business processes have gone down by 56%. This platform is the reason for a 238% increase in application volume per customer with 47% less IT infrastructure staffing. On top of that, performance tuning is 61% more efficient in database management, and storage provisioning is 56% faster (11).

Conclusion

Essentially, SAP S/4HANA Cloud is the platform of choice for enterprises looking to digitally transform their business. It is a combination of advanced architecture, secure infrastructure, and intelligent automation that is very powerful. Organizations can use the flexible multi-cloud deployment model and the integration capabilities without any inconvenience to them to optimize their operations and reduce the total cost of ownership. As companies increase their digital maturity level, SAP S/4HANA Cloud becomes the main turning point for innovation with its continuous upgrade and comprehensive features capable of supporting scalable growth and maintaining operational excellence in the long run.

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Conflict of interest

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