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A System Perspective on Implementation and Usage of the Da Vinci Technology at a Large Norwegian Regional Hospital'

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Abstract

The aim of this research paper is to identify advantages and barriers to implementation and usage of robotic-assisted surgery (RAS), specifically the Da Vinci robot, at a larger regional hospital in Norway and from a multiple stakeholder perspective. The identified advantages and barriers are connected to the socio-technical system framework SEIPS, thereby establishing a broader contextual system perspective on RAS implementation and usage. Our findings both align and extend upon existing human factors and ergonomics (HFE) knowledge on RAS in the operating room. In terms of specific future directions, we believe that a pressing concern for both management and current HFE research involving RAS implementation and usage relates to exploring and accounting for the close connections between the organization itself and the external stakeholders that exert a considerable influence on the internal work system and processes and the ability to achieve cost-efficiency and safety levels. We further conclude that the SEIPS framework can be a powerful tool in drawing or eliciting the larger contextual picture of RAS implementation and usage, and we encourage further HFE research to explore its application in different contexts to improve the current knowledge base.

Keywords

ergonomics, social sciences, System Engineering Initiative for Patient Safety SEIPS, robotic-assisted surgery RAS, computer-assisted qualitative data analysis software (CAQDAS)

Introduction

The first documented robotic-assisted surgery (RAS) was undertaken in 1985 as a delicate neurosurgical biopsy procedure. In the wake of this procedure's successful outcome, the first robotic-assisted laparoscopic cholecystectomy was conducted in 1987 in Lyon, France (Reynolds, 2001; Samadi, 2018). Robotic surgery was first commercially introduced in 2000, following the US Food and Drug Administration's (FDA) approval of Intuitive Surgical's Da Vinci technology. The technology has since seen constant growth and demand within numerous medical fields and procedures, partially backed by studies documenting the technology's positive effects, including reductions in patient recovery times, blood loss, and pain (Perez & Schwaitzberg, 2019).

The use of RAS entails spreading fixed costs across a higher volume of operations, which can be achieved through efficiency-improving measures such as reducing the patient's length of stay (LOS)/freeing up more inpatient beds, prioritizing RAS, and fostering highly skilled surgeons (Perez & Schwaitzberg, 2019). Another advantage of RAS is that it can facilitate a transition to less invasive surgery, with associated patient benefits such as decreased hospital length of stay (LOS), fewer complications and less pain, quicker return to work, and lowered likelihood of reoperations (Perez & Schwaitzberg, 2019).

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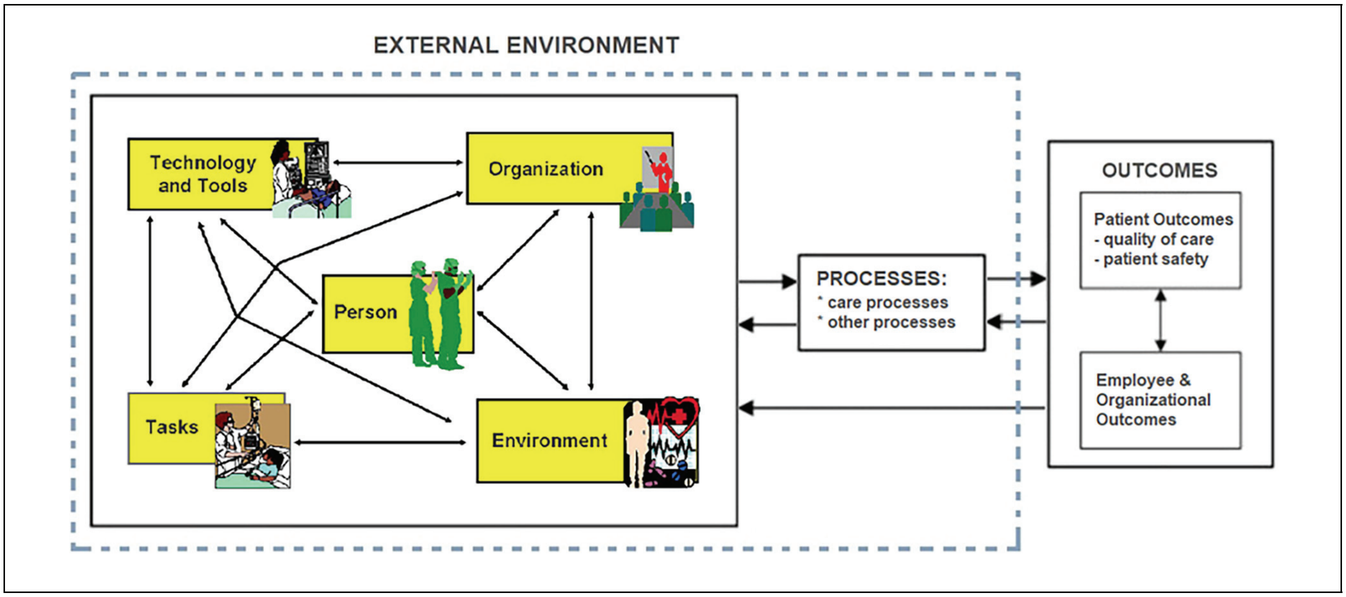

Figure 1. The SEIPS framework of work system, processes, and outcomes, based on Carayon, Xie, and Kianfar (2014).

Specifically, within RAS for rectal cancer, Wang et al. (2020) found lower severe complications and anastomotic leak rates. RAS can also improve access in difficult procedures such as trans-oral robotics and has the potential to take over where the limits of human dexterity set in, which is quickly approaching (Dobbs et al., 2017). Within plastic and reconstructive surgery, and compared to conventional approaches and techniques, RAS can improve cosmesis, surgeon's operating mobility, and patient's functional (physical) outcomes. However, RAS also introduces demanding learning curves, preparations, operating times, sensitive instruments (microneedles that break), and high costs of the technology (Nehme et al., 2017). The costs associated with implementing RAS as well as the fact that yielding a return on the investment may take years and, in some cases, may never happen, represent a major adoption barrier for smaller-sized health care systems (Perez & Schwaitzberg, 2019). Adding to these costs, practitioners and critics have identified several weaknesses of the current technology, specifically related to the system's haptic feedback, docking/setup, and stapling devices (Henry et al., 2015). Nuancing the above picture of Da Vinci robot cost-benefit aspects, Turchetti et al. (2012) compared RAS to manual laparoscopic surgery and found that while RAS brings higher procurement and maintenance costs as well as an increase in operating room times, operating room times also decrease with RAS experience.

Furthermore, an increasing body of literature is now pointing to how RAS alters the organization of work. It is shown that RAS entails the redistribution of workload, workflow disruptions, and changes in communication and teamwork, and where workflow disruptions are linked to coordination, challenges with equipment, and communication (K. R. Catchpole et al., 2018; K. Catchpole et al., 2019). Moreover, studies have pointed to the learning of new skills including non-technical team communication and personal interaction with new modes of nonverbal communication (Gillespie et al., 2021; Schreyer et al., 2022). A review looking at work system barriers for efficiency and safety addresses changes in coordination, communication and teamwork, procedures, preparation, and layout issues (Kanji et al., 2021). This review concludes with the need for system-level solutions, and where an issue discussed is how hospitals vary in how to prepare their staff for introducing new technologies and at what level (individual vs. system) (Kanji et al., 2021).

As shown above, RAS has the characteristics of a complex intervention, as evident in the specific challenges having non-technological components, being individual, social, and organizational, and as seen in the changing delivery and organization of health care services (Gillespie et al., 2021). This calls for the application of a human factors and ergonomics (HFE) approach, also highlighted in BMJ and BMJ Quality and Safety (Carayon, Xie, & Kianfar, 2014; K. Catchpole, 2013; Gurses et al., 2012; Koch et al., 2020; McCulloch et al., 2010; Waterson & Catchpole, 2016; Wiegmann & Sundt, 2019), due to its ability to capture the dynamics, complexities, and emerging behaviors of hospitals and hospital departments nested within larger health care systems (Dekker & Leveson, 2015). Anchored within this tradition is the SEIPS (System Engineering Initiative for Patient Safety) framework, shown in Figure 1 (Carayon et al., 2006). The framework details elements within a work system (leftmost side of Figure 1) that interact and are mutually interdependent, including person, technology and tools, task, environment, and organization. The external environment surrounding and influencing the work system and processes aspects of the model encompasses macro-level factors outside an organization and related to society, economics, and politics (see Carayon, 2009; Carayon et al., 2006, 2020; Carayon, Wetterneck et al., 2014; Holden et al., 2013; Høyland et al., 2019).

The constellation of elements in the work system affects different processes (e.g., the use of the Da Vinci robot) that in turn influence different outcomes related to patients, the employees, and the organization (Carayon et al., 2006). A core aspect of the SEIPS framework lies in its ability to inform implementation, change management, and the design of complex systems, where specifically the feedback loops in the framework suggest that insights into the dynamics of the model including outcomes can be applied to adjust and redesign a work system (Xie & Carayon, 2015). Thus, the framework contributes toward the prevention of undesired outcomes across system performance and well-being in a health care context, specifically in terms of patient outcomes (mortality, complications, quality of life, medical errors), organizational outcomes (efficiency, treatment time), and employee outcomes (well-being aspects such as job satisfaction and motivation) (Xie & Carayon, 2015).

Up to now, most studies on RAS using an HFE approach have mainly been occupied with what is going on in the operating room. In their review of HFE-based health care system redesign approaches, Xie and Carayon (2015) criticize research projects that apply a microergonomics-focused HFE approach to medical devices and Health IT mostly without accounting for the complexity of sociotechnical systems (STS) including mesoergonomics. Mesoergonomics is understood as "an open systems approach to human factors and ergonomics (HFE) theory and research whereby the relationship between variables in at least two different system levels or echelons is studied, and where the dependent variables are human factors and ergonomic constructs" (Karsh et al., 2014: p. 45). HFE research has pointed to the need to consider overlaps and interactions between different system levels including (the gap between) the domains of micro- and macroergonomics (Karsh et al., 2014; Waterson & Catchpole, 2016).

Our study adds a system-level understanding of RAS implementation and usage, which includes the perspectives of middle and upper-level managers. In this way, this study contributes to the current state-of-the-art on RAS implementation and usage, by extending the sharp end/work system perspectives to include also the surrounding organizational and external context (see the circular model in Carayon et al., 2015). This approach meets the need for studies that try to connect different system levels including micro- and macroergonomics. In particular, the approach is in line with Randell et al.'s (2019) call for more knowledge "about the contextual factors necessary for successful integration of robot-assisted surgery more broadly" (p. 2). Thus, the aim of this research paper is two-fold: (i) To identify advantages and barriers to RAS implementation and usage in the case organization (a larger regional hospital in Norway), and (ii) to connect the identified advantages and barriers to the STS framework SEIPS developed by Carayon, Wetterneck et al. (2014), Carayon (2009), Carayon et al. (2006) and thereby achieve a holistic/contextual system perspective on RAS implementation and usage.

Methods

Study Setting

The study was conducted at a large Norwegian hospital, which ordered the da Vinci robot in 2010. Like all public hospitals in Norway, the case hospital has been owned by the state since the hospital trust reform in 2002 when ownership was transferred from the county to the state level and five regional health trusts were established (later merged into four). The Patient Rights Act ensures patients' free choice of hospital, however, well-educated patients with high income predominate in exercising this right (Bjorvatn & Ma, 2012). Most patients are treated in their nearest hospital. The studied hospital serves a population of 350,000 plus. Anonymity concerns restrict further detailing of the study setting.

Data Collection

This paper includes 13 semi-structured in-depth interviews with higher- and middle-level managers as well as sharp-end personnel at a large regional hospital in Norway (Table 1). We randomly included stakeholders at multiple levels of the hospital organization, to gain broad insights and perspectives on the Da Vinci robot implementation process and usage. The donor/gift giver financed the study, and we chose to interview a representative of the donor to explore the motivations and premises for the donation. The interviews were undertaken between October 2014 and March 2015, face to face and following a predefined interview guide. The guide included topics such as how the implementation and adaptation of medical technology were done at the hospital, why they decided to introduce the technology, expectations of the new technology, if they reorganized units and relations, what kind of challenges they met, and so forth. The length of each interview was approximately an hour. All interviews were digitally recorded and transcribed with anonymization including the

Table 1. Managers, Personnel, and External Stakeholders Interviewed.

Interview #	Interview category	Interview sub-category
1	Higher-level manager	Director 1
2		Director 2
3		Director 3
4		Director 4
5		Director 5
6	Middle-level manager	Section Chief 1
7		Section Chief 2
8	Sharp-end personnel	Gynecologist
9		Gastrologist
10		Urologist
11		Operating room nurse
12		Service technician
13	External stakeholder	Da Vinci gift giver

removal of all names, affiliations, and other sensitive information. The transcribed material comprised a total of 272 pages.

The interview material with higher-level managers included in this paper focuses on the background and considerations involved in the planning and implementation of new technology at the hospital level, including the Da Vinci robot. The sharp-end interviews with operators, nurses, technicians, and so forth focus more specifically on experiences with the Da Vinci robot and therefore feature more frequently in the results section including the results tables.

Data Analysis

The empirical data were systematically analyzed using QSR NVivo 11, which is a "computer-assisted qualitative data analysis software" (CAQDAS). CAQDAS increases the researcher's ability to gain an overview of and map emerging patterns and relationships in the data material, in this case, related to our research aim of identifying advantages and barriers to Da Vinci robot implementation and usage as well as the connections between the identified advantages and barriers and the SEIPS framework (Talanquer, 2014). Thus, as an analytical tool, CAQDAS strengthens the researcher's ability to operate systematically when analyzing data, thereby improving reliability (de Ruyter & Scholl, 1998). CAQDAS also supports "creative management of multiple data sources and enables researchers to make visible their methodological processes for a more 'trustworthy' study" (Ryan, 2009, p. 159), which highlights the importance of outlining in detail the researcher's analytical process (Kapoulas & Mitic, 2012). For this study, we applied a "meaning unit-category-theme" coding approach to identify patterns and ultimately themes in our data material (Høyland, 2018a, 2018b; Høyland et al., 2014, 2017, 2018, 2019; Leech & Onwuegbuzie, 2007). Meaning units express stand-alone meanings in the interview material, in this paper connected to the Da Vinci robot technology implementation and usage. Related meaning units form categories of meaning, and related categories become themes (highest abstraction level). In the NVivo terminology, and as shown in Tables 2 to 5, lower-level nodes equal meaning units and higher-level nodes categories, that is, the nodes serve as means of coding.

Aimed at identifying advantages and barriers to Da Vinci robot implementation and usage at the case hospital, Author 1 conducted an electronic content analysis of the interview transcripts using QSR NVivo. The 13 interview transcripts were imported into NVivo as "document sources" (program term). Author 1 read each source document and identified standalone meanings regarding Da Vinci implementation and usage. This produced multiple lower-level nodes (66), higher-level nodes (8) comprising related nodes, and at the largest abstraction level themes (4) combining the higher-level nodes. For each node, Author 1 identified advantages and barriers to Da Vinci robot implementation and usage as well as specific connections to the SEIPS model including work system, external environment, processes, and outcomes. The results of the content analysis were subjected to discussions at an internal workshop with Authors 1 to 3. Having conducted the interviews and previously analyzed the data, the coding outcome resonated with the impressions of Authors 2 and 3. In addition, the workshop improved the understanding of advantages and barriers, and their nuances, associated with Da Vinci implementation and usage. In other words, the workshop applied analytical triangulation and consensus-seeking (to reach coding agreement), thereby improving the validity of the content analysis process (Bradley et al., 2007; Denzin, 1978; Hruschka et al., 2004; Patton, 1990). The results of the coding process, including identified advantages and barriers to Da Vinci robot implementation and usage and associated SEIPS framework connections, are presented in the next section.

Ethical Aspects of the Study

The study was approved by the Norwegian Centre for Research Data (NSD). Participation in the study was voluntary, and all stakeholders agreed to participate. Written consent was obtained from all study participants. All interviews were de-identified and all data were kept confidential. The donor/gift giver financed the study but was not involved in the study beyond being interviewed as a study participant.

Table 2. Coding Outcome Related to Theme I.

Theme I: Balancing costs, benefits, and operational utilization of the Da Vinci robot

Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
H1: A large volume across multiple operations and constant use required to justify robotic surgery *(Sources: 3; References: 5)*	**N1:** The Da Vinci robot must be up and running all the time to pay off economically	The technology demands constant use **(B)**	Section chief 2
	N2: The Da Vinci robot must be used frequently and on multiple types of operations to justify the investment; currently, several professions (gastrointestinal and urologist surgeons) use the robot 4 to 5 times a week	Expensive investment requires frequent use **(B)**; use on multiple types of operations and professions **(A)**	Service technician
	N3: The Da Vinci robot requires large operations or volumes of operations to pay off economically as well as investment in using it to develop experience and skills	The technology requires production volume as well as invested use **(B)**	Section chief 2
	N4: The Da Vinci robot requires many operations to justify the investment	The technology requires volume to pay off **(B)**	Section chief 2
	N5: There is an economic focus on utilizing the Da Vinci robot as much as possible when it is available	There is an economic incentive to utilize the robot **(A)**	Gynecologist
H2: The initial investment and follow-up running and maintenance costs of robotic surgery must be weighed against the benefits in terms of patients seeking hospitals using this technology and achieving shorter patient stays and competency improvements *(Sources: 7; References: 10)*	**N6:** Compared to alternative surgery, the Da Vinci robot is more costly and time- demanding in everyday operations	The technology is more expensive and time-demanding **(B)**	Director 4
	N7: Compared to traditional procedures, the Da Vinci robot costs more given that it does not use long-lasting and reusable equipment and has a higher procurement cost	The technology has high procurement and equipment costs **(B)**	Gastrologist
	N8: Costs associated with running the Da Vinci robot, in terms of initial investment, service agreement, and associated consumables are weighed against the patient's preference for hospitals that are using robot-assisted surgery	Balancing the costs and benefits for the organization and patients **(A & B)**	Urologist
	N9: Da Vinci robot-assisted operations are expensive—economy versus benefits of its use is important to consider; the robot must be utilized, and people only want to be operated on if the hospital has a robot; people like new and fancy things but the robot is only an aid and not a gimmick	Expensive technology requires frequent use and attracts patients that desire the newest technology **(A & B)**	Gynecologist
	N10: Sterilizing the Da Vinci robot requires more preparations (20–30 min) than regular operations	The technology makes preparations more demanding **(B)**	Operating room nurse
	N11: The Da Vinci robot is costly since it requires expensive service, and the use of the robot was therefore postponed for several years at one of the hospital sections	Service of the technology is expensive **(B)**	Section chief 2
	N12: The Da Vinci robot is more expensive to run compared to conventional open surgery, but patients will have a shorter length of stay (LOS) at the hospital and quicker recovery to work	The technology is costlier than conventional surgery **(B)**, but reduces patient LOS and improves recovery **(A)**	Urologist
	N13: The Da Vinci robot product is in a monopoly situation, which is costly for the hospital both with regards to courses and the investment in the robot itself	The monopoly situation leads to high costs **(B)**	Gynecologist
	N14: Total cost related to daily operations is the most important challenge when it comes to new technology such as the Da Vinci robot	Using new technology is expensive **(B)**	Section chief 1
	N15: When deciding on whether to acquire the Da Vinci robot, the hospital had to weigh the costs of running the technology against the benefits of shorter patient stays and technical competency improvements for surgeons	Balancing the costs and benefits for the organization, personnel, and patients **(A & B)**	Urologist

Table 3. Coding Outcome Related to Theme II.

Theme II: The Da Vinci robot challenges internal support and surgical operations through distance to patient and services			
Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
H3: Communication in robotic surgery is critical due to the operator's distance to the patient and thereby reduced overview of the operation *(Sources: 3; References: 3)*	**N16:** Communication is essential in robot surgery, given that the operator is occupied with the console and does not have an overview of the field	Due to the physical distance to the operating area, communication is critical to Da Vinci operations **(A & B)**	Operating room nurse
	N17: Given that the focus is on the operating area, the Da Vinci robot reduces the overview of the overall operation, thereby creating an overall operational distance	The technology reduces the overall overview of the operation **(B)**	Gastrologist
	N18: Physical distance to the patient makes communication during robot-assisted operations central, including mastering robot surgery	Communication is central to coping with patient distance and mastering **(A & B)**	Gynecologist
H4: Specialized overseas service agreements for the Da Vinci robot hamper the organization's ability to address errors internally, causing downtime, operator helplessness, and change to an alternate type of operation—compensating efforts include internal technical expertise and preventive maintenance by the Da Vinci supplier *(Sources: 5; References: 6)*	**N19:** If there is downtime, in-house technical personnel try to fix the problem, but these are not approved or authorized by the supplier; the supplier itself runs the service and does not offer training to in-house personnel, which is impractical since the service is stationed abroad and have resulted in a transition to open surgery	Unauthorized/untrained technical in-house personnel **(B)**; supplier service monopoly **(B)**; physical distance/abroad has required operational transitions **(B)**	Service technician
	N20: The company behind the Da Vinci robot does not want the internal medical-technical division involved in technical Da Vinci training, even though the operating room team is fully dependent on medical-technical support when the machine fails	External environmental restrictions on technical support hinder internal use of technology **(B)**	Operating room nurse
	N21: The company behind the Da Vinci robot performs preventive maintenance, resulting in high uptime for the robot	Technology support ensures high uptime **(A)**	Director 5
	N22: The Da Vinci robot has failed, making the operator helpless until the error is rectified	The technology fails and affects tasks during operations **(B)**	Gynecologist
	N23: The Da Vinci robot requires special service expertise that is procured through oversea service agreements, which means that it takes longer to get help. This is somewhat compensated for through internal expertise	The technology requires special oversea service expertise **(B)**, compensated for through informal internal support **(A)**	Section chief 1
	N24: The Da Vinci robot sometimes fails and requires a change to open surgery	The technology can fail **(B)**	Operating room nurse

Table 4. Coding Outcome Related to Theme III.

Theme III: Da Vinci robot suitability, familiarity, and specialization required to reap improved workplace design and patient safety

Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
H5: Compared to traditional operations, robotic surgery improves workplace design including precision, patient access using thinner instruments, and sitting working position using sticks, which in turn improves patient safety – however, the technology requires specialization *(Sources: 3; References: 6)*	**N25:** Compared to traditional operations, the Da Vinci robot is better across several parameters such as working position, precision (incl 3D image), and consequently patient safety	The technology improves comfort levels, precision, and patient safety **(A)**	Gastrologist
	N26: The Da Vinci robot enables the surgeons to work in a sitting position	The technology improves workplace design **(A)**	Operating room nurse
	N27: The Da Vinci robot improves mobility and access due to thinner instruments, compared to traditional techniques	The technology makes operations easier **(A)**	Gastrologist
	N28: The Da Vinci robot is very ergonomic in practice due to the ability to use sticks and sit comfortably, but requires existing competency and knowledge	Ergonomic design benefits practice **(A)** but requires specialization **(B)**	Gynecologist
	N29: The Da Vinci robot results in more precise surgery with 3D visualization and easier access to patients, while also offering a much better working position or sitting position	The Da Vinci robot enables more precise surgery and better workplace design **(A)**	Gynecologist
	N30: Unique to the technology, the Da Vinci robot can be operated from anywhere, via the Internet, and by several consoles and users and control units	The technology can be operated remotely from anywhere and by several users **(A)**	Gastrologist
H6: Selecting robotic or open surgery depends on the operator's familiarity level, direct patient contact need, and the technical and side-effects suitability of the type of patient and procedure—the Da Vinci robot requires specialization and operating time *(Sources: 8; References: 16)*	**N31:** It is easier to use the Da Vinci robot compared to traditional laparoscopy, but if you already know laparoscopy the "robot benefit" is not that large	The technology makes operations easier **(A)**	Gastrologist
	N32: Operations that are tight and with limited visibility are much easier to do using robot technology	The technology makes operations easier **(A)**	Gastrologist
	N33: Selecting a Da Vinci robot surgery or open surgery is based on what benefits the patient the most and not the economy	Use of the Da Vinci robot or not depends on an assessment of patient benefits **(A or B)**	Gynecologist
	N34: The Da Vinci robot can result in less pain for the patient due to fewer side effects and infections. However, Da Vinci operations last longer and require more specialized education compared to open surgery; this can lead to a need to hire personnel (economic effect)	The technology can reduce patient pain and thereby improve patient safety **(A)**, but is more competency and time-demanding **(B)**	Director 2
	N35: The Da Vinci robot has large benefits, given that less competency and training are required to use the robot compared to traditional procedures. At the same time, those who already have a mastery of laparoscopy can expand their competency	The technology improves competencies and is less demanding to use compared to traditional procedures **(A)**	Gastrologist
	N36: The Da Vinci robot is gentler for obese people and operations that involve sewing, and the 3D visualization that the technology enables also improves precision when using instruments	The technology is more precise, reducing patient pain and thereby improving patient safety **(A)**	Section chief 2
	N37: The Da Vinci robot is gentler for several types of operations, such as obesity and lymph nodes	The technology is gentler for several types of operations **(A)**	Section chief 2
	N38: The Da Vinci robot made it easier to do prostate operations and one could operate on a lot more patients (effective). High demand for this type of operation is remedied by the Da Vinci robot	The technology increases the number (satisfying demand) and ease of prostate operations **(A)**	Gastrologist

(continued)

Table 4. (continued)

Theme III: Da Vinci robot suitability, familiarity, and specialization required to reap improved workplace design and patient safety			
Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
	N39: The Da Vinci robot operates more elegantly and does less damage to functions, which again results in fewer side effects of the treatment	The technology reduces patient pain and thereby improves patient safety **(A)**	Director 3
	N40: The Da Vinci robot operates more elegantly and has fewer side effects, but is more resource-demanding	The technology reduces patient pain and thereby improves patient safety **(A)**, but is resource-demanding **(B)**	Director 3
	N41: The Da Vinci robot robs the operator of direct physical contact with the patient, which alienates or excludes some older operators, and makes the robot unsuited to many cancer operations where you need to "feel your way"	The Da Vinci robot creates a physical distance to the patient and is therefore unsuited for certain operations **(B)**	Gynecologist
	N42: The Da Vinci technology is more suited to some groups, and new technology requires research that can document results from its use	The technology requires research and is more suited to certain groups **(B)**	Director 5
	N43: The gains (cost-benefit) of using the Da Vinci robot are higher for complex and open operations than for routine operations that are already considered safe	The technology benefits more risky operations **(A)**	Gastrologist
	N44: The robot is particularly suited to operating in the pelvis region	The technology suits certain procedures in particular **(A)**	Operating room nurse
	N45: There are several operations where the Da Vinci robot is unsuited for the task, but this number is less over time than for traditional laparoscopy	The technology is not suited to all operations and tasks **(B)**	Gastrologist
	N46: Urology is technically orientated as seen in the increasing application of numerous advanced instruments, producing a low threshold for adopting robot-assisted surgery	A low threshold for technology adoption among urologists **(A)**	Urologist

Table 5. Coding Outcome Related to Theme IV.

Theme IV: Broader organizational commitment of personnel (training) and infrastructure required to improve systemization, standardization, and safety and efficiency of operations			
Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
H7: Robotic surgery training and procedures can be standardized but require improvements in infrastructures including physical rooms and resources for using new technology—the payoff can be improvements in systemizing of operations that can increase team awareness and safety considerations *(Sources: 6; References: 10)*	**N47:** Da Vinci training and procedures can be standardized	The technology enables standardization of training and procedures **(A)**	Operating room nurse
	N48: Improving the overview of health services consumption can increase the use of new technology such as the Da Vinci robot	Improving health services overview and increasing the use of new technology **(A)**	Director 4
	N49: To use the Da Vinci robot, both permanent physical room and training must be in place	There are organizational conditions for using the technology **(B)**	Gastrologist
	N50: Infrastructure for training specific technology competency must be in place before the technology can be implemented	Infrastructure conditions required before implementing technology **(B)**	Director 5
	N51: Running the Da Vinci robot requires enough staff and regular use of the robot, which becomes problematic when people are away on holiday, courses, and so forth	The technology requires staff and regular use of the robot **(B)**	Section chief 2
	N52: The Da Vinci robot was a gift that required a lot of adjustments (implicit, at organizational and individual levels) before it could be used	Several organizational obstacles to the use of technology **(B)**	Operating room nurse
	N53: The Da Vinci robot has resulted in increased standardization of open surgery and surgery in general. One has become more categorical and systematic; this improves the sense of safety since one can anticipate what is going to happen and one becomes more aware of deviations that again result in fewer errors	The technology has improved standardization, systematics, and thereby safety during surgery **(A)**	Gastrologist
	N54: The Da Vinci robot was received as a gift, but required restructuring, a special washing machine, and a formal tender before it could be used	Several organizational obstacles to the use of technology **(B)**	Service technician
	N55: The Da Vinci robot with a washing machine for special pliers requires a lot of physical space and a dedicated operating room. The robot's high technological nature also requires dedicated training	Both organizational and personal/individual obstacles to the use of technology **(B)**	Operating room nurse
H8: Using the Da Vinci robot requires an organizational commitment of time and priorities, including broader individual and team training and competency development, resulting in initial inefficiency in terms of volume of operations *(Sources: 8; References: 12)*	**N56:** Hierarchy and prestige resulted in the Da Vinci robot initially being used by a leading surgeon with little Da Vinci experience, even though personnel from another hospital with Da Vinci experience was present during the first operations and provided training; the operations took considerably longer than normal (10–11 hr rather than 2–3 hr)	Status and prestige resulted in far longer than normal operations in the initial phase of implementation **(B)**	Service technician
	N57: To use the technology, competency must be present or developed	Using the technology requires specific competency **(B)**	Director 5
	N58: In the beginning, the organization was not ready to use the Da Vinci robot due to a lack of competency (in its use) and insufficient staffing to manage half a year of training; also, concerns about early adopter issues did not facilitate the use	Several organizational obstacles to the use of technology as well as technical concerns **(B)**	Gynecologist
	N59: In the beginning, training in the Da Vinci robot was somewhat demanding due to a large user group, which resulted in longer workdays	Time demanding training in the use of new technology **(B)** with spillover effects/longer workdays	Operating room nurse

(continued)

Table 5. (continued)

Theme IV: Broader organizational commitment of personnel (training) and infrastructure required to improve systemization, standardization, and safety and efficiency of operations			
Higher-level nodes **(A1-X)**	Lower-level nodes **(N1-X)**	Advantages **(A)** & barriers **(B)**	Actors
	N60: Initially, the Da Vinci robot was demanding to learn and therefore time-consuming, which reduced the total number of operations	The learning curve of the technology limited the number of operations **(B)**	Section chief 2
	N61: Internal change in management and internal disagreement on whether the Da Vinci robot should be prioritized made the introduction of the robot taxing	Several organizational barriers to introducing the technology **(B)**	Director 3
	N62: The conditions for using the Da Vinci robot are becoming worse, given the increasing political focus on the centralization of operations that utilize the robot	The focus on centralization of operations reduces utilization of the robot **(B)**	Director 1
	N63: The Da Vinci robot has a steep learning curve and requires experience and dedication from the surgeon	The technology is demanding to learn and operate **(B)**	Section chief 2
	N64: The Da Vinci robot requires more time for sterilization and the learning curve is demanding for surgeons.	The technology makes preparations and training more demanding **(B)** but enables standardization **(A)**	Operating room nurse
	N65: The use of teams and the "team feeling" is important during robot surgery in terms of mastering robot surgery, especially in the beginning when the robot was first introduced and used	The team is important to coping and mastering robot surgery **(B)**	Gynecologist
	N66: When challenged to adopt something a little revolutionary, such as the Da Vinci robot technology, the hospital did not dare to propose it for their organization and fell back on the argument that they are not there yet or that acceptance of a monetary gift (for financing the technology implementation) must be decided by the hospital board	Organizational maturity to technology and regulations decisive for acquisition and implementation **(B)**	Da Vinci gift giver

Results

In this section, we present the outcome of our data coding, following the logic of identifying and combining text segments that convey a standalone meaning, ranging from lower-level nodes and higher-level nodes to themes (highest abstraction level). Each of the four themes is presented in table format (Tables 2–5) for transparency and overview, followed by quotations illustrative of the specific theme with descriptions of advantages and barriers and SEIPS model connections. Each table documents how many sources and references support each higher-level node, which improves the validity of the results. The column "actors" in each table represents the interview object/respondent and indicates support for higher-level nodes and themes.

Theme I is about weighing the total cost-benefit picture of RAS from both operational and patient standpoints. On the one hand, this weighing act focuses on achieving a high enough (critical) mass or volume of operations that justify initial investment and continuous maintenance costs, and on the other, on meeting patients' preference for Da Vinci operations in combination with favorable operational outcomes. Thus, the barriers to Da Vinci technology use lie in the overall costs and are connected mainly to the organization element of the work system in the SEIPS model, which includes detailed robot utilization, production volume, constant/frequent use, procurement and equipment costs, and expensive technology and services. In addition, the issue/aspect of (time) demanding preparations represent the task element of the work system in SEIPS. The perceived advantages of Da Vinci technology are mainly centered on quicker recovery time and shortened patient stays, that is, patient-related processes and outcomes of the SEIPS model. There is also an interesting duality taking place between advantages and barriers and elements of the SEIPS model where, for instance, the technology is expensive and requires frequent use (organization) and at the same time the technology draws patients that prefer the newest innovations (external environment). The following excerpts are illustrative of the barriers and advantages identified in relation to Theme I:

> It [the Da Vinci robot] is an expensive piece of equipment to leave unused. So, we talked to the suppliers who said that if the robot is not being used 180 working days a year, then it is basically a waste of money. […] For now, the urologist uses it two days a week, usually on Monday and Wednesday. Then the gastrologists use it on Tuesdays and then the gynecologists regularly on Thursdays. Sometimes the urologists have it on Fridays for kidney tumors. […] At most, [the robot is in use] five days a week but on average four.—*Service technician*
>
> Research shows that it is not profitable for small hospitals to introduce the Da Vinci robot. It is used too little, and the experience is too little, both financially and in terms of getting good at using it. You need a large hospital, that there is a volume [of operations].—*Section Chief 2*
>
> It is a very expensive operation. Then it is a question about gain, once the robot is in place, there are two things; once you have the robot, you have to use it. Then people generally have a very strong belief in new technological things. So, if you do not have a robot at the hospital, then people will not be operated on [by you]. […] Many are very informed about it, whether we have a robot here or not.—*Gynecologist*

Theme II concerns the multiple levels of distance (to services and the patient) introduced through the implementation and use of RAS in the operating room and the associated advantages and barriers this distancing entails. In terms of distancing at the operational level, the operator's reduced contact with the patient and the overall operation forms a barrier to operational overview but at the same time increases awareness of and focus on team communication, which can strengthen both overall teamwork and mastering of robot surgery (advantages to using the robot). In terms of distancing at the service level, the barrier of being "locked-in" and dependent on external overseas support introduces several consequent barriers (downtime, operator helplessness, change of operation) to achieving reliable operations that must be circumvented through informal/ad-hoc internal preventive maintenance and immediate assistance as well as manufacturer's preventive maintenance (advantages to using the robot). Overall, the barriers and advantages correspond to work system elements of the SEIPS model, that is, the design of the Da Vinci robot (technology), a reduced operational overview and increased need for communication (individual), the technology occupying much of the operating space (environment), and a dependency on overseas support (external environment). The SEIPS work processes, that is, using the Da Vinci robot and conducting the operation, are affected correspondingly, as indicated in the following excerpts (illustrative of Theme II):

> The point is that we have communication. There is always someone standing in the vicinity of the patient. Then there is an operator, so there are always two people on robot operations. And communication is very important.—*Gynecologist*
>
> With all the technical equipment, including laparoscopy, yes, as an operator you are a bit disconnected from the patient, you do not see the patient in front of you, it can be negative. I have not experienced it, but you only see where you operate, you do not see the whole picture, but of course, when the patient is covered with a sterile cloth you do not see the whole patient even if you stand right next to [him/her], but it will still be different, it becomes a distance.—*Gastrologist*
>
> The first ones that we contact, if there is a problem and we cannot solve it ourselves, is the medical-technical

> [department]. And in principle, they have not received training, but they have learned on their own initiative [how the robot works], and they are competent. Plus, they contact [the company behind Da Vinci] and call them. [...] If we did not have such dedicated people in the medical-technical department, we would not have been able to get the help that we have actually received when [something has happened]. We can always contact the company, but sometimes you are unable to reach them. But you have the 24-hour open service line. And they [the company] can go in and inspect the program for the source of the error. But for us, we naturally call a medical technician; can you come up and see what the reason for this may be.—*Operating room nurse*

While Theme III suggests that RAS can bring quality improvements in workplace design including patient access and precision, also strengthening to patient safety, RAS requires specialized operator skills/familiarity, patient-procedure suitability/side-effects considerations, and longer operating time. Thus, we are presented with a barriers-advantages weighing act—comparable to Theme I—where RAS on the one hand positively affects both individual and task elements of the SEIPS work system and processes (operator's surgical precision, access to the procedure, comfort levels, and so forth) as well as individual outcomes in SEIPS (improvements in operator's RAS skills and patient's safety and quality of life). On the flip side, we find the (work system) organizational barriers of time commitment (for RAS specialization and time consumption of RAS operations) as well as having to select/assess the suitability of patients, potentially reducing production volumes/throughput (organizational outcome in SEIPS). The latter barrier may be enhanced by the surgeon's loss of direct patient contact (individual and task elements in SEIPS), which can reduce RAS adoption willingness among surgeons and thereby affect the number of RAS operations being undertaken (organizational outcome in SEIPS). The following excerpts are illustrative of the barriers and advantages identified in relation to Theme III:

> Robot surgery is exciting, and we can do a lot of accurate surgery. We look three-dimensionally into the abdomen, and for many patients who may otherwise be difficult to operate on, it can be beneficial to operate with a robot, as you do not have to "open up" and get better access. You can see the smallest detail, so it is very beneficial. Also, in terms of work, being able to sit and operate is very beneficial—*Gynecologist*
>
> Keyhole surgery often results in fewer side effects, fewer infections, and less pain for the patient. However, it often takes longer. It requires more specialized education compared to open surgery—*Director 2*
>
> The downside [of robot technology] is that you cannot feel what you are doing inside the abdomen [...] You can feel it [during open surgery] and you can feel around the stomach to determine if there is any tumor. You have no feeling when using a robot. So that is a disadvantage. And there are a good number of older operators who swear to open surgery. And I understand that very well. And therefore, there are many cancer surgeries and other surgeries that are not suitable for robots—*Gynecologist*

Theme IV further elaborates on the organizational element of the work system, processes, and outcomes embedded in RAS operations, thus far in our analysis mainly related to the volume of operations/production and maintenance costs (Theme I) and commitment of time for operations and specialization (Theme III). Specifically, Theme IV both supports and connects Themes I and III, highlighting that time commitment is needed for improving individual and team training and competency levels, which in turn can improve operational efficiency/throughput of patients (organizational outcome in SEIPS). In addition, Theme IV identifies a need for investing in improved infrastructures supportive of hosting and using RAS (physical rooms and resources), which can trigger operational advantages related to systemizing and standardizing operations extending to improved operational awareness and safety considerations among surgical teams (connects to individual, task, and organizational elements of the SEIPS work system and processes). The following excerpts are illustrative of Theme IV:

> The robot has made us more categorical, that the operation should be done in much the same way. Of course, there are individual variations, the situation is not always the same, the anatomy can be different, but in principle, each operation begins the same without major variations, that everyone knows what is happening, that the steps are the same.—*Gastrologist*
>
> You need space, because it is large, and there are different parts of the robot, you could say. Speaking as a surgical nurse you need a washing machine, to get the equipment washed. There are special pliers, which are expensive and are used only by the robot. It requires training, not least, because this is high-tech equipment [...] So we also had to find an operating room that we could use, and initially that room was also used for other things occasionally. But we have managed to make sure that the robot has a permanent operating room.—*Operating room nurse*
>
> It has to do with the learning curve and maintaining the skills. You must be experienced, and you must be dedicated to it. It is this way in surgery that the dedicated, those who live and breathe to research and develop the technology, they must invest. You need to specialize in it, to get enough volume of operations.—*Section Chief 2*
>
> It is the joystick generation that will be using it, right. There is a big difference, practice shows this, and it requires training. If we also struggle to recruit urologists, for example, then there is no point in buying a Da Vinci robot if we cannot use it. There must be a strategy of recruiting people that

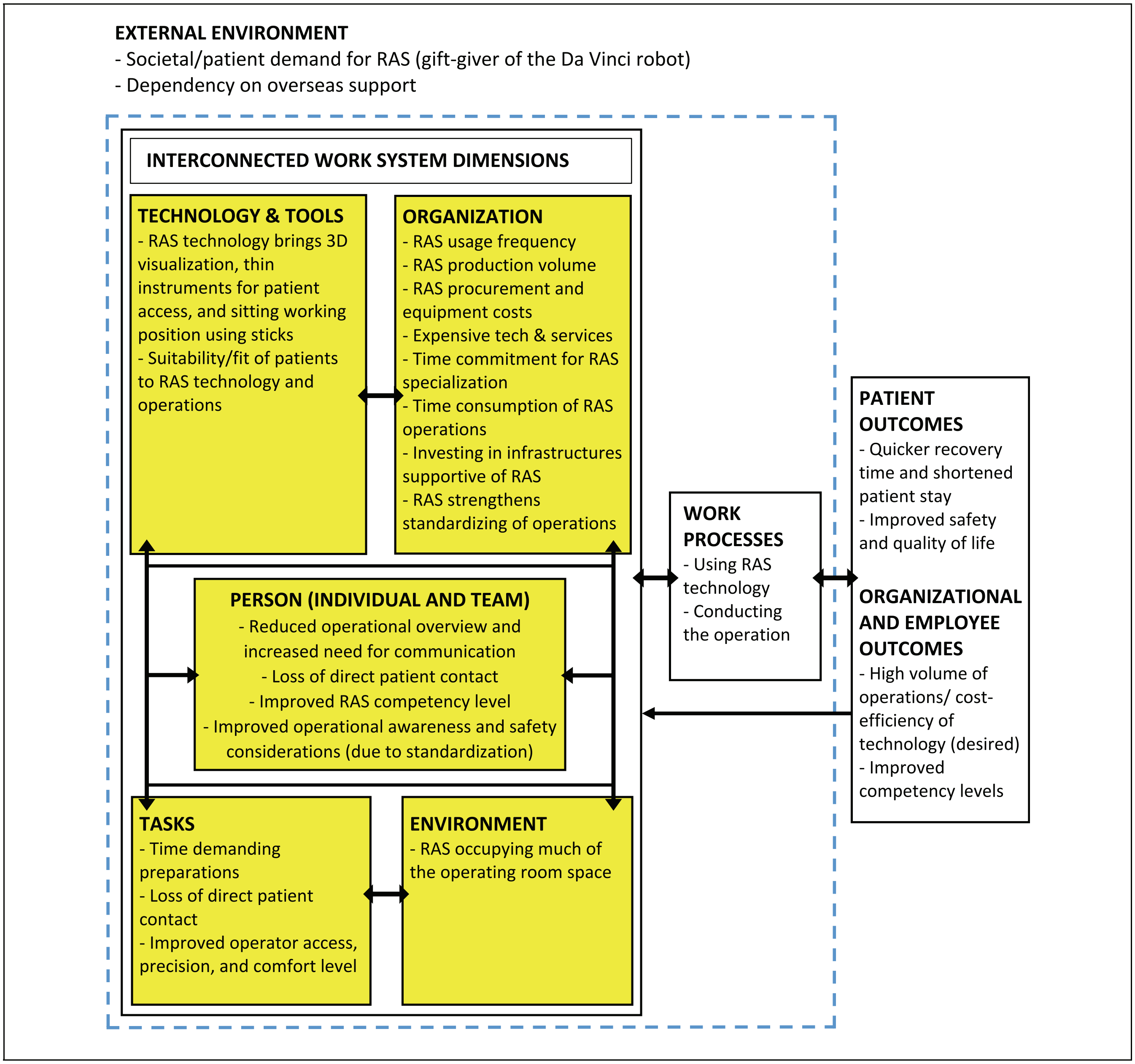

Figure 2. An empirical-informed SEIPS model, based on the coding outcome of our systematic data analysis.

> we train in the use of the Da-Vinci robot elsewhere. Then we carefully introduced it [at our hospital]. And today the Da Vinci robot is in full use.—*Director 5*

A System Perspective on the Empirical Results

Figure 2 provides a visual overview of the coding outcomes in Tables 2 to 5, viewed from a STS perspective using the SEIPS framework. The figure highlights the dynamic nature of the SEIPS system, where multiple system elements (work system dimensions, work processes, and outcomes) exist in mutually interconnected relationships, as indicated by the bidirectional arrows. The results are discussed in the next section.

Discussion

The results presented in this paper are in line with existing studies of RAS in the operating room setting. There is uncertain and varied reporting of operating times, learning curves, and retrieved lymph nodes but a consensus on reduced blood loss and post-operative LOS (Hyun et al., 2013; Liu et al., 2018; Pal & Koupparis, 2018; Soomro et al., 2020; Wang et al., 2017) when comparing RAS to conventional surgical approaches. Our informants described shorter recovery time and hospital stay (Theme I), RAS operations lasting longer compared to open surgery (Theme III), and the presence of a steep, demanding, and time-consuming learning curve (Theme IV). Moreover, our study also adds to the body of literature pointing to how RAS alters the organization of work in the operating room (K. R. Catchpole et al., 2018; K. Catchpole et al., 2019; Gillespie, 2021; Schreyer, 2022), finding alterations in patterns of communication and collaboration through teams (Theme II and IV) and changed procedures and standardizations (Theme IV).

However, our study extends beyond the operational and safety-related findings and what is going on in the operating room. Using the STS framework SEIPS, we gain insight into the context of RAS implementation and usage from the perspective of various stakeholders including both staff and middle and upper management, thus both aligning with and extending Randell et al.'s (2019) detailed empirical account at a cross-hospital staff level. Specifically, we identified four themes in our data material, all of which elaborate on contextual system challenges related to RAS implementation and usage. The first RAS-related contextual challenge involves the case organization/hospital and the environment external to the hospital, and concerns perceptions of friction between societal/patient demand for RAS and associated patient benefits and the ability to deliver a high enough volume of operations/cost-efficiency of the technology (Theme 1). The latter aspect (cost-efficiency) requires a commitment of time for operations and specialization as well as investment in improved infrastructures supportive of hosting and using RAS (Themes III and IV), which in turn can improve surgical teams' operational awareness and safety considerations (Theme III). Thus, a second RAS-related contextual system challenge (closely linked and extending the first) lies in the scope of the organizational investments necessary for achieving cost-efficiency and safety and, ultimately, being able to deliver on the societal/patient demand for RAS and associated benefits. The third RAS-related contextual system challenge lies in the distancing RAS introduces to the patient and overall operation as well as the external service supplier/support located in a different region of the world (Theme II). This distancing increases the daily complexity of management and staff at both the overall hospital organization and operational level, and by extension complicates the ability to deliver on cost-efficiency, safety, and the societal/patient demand for RAS and associated benefits. Moreover, the three identified system challenges demonstrate a simultaneous multilevel span (from external context to internal sharp-end operations) and interconnected nature (dependency between external and internal conditions) of RAS implementation and usage.

As pointed out in the introduction section, the costs associated with implementing RAS technology represent a major adoption barrier for smaller health care systems and hospitals (Perez & Schwaitzberg, 2019). This is also shown in our results, specifically through the friction between societal/patient demand for RAS and associated patient benefits and the ability to deliver a high enough volume of operations/cost-efficiency of the technology. This friction might be due to how different stakeholders perceive different values in such a technology (Perez & Schwaitzberg, 2019). Considering that the Norwegian regional hospital in our study received the robot as a gift, this points to how a given technology might bring high esteem (as a value) to the region and the hospital as well as a certain attractiveness for patients. An externally stimulated technology adoption process, as in our case, likely differs substantially from an internally triggered organization and procurement process conducted deliberately. In the latter internal case, the hospital organization stands freer to weigh and assess the specific technology needs compared to other priorities. The hospital can also map out and work on the necessary organizational conditions including infrastructure and cost models. Consequently, studying an internally triggered adoption process might produce a different socio-technical understanding compared to Figure 2. As for the former case of external stimuli, the gift giver becomes a highly influential actor/stakeholder in the adoption process, exerting a direct and likely unintended effect on priorities and decision-making and consequently sharp-end practices in the hospital organization. Thus, both the technology gift-giver and the very technology become an external force that puts pressure on a regional hospital that did not have the patient volume (in the region) nor the organizational infrastructure to yield a return on the technology investment. Specifically, concerning the latter aspect, our study shows how the new technology/Da Vinci robot entailed new investments for the organization to utilize the technology, which is reasonable to assume will influence other priorities within the organization, at the expense of other patient groups. It must be noted that challenges inherent to a particular technology, that is, the Da Vinci technology leading to loss of patient contact and operational overview, are likely to exist regardless of the technology adoption process being internally or externally triggered or motivated.

Within HFE research including the study of surgical flow disruptions (SFD), there is a growing awareness and sophistication in methodological and analytical approaches that also consider contextual variations and cascading effects (Wiegmann & Sundt, 2019). At the same time, a comprehensive systematic review by Koch et al. (2020) revealed that many studies largely neglect to consider "the complexity and dynamics of surgical work" including provider and contextual factors such as "disruption handling strategies or organizational-level influences" (p. 1042). The implication is that a system perspective (as applied in our study) that considers the contextual factors as well as nuances of complexity (as identified in our study), is important to advance the current state-of-the-art in the operating room including the technology and safety levels involved. More precisely, future HFE research needs to consider STS characteristics and factors in the broadest sense including micro- and mesoergonomics that accounts for overlaps and interactions between different system levels (Karsh et al., 2014; Waterson & Catchpole, 2016; Xie & Carayon, 2015). Our contribution to this advancement lies in identifying three specific contextual system challenges related to RAS implementation and usage: (i) The challenge of matching the organization's capacity to society's demand for new technologies including RAS, (ii) the challenge of "technology-committing" the organization including via associated investment requirements (infrastructures, training, resources, etc.), and (iii) the challenge of operating from a distance to patient and the external RAS supplier.

The recent development in the USA with several hospitals filing class-action lawsuits against the supplier, arguing market power misuse by forcing restrictive repair contracts and high-priced replacement parts (https://medcitynews.com/2021/07/hospitals-sue-surgical-robot-maker-saying-it-forced-them-into-restrictive-contracts/), indicates that the Da Vinci robot supplier dependency identified in the third challenge is of particular importance. The supplier's monopoly situation extends to restricting service and support of the technology to in-house departments, which directly challenges the very nature of surgical operations, where time and efficiency are of paramount importance and service and support must be readily available (Høyland et al., 2014). Our findings highlight how this "supplier-operations friction" has spurred ad-hoc and non-approved (by the supplier) internal services practices by the case hospital. The lawsuits in the USA can be viewed as a consequence of this friction, and support the need identified in HFE research to consider how the introduction and usage of new technologies including RAS influence the larger contextual overlaps and interactions as well as interdependencies across different system levels including organizations, time zones, and professions/cultures. This interdependency is enhanced due to the monopoly situation (Karsh et al., 2014; Waterson & Catchpole, 2016).

In terms of limitations and strengths of our study, the empirical results represent a qualitative snapshot in time of a specific (case) hospital in a Norwegian context very different from that of studies traditionally conducted in the U.S. Thus, the study expands on the existing knowledge base related to Da Vinci testing and exploration. While extrapolation and generalizability of the resulting findings can be problematic and a limitation of our study (Erlandson et al., 1993; Lincoln & Guba, 1985), our empirical account covers multiple organizational levels/stakeholders as well as methods (in-depth interviews, electronic coding, analytical triangulation) aimed at establishing rich insight into the complex and multi-faceted nature of RAS implementation and usage at a contextual system level (Denzin, 1978; Moran-Ellis et al., 2006; Olsen, 2004; Patton, 1990). We consider the contextualization of a detailed multi-level empirical account with identified system challenges—combined with a systematic analytical approach to data using electronic coding—as a main strength and contribution of our study to existing research on RAS implementation and usage including HFE research. Moreover, while the data material included in this publication is less recent, we apply a novel analytical system lens that directly responds to Randell et al.'s (2019) call for more insight into contextual factors necessary for successful RAS integration more broadly.

Conclusion

In our study, we have identified several themes and challenges related to the implementation and usage of RAS from a hospital and multiple stakeholder perspective, which highlight contextual factors as well as nuances of complexity within and beyond the hospital organization under study. Our findings both align and extend upon existing HFE knowledge on RAS in the operating room. In terms of specific future directions, we believe that a pressing concern for both management and current HFE research involving RAS implementation and usage relates to exploring and accounting for the close connections between the organization itself—including the scope/broadness of the organizational RAS investment—and the external stakeholders/actors that exert a considerable influence on the internal work system and processes and the ability to achieve cost-efficiency and safety levels. We further conclude that the SEIPS framework can be a powerful tool in drawing or eliciting the larger contextual picture of RAS implementation and usage, and we encourage further HFE research to explore its application in different contexts to improve the current knowledge base.

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