

Governing the adoption of robotics and autonomous systems in long-term care in Singapore

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ABSTRACT

Robotics and autonomous systems have been dubbed as viable technological solutions to address the incessant demand for long-term care (LTC) across the world, which is exacerbated by ageing populations. However, similar to other emerging technologies, the adoption of robotics and autonomous systems in LTC pose risks and unintended consequences. In the health and LTC sectors, there are additional bioethics concerns that are associated with novel technology applications. Using an in-depth case study, we examined the adoption of novel technologies such as robotics and autonomous systems in LTC to meet the rising social care demand in Singapore consequent to its ageing population. We first described the LTC sector in Singapore and traced the development of robotics and autonomous systems deployed in the LTC setting. We then examined technological risks and ethical issues that are associated with their applications. In addressing these technological risks and ethical concerns, Singapore has adopted a regulatory sandbox approach that fosters experimentation through the creation of a robotics test-bed and the initiation of various robotics pilots in different health clusters. The stakeholders largely envision positive scenarios of human-robot coexistence in the LTC setting. When robots can take over routine and manual care duties in the future, human care workers can be freed up to provide more personalised care to the care recipients. We also highlighted existing gaps in the governance of technological risks and ethical issues surrounding the deployment of robotics and autonomous systems in LTC that can be advanced as future research agendas.

KEYWORDS

Robotics; autonomous systems; technological risks; ethics; governance; Singapore

Introduction

Robotics and autonomous systems are now presented as promising and viable assistive technologies in LTC in many countries, especially those experiencing ageing populations, to address the issue of supply-demand mismatch in LTC (Abdi, Al-Hindawi, Tiffany, & Vizcaychipi, 2018; Gerling, Hebesberger, Dondrup, Körtner, & Hanheide, 2016; Maalouf, Sidaoui, Elhadj, & Asmar, 2018; Robinson, MacDonald, & Broadbent, 2014). This supply-demand mismatch occurs because of rising care needs from an ageing population that outpaces the speed of supplying trained care workers to the LTC sector. As an industrialised nation that has gone through a phenomenal pace of economic growth and human

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development over the last five decades, Singapore is not spared from experiencing an unprecedented pace of population ageing. For example, only 9.1% (1 in 11) of the citizen population were aged 65 and above in 2005 (PopulationSG, 2019). By 2020, it is estimated that the citizen population aged 65 and above would reach approximately 16.7% (1 in 6). Based on a similar projection of the current demographic trends, 25% (1 in 4) of the citizen population will be aged 65 and above by 2030 (PopulationSG, 2019). Furthermore, the old-age support ratio¹ in Singapore has declined substantially from 13.5 in 1970 to 4.8 in 2018 (Department of Statistics Singapore, 2019). This downward trend is expected to continue, and it is projected that by 2050, almost half of the resident population will reach at least 65 years of age (Siau, 2019).

The changing demographic structure in Singapore implies that the demand for long-term care (LTC) services and public spending on LTC would rise exponentially in the coming decades (Basu, 2017). In the US, LTC services are defined as ‘a variety of services designed to meet a person’s health or personal care needs during a short or long period of time’ (National Institute of Aging, 2019). In Singapore, the equivalent is known as ‘intermediate and long-term care’ (ILTC) services that are typically required for persons who need further care after being discharged from an acute hospital, as well as community-dwelling older people who are physically frail and need care and support to fulfil their daily needs (Ministry of Health Singapore, 2019a).

At the supply-side, LTC service providers are facing tremendous challenges to meet the rising LTC demand from the older populations. Based on a recent study, the LTC workforce is projected to require approximately a 130% increase in manpower by 2030 to adequately serve the older population (Lien Foundation, 2018). Nevertheless, the LTC workforce has not been increasing in direct proportions with the population ageing trends. Furthermore, the lower remunerations for LTC care workers as compared to other occupational roles that require similar skill sets, such as those in banking and logistic industries, pose difficulties for service providers to retain talent within the LTC workforce (ibid).

The use of social robots and assistive technologies in the context of LTC and nursing care is already gaining traction in the European countries such as the UK, The Netherlands, Denmark, Finland (Coco, Kangasniemi, & Rantanen, 2018; Jenkins & Draper, 2015; Klein & Schlömer., 2018), as well as in countries the Asia and the Pacific region such as Japan (Leroi, Watanabe, Hird, & Sugihara, 2018; Obayashi, Kodate, & Masuyama, 2018), Australia (Moyle et al. 2019) and Taiwan (Chou, Wang, & Lin, 2019). The deployment of autonomous systems in long-term care can accrue productivity benefits and cost-savings by catering to the rising demand for LTC driven by ageing populations and labour shortages in these countries amidst (Taeihagh, 2020). While there are clear physical, psychosocial and emotional benefits associated with the deployment of social robots and autonomous systems to the older people such as enhancing mobility, facilitating the physical transfer, and providing companionship (Draper & Sorell, 2017; O’Brolchain, 2019; Sharkey & Sharkey, 2012), scholars have increasingly highlighted that AI systems can introduce technological risks and ethical dilemmas where outcomes conflict with broad societal values (Taeihagh, 2020), which have been examined by some studies in the context of LTC (Dickinson, Smith, Carey & Carey, 2020;

¹Old-age support ratio is calculated by dividing the number of resident population aged 20 to 64 over the number of resident population aged 65 and above (Department of Statistics Singapore, 2019).

Table 1. Brief explanations of technological risks and ethical issues associated with the applications of robotics and autonomous systems in LTC.

Technological risks/ethical issues	Brief explanations
1. Safety	<ul style="list-style-type: none"> Robots and autonomous systems veering away from what they have been programmed to do as a result of autonomous learning, especially when deployed in an unstructured environment externally, or when experiencing mode transition internally.
2. Privacy and data security	<ul style="list-style-type: none"> Privacy entails both physical privacy and informational privacy. It relates to the extent to which surveillance functions of robotics and autonomous systems are infringing the personal spaces of carers and care recipients. Data security encompasses detailing the purpose and types of data collected, stipulating the level of access to the data by different stakeholders, and ascribing ownership of the data.
3. Liability	<ul style="list-style-type: none"> The right allocation of responsibilities and compensation risks in the event of accidents and harms imposed by robotics, autonomous systems, or smart health technologies during the caregiving process.
4. Effects to the incumbent workforce	<ul style="list-style-type: none"> The disruptive employment consequences created by the potential replacement of the existing social care workers by robotics and autonomous systems.
5. Autonomy and independence	<ul style="list-style-type: none"> The ability of care recipients to exhibit self-determination and assert preferences regarding the extent to which robotics and autonomous systems should be deployed in the caregiving process.
6. Social connectedness and human interactions	<ul style="list-style-type: none"> The possibility of compromising social interactions and human touch, which are needed to ease loneliness and preserve the well-being of the older people during the caregiving process, when robotics and autonomous systems are applied.
7. Objectification and infantilisation	<ul style="list-style-type: none"> Undermining the dignity of the care recipients by subjecting them to the command and control of robots and through robot behaviours that potentially infantilise them.
8. Deception and anthropomorphisation	<ul style="list-style-type: none"> Counterfeiting authentic social engagement and mislead care recipients to falsely believe that robotics solutions deployed to facilitate their care deliveries are genuine social companions.
9. Social justice	<ul style="list-style-type: none"> Preserving social equity by ensuring that the level of access to and mechanisms of distribution of robotics and autonomous systems in LTC benefit all segments of the older population.

Adopted from: Tan et al. (in press).

Sharkey & Sharkey, 2012; Tan, Taihagh, & Tripathi, in press).² It is thus important to infer these governance debates to the context of Singapore to examine if similar concerns are exhibited in the applications of these cutting-edge technological solutions.

This paper poses two research questions: (i) how do actors within the LTC settings in Singapore perceive the technological risks and ethical issues associated with the adoption, deployment and development of robotics and autonomous systems in LTC? (ii) what are the specific strategies employed to manage those issues?

The remainder of this paper is organised as follows: the next section discusses the various applications of robotics and autonomous systems in LTC, before highlighting nine different technological risks/ethical issues associated with the deployment of robotics and autonomous systems in LTC. The methods section describes the inquiry process, data collection and data analysis. The findings section first describes the landscape and development of robotics and autonomous systems in Singapore, and its recent adoption and deployment. It then analyses the perceived risks and ethical issues involved in the deployment of robotics and autonomous systems applications in LTC. The discussion section brings forth a vision of human-robots coexistence in embracing the potential of health technologies and illustrates the policy challenges that need to be

²For more details about these technological risks and ethical dilemmas see Table 1.

managed and revamped to reap the benefits of robotics and autonomous systems in LTC. The conclusion section highlights policy implications and suggests future research directions.

Technological risks and ethical concerns

Emerging technologies, such as robotics, and autonomous systems could pose risks and unknown and unintended consequences, especially at the early stages of their deployment (Lim & Taelhagh, 2018; Taelhagh & Lim Hazel, 2019). In the context of LTC, the adoption and deployment of robotics, autonomous systems is associated with technological risks³ (safety, privacy and data security, liability, effects to the incumbent workforce) and ethical issues (autonomy and independence, social connectedness and human interactions, objectification and infantilisation, deception and anthropomorphisation, social justice) (Tan et al., *in press*). Table 1 summarises and explains each of these concepts. These concepts emerged from a systematic review of literature that addresses technological risks and ethical issues that intersect with artificial intelligence and LTC in the medical, bioethics and social sciences journal (Tan et al., *in press*). We adopted an established definition of technological risk which is described in the literature as the potential for physical, economic and/or social harm/loss or other negative consequences stemming from the adoption of a technology over its lifecycle (Li, Taelhagh, de Jong, & Klinke, 2020; Li, Taelhagh, & De Jong., 2018; Renn & Benighaus, 2013). In terms of ethical issues, we drew definitions and findings derived from emerging themes reported in a primary study that examined ethical concerns for emerging technology use in LTC among various stakeholders in the US (Dorsten, Susan Sifford, Bharucha, Mecca, & Wactlar, 2009).

Methods

An in-depth single case study examining the adoption, deployment and development of robotics and autonomous systems in Singapore's LTC sector was conducted. The case study method, which is centred on the examination of a contextualised contemporary phenomenon within its real-life context (Yin, 2018), is often intended to be 'an intensive study of a single unit for the purpose of understanding a larger class of similar units' (Gerring, 2004, p. 342). Following these conceptualisations, this paper develops a contextualised contemporary case study to generate empirical insights and contribute to theory development of novel technology adoption. Singapore is one of the top seven economies in the world that has achieved among the highest performances in innovative technology adoption (Baller, Dutta, & Lanvin, 2016). It has seen tremendous progress in the development of robotics and autonomous systems in healthcare in recent years (Ministry of Health Singapore, 2018). Singapore's experiences in implementing, which include adopting and applying these technologies in the health and LTC sectors, would thus be an illuminating case to glean transferrable policy lessons on the governance of novel technologies.

³Technological risks are defined as 'the potentially negative social, economic, and physical consequences related to citizens' concerns in adopting innovative technologies' (Li et al., 2018, p. 3).

Both primary and secondary data were collected. Primary data collection, conducted from March to May 2019, involved 25 key informant interviews with various actors within the healthcare and LTC sectors in Singapore. They are practitioners, policy-makers, managers of nursing homes and research centres, as well as academics in the health and LTC sectors. A preliminary list of respondents was compiled based on information on contacts and professional portfolio in healthcare robotics available online (i.e. official public servant's directory and LinkedIn profiles). A purposive sampling approach was adopted to conduct the first wave of interviews. From there, a snowballing approach was taken to recruit more respondents through recommendations and referrals. Semi-structured interviews were conducted to obtain information with regard to the policy process of the adoption of robotics and autonomous systems in LTC, perception of risks and ethical concerns on the deployment of these technologies, and strategies that have been undertaken to manage the risks and ethical concerns. On average, each interview lasted for about 45 minutes to an hour; field notes were taken by the first author during all the interviews. In addition, secondary information were collected from news articles, governmental departments' websites, policy documents and Voluntary Welfare Organisations' (VWO) reports.

We traced the development of policy process in the adoption, deployment and development of robotics and autonomous systems in LTC, and identified emerging themes in our data using explanation building and pattern matching (Yin, 2018). From here, we use deductive reasoning in the data analysis process, analysing the governance strategies employed by the core actors to manage various risks and ethical issues arising from the implementation of robotics and autonomous systems in LTC by anchoring to the themes in Table 1 which was identified from an earlier review (Tan et al., in press).

Findings

Case description

Service provisions and referral processes in the LTC system in Singapore

The LTC services in Singapore aim to address various aspects of care management that an older person needs. Designed for treatment maintenance, rehabilitative and palliative care, the LTC services in Singapore can be divided into three types: (i) home-based care, (ii) centre-based or community-based care, and (iii) intermediate and long-term formal institutional care (Ministry of Health Singapore, 2019a). Home-based care targets either sporadically to older people who need intensive care monitoring and social support at the initial stage of care immediately upon hospital discharge, or continuously to older people who need LTC monitoring and support services to manage chronic diseases or long-term functional limitations (Ng, 2018). Centre-based or community-based care is usually extended to older people who need either nursing, rehabilitation, or skills training services during the day regularly, and the services can be accessed close to where they live (Ministry of Health Singapore, 2019a). Formal institutional care is delivered by care facilities such as community hospitals, chronic sick units, nursing homes and inpatient hospices (ibid). Table 2 provides a summary of different types of LTC services and their nature.

Table 2. Types of LTC services and their nature.

Types of LTC services	Nature of services	
	<i>Transitional</i>	<i>Continual</i>
Home-based (Medical)	<ul style="list-style-type: none"> ● Nursing procedures ● House-call by doctors ● Home-based restorative rehabilitation ● Rostered stay-in nurse ● Medication delivery 	<ul style="list-style-type: none"> ● Telehealth support ● Home-based medical care ● Medication delivery ● Home-based nursing care ● Home-based maintenance rehabilitation
Home-based (Social)	<ul style="list-style-type: none"> ● Counselling and psycho-emotional support 	<ul style="list-style-type: none"> ● Befriending services ● Meals delivery
Community-based	<ul style="list-style-type: none"> ● Day rehabilitation services ● Halfway houses 	<ul style="list-style-type: none"> ● Day care centres ● Dementia day care centres ● Day hospices ● Day psychiatric care centres ● Physically-disabled
Institutional-based	<ul style="list-style-type: none"> ● Community hospitals 	<ul style="list-style-type: none"> ● Nursing homes ● Chronic sick units ● Inpatient hospices ● Sheltered homes ● Destitute services

Data source: Authors, the information is compiled from a series of key informant interviews and the Ministry of Health Singapore website.

In Singapore, LTC planning for an older person typically starts at the point of acute hospital admission.⁴ As acute hospitals are established to meet the needs of patients who require critical and intensive medical care, older people with LTC needs that are rehabilitative and restorative will be referred to other LTC facilities as soon as their medical conditions stabilise. Subjected to the various care needs based on their functional status, family support structure, the strength of social and community ties, and personal financial resources, older people who need LTC services will be referred to different care services.

The applications of robotics and autonomous systems in LTC

In the context of LTC, robotics and autonomous systems are deployed to serve various functional roles to perform different care tasks and deliver different services for older people (Abdi et al., 2018; Robinson et al., 2014). Companion robots could provide companionship by engaging in verbal and non-verbal interactions with older people, rehabilitation robots or manipulator arms can be programmed to detect nerve signals on the arms and limbs of an older person and help to automatically move their muscles, while mobile servant robots and wheelchair/mobility robots could assist older people with various activities of daily living (Tan et al., *in press*). Beyond companionship, rehabilitative and assistive roles, they can also be utilised as effective surveillance tools to monitor the health and living conditions of older people. Wearable devices, motion sensors and tele-monitoring robots are examples of autonomous systems that could monitor older people for medication compliance, reminding them of their medical appointments and routine activities, and checking for vital signs to prevent the onset of acute coronary diseases (Tan et al., *in press*).

⁴Acute hospitals in Singapore can be either restructured hospitals (hospitals that receive subsidies and subventions from the government but are privately operated and managed) or private hospitals. Patients who require intensive medical care are admitted either directly from Accident and Emergency (A&E) Units of these hospitals, or through referrals from general practitioners at the primary health level (Ministry of Health Singapore, 2019b).

The adoption, deployment and development of robotics and autonomous systems in LTC in Singapore (2014-2022)

Two national-level initiatives were launched by the Ministry of Health (MOH) since 2014 to bolster the agenda to deploy robotics and autonomous systems in the health and LTC sectors in Singapore. In 2014, the National Health Innovation Centre was established to support the development of innovative healthcare technologies to improve health services delivery. It also provides translational funding to publicly-funded clinical research centres in Singapore to turn health innovations into market-ready products (Ministry of Health Singapore, 2018). In July 2015, the Centre for Healthcare Assistive and Robotics Technology (CHARTS) was officially launched. The overarching aims of CHARTS are to develop virtual hospitals,⁵ transform aged care, optimise rehabilitation and automation processes as well as enhance medical training through the applications of assistive and robotics technologies in healthcare. Two labs (design lab and living lab) were set up to facilitate cross-industrial and cross-sectoral collaborations between healthcare professionals, academia, industries, and research institutions (Cheok, 2015). Over and above, a fiscal injection of S\$450 million was made to scale up the National Robotics Programme, which was announced in 2015 to support the development of robotics and autonomous systems in several key sectors in Singapore, including the health and LTC sectors (Sengupta, 2016).

Following the roll-out of high-profile national-level agendas which were backed with strong fiscal commitment, adoptions and implementations of robotics and health technologies started to flourish in various LTC settings. In centre-based LTC setting, a robotic exercise coach equipped with sensors that could react to the movement of older people has been deployed in a senior's day care centre in Singapore since 2015 (Driscoll, 2015). This robotic exercise coach was deployed as the first robo-canine in Singapore to lead exercise routines for senior citizens attending the day care centre. On the other hand, A*STAR has also developed robotic pets that aim to mimic pet therapy to improve the well-being of older people (ibid).

In formal institutional care, the deployment of robotics and autonomous systems to facilitate the care and logistic processes of health and nursing care institutions is also gaining momentum. Since 2015, rehabilitation robots and exoskeletons have been introduced in a local community hospital and adopted in the physical therapy processes to assist post-stroke patients to regain control of their shoulders and limbs as well as to restore their functional capabilities (Zaccheus, 2016).

In 2016, the Housing Development Board (HDB) and MOH rolled out pilot projects that installed elderly monitoring systems in HDB flats occupied by lone older residents. These systems aimed to monitor the activity levels of seniors and to alert caregivers whenever there were extended periods of inactivity noticed (Yong, Rachel, 2016). In early 2018, a pilot project was rolled out to test the potential of motion sensors to monitor the safety of older people as part of an ongoing project known as 'SHINESenior'. Motion sensors were installed at the main door, bedroom, bathroom and living room to track the movement and activities of older persons. For instance, should there be no activity

⁵Virtual hospitals are used to monitor the medical conditions and physical functioning of older people at home after they are discharged from the health and LTC facilities. Medical consultations and care monitoring are conducted by a multidisciplinary healthcare teams that comprise doctors, nurses, therapists and dietitians, through technologies such as video-conferencing (Basu, 2019).

tracked at the doorstep for more than 24 hours, an alert will be sent to operators at the care line (Choo, 2018).

Within the same year, ‘Smart Health Video Consultation’ and ‘Smart Health TeleRehab’ were launched as part of the Integrated Health Information Systems initiatives by MOH. These initiatives adopted the use of health technologies developed by German technology company TUV SUD to deploy robotics and smart health solutions that enable rehabilitation and video consultations between patients and their doctors to be conducted in the comfort of one’s home. These technologies also enable doctors to monitor the patients from home by installing smart cameras to track their medical compliance in real-time (Tan, 2017).

In 2018, the first Robotics Middleware Framework (RMF) for healthcare was launched in Singapore. The RMF for healthcare, which is one of the most comprehensive frameworks in the world (Sharon, 2018), is a technology adoption and integration framework that allows various technology systems within and outside of healthcare to communicate in order to reduce the complexities in the integration of various information systems and equipment. Besides, it is also intended to be a guideline for various government and non-government entities to co-create solutions to facilitate the development of smart health systems in Singapore (Sharon, 2018). Comprising four domains (machine domain, control domain, central domain, and integration domain),⁶ the RMF can aid the development of robotic agents, smart logistics, smart wards and smart homes to improve healthcare operation and patient care delivery (National Health Innovation Centre Singapore, 2018).

Over a five-year period from 2014 to 2019, organisational level initiatives, self-initiated professional groups, robotics pilots started by various service providers and government-led initiatives have been increasing. During this period, transformation offices, medical technology departments, and innovation centres were established across various integrated health clusters across Singapore.⁷ In early 2019, Asia-Pacific Assistive Robotics Association (APARA), a self-initiated professional group that aims to promote education and increase the community digital capacity in understanding, applying and controlling assistive technologies, was established by several actors from both the healthcare and private spheres (Respondents 6 and 7). In April 2019, two Automated Guided Vehicles (AGVs) were officially implemented in The Salvation Army’s Peace Haven Nursing Home after a one-year trial. These AGVs are equipped with built-in sensors and 3D cameras to navigate the entire three-storey nursing home safely by detecting their programme routes through magnetic strips installed in the entire building. Besides enabling care workers to spend more time with the seniors, the automation of meal delivery tasks using AGVs culminates in cost-savings of up to 12,000 USD per month for the nursing home (Chiu, 2019).

⁶The machine domain is typically an intra-system or part of a single robotic system and provides hardware abstraction layer such as sensors, actuators, micro-controller layers to support healthcare robotics development. The control domain is also usually an intra-system or part of a single robotic system that contains some intelligence such as control algorithms. The central domain is the control, command, and management layer of RMF that serves as an interface between Healthcare Smart Systems and Smart Nation Middleware (i.e. robot to robot, robot to infra, robot to IOT and robot to ICT). The integration domain is the software abstraction layer for application integration within the RMF systems (mobile apps, web apps and ICT systems integration) (National Health Innovation Centre Singapore, 2018).

⁷There are currently three integrated health clusters in Singapore that are clustered based on geography (central, eastern, and western regions). Each integrated health cluster comprises a full range of health facilities, services, capabilities, and networks ranging from primary care, acute hospital care, community care to LTC (Ministry of Health Singapore, 2017).

Case analysis

Our case analysis addresses the two research questions posed in the introduction. Firstly, how do actors within the LTC settings in Singapore perceive the technological risks and ethical issues associated with the adoption, deployment and development of robotics and autonomous systems in LTC? Secondly, what are the specific strategies employed to manage those issues? In doing so, we anchored the analysis on the nine issues of technological risks and ethical concerns that we have identified in [Table 1](#).

Safety

Most respondents are synonymous in perceiving that safety takes precedence in the governance of robotics and autonomous systems in health and LTC, as these industries can afford smaller margins of error relative to other industries that are not dealing with saving lives on a daily basis (Respondents 1, 2, 4, 11, 14 15 and 17). Unlike more controlled settings such as construction and manufacturing, there the volume of human traffic is larger in the healthcare setting, especially in the hospitals (Respondent 11 and 22). Recent studies highlight that various safety risks can arise from technical issues in autonomous systems and during human-machine interactions that may fail to interpret or anticipate various human behaviours in unexpected scenarios (Lim & Taeihagh, 2019). While the deployment of task-oriented logistic robotics and autonomous systems that enhance operational efficiency is less complicated, the deployment of robotics and autonomous systems that facilitate patient care will inevitably be subjected to a higher level of scrutiny (Respondent 11).

Different strategies have been employed to address the safety issues of robotics and autonomous systems in Singapore. At the micro-setting, usually within a department in an institution, pilots/experiments and programme evaluations of new robotics and health technologies that contribute to safety enhancement are conducted. Besides, ongoing training and staff competency evaluations are also provided to ensure full competence in the applications of robotics technologies among the staff (Respondents 2, 15 and 17). Pilots are built with co-development and pre-emptive processes where robot designers, developers and healthcare practitioners brainstorm various risky operational scenarios that can pose harm to the older people (Respondents 2 and 14). In CHARTS, prototype process simulations are conducted in a 'mock ward' to test all robotics and assistive technologies to ensure that the applications are well-targeted and well-suited to address the unique care needs of each care institution. Healthcare professionals such as doctors, nurses and therapists are mobilised to take part in various real-time simulations through role-plays to experience the implementation of robotics and novel health technologies first-hand as either healthcare providers or patients (Respondent 14). At the organisational level, stringent procurement procedures that entail open tender, dry-run, test-bed, call-for-evaluation and at times, customisation of technology, are adopted. For instance, all procurement decisions will be subjected to different degrees of panel reviews in the hospital based on the quantum of purchases (Respondent 11). At the macro-institutional level, Health Sciences Authority (HSA) is the central authority that regulates the deployment of new health devices through safety validation and licensing after evidence of their reliability, robustness and effectiveness are proven (Respondents 4 and 11) At this point, HSA has not issued specific regulatory guidelines pertaining to the regulation of risks on

robotics and autonomous systems in health and LTC, but it has devised a general risk classification system for medical devices that categorises all medical devices into four classes (A – low risk; B – low-moderate risk; C – high-moderate risk; D – high risk) through a rule-based system (Health Sciences Authority (HSA), 2018).

Privacy and data security

The intrusion of personal space exhibited through authoritarian monitoring and surveillance styles, and exposure of confidential and sensitive personal health data to third parties, are some examples of physical and information privacy concerns that have been raised in the literature (Dickinson et al., 2020; Ienca, Wangmo, Jotterand, Kressig, & Elger, 2018; Sharkey & Sharkey, 2012; Ulnicane et al., 2020). In addition, the breach of data security through tampering and manipulation of health data via unauthorised access to the health information system is also raised as data security issues (Respondents 6, 12 and 19). Despite the existence of privacy and data security concerns, it was surmised that older peoples' attitudes towards privacy and data security in LTC are more lax, and could be more easily influenced (Respondents 12, 13 and 20). Older people may not perceive that granting a certain level of real-time access to their daily living activities at home through the installation of video cameras to their immediate family members as an intrusion to their physical privacy (Respondent 12). Besides, the extent to which the older people are concerned about health data privacy violation and whether individuals should own their personal health data remains unclear (Respondent 13).

As the issue of health data breaches has stirred debates and heightened national attention, various strategies have been put in place to enhance privacy and data security in the health and LTC settings. At the organisational level, policies, and guidelines to promote greater awareness in data privacy protection among the employees have been enforced. These include separating internet access from work computers, using encrypted thumb-drives for data transfer at the workplace, mandating stronger passwords for system log-in, and performing regular audits to monitor employees' compliance towards data security. Besides, different health information systems have also been designed to detect unauthorised access by unknown parties (Respondents 2, 5, 9, 13). At the technical front, the use of infrared imaging to block the facial images of the patients when robotics are deployed to capture patients' behaviours in the wards during the pilot phase of a robotics intervention programme is an example of a technology-driven measure that a local health provider is adopting to protect patients' privacy and to avoid identity recognisability (Respondent 24). Besides, privacy-preserving analytics can be introduced during data processing either at the device level or through the creation of synthetic data that are operationally identical and functionally equivalent to the actual data collected without the ability of individual identification (Respondent 23). For instance, edge analytics that process data at real-time at the device rather than the central server has been dubbed as a mechanism that could potentially strengthen privacy and data security (Bui & Jung, 2019).

Some respondents opined that the current Personal Data Protection Act (PDPA) needs to be further enhanced for governing privacy and data security in the LTC setting. Furthermore, a paradigmatic shift towards individual ownership of health data could be explored in the future by emulating the practices adopted by the banking and finance

industries (Respondents 6, 7, 20 and 23). For instance, the authorisation of third-party access to personal health data using a dual-key safeguard mechanism could be one direct way that enhances personal health data protection, although the feasibility and acceptability of this proposal has yet to be explored (Respondents 6 and 7).

Liability

Determining which party is responsible for transgressions in the behaviour of robots or autonomous systems in health and LTC is tricky, as fault-lines are often difficult to ascertain, and the unintended consequences are likely to be multi-factorial and context-dependent (Respondents 5 and 10). This has been highlighted by recent studies as a key concern of AI in other domains, such as in transport sector as well where liability for defects or negligence will be distributed among various parties (Leiman, 2020). However, operators often turned out to be the primary party to be held accountable for any transgression in robots' behaviours. This is regardless of whether these transgressions are due to technical faults, such as robotics malfunctions consequent to manufacturing or programming anomalies, or shortcomings in the providers' skills when operating the robots (Respondent 11).

While the formulation of guidelines to govern liabilities in the implementation of healthcare robots remains a work in progress, clarity can be enhanced at the design level through collaborations between robotics scientists and healthcare professionals to optimise the programming of robots' behaviours to minimise harm (Respondents 1 and 2). Regular staff competency audits and training in using robotic devices should also be enforced before scaling up deployment (Respondents 2 and 5)

Effects on the incumbent workforce

At its core, the health and LTC sectors are human-centric, and holistic care cannot be entirely replaced by robotics and autonomous systems. This is especially the case for managing patients with complex medical issues who require customised care plans that involve intricate care processes and a fair amount of human judgement, which include clinical reasoning, professional acumen, and effective communication (Respondents 2, 4, 5, 6, 7, 14 and 15). Despite tremendous progress, robotics technologies still fall short of achieving the state of artificial general intelligence that could perform the entire range of cognitive functionalities akin to a human being, which is important in the implementation of precision medicine (Respondents 6, 14, 18 and 19). Some respondents opined that the current technology has not been able to miniaturise the human brain that could process the entire spectrum of visual and sensory functions of a human being (Respondents 18 and 19). In the deployment of robotics and autonomous systems in the health and LTC sectors, the concept of Moravec's paradox – the need for high-level computational power to perform low-level sensorimotor skills meaningfully (contrary to the ability to perform high-level cognitive reasoning with only low-level computational power) – may still hold true (Respondent 23). While they can perform task-oriented roles that are repetitive and predictable, it would be difficult for ironclad robots to reproduce the emotional and personal connection offered by human care workers in therapeutic roles, such as counselling and psychotherapy (Respondents 1 and 3). Similar sentiments are echoed by stakeholders in Australia's care industry, as shown by Dickinson et al.,

(2020) case study highlighting the difficulties of automating the non-routine nature of care work and of replacing ‘human contact’.

On the contrary, many saw robotics and autonomous systems to be playing complementary roles to the healthcare workers. When robots and autonomous systems are able to take over routine jobs, nurses and other care workers can then be freed up from performing these manual tasks, to spending more time in personalised care by attending to the emotional needs of the patients, and as a result, becoming more productive (Respondents 4, 5, 8, 9, 20 and 24). Given Singapore’s ageing population and thus, heavy reliance on foreign nurses and foreign care workers in the LTC settings (Respondents 4, 8, 17 and 24), massive displacement of local nursing care staff and therapists is unlikely and could potentially reduce Singapore’s dependence on foreign labour in LTC in the future (Respondent 5).

Many respondents foresee a scenario of human-robots coexistence in the delivery of seamless health services to the older people whereby robots perform manual tasks, while human healthcare workers can be upskilled to assume supervisory roles and become more effective communicators in delivering care (Respondents 4, 5, 6, 7, 8, 10 and 20). Human care workers can be expected to move up the skill ladder via job redesign or retraining in the future (Respondents 4 and 5). In the longer term, the deployment of robotics and autonomous systems in LTC might even create desirable economic opportunities for Singapore by spawning new markets through the development of new robotics prototypes and create new job opportunities (Respondent 13).

Autonomy and independence

It was unanimously perceived that robotics and autonomous systems should be deployed to assist older people in LTC without compromising their autonomy and independence (Respondents 2, 5 and 20). While studies have suggested that giving full autonomy and independence for the older people to decide on their LTC arrangements could sometimes be achieved at the expense of compromising their health and personal safety (Bedaf, Draper, Gelderblom, Sorell, & Luc, 2016; Sharkey & Sharkey, 2012), there were also concerns pertaining to the possibility of robotics and autonomous systems being programmed to display authoritarian caregiving styles that can restrict older people’s movements and compromise their quality of life (Respondent 5). The restriction of personal autonomy illustrates AI’s ability to generate meaning by governing individuals’ behaviour and redefining social and political organisations (Gahnberg, 2020). Besides, the nature and stage of an older person’s illness, their changing care needs, as well as their illness trajectories ought to be taken into consideration in deciding the extent of autonomy and independence that should be afforded to a particular patient. For instance, the care needs for an end-stage terminally ill patient would be starkly different from another suffering from early-stage chronic diseases, such as stroke or hypertension, and these heterogeneous scenarios need to be accounted for when programming care robots’ behaviours (ibid). In addition, weaving more granularities into the consent taking experience from older people and ensuring that they understand the intended purpose of deploying robotics and autonomous systems for their care services, including being transparent to the care recipients about the systems recording their lives, is important for providers and developers to facilitate autonomy of care (Respondent 23).

Social connectedness

LTC is an industry that espouses values such as encouragement, love, empathy, and human touch. It is perceived that some of these values can be violated when robotics and autonomous systems are deployed on a large-scale (Respondents 4, 8, 12, 23, and 25). Older people may feel disenchanting if most of the human-centred elements of care are replaced by impersonal robots and machines (Respondents 12 and 23). While robotics and autonomous systems can be applied to replace manualised and task-oriented functions, they cannot be applied entirely to manage complex human emotions (Respondents 4 and 25). Regardless of the level of advancement of robotics and autonomous systems, human intuitive judgement and human connection are important elements that are irreplaceable (Respondents 12, 23 and 25). Human beings will always be a preferred choice in directing the care process as opposed to robots and autonomous systems (Respondent 23). If robots were to completely replace humans as companions to the older people, the loss of human touch might perpetuate social isolation and loneliness rather than alleviating them (Respondent 25). Besides, existential issues such as experiencing illnesses and anticipating deaths are inevitable for older people that can only be worked through substantial human involvement which is better than robots in addressing these emotional needs in their last stretches of care (Respondent 12).

Nevertheless, it was also counter-argued that human needs may evolve and the older generations in future may be more receptive towards the idea of working with robotics and autonomous systems in their LTC arrangements (Respondents 2 and 20). Besides, human preferences regarding human-machine interaction will evolve too as culture and values change over time. Furthermore, in some of the LTC care processes that concern with physical privacy such as bathing and diapers changing, having a robot to perform these tasks may actually be more dignity-enhancing to older persons experiencing a gradual decline in their physical functioning, as opposed to having a human care worker performing these tasks (Respondent 20).

Objectification and infantilisation

Contrary to what the literature has suggested about the possibility of objectification and infantilisation in the applications of robotic pets to ease loneliness among the older people (Chou et al., 2019; Ienca, Jotterand, Vică, & Elger, 2016; Moyle et al., 2016; Sharkey & Sharkey, 2012), these issues were not seen as problematic in the LTC settings in Singapore (Respondents 2, 5 and 12). Instead, respondents opined that ends are more important than means, especially if robotics and autonomous systems can stimulate social engagement and keep older people occupied (Respondent 2, 5, 20 and 24). For instance, should robotic pets make patients feel energetic and generate similar gestures and satisfactions as actual pet therapies, they still serve the intended purpose of improving older people's mood and generating positive emotions (Respondent 5). Some respondents raised the importance of customising LTC arrangement to different older people based on their life histories. For instance, consideration of their inclinations towards robotics pets based on oral histories of their past behaviours should be factored in when making decisions on robotics applications (Respondents 12 and 20).

Deception and anthropomorphisation

The issue of deception and anthropomorphisation in the deployment of robotics and autonomous systems is contentious and lacks consensus. Some respondents perceived that it is both dehumanising and culturally irrelevant to expose older people to robotic pets such as PARO seals or robotic coaches that do not possess human touch; or deceptive to expose them to companion robots that may create a false sense of realities (Respondents 8 and 25). Other respondents expressed differing views, believing that if robotics and autonomous systems serve the end goals of elevating the well-being and health outcomes of older people without undermining their dignities, the deployment of robotic pets is justifiable (Respondents 2, 5, 9, 20 and 24). To this end, having appropriate and adequate levels of communication to ensure that care recipients understand the intentions of the deployment of robotics and autonomous systems is emphasised (Respondent 24). For older people with degenerative cognitive conditions such as Dementia and Alzheimer's disease who have lost their cognitive capacities and unable to develop meaningful interactions with their social environments, some respondents opined that the issues of deception and anthropomorphisation might no longer exist (Respondents 1 and 2). Ultimately, when robotics and autonomous systems are deployed extensively, older people could become more receptive to the deployment of robotic coaches and robotic pets (Respondents 3 and 5)

Social justice

Affordability, accessibility, and equity in the distribution of robotics and autonomous systems in health and LTC settings are central social justice issues that have been raised (Respondents 1, 2, 8 and 9), echoing the recent discourse in AI policy documents that emphasise the need for AI to be inclusive and for their benefits to be equitably distributed among diverse groups in society (Ulnicane et al., 2020). In the LTC sector in Singapore, widespread adoption of robotics and autonomous systems tend to be hindered by high production costs (Respondent 1). In the face of scarce medical resources whereby decisions need to be made on who benefits, bioethics questions regarding the types of illnesses, the extent of disease severities, disease prognoses, and treatment modalities will have to be accounted for when making decisions for the beneficiaries or recipients (Respondent 1). As most of these technologies are not affordable to most older people due to their exorbitant costs, government interventions in the forms of subsidies or subventions might be required to ensure their accessibility and fair distribution (Respondents 8 and 9).

Discussion

In spurring the adoption, deployment and development of robotics and autonomous systems in LTC, Singapore has adopted a mix of fiscal, informational, and organisational instruments. Generous government funding, public-private partnerships in the form of co-development and co-creation of robotics in design and living labs, the roll-out of various pilots to test robotics solutions in health and LTC, the development of an RMF, stringent health technology assessment and procurement decisions, are some of the most prominent instruments adopted by Singapore. The designation of CHARTS as a test-bed for robotics in healthcare and the establishment of various innovation centres within

different integrated health clusters demonstrate a regulatory sandbox approach that fosters experimental spirits and enables flexibility in future regulatory development.

In governing safety, privacy, data security and liability in robotics and autonomous systems applications in LTC, specific regulations in the forms of hard and soft laws have not been formulated. While HSA is the highest authority that governs licensure to medical technology devices based on their safety and liability track records, PDPA is the overarching legislation that governs privacy. To enhance this legislation, a public consultation was launched from May to July 2019 to solicit feedback on the proposed data portability and data innovation provisions which will endow individuals with greater autonomy and control over their personal data (Personal Data Protection Commission (PDPC), 2019). Besides, specific ethical issues such as the potential of robotics in undermining individual autonomy, compromising social connectedness, exacerbating social injustice, or perpetuating objectification and deception, are still subjected to debates. Ethical views from the respondents regarding the use of robotic pets, for instance, strongly reflect utilitarianism or consequentialism that emphasises on the outcomes and the greater good for the older people. However, it needs to be acknowledged that these normative views may not reflect the society's preferences, and they are likely to differ in different communities with different value predispositions and preferences. It has also been shown that social and political cultures are likely to play a significant role in the adoption of robotics in LTC based on factors such as ingrained historical and traditional values as well as social exposures to robotics. A good example of this is the Japanese society which conventionally has higher receptivity towards social robots due to widespread and daily exposures to social robots and the efforts in promoting the adoptions of social robots by the Japanese government and industries (Šabanović, 2014). As such, opinion surveys targeting existing or prospective users, current users, and the general public could be conducted to glean insights on the ethical preferences of different individuals or groups of individuals in the community, and the results from these surveys would be useful for informing the ethical design of robots and autonomous systems in LTC in the long run. Besides opinion surveys, the voices of the communities can also be recorded via other qualitative methods such as participant observation, key informant interviews and focus group discussion with the important stakeholders. Studies have shown that active engagement of prospective elder users in the robotics prototype design process (Neven, 2010), and incorporating sensory experiences of the users in health technology development (Oudshoorn, 2020), are important in the process of dissemination of novel health technologies. Over and above, it would be important to sustain the engagement with industry players and gauge the sentiments, knowledge and preferences from other actors such as the developers of these technologies.

Amidst projections on the potential of job displacement by robotics and autonomous systems (Makridakis, 2017; Smith & Anderson, 2014), our research shows that most of the actors in the LTC sector in Singapore are cautiously optimistic. The benefits that robotics and autonomous systems deployment could accrue to advance both operational efficiency and patient care are expected to outweigh their shortfalls, including the displacement of jobs at various functional levels. It is largely envisioned that future collaborations between robots and humans are likely to free up time for human care workers to render personalised care to the older people and better attend to their emotional needs rather than performing manual, repetitive tasks. In healthcare,

technologists have increasingly advocated for the cultivation of symbiotic relations between human and robots, whereby human roles can be transformed to display more empathy and compassion (Lee, 2018).

With a proven track record in accelerating the adoption of novel technologies such as ride-sharing (Li et al., 2018), autonomous vehicles (Tan & Taeihagh, *in press*) and synthetic biology (Trump, 2017), the Singapore government has signalled its commitment to bolster its policy capacity for the implementation of robotics and autonomous systems applications in the healthcare and LTC sectors. Nevertheless, there exist implementation challenges as far as policy capacity is concerned. Politically, ongoing public communications are needed to create stronger buy-in from the citizens. To avoid backlash from care providers, it is crucial to deliberate on how meaningful robot-human collaboration can be achieved, which would require carefully augmenting the speed and quality of care instead of replacing all human roles at the frontline. In addition, developing the required infrastructure for a smart health system will take time. From the human resources development perspective, there is room to develop more technical capacity by investing in structured programmes to train sufficient roboticists locally that could see through the entire implementation cycle of robotics and autonomous systems in LTC.

In the long run, there is a need to consider the cost implications of large-scale deployment of robotics and autonomous systems in LTC. Health technology assessment that entails cost-effectiveness studies of large-scale deployment of robotics technologies in LTC remains nascent, and limited evidence exists to justify their feasibility. A recent cluster-randomised control trial conducted among 415 nursing home residents in Australia demonstrated that a plush toy offered marginally greater value for money than a PARO (robotic pets) in improving social functions, even though both interventions are generally cost-effective (Mervin et al., 2018). With perpetually rising healthcare costs, cost-benefit and cost-effectiveness evaluations of these technologies would be pertinent in facilitating procurement decisions at the organisational level as well as the design of incentive mechanisms at the systemic level. As the exacerbation of existing social and economic inequalities has emerged as a key concern in recent AI policy debates, governments play a central role in ensuring AI's inclusivity and equity, which has been analysed by Ulnicane et al. (2020) from the perspective of participatory governance and by Radu (this issue) who analyses the changing roles of the government vis-a-vis the private sector through the lens of hybrid governance.

Singapore's capability in adoption, deployment and development of robotics and autonomous systems in LTC has been realised in large part by its many unique characteristics and its integrated healthcare policies. Its health system comprises three major integrated health clusters, which create multiple test-beds for robotics pilots to be conducted. Also, its politics are influenced by a majority parliamentarian rule by one political party that could shape public agenda effectively, and accelerate implementations of new technologies faster than countries with vast geographies. In the future, conducting cross-jurisdictional comparisons with other advanced ageing cities to examine the regulatory approaches taken in the governance of robotics in LTC will be important to advance policy learnings and facilitate policy transfers.

Conclusion

Our research provides insights about the applications of robotics and autonomous systems in LTC in Singapore. Organisational level strategies have been instituted to address safety, privacy, data security and liability issues in the meantime. A vast majority of LTC stakeholders display optimism and envision positive scenarios of human-robot coexistence in the future. When robots can take over routine and manual care duties, human care workers can be freed up to provide more personalised care to the care recipients, including attending to the emotional needs of the care recipients better. The stakeholders' ethical views surrounding the deployment of social robots capable of autonomous learning are divided, largely driven by the opposing views concerning whether the autonomy of the older people will be compromised and whether objectification and deception will be exacerbated. Because of this, there is a need for greater public discussion and consensus-building around the values that care robots should be designed with.

While robotics and autonomous systems are poised to become promising solutions to the rising demand for and stagnant supply of labour in the LTC sector in Singapore, long-term solutions to tackle technological risks and ethical concerns in their large-scale deployment are warranted. Sustained efforts in conducting pilots or experiments to establish the safety and efficacy of these technologies are imperative. Besides, ongoing health technology assessments and cost-benefit analyses will need to be conducted to establish their cost-effectiveness. Above all, governments need to make a deliberate effort to reach out to and gauge the acceptance of the general public and expectations of the older populations when these technologies are integrated into LTC.

Three valuable and transferrable policy lessons are derived from Singapore's experience in adoption, deployment and development of robotics and autonomous systems in LTC. First, rapid implementation of novel technology can be achieved via government taking the lead in steering the applications of novel technology (i.e. through the establishment of a secretariat or implementation of a task force such as CHARTS), fast-tracking the adoption and deployment rate of autonomous systems among the LTC institutions that could address the unique care challenges faced in different care institutions and care settings. Second, long-term capacity-building is important through multi-party collaborations among the government, industries, academia and LTC institutions to sustain implementation. This can be achieved by tapping into the unique expertise of each party. Lastly, the cost implications of robotics and autonomous systems adoption need to be accounted for, especially when considering issues pertaining to both cost-effectiveness of the technologies, as well as equity and justice in the deployment of these technologies.

Acknowledgements

Araz Taeihagh is grateful for the funding support provided by the Lee Kuan Yew School of Public Policy, National University of Singapore and The Humanities & Social Science Research Fund, National University of Singapore.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National University of Singapore.

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