

Robotic Surgical Administrative Readiness: A Comprehensive Framework

Babu George^{1,*}

¹ School of Business, Alcorn State University, Lorman, USA

***Correspondence:** Babu George, School of Business, Alcorn State University, Lorman 39096, USA.
E-Mail: bgeorge@alcorn.edu

Abstract

The integration of advanced surgical robotic systems in healthcare creates organizational and managerial challenges that extend well beyond clinical training. While the literature on robotic surgery has focused primarily on surgical technique, patient outcomes, and technological capability, comparatively little attention has been given to the administrative infrastructure required to govern, finance, staff, operate, and manage the risks of these complex socio-technical systems. This paper addresses that gap through a structured conceptual analysis grounded in socio-technical systems theory, high-reliability organization theory, and dynamic capabilities theory. Drawing on a synthesis of current literature, the paper identifies six interdependent domains of administrative readiness: governance and strategic oversight, financial management and capital strategy, workforce planning and role reconfiguration, operational integration and process redesign, risk management and liability structures, and data governance and digital infrastructure. These domains are integrated into the Robotic Surgical Administrative Readiness (RSAR) framework, a maturity model that classifies organizational preparedness across four levels (reactive, operational, strategic, and adaptive) and maps cross-dimensional failure modes.

Keywords: robotic surgical systems, administrative readiness, healthcare management, socio-technical systems, surgical robotics governance, Robotic Surgical Administrative Readiness framework, healthcare technology management, organizational maturity model

Introduction

The integration of advanced surgical robotic systems in healthcare is rapidly transforming not only clinical practice but also the organizational, managerial, and governance structures of hospitals and health systems. While robotic surgery offers clear clinical benefits (including enhanced precision, minimally invasive approaches, and improved patient outcomes), the literature increasingly frames

its adoption as a complex socio-technical challenge in which managerial preparedness is an underappreciated bottleneck to value realization^[1-3].

The surgical robot is undergoing a meaningful technical evolution. The device began as a telemanipulation instrument (essentially a mechanical extension of the surgeon's hands) and has since become a platform with growing algorithmic capabilities: automated assistance

Received: 4 February 2026; **Accepted:** 24 April 2026

DOI: 10.15302/ISR.2026.000001

© The Author(s) 2026. This article is published by Higher Education Press at journal.hep.com.cn.

This is an open access article distributed under the Creative Commons Attribution License 4.0 (CCBY), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

with suturing, tissue identification, real-time anatomical mapping, and decision-support functions that inform surgical planning^[4-6]. Broader reviews of artificial intelligence (AI) integration in healthcare confirm the expanding role of algorithmic guidance in surgical practice^[7,8]. It is important to calibrate this claim carefully. Today's commercially deployed systems operate primarily at assistive and supervisory autonomy levels, meaning that human surgeons retain decisive control over all clinical actions^[9-11]. Existing surgical autonomy taxonomies, such as the levels-of-autonomy (LoA) framework proposed in the robotics literature, classify systems along a spectrum from teleoperation (Level 0) through task-autonomous operation (Level 3) to full autonomy (Level 5). Most commercially available platforms today operate at Levels 0 through 1, with emerging capabilities reaching toward Level 2 (task autonomy under close supervision). The next generation of systems is designed toward conditional autonomy, defined as the capacity to execute bounded procedural tasks under human supervision, and eventually toward higher autonomy levels in carefully defined contexts. This trajectory has significant administrative implications even before fully autonomous operation is realized.

Healthcare organizations are ill-prepared for this evolution. The administrative infrastructure surrounding surgical robotic systems, including governance policies, reimbursement logic, asset management practices, workforce planning models, and risk frameworks, was designed for an earlier technological era. It is increasingly inadequate as systems become capable of algorithmic recommendations and graduated supervised autonomy^[12,13]. This framing made practical sense when the da Vinci system first entered operating rooms (ORs) two decades ago^[14]. Hospitals still evaluate robotic systems primarily as high-cost capital equipment, calculating return on investment (ROI) on a per-procedure basis and treating the robot as a sophisticated tool that serves the surgeon's expertise^[3,15].

This paper advances a consequential but qualified argument: managerial unpreparedness constitutes a significant and underrecognized bottleneck in realizing value from surgical robotic systems. This is not a claim that management matters more than clinical excellence (both are necessary) but that the administrative dimensions of robotic integration have received disproportionately

little attention relative to clinical dimensions. The technology is maturing faster than the organizational structures designed to govern it. Policies written for passive instruments are poorly suited for machines that generate recommendations. Training programs built around surgeon skill acquisition tend to neglect the coordinators, analysts, and safety officers that robotic programs also require^[16,17]. Financial models that demand short-term payback fail to capture the strategic value of data assets, learning curves, and future optionality^[4,18]. Risk frameworks that assign responsibility to individual practitioners encounter difficulties when algorithms share decision-support authority^[5,19].

A brief illustration makes the stakes concrete. Consider a community hospital that acquires a robotic platform capable of task-level autonomy (automated suturing, tissue identification under surgeon supervision). The surgical team is well trained; clinical outcomes are strong. Yet the hospital has no standing robotics committee, no policy governing which autonomous functions may be activated, and no protocol for reporting software-related anomalies. When the system's tissue-identification algorithm produces an incorrect classification during a procedure, no audit trail documents who approved the algorithm's activation, no accountability structure distinguishes surgeon error from algorithmic error, and no reporting pathway connects the event to the vendor's engineering team. Clinical excellence, in this case, coexists with administrative exposure that conventional governance arrangements were never designed to address.

This paper is a work of conceptual theory-building rather than an empirical study. The arguments advanced here are grounded in a synthesis of existing literature, theoretical reasoning, and cross-sector analogy. Where the paper describes managerial unpreparedness as a bottleneck, the claim is normative and theoretical: it reflects what the accumulated literature suggests and what organizational theory would predict, not a finding derived from original empirical data. The framework proposed in this paper is intended as a structured conceptual map and hypothesis-generator, designed to guide future empirical research. Readers should evaluate the Robotic Surgical Administrative Readiness (RSAR) framework on the basis of its internal coherence, its fidelity to the source literature, and its capacity to generate testable propositions, rather than as a validated assessment instrument.

This paper addresses multiple audiences. Its primary contribution is academic: it develops a conceptual framework intended to organize future empirical research on the administrative dimensions of surgical robotic integration. At the same time, the analysis is written to be accessible and actionable for hospital executives, healthcare technology management (HTM) professionals, and policy or accreditation bodies who confront these challenges in practice. Readers in applied settings should find the RSAR framework useful as a diagnostic lens for identifying organizational gaps, even as its maturity levels and behavioral markers await empirical validation.

The central research question guiding this analysis is: What administrative and managerial preparations are required for healthcare organizations to safely, efficiently, and strategically integrate advanced surgical robotic systems? Answering this question requires a reframing: surgical robotic systems must be understood not only as clinical innovations evaluated by medical staff, but as socio-technical systems that reshape governance, labor, capital allocation, and institutional accountability. Clinical excellence, while necessary, is insufficient. Organizations that master the administrative dimensions of robotic integration are better positioned to realize sustained value, and the performance gap will likely widen as autonomy expands.

Surgical robotics

Moving beyond the capital equipment paradigm

The literature critiques the traditional “capital equipment” paradigm, which frames surgical robots as high-cost devices evaluated primarily on per-case ROI^[3,15,20]. This paradigm is breaking down for reasons that are structural, not incidental.

First, the boundaries of the “device” are increasingly unclear. A modern robotic surgical system is not a discrete machine but a platform integrating hardware, software, data streams, cloud connectivity, vendor services, and algorithmic decision support. The physical robot in the OR is the visible component of an extended network that includes remote monitoring, vendor-controlled software updates, performance analytics, and machine learning models trained on aggregated procedural data.

Evaluating this ecosystem as capital equipment captures only a fraction of its actual organizational implications^[21].

Second, the system’s capabilities change over time in ways that traditional depreciation schedules cannot capture. Software updates alter functionality, sometimes substantially. A robot purchased in 2024 may operate differently by 2027, not because of hardware modifications but because its algorithms have evolved. The asset appreciates and depreciates simultaneously along different dimensions, and the organization often has limited control over that trajectory^[22].

Third, and most fundamentally, advanced robotic platforms are increasingly capable of generating recommendations that influence clinical decision-making, drawing on cloud-connected analytics and machine learning trained on aggregated procedural data^[23,24]. Even where final authority remains with the surgeon, as systems move along the autonomy spectrum, from passive (surgeon controls all motion) through assistive (stability, haptic feedback) to conditional autonomy (robot executes specific bounded tasks under supervision), they cease to fit neatly into the conceptual category of equipment^[11,25]. They become participants in surgical workflows, with implications for accountability, authority, and organizational structure that equipment models cannot address.

We propose that surgical robotic systems should be understood as cyber-physical production systems: integrated assemblages of computation, networking, physical machinery, and human operators that produce outputs (specifically surgical procedures and their associated data) through coordinated action^[26,27]. This framing highlights systemic interdependencies, positions data as a primary output rather than a byproduct, and connects surgical robotics to a broader literature on advanced production systems in which longer experience with human-machine integration exists.

Theoretical background

Socio-technical systems theory emerged from organizational studies in the 1950s and remains foundational for understanding technology in workplace contexts. Its core insight, that technical systems and social systems must be jointly optimized, applies directly to surgical robotics^[20]. Introducing a robot changes not just OR procedures

but communication patterns, authority relationships, skill requirements, and professional identities^[2,10]. A technically superior system risks failure if it disrupts social arrangements that the organization depends on.

High-reliability organization (HRO) theory studies how organizations in high-hazard industries maintain safety over extended periods. HRO research identifies characteristic practices: preoccupation with failure, reluctance to simplify, sensitivity to operations, commitment to resilience, and deference to expertise^[1]. Surgical robotics introduces new failure modes, including the automation paradox, in which reduced routine engagement degrades the ability to handle non-routine situations, that challenge each of these practices.

Dynamic capabilities theory addresses how organizations sense opportunities, seize them through resource deployment, and transform themselves to maintain competitiveness^[21]. The capacity to reconfigure assets, routines, and structures around new technologies is not uniformly distributed. Organizations with strong dynamic capabilities will treat robotic surgery as an occasion for strategic renewal; those without will treat it as a procurement decision. Human-robot interaction theory provides tools for understanding how surgical teams adapt to working with increasingly capable machines^[17,28]. This literature examines trust formation, authority relationships, and the cognitive demands placed on human operators who must supervise rather than directly control surgical actions. As Rasmussen et al. observe in their scoping review of robots in hospitals^[9], barriers and facilitators of adoption extend beyond technical capability to user acceptance, workflow integration, and organizational culture.

Taken together, these frameworks establish surgical robotics as a dynamic managerial object rather than a static tool. The robot changes; the organization must change with it; the relationship between the two must be actively managed over time.

Dimensions of administrative readiness

Overview and relationship to existing frameworks

The following six domains constitute the empirical

and conceptual foundation of the RSAR framework. They represent the organizational systems that need to be developed, not sequentially but in coordination, for healthcare organizations to manage advanced surgical robotic systems effectively. Weakness in any domain constrains performance in others; misalignment between domains creates organizational friction that degrades both efficiency and safety. Each subsection that follows examines one domain individually, but readers should keep the systemic character of these domains in view: governance decisions constrain financial strategy, workforce availability limits operational redesign, and data governance intersects with both risk management and vendor negotiations. The domains are presented separately for analytical clarity, not because they operate in isolation. The RSAR framework formalizes these interdependencies and identifies the failure modes that emerge when organizational readiness is uneven across domains.

It is important to distinguish RSAR from adjacent frameworks it may superficially resemble. Digital health maturity models, such as the Healthcare Information and Management Systems Society (HIMSS) Electronic Medical Record Adoption Model (EMRAM) or HIMSS Infrastructure Adoption Model (INFRAM), assess an organization's electronic health record adoption and information infrastructure along staged progressions. HTM governance frameworks focus on regulatory compliance, device lifecycle management, and biomedical engineering stewardship. The RSAR framework is differentiated in three respects. First, it is specifically constructed around the socio-technical characteristics of semi-autonomous surgical robotic systems, not general digital health adoption. Second, it integrates governance, financial, workforce, operational, risk, and data dimensions under a single surgery-specific readiness construct rather than treating them as parallel but separate assessments. Third, it explicitly maps interdependencies and failure modes across dimensions, a structural feature that existing frameworks do not provide in this context. The RSAR framework draws on and complements these prior models; it does not supplant them, but it addresses a specific gap they leave unoccupied.

Table 1 below summarizes the principal differences among these frameworks, highlighting the unique contribution of the RSAR model.

A concrete scenario clarifies the practical difference. A hospital with a Stage 7 HIMSS EMRAM rating (full EHR integration, advanced analytics, population health management) deploys a robotic surgical platform with Level 2 autonomous capabilities. By EMRAM criteria, the organization is digitally mature. By HTM governance standards, the device may be properly procured, maintained, and compliant. Yet the hospital lacks a policy governing which autonomous functions may be activated in surgery, has no framework for attributing accountability when an algorithmic recommendation contributes to an adverse outcome, and has not negotiated data ownership terms that prevent the vendor from aggregating its surgical performance data. Under the RSAR model, this organization would be classified as reactive in governance, risk management, and data governance, exposing it to vendor dependency, unmanaged liability, and strategic information loss, despite its high maturity ratings on adjacent frameworks. The gap is not digital infrastructure; it is organizational preparedness for the specific challenges that semi-autonomous surgical systems introduce.

The evidence base is strongest for the need for robust governance structures, multidisciplinary training, and new financial models, with moderate evidence for the effectiveness of specific operational redesigns and risk management strategies^[1,3,15]. Where evidence is limited, we draw on theoretical reasoning and cross-sector analogy.

Governance and strategic oversight

The first question any organization must answer is: who owns robotic strategy? In most hospitals, the answer remains unclear. Surgical robotic systems sit at the intersection of multiple domains: clinical operations, information technology (IT), biomedical engineering, finance, and executive leadership. Multiple studies show that governance gaps lead to inefficiencies, safety risks, and vendor-driven agendas^[1,15,29].

When governance is absent, predictable problems follow. Vendor representatives fill the strategic vacuum, shaping technology roadmaps according to commercial priorities that may not align with institutional interests. Decisions about software updates, new capabilities, and expansion plans are made ad hoc. Conflicts between departments are resolved through political maneuvering rather than strategic analysis.

Effective integration demands enterprise-level robotics governance structures with real authority^[29]. This means establishing robotics steering committees with clinical, technical, financial, legal, and executive representation, with clear decision rights and accountability. It requires explicit policies for consequential choices: What autonomy levels are acceptable for which procedures? Who approves software updates that change system behavior? How are algorithmic recommendations

Table 1: Comparison of RSAR with adjacent frameworks.

Feature	HIMSS EMRAM/INFRAM	HTM governance models	RSAR framework
Primary focus	EHR adoption; IT infrastructure maturity	Regulatory compliance; device lifecycle; biomedical stewardship	Administrative readiness for semi-autonomous surgical robotic systems
Scope of dimensions	Primarily IT and informatics	Equipment safety, maintenance, procurement	Six integrated domains: governance, finance, workforce, operations, risk, data
Technology specificity	General digital health	General medical devices	Surgery-specific; calibrated to robotic autonomy levels
Interdependency mapping	Not explicitly modeled	Not explicitly modeled	Cross-dimensional failure modes and synergies explicitly mapped
Maturity levels	Staged (0–7 for EMRAM)	Varies by model	Four levels (reactive, operational, strategic, adaptive) with behavioral markers
Data governance treatment	IT infrastructure focus	Device data in maintenance context	Surgical performance data as strategic asset; vendor relationship governance

Abbreviations: RSAR, Robotic Surgical Administrative Readiness; HIMSS, Healthcare Information and Management Systems Society; EMRAM, Electronic Medical Record Adoption Model; INFRAM, Infrastructure Adoption Model; HTM, healthcare technology management; HER, electronic health record; IT, information technology.

validated before clinical deployment? What data may be shared with vendors, and under what conditions?

The practical relevance of such governance structures is visible in published accounts of major robotic programs. The Henry Ford Health System's robotic surgery governance model, for instance, established a multidisciplinary committee that integrates surgical, financial, and technical oversight into a single decision-making body, an arrangement credited with improving utilization rates and reducing vendor dependency^[3,29]. Conversely, institutions that have expanded robotic programs without centralized oversight have reported fragmented decision-making, underutilization of installed systems, and difficulty negotiating favorable terms with vendors^[15].

The deeper challenge is organizational: as surgical robots take on advisory roles in the OR, governance frameworks designed for passive tools become structurally insufficient. Organizations need accountability mechanisms for algorithmically assisted action, specifying who monitors algorithmic performance over time, how drift is detected, and under what conditions machine recommendations are overridden or suspended. These responsibilities require governance structures that most healthcare organizations have not yet built.

Financial management and capital strategy

Traditional financial models for surgical robotic systems center on a per-case ROI calculation: acquisition cost against procedure volumes, adjusted for reimbursement rates and operating expenses. Evidence consistently shows that this approach fails to capture hidden costs, learning curve effects, and the strategic value of robotics-generated data^[3,4,15].

Learning curves illustrate one important limitation. Robotic surgery involves extended skill acquisition for surgical teams, during which procedure times are longer and outcomes may be suboptimal relative to experienced conventional surgeons^[3,30]. A per-procedure model penalizes this necessary investment in capability development. Organizations that demand immediate returns risk either abandoning programs prematurely or pressuring teams to operate before adequate proficiency is established.

The value of procedural data represents a second limitation of conventional financial evaluation. Every robotic procedure generates detailed performance information: video recordings, instrument motion trajectories, force measurements, timing data, anatomical annotations, and decision logs^[7,13]. This data has near-term value for quality improvement and training, and longer-term strategic value for benchmarking, research, and potentially for training next-generation surgical AI systems. Traditional capital models assign this value as zero because it does not appear on procedure-level income statements, an accounting convention that may lead organizations to surrender a significant asset in exchange for marginal concessions on service contracts.

Hidden costs accumulate systematically. Software subscriptions create ongoing expenses that grow over time. Forced upgrades require unplanned capital outlays. Training investments are lost when staff turn over. Consumable pricing often increases after the platform is installed and switching costs make alternatives impractical^[4,31].

The necessary strategic shift is from simple capital equipment logic toward portfolio investment thinking: evaluating surgical robotic systems as infrastructure that positions the organization for an uncertain technological future. This implies scenario-based financial modeling across multiple technology trajectories, longer evaluation horizons that capture learning and data value, and explicit recognition that early inefficiency may be the price of long-term competitive positioning. This is not an argument for undisciplined spending; it is an argument for more sophisticated financial instruments calibrated to the actual properties of these systems.

Workforce planning and role reconfiguration

When healthcare organizations consider the workforce implications of surgical robotic systems, attention focuses almost exclusively on surgeons, specifically on training programs, credentialing requirements, and competency assessments. This focus is understandable given the clinical primacy of surgical skill, but it is insufficient to prepare organizations for advanced robotic programs. Studies show that neglecting non-surgeon roles leads to systematic underperformance^[1,16,17].

Advanced robotic surgery creates demand for roles that do not exist in traditional OR staffing models. Robotics coordinators manage scheduling, equipment preparation, and cross-departmental logistics. Data analysts interpret the performance information that robotic systems generate, identifying patterns that inform quality improvement and training. Automation safety officers monitor system behavior for anomalies, manage software updates, and serve as organizational experts on machine failure modes. Technical specialists maintain complex electro-mechanical systems that combine surgical instruments with computing platforms. None of these roles map cleanly onto existing job categories; all become essential as programs mature^[16].

Automation also reconfigures existing roles in ways that require proactive management. Surgical assistants may find functions partially absorbed by robotic arms. Circulating nurses face new technical responsibilities. Anesthesiologists must coordinate with systems that have their own timing requirements^[1]. These shifts create both deskilling risks and reskilling demands, often for the same workers simultaneously. Organizations that fail to manage these transitions encounter resistance, recruitment challenges, and quality problems stemming from role confusion.

Workforce preparation requires new role taxonomies defining emerging positions with clarity, career ladders showing how workers can develop from current roles into robotics-related positions, and workforce impact modeling that anticipates who gains and loses authority as automation advances. Attention to union relationships and credentialing structures, which may not accommodate new hybrid roles without renegotiation, is also necessary^[30].

A counterintuitive insight from this analysis is that robotic surgery may disrupt informal coordination labor more severely than formal clinical roles. The tasks most vulnerable to workflow disruption are often invisible in formal job descriptions: the experienced scrub nurse who anticipates instrument needs, the technician who recognizes subtle equipment problems before they cause failures, the coordinator who navigates scheduling conflicts. This tacit knowledge, embedded in experienced workers and informal relationships, is precisely what organizations struggle to replace when automation disrupts traditional arrangements^[2,10].

Operational integration and process redesign

The standard approach to implementing surgical robotic systems is additive: layering the new system onto existing OR workflows with minimal disruption to established routines. This approach minimizes organizational stress but consistently fails to capture efficiency gains that require genuine process redesign. Evidence documents inefficiencies when robots are overlaid on legacy workflows; fewer studies document successful redesign approaches, representing a gap in the literature^[2,3,8].

Surgical robots have different operational characteristics than conventional surgical instruments. Setup times are longer and more technically demanding. Equipment failures cause more severe workflow disruptions because specialized support is required. Software updates can change system behavior in ways that affect surgical planning. Maintenance windows must be coordinated with clinical schedules. These characteristics demand workflows designed specifically for robotic operations.

Robotics-first process mapping starts from the capabilities and constraints of automated systems rather than retrofitting existing arrangements. It treats setup and breakdown as integral parts of the procedure. It builds redundancy and recovery pathways for the characteristic failure modes of cyber-physical systems. It integrates robotic operations with computerized maintenance management systems (CMMS), enterprise resource planning (ERP), and OR scheduling software so that equipment status, supply chain logistics, and clinical scheduling function as a coherent system rather than in isolation^[3].

One operational challenge deserves particular attention: downtime. Conventional medical equipment is maintained on scheduled intervals with relatively predictable outages. Robotic systems introduce software-related downtime (updates, patches, compatibility issues), cybersecurity-related downtime (vulnerability remediation), and complex electromechanical failures that may require vendor support unavailable at convenient times. Organizations that treat downtime as exceptional rather than routine will face repeated disruptions that erode confidence in robotic programs.

Healthcare organizations can learn from advanced manufacturing, which has spent decades optimizing

production systems integrating human workers with automated machinery^[27]. Concepts like predictive maintenance, total productive maintenance, and overall equipment effectiveness translate meaningfully to surgical robotic systems. This cross-sector transfer requires adaptation, since clinical environments differ from manufacturing in important ways, but the underlying principles of systematic uptime management are directly applicable.

Risk management, liability, and accountability

Current risk frameworks for surgical robotic systems assign responsibility in familiar ways: surgeons bear primary accountability for clinical decisions, hospitals maintain responsibility for equipment safety and staff competence, and manufacturers warrant that devices perform as specified. These arrangements encounter structural problems when machines participate in clinical decision-making. Blurred accountability among surgeon, hospital, vendor, and algorithm; underreported near-miss data; and cybersecurity risks are consistently identified across the literature^[5,19,22].

Consider a scenario within current technological capability: a robotic system identifies tissue that its algorithm classifies as potentially malignant and recommends a modified surgical approach. The surgeon follows this recommendation. Pathology later reveals the classification was incorrect, and the modified approach caused unnecessary complications. Attribution of responsibility in this scenario is genuinely complex. The surgeon chose to follow the recommendation; the recommendation came from an algorithm whose decision process may be opaque; the hospital selected and configured the system; the manufacturer designed the algorithm but cannot control how surgeons respond to its outputs^[19]. Current legal and regulatory frameworks have not evolved to accommodate this form of shared human-machine agency^[22,25].

Controversies over data ownership have begun to surface publicly. Vendor contracts for major robotic platforms have drawn scrutiny for provisions granting manufacturers broad access to procedural data generated by hospital surgical teams. In some cases, hospitals discovered that their own performance analytics were being aggregated and used to train proprietary algorithms without explicit institutional consent, raising questions about

whether existing contract structures adequately protect hospital and patient interests^[5,7,23].

Incident reporting poses a parallel challenge. Robotic systems generate extensive performance data that could reveal emerging safety problems, but this information is typically siloed. Clinical incident reports capture adverse events visible to surgical teams. Technical maintenance records track equipment malfunctions. Vendor analytics identify performance anomalies. These data streams rarely converge into integrated risk assessment, meaning that patterns of minor automation surprises that would be visible in aggregate may go undetected when information remains distributed across organizational boundaries.

Cybersecurity presents additional risk dimensions that conventional surgical risk frameworks do not address^[24]. Surgical robots are networked devices vulnerable to ransomware, data breaches exposing surgical recordings, and supply chain compromises through software updates. Yet cybersecurity risk is typically housed in IT departments with limited connection to clinical risk management.

Organizations can prepare by developing new accountability frameworks that explicitly address algorithmically assisted action, implementing automation-specific incident reporting systems that integrate clinical and technical data streams, and establishing structures that bring IT risk, clinical risk, and legal oversight together around robotic programs. The underlying principle: as systems take on greater advisory roles, organizational accountability for their configuration, oversight, and deployment decisions increases correspondingly.

Administrative readiness offers specific mechanisms for mitigating the legal risks inherent in algorithmically assisted surgery. Algorithmic performance monitoring protocols, in which organizations continuously track system recommendation accuracy, false-positive rates, and deviation patterns, create an evidentiary record demonstrating institutional due diligence. When a hospital can show that it maintained systematic oversight of algorithmic outputs, tested software updates before clinical deployment, and documented its criteria for accepting or overriding machine recommendations, it establishes a defensible position in liability disputes.

Structured audit trails that log each instance of algorithmic recommendation, the surgeon's response, and the clinical outcome convert what would otherwise be ambiguous shared human-machine responsibility into a traceable decision chain. Organizations that institutionalize these monitoring practices are better positioned both to prevent adverse events and to demonstrate reasonable care when adverse events do occur. Without such protocols, accountability defaults to post hoc reconstruction of opaque decision processes, a situation that disadvantages every party involved.

Data governance and digital infrastructure

Every robotic procedure generates rich data: video recordings of the surgical field, instrument motion trajectories, force measurements, timing data, anatomical annotations, and algorithmic decision logs. This information has immediate value for quality improvement and training, and longer-term strategic value for research, benchmarking, and developing next-generation surgical AI systems^[7,13]. Yet data ownership, vendor-controlled analytics, and limited interoperability are persistent structural challenges^[5,7,23].

Vendor contracts often include provisions granting manufacturers access to procedural data for product improvement and research. Analytics dashboards provide hospitals insight into their own performance but retain underlying data on vendor-controlled infrastructure. Hospitals that lack the technical capacity to store, process, and analyze robotics-generated data become dependent on vendor interpretations of their own performance, a form of strategic dependency that extends beyond equipment into information.

Platform consolidation amplifies these concerns. Surgical robotics is consolidating around a small number of major platforms with proprietary data formats and limited interoperability. A hospital that builds its robotic program around one vendor ecosystem will find it difficult to benchmark performance against industry standards or migrate to alternative systems if relationships deteriorate.

Data governance preparation involves several components: institutional data ownership policies establishing that surgical performance data belongs to the hospital

or patients regardless of where it is stored; internal analytics capacity so hospitals can interpret their own data; data architectures designed for interoperability across platforms and compliance with privacy regulations; and strategic alignment among HTM, IT, and compliance functions that typically operate independently^[23].

The broader strategic reframing is that comprehensive surgical performance data, properly governed and analytically developed, may ultimately constitute a strategic asset of comparable significance to the clinical value of individual procedures. Organizations that treat data as a byproduct of clinical operations risk disadvantage relative to those that actively govern it as a primary organizational resource.

Implementation barriers and global disparities

The readiness challenges identified above are compounded by significant implementation barriers, particularly for healthcare systems operating with constrained resources. High capital costs, ongoing maintenance requirements, limited training infrastructure, and ethical and regulatory concerns are substantial barriers to robotic surgery adoption, especially in low-resource settings^[4,31,32]. The capital requirements for robotic systems, combined with ongoing consumable costs, place these technologies beyond reach for many healthcare systems globally.

Infrastructure requirements, including reliable power, network connectivity, and climate control, may not be met in facilities that would otherwise benefit from robotic capabilities. Training pathways assuming access to simulation centers, fellowship programs, and high case volumes are unavailable in many regions.

These disparities raise equity concerns that extend beyond resource constraints. If administrative readiness becomes a prerequisite for safe and effective robotic surgery, and if the capacity for such readiness is concentrated in well-resourced health systems, the benefits of surgical robotics may accrue disproportionately to populations already advantaged by healthcare infrastructure. Addressing this tension requires policy attention to technology transfer, training support, and governance frameworks adapted to diverse organizational contexts^[33].

The RSAR framework can be modularized to accommodate these realities. Low-resource settings adopting robotic systems at lower autonomy levels (Levels 0 through 1) may reasonably prioritize operational-level readiness in selected domains rather than pursuing strategic or adaptive maturity across all six dimensions simultaneously. In practice, this means concentrating initial investment on the governance, workforce, and operational integration domains, which address the most immediate barriers to safe deployment: clear authority over robotic programs, adequately trained support staff, and workflows redesigned for robotic operations. Financial management can be adapted to simpler capital models appropriate to lower case volumes, while risk management and data governance can initially follow streamlined protocols calibrated to assistive-level systems that generate less complex accountability questions. As institutional capacity grows and autonomy levels increase, organizations can progressively expand readiness across the remaining domains. This tiered approach prevents the framework from functioning as a gate-keeping mechanism that excludes resource-constrained systems; instead, it provides a structured progression that meets organizations where they are and builds capacity incrementally.

Implications for healthcare technology management

Surgical robotic systems transform the role of HTM from a support function concerned primarily with equipment maintenance to a strategic governance function at the intersection of clinical operations, IT, and enterprise risk management.

Traditional HTM responsibilities centered on device safety: ensuring that medical equipment meets specifications, is properly maintained, and complies with regulatory requirements. These responsibilities remain important but no longer capture the full scope of what surgical robotic systems require. When the “device” is a cyber-physical system with algorithmic decision-support capabilities, the stewardship function expands correspondingly.

HTM professionals increasingly need competencies that extend beyond biomedical engineering^[23]. AI literacy, meaning an understanding of how machine learning

systems work, how they fail, and how to evaluate algorithmic performance over time, has become relevant. Contract strategy expertise matters because vendor relationships for robotic platforms involve complex negotiations over data rights, upgrade commitments, and service levels with strategic implications. Risk analytics capabilities are required to integrate the technical, clinical, and cybersecurity risk streams that converge around robotic systems^[24].

To be more specific about what AI literacy entails for HTM professionals: the competency set includes the ability to interpret algorithmic validation reports, understanding metrics such as sensitivity, specificity, and confidence intervals that characterize system recommendation quality; familiarity with software version control and regression testing, so that HTM staff can evaluate whether a vendor software update introduces performance changes warranting clinical review; knowledge of data pipeline architecture sufficient to assess where procedural data is stored, how it flows between institutional and vendor systems, and what privacy protections apply at each stage; and the capacity to design and maintain algorithmic performance dashboards that track recommendation accuracy, drift indicators, and anomaly rates over time. These competencies do not require HTM professionals to become data scientists, but they do require fluency with the concepts and tools necessary to hold vendors accountable, advise clinical leadership on system behavior, and identify emerging risks before they produce adverse events.

Perhaps most importantly, HTM is positioned to serve as an organizational translator between clinical, IT, legal, and executive domains that often struggle to communicate effectively about surgical robotic systems. Surgeons understand clinical capability but may not appreciate software risks. IT understands cybersecurity but may not grasp clinical workflow constraints. Legal understands liability but may not comprehend how algorithms contribute to clinical decisions. Finance understands investment return but may not recognize strategic optionality. HTM professionals who can bridge these perspectives provide coordination value that transcends their technical responsibilities.

Organizations that continue to position HTM as a technical service department will lack the coordination

capacity that advanced surgical robotic systems increasingly require. Those that recognize and invest in HTM's potential as an integrative governance function will be better prepared for the administrative challenges ahead.

The six domains examined each address a distinct organizational system that surgical robotic integration places under stress. No domain operates in isolation; governance decisions constrain financial strategy, workforce availability limits operational redesign, and data governance intersects with both risk management and vendor negotiations. We synthesize these domains into the RSAR framework, which operationalizes the preceding analysis into a maturity model. The framework structures the six domains along four progressive maturity levels, provides behavioral markers for each level, and explicitly maps the cross-dimensional failure modes that emerge when organizational readiness is uneven across domains.

The RSAR framework: synthesis and maturity assessment

Framework structure

The preceding analysis identifies six interdependent domains of administrative readiness. The RSAR Framework synthesizes these into a structured approach to organizational assessment and strategic planning. Figure 1 provides a schematic overview of the RSAR framework, illustrating the six interdependent domains and the four-level maturity progression.

The framework's six dimensions are: governance and strategic oversight; financial management and capital strategy; workforce planning and role configuration; operational integration and process design; risk management and liability structures; and data governance and digital infrastructure. Within each dimension, organizations can be assessed at four maturity levels (reactive, operational, strategic, and adaptive), defined below with behavioral markers to improve assessment specificity.

Readiness requirements are not static; they scale with the autonomy level of the robotic systems being deployed. At lower autonomy levels (Levels 0–1 in standard surgical autonomy taxonomies), administrative demands center on procurement, basic governance, and

surgeon training. As systems approach Level 2 (task autonomy under supervision), requirements intensify across all six domains: algorithmic oversight policies become necessary, liability frameworks require revision, and data governance takes on strategic significance. At Level 3 and beyond (conditional and high autonomy), adaptive-level readiness across all domains becomes a precondition for safe deployment. The RSAR maturity levels are therefore best understood not only as stages of organizational development but as prerequisites calibrated to the autonomy level of the technology in use^[11,25].

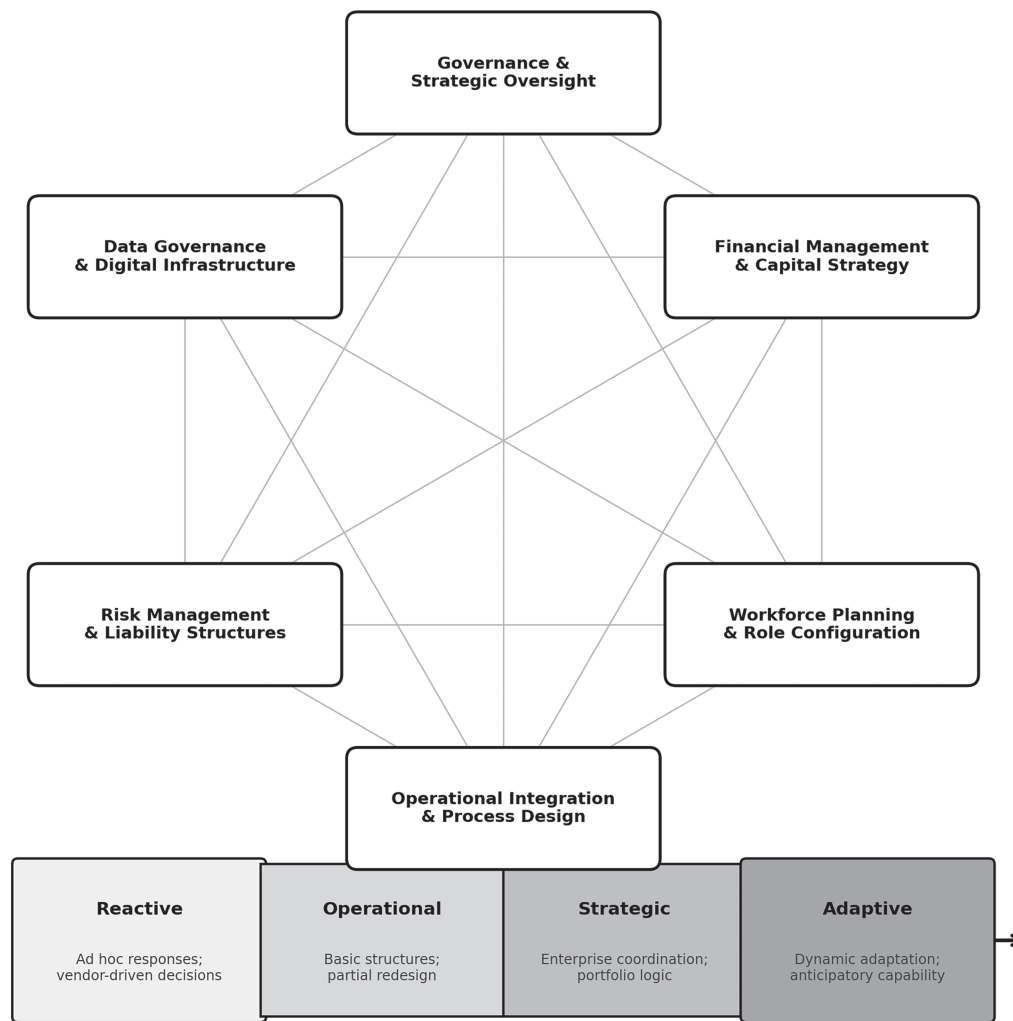
Reactive: Organizations respond to robotic surgery challenges as they arise, without systematic preparation. Governance is ad hoc, driven by individual department decisions and vendor proposals. Financial evaluation uses standard capital equipment models with no adjustment for learning curves or data value. Workforce planning focuses narrowly on surgeon training with no defined non-surgeon roles. Operations layer robots onto existing workflows. Risk management applies conventional frameworks without addressing automation-specific failure modes. Data governance is undefined, defaulting to vendor terms.

Behavioral indicators at this level: No standing robotics committee; vendor selected by department head without enterprise input; data-sharing terms accepted without institutional legal review; OR setup delays attributed to “new technology” without systematic redesign; no dedicated robotics coordinator position.

Operational: Organizations have established basic structures for managing robotic programs. Formal governance committees exist but may lack authority to override departmental decisions. Financial models account for some hidden costs and learning curve effects. Workforce planning recognizes technical support roles, though career pathways are undefined. Operations have been partially redesigned for robotic workflows. Risk frameworks address equipment-specific concerns but not algorithmic accountability or cybersecurity. Data policies exist but may not be enforced consistently.

Behavioral indicators at this level: Robotics committee meets regularly but refers major decisions upward; robotics coordinator role exists but is informally defined;

RSAR Framework: Domains and Maturity Levels



Lines indicate cross-dimensional interdependencies; shading darkens with increasing organizational maturity.

Figure 1: Schematic figure summarizing the six domains and four maturity levels of the framework. The arrow indicates the plausibility of other higher level maturity levels, which future researchers might unravel.

incident reporting covers mechanical failures but not software-related anomalies; vendor analytics accepted as primary performance source.

Strategic: Organizations treat surgical robotic systems as a strategic investment requiring enterprise-level coordination. Governance has clear authority, explicit policies, and defined accountability for algorithm performance. Financial evaluation uses portfolio models with longer time horizons and recognition of data value. Workforce planning anticipates role evolution and develops defined

career pathways. Operations are designed robotics-first. Risk management integrates clinical, technical, and cybersecurity dimensions. Data strategy includes institutional ownership policies and internal analytics capability.

Behavioral indicators at this level: Robotics steering committee holds budget authority; data-sharing terms with vendors negotiated with legal and HTM input; financial models include scenario analysis; workforce impact assessments conducted before expansion; downtime management protocols exist and are tested.

Adaptive: Organizations have developed dynamic capabilities that allow continuous adjustment to technological change. Governance can rapidly address novel challenges as autonomy levels increase. Financial models incorporate uncertainty and option value explicitly. Workforce systems support ongoing skill development as roles continue evolving. Operations can reconfigure around new capabilities with minimal disruption. Risk management anticipates emerging threats rather than responding to realized ones. Data architecture enables new analytical applications as capabilities mature.

Behavioral indicators at this level: Governance includes a standing process for evaluating autonomy escalation proposals; financial scenarios updated annually with technology roadmap input; predictive maintenance integrated with OR scheduling; near-miss detection spans clinical, technical, and vendor data streams; institutional data is analyzable independently of vendor platforms.

Table 2 provides a summary of the dimensions and corresponding maturity level attributes of the RSAR framework that we propose.

Interdependencies and failure modes

The RSAR dimensions are not independent silos. Each interacts with others in ways that create both synergies and failure risks. Organizations that advance unevenly across dimensions may find that strength in one area is undermined by weakness in another. High-reliability and socio-technical systems theories provide robust

frameworks for understanding how governance, financial strategy, workforce planning, and operational processes interact^[1,2,20].

Three failure patterns emerge from cross-dimensional misalignment:

Vendor dependency occurs when an organization acquires advanced robotic technology without governance structures capable of overseeing its use. Without clear policies for autonomy thresholds or algorithmic accountability, vendor representatives become de facto decision-makers. The technology roadmap reflects commercial priorities rather than institutional strategy. The organization has sophisticated equipment under external strategic control, a configuration that creates both performance risk and data exposure.

Throughput underperformance occurs when highly skilled robotic surgeons operate within workflows not redesigned for robotic operations. Surgical capability exceeds operational capacity to deploy it effectively. OR utilization rates disappoint despite excellent clinical outcomes. The investment in surgical training cannot be fully recovered because operational constraints limit case volume and create recurring inefficiencies that erode program confidence.

Intelligence failure occurs when an organization treats surgical robotics data as a strategic asset but fails to integrate risk management across clinical and technical domains. Data may reveal patterns predictive of safety

Table 2: RSAR framework: dimensions and maturity level characteristics.

Domain	Reactive	Operational	Strategic	Adaptive
Governance	Ad hoc decisions; vendor-driven	Formal committee; limited authority	Enterprise oversight; clear policies	Dynamic policy adaptation
Finance	Standard CAPEX models	Hidden costs recognized	Portfolio investment logic	Scenario-based; option value
Workforce	Surgeon training only	Technical roles defined	Career pathways; impact modeling	Continuous role evolution
Operations	Robots on legacy workflows	Partial redesign	Robotics-first processes	Reconfigurable systems
Risk	Conventional frameworks	Equipment-specific focus	Integrated clinical/tech/cyber	Anticipatory threat detection
Data	Undefined; vendor default	Policies exist; weak enforcement	Strategic asset; ownership secured	Interoperable; analytics-enabled

Abbreviation: CAPEX, capital expenditure.

problems, but the organizational structures to act on this information do not exist. Preventable adverse events occur despite available warning signals, because the data flows and the risk response mechanisms belong to separate organizational silos.

These examples illustrate why readiness is best assessed holistically. An organization at the strategic level in one dimension but reactive in another may perform worse than an organization at consistently operational levels across all dimensions. The RSAR framework should be used to identify not just current positions but also critical interdependencies and the specific misalignments most likely to produce failure.

A hypothetical case illustrates how the RSAR maturity markers function in practice. Consider a mid-sized community hospital currently at Level 1 (reactive) across most RSAR dimensions, which acquires a robotic surgical platform with Level 2 autonomous capabilities (task autonomy under supervision). The system can execute bounded procedural tasks such as automated suturing and tissue identification under surgeon oversight. At the reactive maturity level, this hospital has no standing robotics committee; its chief of surgery selected the vendor without enterprise input; data-sharing terms were accepted under standard procurement review; and OR workflows remain unchanged from conventional surgery. The mismatch between the technology's autonomy level and the organization's readiness level generates predictable problems across multiple RSAR dimensions. In governance, no policy exists to define which autonomous functions may be activated, so individual surgeons make these decisions inconsistently. In risk management, when the system's tissue identification algorithm produces an incorrect classification, the hospital has no audit trail documenting who approved the algorithm's activation, no protocol for reporting automation-related near-misses, and no basis for determining accountability. In workforce planning, OR staff have received no training on monitoring autonomous task execution or recognizing system failure modes, leaving the surgical team unable to intervene effectively when the system behaves unexpectedly. In data governance, the vendor's default contract provisions grant broad access to procedural recordings, and the hospital has no institutional policy establishing ownership of surgical performance data. The RSAR framework would identify this hospital's

critical gap as the mismatch between Level 2 technology and reactive-level readiness, and would prescribe targeted advancement to at least strategic-level maturity in governance, risk management, and data governance as preconditions for safe deployment of the system's autonomous functions.

Research agenda and policy implications

Limitations of the present framework

This paper advances a conceptual framework based on literature synthesis and theoretical reasoning. Its primary limitation is the absence of empirical validation. The RSAR dimensions and maturity levels have not been tested against organizational performance data; the interdependencies proposed are theoretically grounded but not yet empirically confirmed; and the specific behavioral indicators offered as markers of maturity levels reflect expert judgment rather than validated criteria. Readers should treat the framework as a structured conceptual map and hypothesis-generator, not as an empirically verified assessment instrument. This limitation motivates the research agenda described below.

Future research directions

First, the RSAR framework's dimensions and maturity levels should be operationalized through measurable indicators that allow organizations to assess their current positions and track progress. This requires both quantitative metrics (governance committee authority as measured by budget and decision scope) and qualitative assessment protocols (structured interviews with stakeholders across functional domains). Psychometric validation, covering internal consistency, inter-rater reliability, and predictive validity, should be a priority.

Second, comparative studies of governance models across organizations at different maturity levels would illuminate which structural arrangements are most effective. How do different governance configurations affect the safety and efficiency of robotic surgery integration? What distinguishes organizations that successfully redesign operations for robotic workflows from those that do not? Such comparative studies are needed to move beyond conceptual frameworks toward evidence-based best practices.

Third, the vendor-hospital relationship deserves systematic investigation. How do vendor-hospital power dynamics influence data ownership, interoperability, and strategic decision-making? Research examining negotiation dynamics, contract structures, and long-term relationship evolution would inform both organizational strategy and policy intervention.

Fourth, what are the long-term financial and operational outcomes of portfolio investment approaches relative to conventional capital equipment evaluation? Understanding these outcomes will inform sustainable investment strategies and provide evidence for or against the financial arguments advanced in this paper.

Fifth, as robotic systems gain conditional autonomy, new frameworks for understanding human-machine collaboration in surgical settings are required^[17,28]. Research at the intersection of clinical practice, organizational behavior, and AI should examine how surgical teams adapt to working with increasingly capable systems, what factors support effective human-machine teaming, and how trust and authority relationships evolve.

Table 3 recaps the managerial challenges associated with robotic surgery, in terms of the key themes identified in the literature.

Policy and accreditation implications

Current accreditation standards for surgical robotic systems focus primarily on clinical competency, ensuring that surgeons and surgical teams have adequate training to operate robotic systems safely. While clinical standards

remain important, this paper's analysis suggests they are insufficient on their own. There is a growing call in the literature for robotics-specific accreditation standards, reconsidered capital approval mechanisms, and regulatory frameworks that account for the dynamic nature of software-driven surgical systems^[4,19,29].

Accreditation bodies should consider standards that address governance structures (requiring clear authority and accountability for robotic programs), data governance (ensuring institutions maintain ownership of surgical performance data), risk integration (requiring unified assessment of clinical, technical, and cybersecurity risks), and workforce planning (ensuring adequate staffing beyond surgeon operators). These standards should scale with autonomy levels: organizations deploying systems with higher autonomous capabilities should meet correspondingly higher administrative readiness requirements.

Capital approval mechanisms also warrant reconsideration. Certificate-of-need processes and internal capital allocation procedures that evaluate robotic systems as conventional equipment fail to account for the strategic dimensions this paper identifies. Policy frameworks that encourage longer evaluation horizons, recognize data value, and require assessment of administrative readiness, alongside clinical readiness, would better align approval processes with the actual organizational challenges of robotic surgical integration.

A phased approach to policy development could proceed along three horizons. In the near term (one to three years), accreditation organizations such as The Joint Commission and relevant specialty boards could incorporate administrative readiness assessment into existing robotic surgery credentialing processes. This would involve requiring hospitals to demonstrate governance structures, designate responsible oversight bodies, and establish basic data governance policies as preconditions for robotic program accreditation. In the medium term (three to five years), regulatory agencies could develop technology assessment standards that require administrative readiness review alongside clinical safety evaluation when robotic systems with expanded autonomous capabilities enter the market. This would link device-level approval to facility-level preparedness, ensuring that advanced systems are deployed in organizations

Table 3: Managerial challenges for robotic surgery.

Themes	Key sources
Robust governance structures are essential	[1,3,29]
Traditional ROI models are inadequate	[4,5,15]
Multidisciplinary training and new roles are critical	[16,17,28]
Data governance is central to robotics value	[5,7,13]
Operational redesign is necessary but under-addressed	[3,8,26]
Empirical validation of frameworks is lacking	[2,15,22]

Abbreviation: ROI, return on investment.

equipped to govern them. In the longer term (five years and beyond), policymakers could consider tiered regulatory oversight in which the administrative readiness requirements scale with the autonomy level of deployed systems, paralleling the approach used in aviation automation regulation. Organizations deploying Level 2 or Level 3 autonomous surgical systems would be required to demonstrate adaptive-level readiness across RSAR domains as a condition of licensure.

Such a roadmap would also benefit from attention to technology assessment committees within hospitals. These bodies, which currently evaluate new devices primarily on clinical evidence and cost, could be expanded in scope to assess administrative readiness before approving robotic platform acquisitions or autonomy-level upgrades. Integrating RSAR-aligned criteria into technology assessment would shift institutional purchasing decisions from a procurement logic to a preparedness logic, with measurable implications for patient safety and organizational performance.

Conclusion

The integration of advanced surgical robotic systems is a transformative organizational challenge. The next phase of development, characterized by expanding algorithmic capabilities and graduated autonomy, will impose demands on healthcare organizations that clinical training programs alone are not designed to meet. The RSAR framework provides a conceptual map for navigating these demands. Its six dimensions, covering governance, finance, workforce, operations, risk, and data, identify the organizational systems that should be developed in coordination. Its four maturity levels, anchored by behavioral markers, offer a progression from reactive response to adaptive capability. Its emphasis on cross-dimensional interdependencies highlights the failure modes that emerge when organizations advance unevenly.

The implications extend beyond individual institutions. As surgical robotic systems become more capable and more prevalent, a growing share of adverse outcomes and missed value opportunities will be attributable to administrative gaps: governance structures that failed to keep pace with technology, financial models that discouraged necessary investment, workforce systems that left critical roles unfilled, operational designs that

generated recurring inefficiency, risk frameworks that missed emerging threats, and data practices that surrendered strategic assets.

The evidence base is strong for the need for robust governance, innovative financial strategies, multidisciplinary workforce planning, operational redesign, integrated risk management, and active data governance. Empirical research on implementation and effectiveness remains limited, and bridging that gap should be a research priority. Until that empirical work is completed, the RSAR framework should be understood as a diagnostic and generative tool: it identifies where organizational gaps are likely to occur and generates testable propositions about their consequences, but it is not yet a validated assessment instrument. Addressing it will be critical for realizing the sustained value of surgical robotic systems in healthcare and for ensuring that its benefits are distributed equitably across diverse health system contexts. It bears emphasizing that the RSAR framework occupies a distinct position relative to existing models such as HIMSS EMRAM, HIMSS INFRAM, and general HTM governance frameworks. Those models assess digital health adoption and device lifecycle management broadly, but none integrates governance, financial, workforce, operational, risk, and data dimensions under a single readiness construct calibrated specifically to semi-autonomous surgical robotic systems. The RSAR framework's unique contribution lies in its surgery-specific focus, its cross-dimensional failure mode mapping, and its explicit linkage of organizational maturity levels to the autonomy level of deployed technology. The call to action is proactive, system-level preparation for surgical robotics that extends well beyond clinical training. Organizations that begin this preparation now, even before highly autonomous systems are clinically deployed, will be positioned to integrate new capabilities safely and effectively. Those that wait risk managing crises rather than realizing opportunities. Administrative preparedness is a strategic priority. The time to address it is before capability outpaces governance. The RSAR framework reframes surgical robotic adoption as an organizational capability problem, not a procurement decision.

Author contributions

BG: conceptualization, methodology, research, writing.

Acknowledgments

This research received no external funding.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

AI statement

The author declares that no generative AI or AI-assisted technologies were used in the preparation, analysis, or writing of this manuscript.

Ethical statement

Ethical review is not applicable to this article.

Conflicts of interest

The author declares no conflicts of interest.

References

- Catchpole K, Cohen T, Alfred M, et al. Human factors integration in robotic surgery. *Hum Factors*. 2024;66(3):683-700.
- Randell R, Honey S, Alvarado N, et al. Embedding robotic surgery into routine practice and impacts on communication and decision making. *Cogn Tech Work*. 2016;18:423-437.
- Giedelman C, Covas Moschovas M, Bhat S, et al. Establishing a successful robotic surgery program and improving operating room efficiency: literature review and our experience report. *J Robot Surg*. 2021;15(3):435-442.
- Olawade DB, Marinze S, Weerasinghe K, Egbon E, Onuoha JU, Teke J. Robotic surgery in healthcare: current challenges, technological advances, and global implementation prospects. *J Robot Surg*. 2025;19(1):577.
- Pal H. Advancements and limitations in integrating robotics into medicine: a comprehensive review. *Multidiscip Rev*. 2024;7(11):2024248.
- Kok Wah JN. AI-driven robotic surgery in oncology: advancing precision, personalization, and patient outcomes. *J Robot Surg*. 2025;19(1):382.
- Mizna S, Arora S, Saluja P, Das G, Alanesi WA. An analytic research and review of the literature on practice of artificial intelligence in healthcare. *Eur J Med Res*. 2025;30(1):382.
- Bramhe S, Pathak SS. Robotic surgery: a narrative review. *Cureus*. 2022;14(9):e29179.
- Rasmussen MK, Schneider-Kamp A, Hyrup T, Godono A. New colleague or gimmick hurdle? A user-centric scoping review of the barriers and facilitators of robots in hospitals. *PLOS Digit Health*. 2024;3(11):e0000660.
- Randell R, Honey S, Hindmarsh J, et al. A realist process evaluation of robot-assisted surgery: integration into routine practice and impacts on communication, collaboration and decision-making. *Health Soc Care Deliv Res*. 2017;5(20):1-140.
- Saqib U, Ilyas S, Abdullah M. Implementation of artificial intelligence (AI) into robotic surgical systems. *AIJSS*. 2025;4(3):2611-2624.
- Nimkar P, Kanyal D, Sabale SR. Increasing trends of artificial intelligence with robotic process automation in healthcare: a narrative review. *Cureus*. 2024;16(9):e69680.
- Shang Z, Chauhan V, Devi K, Patil S. Artificial intelligence, the digital surgeon: unravelling its emerging footprint in healthcare—the narrative review. *J Multidiscip Healthc*. 2024;17:4011-4022.
- Razek A. From open, laparoscopic, or computerized surgical interventions to the prospects of image-guided involvement. *Appl Sci*. 2025;15(9):4826.
- Szold A, Bergamaschi R, Broeders I, et al. European Association of Endoscopic Surgeons (EAES) consensus statement on the use of robotics in general surgery. *Surg Endosc*. 2015;29(2):253-88.
- Ghattas S, Piliounis C. Navigating human resources issues in healthcare: the intersection of humans and robots. *J Organ Psychol*. 2025;25(3):15-37.
- Kim S. Working with robots: human resource development considerations in human-robot interaction. *Hum Resour Dev Rev*. 2022;21:48-74.
- Martins O, Oosthuizen C, Desai D. Exploring the import of mechatronics engineering in medicine. *Beni-Suef Univ J Basic Appl Sci*. 2025;14:26.
- Corfmat M, Martineau JT, Régis C. High-reward, high-risk technologies? An ethical and legal account of AI development in healthcare. *BMC Med Ethics*. 2025;26(1):4.
- Ang KCS, Sankaran S, Liu D. Advancing sociotechnical systems theory: new principles for human-robot team design and development. *Appl Ergon*. 2025;129:104604.
- Yu X, Xu S, Ashton M. Antecedents and outcomes of artificial intelligence adoption and application in the workplace: the socio-technical system theory perspective. *Inf Technol People*. 2023;36(1):454-474.
- Saroha S, Patel A. Balancing surgical innovation and risk: a narrative review of emerging technologies, regulation, and global access. *Cureus*. 2025;17(7):e87957.
- Arepalli B. Leveraging AI and machine learning in embedded technology for healthcare innovation. *Int J Health Sci*. 2025;8(1):31-40.
- Habbal A, Ali M, Abuzaraida M. Artificial intelligence

- trust, risk and security management (AI TRiSM): frameworks, applications, challenges and future research directions. *Expert Syst Appl.* 2024;240:122442.
25. Sharuk Kumar B, R. Kamaraj. Artificial intelligence and autonomous robotic surgery: innovations, challenges, and regulatory pathways. *Bioscan.* 2025;20(Special Issue-3): 277-285.
 26. Holland J, Kingston L, McCarthy C, et al. Service robots in the healthcare sector. *Robot.* 2021;10(1):47.
 27. Giallanza A, La Scalia G, Micale R, La Fata C. Occupational health and safety issues in human-robot collaboration. *Saf Sci.* 2024;169:106313.
 28. Arslan A, Cooper C, Khan Z, Golgeci I, Ali I. Artificial intelligence and human workers interaction at team level: a conceptual assessment of the challenges and potential HRM strategies. *Int J Manpow.* 2022;43(1):75-88.
 29. Patel V, Saikali S, Kavoussi L, et al. Best practices in telesurgery: framework and recommendations from the society of robotic surgery (SRS) for safe and effective implementation. *J Robot Surg.* 2025;19(1):370.
 30. Jeyaraman M, Jeyaraman N, Ramasubramanian S, Murugan S, Vijayaragavan V. Review of robotics in healthcare education. In: Proceedings of the 6th IEEE International Conference in Robotics and Manufacturing Automation (ROMA). 2025:107-112.
 31. Bharadwaj HR, Wireko AA, Adebusoye FT, et al. Challenges and opportunities in prostate cancer surgery in South America: insights into robot-assisted radical prostatectomies-A perspective. *Health Sci Rep.* 2023; 6(8):e1519.
 32. Falola AF, Singh S, Das U, Oluwagbemi A, Etta R, Adeyeye A. Barriers and recommendations for the implementation of robot-assisted minimally invasive surgery in Africa. *J Robot Surg.* 2024;19(1):16.
 33. Falola A, Ndong A, Adeyeye A. Orienting global surgery initiatives toward advancing minimally invasive surgery in Africa: a commentary based on continent-wide reviews. *BMC Surg.* 2025;25(1):129.