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Technologies for ageing-in-place: The Singapore context

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White Paper

EXECUTIVE SUMMARY

The number of elderly citizens aged 65 and above in Singapore, is expected to double from 440,000 in 2015, to 900,000 by 2030. Along with this "Silver Tsunami" is the upward trend of the number of elderly who are living alone — which is estimated to increase from 35,000 in 2012 to 83,000 by 2030. These exclude elderly who are alone at home when their family members are working.

Elderly who are staying alone are at higher risk of social isolation and tend to have poorer access to healthcare. In addition, the general elderly population is typically more susceptible to deteriorating health conditions, which can manifest in many forms such as mobility and cognitive decline, and onset of chronic illnesses. They require more access to geriatric care services, and increased assistance with their activities of daily living.

Conventional models of institutionalised care such as sheltered or nursing homes have been imperative in providing long-term care for elderly who require such services. Unfortunately, there is often a shortage of available placements for these facilities; prolonged stays in such settings may also lead to costly and undesirable outcomes for the elderly and their family members.

Recent years have witnessed the proliferation of home and community care, to support ageing-in-place whereby the elderly can stay within the comfort of their homes and familiarity of their neighbourhoods, and have minimal disruptions to their lives and activities. Care, support and response is provided by the community in which the elderly is living in. The efficiency, effectiveness and responsiveness of this model is dependent on the integration of care across social and health services, collective effort of the whole-of-society, as well as availability of admissible technological solutions.

This white paper outlines key considerations including the needs, challenges, trends and opportunities that will enable Singapore citizens living alone to age-in-place. The vision for enabling holistic and personalised ageing through technology is presented, together with its exemplification in the form of responsive and pre-emptive care and intervention models. An overview of the technology ecosystem to support such a vision is described; this includes the monitoring system, care platform and data-driven models for measures of elderly well being. Finally, the paper presents the roadmap for the conceptualisation to realisation of technologies for ageing-in-place. The paper also highlights the importance of the involvement of various stakeholders, for successful ageing-in-place to be realised.

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1
THE CHANGING DEMOGRAPHICS

According to the United Nations [1], nearly every country in the world is experiencing an ageing population due to declining fertility, decreasing mortality, and increasing life expectancy. In Singapore, the number of citizens aged 65 and above is expected to increase rapidly from 440,000 in 2015 to around 900,000 in 2030 [2]. Such a "Silver Tsunami" implies that by 2030, one in every five people in Singapore will be aged 65 and above [3].

Elderly Aged Above 65 Years Old

900,000	
440,000	
220,000	

■2000 ■2015 ■2030

Elderly Living Alone

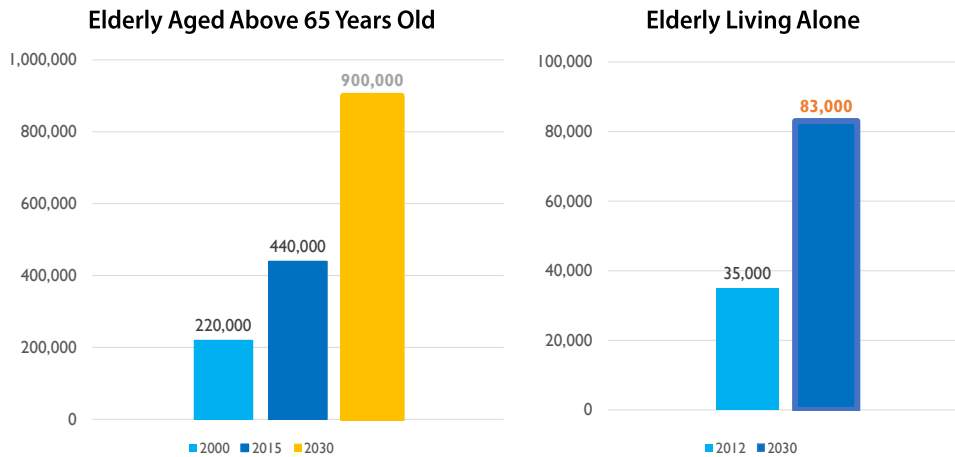|	
83,000	
35,000	

■2012 ■2030

Figure 1: Elderly aged over 65 years old and living alone in Singapore.

The elderly population is generally more susceptible to health deterioration which can manifest in many forms, such as onset of chronic illnesses and decline in cognitive function and mobility. They require more access to geriatric care services, as well as increased assistance with their daily living. Mobility and ambulatory capacity decline necessitates infrastructural changes, both at home and in the community, to improve elderly safety and enhance accessibility, particularly for those who are wheelchair-bound or require mobility aids. With the higher demand for healthcare and aged care provision, it will become extremely challenging for the shrinking workforce to support these needs, as they already face increased tax and economic burden.

In tandem with the increasing ageing population, there is a worrying upward trend of elderly who are staying alone. Singapore's Department of Statistics has estimated that the number of elderly living alone will increase from 35,000 in 2012 to 83,000 in 2030; these numbers exclude the elderly who are left alone at home for most parts of the day when their family members are working.

Elderly who are living alone tend to have poorer access to healthcare and are more susceptible to social isolation, which can lead to poorer health and depression. They face higher risk of not receiving timely attention and assistance, and are more likely to die prematurely. Since 2007, more than 50 elderly have been reported to have died alone at home, only to be discovered much later [4].

"Such a rapidly ageing population implies that by 2030, one in every five people in Singapore will be aged 65 and above."

## 1.1 A NEW PARADIGM FOR AGEING AND ELDERCARE

Conventional models of institutionalised care, such as nursing homes and assisted living facilities, have been imperative in providing long-term care for elderly who require such services. Unfortunately, there is a persistent shortage of available placements for these facilities; prolonged stays in such settings may also lead to costly and undesirable out-

comes for the elderly and their family members.

Recent years have witnessed the emergence of *ageing-in-place*, an ageing paradigm that is harmonious with the aspirations of the elderly to age gracefully, safely and comfortably in the community that they live in, and have access to a range of aged care facilities that will facilitate active ageing. Ageing-in-place shifts the provision of care to the home and community where the elderly is living in, thereby reducing public financial burden and alleviating the shortage of institutionalised placements.

To support the needs and wants of the elderly and to enable them to age-in-place, several government-initiated schemes are currently underway, with focus at the individual, community and city levels [5]. These include the roll-out of initiatives to ensure that the elderly can receive better services from healthcare providers, live in elderly-friendly homes, travel about more easily, and enjoy public spaces [6].

1.2 TRENDS AND OPPORTUNITIES FOR TECHNOLOGY-ENABLED AGEING-IN-PLACE
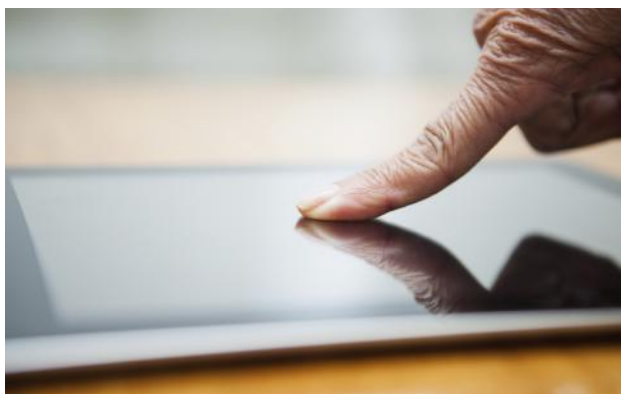
The provision of elderly-centric care services and elderly-friendly infrastructure are essential first steps to the realisation of ageing-in-place. The success of ageing-in-place in general, and home and community care in particular, hinges on the integration of care across social and health services and collective effort of the whole-of-society. Indeed, the need to efficiently coordinate and mobilise limited resources

on a national scale naturally requires the use of admissible technological solutions.

In the Singapore landscape, a growing number of technological solutions are being introduced to tackle the challenges of ageing. These product offerings range from panic buttons that the elderly can press when there is an emergency at home, wearables that can track vital signs such as heart rate and body temperature, in-home monitoring systems that can remotely monitor elderly movements at home [7], telehealth systems that provide remote healthcare services, to robots that can lead exercise workouts for the elderly [8]. In an early trial that involved the use of sensors to remotely monitor the movements of the elderly when they are at home and to notify their caregivers when there are anomalies [9], results indicate that such solutions can improve elderly safety at home, increase the elderly's confidence in staying alone, and reduce manpower requirements of caregivers.

With the plethora of technological innovations that are entering the market, now more than ever, it is imperative that solution providers work together to provide *interoperable*, *extensible* and *scalable* systems that can cater to the constantly changing needs of the elderly population. System platforms must improve the efficiency and effectiveness of community care and support through data-driven approaches and "uberisation" of care provisioning. These platforms must also facilitate data and information flow between the elderly and the community — such as the grassroot leaders, Voluntary Welfare Organisations (VWOs), residents, healthcare providers and government agencies.

The socio-demographic profile of Singapore's elderly is expected to change gradually, within the next decade. The current population of elderly who are aged 65 and above, are generally less literate, do not have smartphones, have little or no exposure to technology, and are more concerned with issues relating to privacy. In contrast, the next generation of elderly population is expected to be more educated, financially stable, and receptive towards technology. As such, we must be prepared to invest and innovate in a wide spectrum of technology solutions for ageing-in-place, to cater to varying elderly profiles and demographics.

2

VISION: HOLISTIC AND PERSONALISED AGEING THROUGH TECHNOLOGY

The multidimensional nature of the ageing problem calls for a comprehensive approach to ensure that various aspects of the elderly's life are considered in the design of technological solutions and the formulation of care and intervention processes. This will ensure that the dignity and quality of the life of the elderly is maintained, while improving the efficacy and effectiveness of the aged care ecosystem. We therefore envisage a *holistic* and *personalised* care model, whereby the needs and aspirations of elderly are given utmost attention, enabled by technologies that understands and respects the uniqueness of every individual elderly.

2.1 A SOLUTION FOR HOLISTIC AND PERSONALISED AGEING

At the heart of our vision is the elderly who aspires to live safely and independently in the comfort of her home and community. A good solution that achieves this vision must understand an elderly's unique circumstances, while respecting her way of life. To this end, the right combination of technology and human touch must be employed, to *understand* her unique situation and needs. We espouse the use of unobtrusive technology to *respect* her lifestyle, so that she can go about her daily routines, undisturbed by the pervasive technology that oversees her health, wellbeing, safety, and security, among others. We will elaborate on the key aspects of our ageing-in-place solution below.

> "A good solution that achieves this vision must *understand* an elderly's unique circumstances, while *respecting* her way of life."

Holistic Care

A holistic care model takes into account the elderly person in her entirety, encompassing the various aspects of the person such as the physical, social, psychological and emotional needs, amongst others. Thus, enabling holistic ageing requires the participation of many stakeholders beyond the traditional "continuum of care", which is mainly concerned with the elderly's physical health; it entails the active support and engagement from other entities in the community - such as social workers, befrienders, and community volunteers.

Here, we provide a case study that highlights the importance of holistic care for the aged. An elderly [Mr A, 70 years old] with multiple chronic illnesses is prescribed with several different types of medicines, prescribed from his recurring visits to the hospital and polyclinic. The deteriorating physical health conditions of this elderly is observed by the volunteer care-giver who visits him on a fortnightly basis. Through conversations with the elderly, the caregiver learns that the elderly is not consuming his medication regularly due to: (i) unwillingness to consume medication, arising from the side effects that are conglomerated by the multiple types of prescriptions; and (ii) financial difficulties, which causes him to be unable to replenish or obtain medicinal packing services on a regular basis. The caregiver refers the case to the social worker, who subsequently: (i) arranges for medication reconciliation services from professional health workers; and (ii) applies for public financial assistance on behalf of the elderly, so that he can now afford to replenish his medication. Through the holistic care involving both the medical and social workers, the physical health of the elderly is starting to show gradual signs of improvement.

Personalised Care

Each elderly is definitively unique, in each and every aspect of her holistic wellbeing. As such, aged care must progressively transition, from conventional standardised care to personalised, elderly-centric care. The personalised aged care model requires a wealth of data and information derived from the elderly's day-to-day living in order to build a personalised wellness profile. This profile can then be used to provide customised care and intervention for the elderly, according to her individual needs, health, and wellbeing. Such personalised care is known to be more effective in improving the elderly's wellbeing, as well as improving the efficiency and productivity of the caregiver.

We illustrate the significance of personalised care through another case study. An elderly [Mdm C, 81 years old] who is living alone and is both physically and socially active, is able to lead her life independently without much assistance. The volunteer caregiver visits her on an ad-hoc basis, at least once a month, to ensure that she has no major ailments, and to check if she requires assistance in any matter. In contrast, another elderly [Mr F, 77 years old] who is also living alone, is less ambulant and has high fall risk. As such, he requires closer monitoring of his activities at home, so that the caregiver can be notified and provide quicker response whenever emergency situations occur.
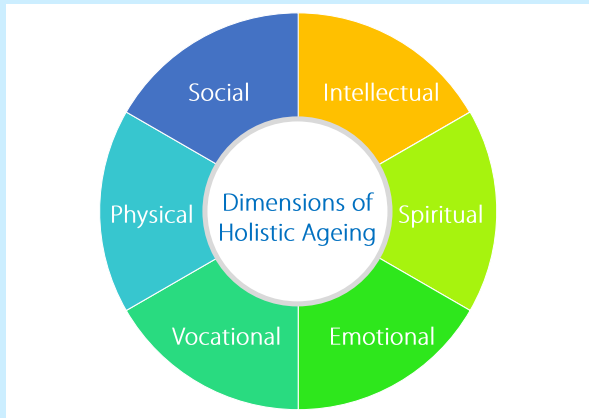
There are six key wellness dimensions of an elderly person, that constitute holistic ageing: *physical, social, intellectual, spiritual, emotional* and *vocational* [10].

The **physical** aspect is related to the body, and in particular, the ailments of aging: decreased strength, feeble health, increased vulnerability to falls, physical disabilities, chronic illnesses, and the inability to cope with the physical stresses and strains of daily life and activities of daily living.

Persons exist in a community, with others, and for others. The need to belong to a community, to have deep, close, intimate relationships — the **social** aspect — is crucial to the development of the social health of the elderly.

The **intellectual** aspect of the person directly affects their capability for cognitive reasoning, and the actions of their will, which impacts their ability to perform the activities of daily living.

The **spiritual** aspect has an effect on the wellbeing and health of the elderly, and no holistic approach towards caring for the elderly can possibly ignore this profound impact of spirituality on the elderly.

If we were to always have in mind the wellbeing of the elderly, it is essential to explore their interior life and empathise with even their most concealed inner **emotions** when expressed by them.

The elderly finds their ultimate fulfilment in making a sincere, disinterested gift of themselves to others. Hence the importance of the **vocational** aspect of the elderly person. When an elderly accomplishes their vocation and mission in life, a serene, peaceful joy can permeate their whole being.

2.2 RESPONSIVE AND PRE-EMPTIVE CARE AND INTERVENTION

Efforts to enable ageing-in-place are incomplete without the inclusion and integration of a care and intervention model. A care and intervention model that exemplifies holistic and personalised ageing must consider various aspects: (i) encompassing the different aspects of each elderly — such as physical, social, and psychological; (ii) taking inputs from various stakeholders — such as healthcare and medical professionals, social befrienders, volunteers, family members and caregivers — and the elderly themselves; and (iii) tailoring to the individual and unique needs of each elderly. Through intervention by the caregivers, the wellbeing of the elderly can be improved by promoting good behaviours, discouraging behaviours that pose health risks, and/or providing timely help and assistance when necessary during unexpected or emergency situations.

Generally, the care and intervention provided by caregivers to the elderly can be classified into two main categories: (i) **responsive** and (ii) **pre-emptive**.

Responsive Care and Intervention

Many unexpected and undesirable situations can arise in the daily lives of the elderly. These are often related to the physical wellbeing of the elderly, and may include incidents

such as falls, fainting spells, shortness of breathing and accidents. Such circumstances necessitate responsive care from the caregivers, for instance, in the form of timely medical assistance. These situations can often lead to severe consequences such as the demise of the elderly, or irreversible health conditions, if timely help is not received by the elderly. It is thus vital that responsive care is made available to the elderly, through the real-timeliness of alerts that are being triggered and sent to the caregivers, when such incidents occur.

> Mr F, 77 years old, fell in his kitchen in the day and was not able to get up. He managed to reach and press the panic button given to him and the alerts were sent to the caregivers from the Senior Activity Centre. The caregivers responded in a timely manner to his situation and called for an ambulance to pick him up.

Pre-emptive Care and Intervention

Oftentimes, the earlier a disease is diagnosed, the more easily it can be cured or properly managed. By working with health professionals, impending acute health conditions or exacerbation of already existing chronic illnesses can be detected earlier. Health professionals can aid in determining if particular patterns and behaviours in an elderly are indicative of, or can be used to measure wellbeing, as well as by identifying changes in elderly's health and behavioural status. Thus, pre-emptive care and intervention can be provided to the elderly before their wellbeing deteriorates.

Typical healthcare expenditures focus on professional consultancy after an individual has fallen ill. Such a reactive healthcare system incurs high costs, and puts financial burden on both the elderly and the public. To alleviate healthcare costs, it is hence imperative that efforts are invested on the pre-intervention chain, ranging from health management, prevention, self-diagnosis to home monitoring.

Aged care must transition from conventional standardised care to personalised, elderly-centric care.

> Mdm S, 70 years old, was found to have irregular medication intake patterns during the night as the sensor data revealed that she woke up to take her medication, sometimes twice / thrice nightly. The caregivers were brought to the attention of the deviation from her normal medication intake patterns and they managed to intervene and check with her if she has been feeling unwell. She expressed that in the recent weeks, she experienced more pain in her legs during the night and had to consume painkillers. The caregivers accompanied her to the clinic and managed to highlight her condition to the doctor.

Integrated Care and Intervention Model

In Table 1, we provide some examples of the situations, and corresponding care and interventions, that are categorised into the two models of care, *viz.* responsive and pre-emptive.

2.3 ENABLING AGEING-IN-PLACE WITH TECHNOLOGY

We have described the importance of holistic and personalised ageing, together with its exemplification in the form of responsive and pre-emptive care and intervention models. Conventionally, technology-based solutions have been designed and implemented in their entirety by technologists. This has resulted in technology-centric solutions that are not widely adopted by the general elderly population and their caregivers, have minimal provisioning for personalised care and intervention by caregivers, and are thus ineffective in improving elderly wellbeing.

To support holistic and personalised ageing, stakeholders from the entire spectrum of aged care must be involved in the design and development of care and intervention processes in the technology platform, so that they can provide insights and observations that are essential for elderly wellbeing. Figure 2 illustrates the relationships between the technology platform and the stakeholders in the aged care ecosystem.

To this end, the technology platform to support ageing-in-place should posses the following attributes: *unobtrusiveness*, so that the elderly can go about her daily routines without

	Potential Situations	Potential Care and Intervention
Responsive	• emergency panic button activation • fall detection • prolonged inactivity detection • accidents • other situations requiring immediate medical assistance	• caregiver is activated to check on the elderly • ambulance is activated to send the elderly to the hospital
Pre-emptive	• onset of chronic illness or other ailments such as depression and dementia • medication non-adherence • anomalies in activities of daily living, such as sleeping habits and toileting habits • change in daily living patterns, such as frequency of going out, and frequency	• visits by social workers or befrienders, to reduce social isolation or depression • medication reconciliation services • counselling services • referrals to healthcare professionals • medical checkups by healthcare professionals

Table 1: Example situations and corresponding care and intervention.
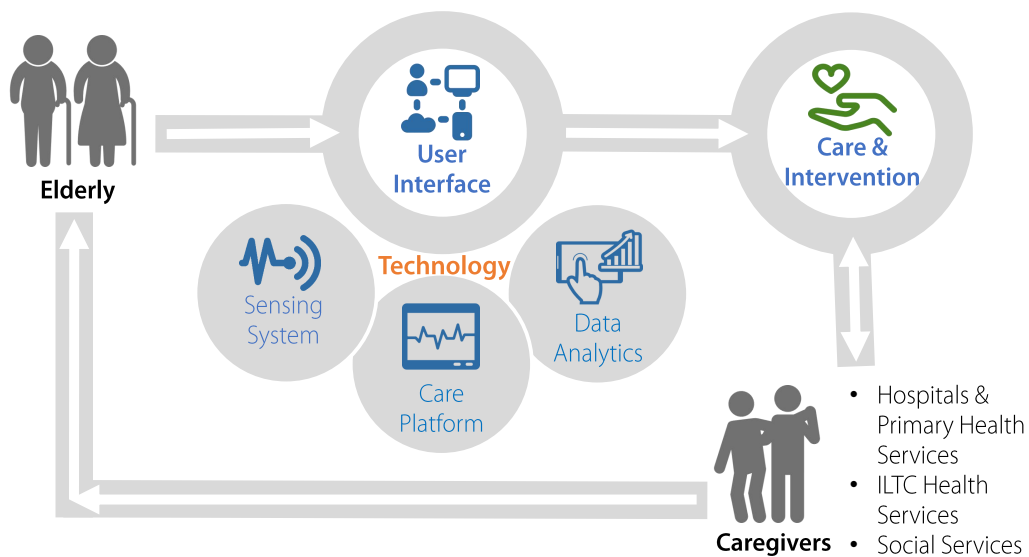

Figure 2: Enabling holistic and personalised ageing with technology.

being encumbered by the pervasive technology that monitors her wellbeing; *scalability*, to support the increasing number of elderly population that require ageing-in-place and facilitate participation and information exchange among caregivers; *real-timeliness* of data acquisition and processing, so that reactive care and intervention can take place; *reliability*, so that both the elderly and caregivers have confidence that the technology system will help to monitor the safety and wellbeing of the elderly and trigger alerts to the caregivers whenever necessary; *sustainability*, so that the support required to maintain the system is minimal; *extensibility*, to allow for the incremental addition of better and more sophisticated sensors and technologies in the future; and *flexibility*, to allow for personalisation of care and intervention.

The technology platform for ageing-in-place should be *unobtrusive, scalable, real-time, reliable, sustainable, extensible,* and *flexible.*

3
THE TECHNOLOGY ECOSYSTEM FOR AGEING-IN-PLACE

Technology will play a vital role in the realisation of our holistic and personalised ageing vision. Its use will be pervasive and multi-faceted, and will cover the broad areas of data collection, integration, storage and analytics, process orchestration, and information dissemination. From the human standpoint, the technology will link up the various ageing-in-place stakeholders, offering them insights about the elderly's wellbeing, and ultimately enabling them to provide pre-emptive and responsive care.

The four key components of the technology for holistic and personalised ageing that will enable pre-emptive and responsive care are:

- *In-home and Community Monitoring Systems* that use sensors and devices to collect data about the daily living patterns of the elderly and their environment;

- *Home and Community Care Platform* that can seamlessly ingest, integrate and store data from heterogeneous data sources and external systems;

- *Data Analytics* to understand the unique profile of every elderly, and provide holistic and personalised care; and

- *User Interfaces* for information dissemination to the stakeholders and to enable caregivers to provide timely and appropriate care.

3.1 UNOBTRUSIVE IN-HOME MONITORING

A traditional in-home monitoring system usually consists of sensors and devices that can track the whereabouts of the elderly while they are at home, for the purpose of monitoring their safety and security. Studies reveal that the elderly generally prefer monitoring systems that are non-intrusive (*i.e.*, do not employ vision-based or audio-based technologies), and require minimal action from participants, among others. In line with this, technology deployments may focus on the use of unobtrusive sensors and devices in the monitoring system. While this may pose limitations in terms of the richness of the data that can be directly collected, we leverage multimodal sensing and data fusion techniques to derive richer and meaningful information about every elderly.

Existing systems in the market can support reactive care whereby loved ones or caregivers can react to emergencies or other untoward incidents at the push of a panic button, or when the system detects that the elderly have fallen. There are also systems that trigger alerts when the elderly does not move for an extended duration at home. We envision that the capabilities of in-home monitoring systems can be extended to provide pre-emptive care, by leveraging data analytics techniques to learn more about the elderly's activities.

First-generation Smart-enabled Home for the Elderly

The first-generation smart-enabled home consists of passive infra-red (PIR) motion sensors and reed switch door contact sensors, such as those that have been deployed in the SHINESeniors project [11]. The PIR sensor is used to detect motion within a region of coverage, while the reed switch is used to detect if the main door is opening or closing. In addition to being unobtrusive, these sensors do not require any action from the elderly, and they do not need to change their daily activities to accommodate these sensors.

In addition to these passive sensors, we have also deployed a medication box in each elderly home to monitor the times at which the elderly have taken medication. The medication box is essentially an off-the-shelf box fitted with reed switches to detect the opening and closing of the box.

A typical home installation is shown in the figure on the right. In SHINESeniors, the target participants are elderly Singapore citizens living alone in the Housing Development Board (HDB) rental flats. Each two-room rental flat consists of one bedroom, one kitchen, one bathroom, and one living room. Every location in the flat is covered by one PIR sensor. The reed switch is attached to the main door of the flat. In addition to the sensors, each home is equipped with a gateway that is responsible for relaying all sensor data to the back-end for storage, analysis, and visualisation.
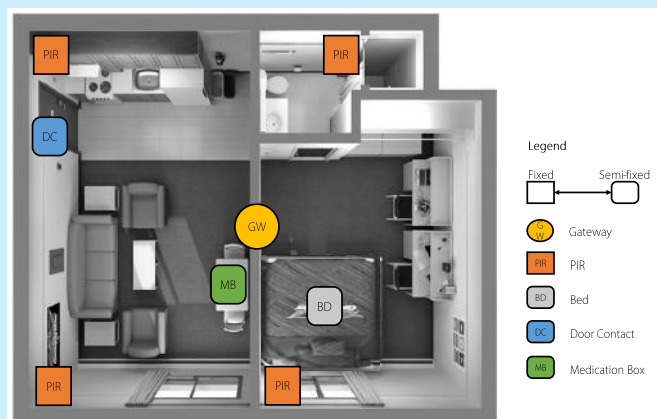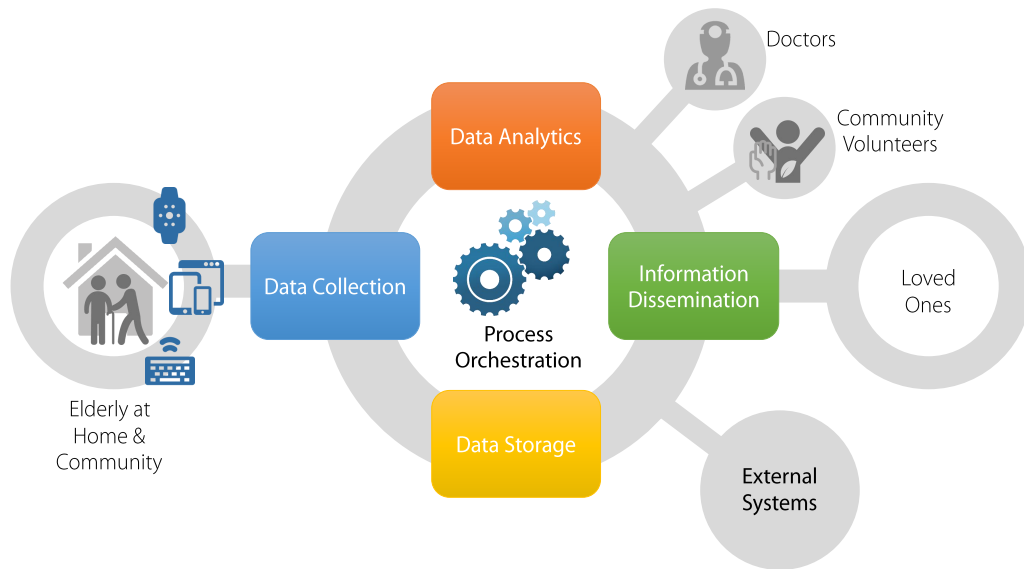
Figure 3: Technology enablers of holistic and personalised care.

Globally, there is increasing availability of ubiquitous and heterogeneous sensing devices that boast lower power consumptions, longer communication ranges, more superior processing power, or wider spectrum of sensing modalities. These may potentially provide richer contextual information about the elderly's wellbeing, or increase the effectiveness and reliability of the in-home monitoring system. As such, the in-home monitoring system should ideally be extensible enough, such that it can interoperate with multi-modal sensing devices from different hardware vendors, through the use of open standards and interfaces.

3.2 COMMUNITY MONITORING

For an elderly to age-in-place, it is important for her to be part of the neighbourhood community, in which she can be involved in various activities, as part of her daily life and holistic ageing. However, the outdoor environment may pose various risks to the elderly.

Undesirable environmental conditions such as uneven floors, dim lightings and lack of ramps may lead to: (i) physical risks, such as tripping or falling down; and (ii) psychological and social consequences, which can manifest in various forms, such as restricting external mobility and social activities in order to protect physical safety. In addition, one in ten elderly who are suffering from dementia may face the risk of getting lost in familiar places. The use of technology plays a pivotal role in minimising these risks, and to create a safe, conducive and liveable environment for the elderly. Through instrumentation of the community with multi-modal sensors, augmented with the potential use of wearable technology by the elderly, we can provide both reactive and pre-emptive care and intervention for the elderly.

Besides enhancing the physical safety of the elderly, it is crucial to create a liveable environment for them, by improving the accessibility of amenities and public spaces. In a focus group discussion conducted by the Ministry of National Development (MND), the elderly raised issues such as the diffi-

culties of navigation of wheelchairs in hawker centres, lack of public handicap toilets in parks, and lack of healthcare equipment rental services in the community [12]. Crowd-sourced data, augmented with a combination of both infrastructured and mobile sensors, can provide valuable information on the usage frequency and accessibility of amenities and public spaces. With this knowledge, urban planners can then improve usage and accessibility of common community spaces for the elderly.

Finally, technology can be harnessed to improve the emotional and social engagement of the elderly in a community setting. Robotic and sensing technology can be used to build intelligent robots that can interact with the elderly, conduct personalised exercise classes for elderly at senior activity centres, and be used as a form of therapy for depressed elderly [8]. The increased proliferation of such technology in the future enables holistic and personalised ageing among the elderly, in the community.

3.3 HOME AND COMMUNITY CARE PLATFORM

The Home and Community Care Platform leverages on the TCS IoT Platform to seamlessly ingest and integrate data from heterogeneous data sources such as sensors, survey responses, wearables, and health/medical records, among others. The platform offers a multitude of open interfaces and options for the extension of its features, along with suitable processes in place to ensure quality assurance. The platform is capable of real-time event processing to facilitate real-time notifications, ultimately enabling timely response to elderly who need care and assistance.

Workflows and Processes

Users have more on-the-ground experience, and are in a better position to decide on the workflow and processes. The Home and Community Care Platform does not dictate the workflow and processes, but empowers the users to make decisions on workflow and processes. For example, the question of when to issue an alert, and to whom, should be answered by the users, not developers. This puts greater

A Safer Community for the Elderly through Smart Technologies

Smart technologies can complement community-led efforts to provide dementia-friendly towns, such as that in the Yishun estate [13]. Through the use of beaconing technology, interactive outdoor environments (for instance, the Hello Lamp Post social experiment [14]) and sensor-equipped footwear with location tracking capabilities [15], wandering elderly with dementia and elderly with anomalies in walking patterns can be detected. These technologies could provide location or navigation information for the elderly if she lost her way. Caregivers can also be alerted whenever it is necessary to provide additional assistance for the elderly.

responsibility and ownership into the hands of the users, granting them maximum flexibility to support the elderly with love and compassion.

Alerts and Escalation

The Home and Community Care Platform will assist caregivers by providing updates and alerts about the elderly who have been entrusted to them. Advanced anomaly detection algorithms, predictive health analytics technologies, and deep diagnostics for activities of daily living will be employed to provide enhanced exceptional care for ageing-in-place – far beyond that which is possible through traditional caregiving practices.

In-Home Monitoring Systems

Miscellaneous Sensors & Devices

Survey Data

Data Ingestion

Data Integration, Storage & Retrieval

Workflows & Processes

Alerts & Escalation

Network & Device Management

Interface to IT/IoT Systems

Information Dissemination
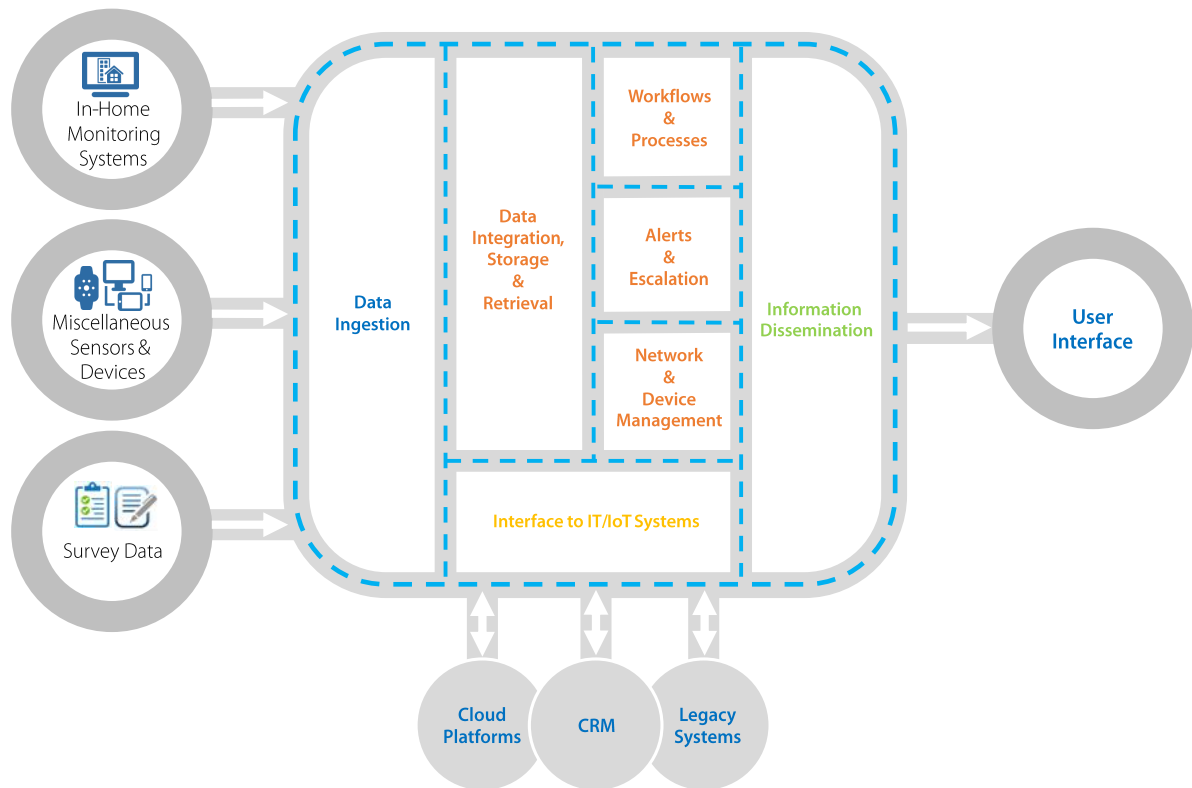
User Interface

Cloud Platforms

CRM

Legacy Systems

Figure 4: Home and community care platform.

Escalation protocols will be implemented on the platform. When users respond to alerts concerning an elderly person, such responses will be tracked to ensure that there is a timely response. An escalation protocol is put in place: if an alert is not responded to by a user within a certain time, the alert will be sent to other users. In addition, if the situation is deemed sufficiently critical, relevant authorities can be alerted.

Network and Device Management

Besides catering to end-users, the Home and Community Care Platform will assist technical support personnel by providing Network and Device Management tools to manage the thousands, if not billions of sensors and related devices in a massive Internet of Things (IoT) machine-to-machine meshed network of wired and wireless links alike. The management sensor and gateway statuses, downtime alerts for sensors, predictive maintenance, battery replacement schedules, and so on and so forth, can all be automated and require just minimal amounts of human supervision.

It is vital to provide a convenient platform to track the outcomes and improvements, so that we can better replicate the care and intervention for other elderly, in a more effective manner. With the manpower crunch in people providing care and intervention, we need to reduce the stress and workload on caregivers. Monitoring, surveys and observations can be used in tandem to provide the overall care and intervention.

Integration with Existing Systems

Some care-providing organisations have existing information technology (IT) systems such Customer Relationship Management (CRM) that are used to log casework, medical history, and other pertinent information about the elderly whom they serve. The Home and Community Care Platform will integrate, assimilate and accommodate such enterprise systems, both legacy and cloud-based, while providing extensible and versatile interfaces to exchange data, communicate, and work together in an automated manner. This

harmonious data exchange is a key enabler in driving analytics algorithms to produce deep insights into the wealth of information that are currently stored in isolated databases.

3.4 FROM DATA TO KNOWLEDGE AND MEASURES OF WELLBEING

The ubiquity of the in-home and community monitoring systems enable the acquisition of data, on the day-to-day activities (both in-home and in the community) of the elderly. Such data is subsequently ingested, integrated and stored by the care platform, together with unstructured data obtained from other sources. With the triangulation of real-time sensor data with data that is gathered by caregivers through surveys, conversations and observations, useful insights can be derived about the elderly's daily living patterns, health conditions, and overall wellbeing. These contribute towards the design of a context-aware system that is tailored to the unique profile of each and every elderly, to enable holistic and personalised ageing. Such information is also essential for caregivers to provide both responsive and pre-emptive care and intervention to the elderly.

Measures of Wellbeing

With inputs from medical and geriatric care professionals, the knowledge and best practices for elderly care can be used to extract meaningful and personalised measures of wellbeing, from the wealth of sensor and survey data acquired by the technology platform. These derived knowledge can then be utilised to quantify the wellbeing and health outcomes of the elderly, thus allowing for the detection of anomalies in elderly behaviour, early detection of health conditions, and prediction of Quality of Life in the elderly. Caregivers can then be empowered with the ability to provide appropriate care and intervention in a timely manner, to alleviate potential threats to the elderly's health.

Every health condition is typically associated with a distinct set of early warning signs or symptoms; such signs may vary significantly with the health status of each individual. It is hence important to work with health professionals to identify the health and wellbeing benchmarks for each elderly. Such personal benchmarks provide the baseline standards to develop measures of short-term and long-term monitoring, and help caregivers to identify elderly who require behavioural intervention to regulate unhealthy behaviours,
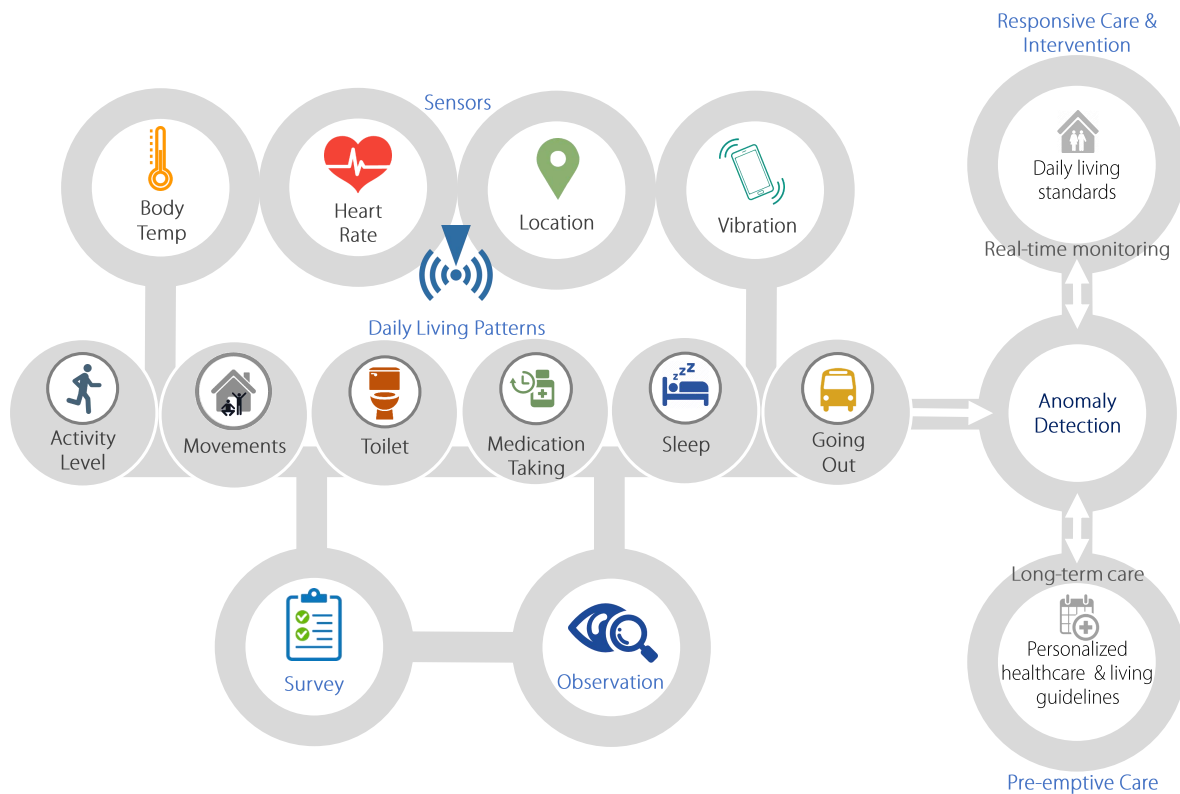
Figure 5: From raw data sources to knowledge and measures of wellbeing.

identify emerging health issues and react to elderly who require immediate care.

Example: Measuring Physical Wellbeing

The physical wellbeing of an elderly is an amalgamation of multiple factors, such as the number and types of chronic illnesses that the elderly is diagnosed with, physical mobility and sleep quality, amongst others. For instance, the sleep quality of the elderly can be derived from the various parameters — such as sleep duration, sleep latency, and proportion of time spent in each of the sleep states. These sleep-related parameters can be extracted from a combination of sensor data (*e.g.*, bed sensors or wearables), and survey data (*e.g.*, Pittsburg Sleep Quality Index). Measurement of the sleep quality of each elderly can then be derived only through the long-term acquisition of the relevant sensor data, and domain expertise knowledge from medical and healthcare professionals.

Pattern and Anomaly Detection

A data-driven approach to improve the elderly's overall wellbeing should involve both short-term and long-term obser-vations of the behavioural patterns of daily living, to provide standards for predictive modeling, and to detect anomalies in these patterns.

For example the long term monitoring of sleep patterns, movements inside an apartment, going-out and socialising activities will help us to generate benchmarks of daily activities for each elderly and to easily track whenever there is an anomaly. Unusual or sudden changes in elderly behavioural patterns can be directly correlated with their psychological and physical health status. For an instance an individual elderly who is suffering from dementia may sleep prolonged hours and would go out less frequently, and a diabetic may use the toilet more frequently than of a healthy individual.

The derived knowledge from various data sources can be utilised to quantify the wellbeing and health outcomes of the elderly.

Therefore, the automated recognition of activities will help family members, caregivers and medical professionals to monitor the functional health of the elderly, determine the wellness of the elderly, and take necessary measures for pre-emptive and reactive care.

> ### Example: Anomaly Detection Using PIR Sensor Data
>
> An in-home elderly monitoring system typically involves the instrumentation of the home with multiple Passive Infra-Red (PIR) sensors. Each of these PIR sensors detect the motion of the elderly in a particular part of the home. Such data can be used to derive real-time information about an elderly's movement within the home, and to raise alerts to relevant caregivers when short-term anomalies arise. For instance, an extended period of inactivity in the home is an indication that the elderly may have fallen or fainted, and the caregivers should be alerted accordingly to provide the necessary assistance.
>
> The same set of PIR sensors in the home can also be used to provide longer-term anomaly detection, using techniques such as machine learning to establish the 'baseline' behaviour of the activities of daily living of each elderly. Through the fusion and aggregation of data from PIR sensors around the house, as well as from other sensing modalities, we can now monitor the sleep pattern and quality of the elderly in a longitudinal fashion, as well as identify the possible causes of poor sleep quality. For example, if the PIR sensor data reveals that the elderly is going to the toilet more frequently at night in the middle of her sleep, it can indicate that the elderly is exhibiting signs of nocturia. Conversely, if the elderly is spending a significant proportion of time in the living room at night, it may indicate that the elderly is suffering from insomnia.

Application of Knowledge

The overall wellbeing of an elderly can be subjectively determined by a composition of dimensions such as: physical, emotional, intellectual, social, spiritual and vocational. Care models must be designed not only to improve the physical health status of the elderly, but also to improve their overall wellbeing. The knowledge derived from data can be also used to identify individual elderly who require interventions with psychosocial behaviours. For instance, based on the information gathered from sensor data, we can monitor the frequency and duration that an elderly ventures out of the home. By aggregating the sensor-derived information on time-out with the information gathered through community care centers and VWOs in a neighbourhood, we can develop baseline measures of the elderly's social wellbeing. Scales such as R-UCLA loneliness scale, Lubben Social Network Scale and social isolation index, which are popularly used by behavioural researchers, can be applied to identify elderly who require interventions to improve social wellbeing. Together with VWOs, community care programs can be designed to enable an environment that enhances social interaction.

3.5 USER INTERFACES

In essence, the Home and Community Care Platform collects data from sensors from any vendor, any manufacturer, with any level of vendor support and technical assistance scheme, and provides visualisation for viewing sensor data, and analytics insights, in real time. This will be presented through a web portal, for use on desktops and laptops, and a mobile web application, for use on mobile devices. The versatility and flexibility of the platform will enable it to easily support future user interfaces.

The user interfaces present information in a way that is user-centric. The interfaces are designed to be simple, intuitive and easy to use, being similar to social media user interfaces, so that users will be presented with a familiar interface. Where necessary, elderly-friendly accessibility features will be built-in and designed for maximum usability by the elderly.

3.6 VALUE ADDED SERVICES

While the technology platform is primarily geared towards enabling holistic and personalised ageing, it can nevertheless be used to offer other related services in the future. Potential application extensions of the platform include elder concierge services, elderly-volunteer matching, elder help or befriending services, and home or community-based rehabilitation. By linking with other data sources such as medical and financial data, the platform can even support personalised financial planning and insurance premium determination for the elderly.

4

ROADMAP: FROM CONCEPTUALISATION TO REALISATION

Majority of current solutions that aim to address ageing-in-place fail, because their designers approach the ageing problem from a technology-centric point of view. Our ageing-in-place vision, and the model that guides us in the realisation, understands that solutions must be reliable, cost-effective, and most importantly, relevant and human-centric, in order to be successful. Hence, it is pertinent that from the onset, and throughout the entire process of conceptualisation and realisation, the continuous engagement and feedback of the various stakeholders are solicited.

4.1 OVERVIEW

Our vision for ageing-in-place involves People, Technology and Processes and we believe its realisation will require the support and participation of the various stakeholders, especially the elderly. Our close contact with volunteers and grassroots will help us reach out to the elderly, to enlighten them about our vision and the benefits of holistic and personalised ageing, and to continuously seek their feedback. Due to our multi-disciplinary linkages, we are in a unique position to bring together experts from the social, health and information sciences, technology, business and public policy, to formulate and validate a truly holistic and personalised technological solution for ageing-in-place in Singapore.

Innovation and Technology Partnerships

We will partner with technology providers who are ready to adapt their existing products and services to better address the requirements and constraints of the different stakeholders in the elderly care domain. The landscape for elderly care in Singapore is constantly evolving, to cater to the changing demographics and needs of the elderly population. For instance, the current generation of elderly are generally technology-illiterate, and are more comfortable with the use of unobtrusive in-home monitoring systems. In contrast, the younger-old population in Singapore are relatively more receptive towards technology, and may be open to other forms of monitoring technologies — such as wearables and telehealth devices. We expect that there will always be gaps in the current market offerings; hence, we intend to co-innovate and co-develop with our collaborators to deliver complete and end-to-end technological solutions to support ageing-in-place.

The lack of a prevailing industry standard for monitoring systems, has also led to the fragmentation of sensors and devices that are available in the market. Although there are several vendors which are offering similar elderly-focused home monitoring systems, most of these solutions are built in-silo, and non-interoperable with one another. There is also a stark scarcity in comprehensive evaluation of the overall performance in large-scale deployments. At SMU-TCS iCity Lab, our aim is not to develop sensors and devices, nor to offer hardware components for in-home and community monitoring. Conversely, we leverage the strength of industry market leaders to provide in-home and community monitoring technologies that can: (i) meet the potentially changing requirements of the elderly and other stakeholders; and (ii) operate under the constraints imposed upon by the environment, as well as other technical and non-technical considerations. Another of the key roles of the iCity Lab is to evaluate the performance of these commercial solutions - in terms of metrics such as reliability, cost-effectiveness, acceptability, sustainability and scalability - and then provide data-driven recommendations for the adoption of different technologies for ageing-in-place.

Process Design

Processes play a key role in our vision because they link People and Technology to enable the seamless delivery of care and intervention. With our expertise in enterprise integration and business process orchestration, iCity Lab will spearhead the formulation of care and intervention processes.

Testbedding and Iterative Approach

To validate the technology and processes, we will conduct testbedding in real-world settings, involving the elderly, caregivers, doctors, and social workers. Using an evolutionary and iterative approach, we will use the testbedding results and feedback from the participants to refine the model.

4.2 CURRENT STEPS

As part of the Land and Liveability National Innovation Challenge (L2NIC) funded SHINESeniors project, the iCity

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Our multi-disciplinary linkages will enable us to formulate and validate a holistic and personalised technology-based ageing-in-place solution in Singapore.

Lab has undertaken several steps to work towards a technology platform to support holistic and personalised ageing-in-place in Singapore.

In-Home Monitoring and Anomaly Detection

Since July 2015, a total of 50 elderly homes in Marine Parade, which is in the eastern region of Singapore, have been instrumented with a set of unobtrusive multimodal sensors. In addition, 10 out of these 50 elderly homes have also been provided with sensor-enabled medication boxes, which are used to infer medication adherence of the elderly. Using data from the PIR sensors and door contact sensors, the system is able to monitor the elderly movements within the home, and trigger alerts to relevant caregivers whenever there is prolonged inactivity in the home, or whenever there is prolonged dwell time in a certain region of the home. This allows the elderly to receive timely assistance from their caregivers when emergency situations arise. The sensor data is also used to derive insights about the daily living patterns of the elderly, which are used to detect subsequent anomalies in the elderly behaviour, if any.

Open and Extensible Care Platform

We have started work on a vendor-neutral care platform with our technology collaborator Tata Consultancy Services, which is able to ingest multimodal data from a variety of data sources. The care platform is open and extensible, and will be able to support both in-home and community monitoring, as well as home and community based care models. This flexibility feature of the platform is essential to support the changing needs of the elderly care industry.

Engagements with Stakeholders

Throughout the course of the 3-year SHINESeniors project, we have been actively engaging and soliciting regular feedback from our stakeholders, which include: (i) the elderly themselves; (ii) GoodLife!, which is a Voluntary Welfare Organisation (VWO) that provides community care services to the elderly living in Marine Parade; (iii) Eastern Health Alliance (EHA), which takes care of regional health system

for the people living in the eastern part of Singapore; and (iv) the Ministry of Health (MOH), which takes care of the health system in Singapore on a city scale. Through the continuous feedback from these stakeholders, we are constantly iterating through and improving our technology platform to support ageing-in-place.

4.3 THE ROAD AHEAD

With the increasing ageing population in Singapore, there are numerous opportunities and challenges to innovate and build technologies that can enable ageing-in-place.

The flagship SHINESeniors project that is led by iCity Lab, currently focuses only on in-home monitoring, for elderly who are staying alone in Singapore. The study is limited to only on a few specific daily living patterns — such as medication adherence and activity within the home. It is focused on improving the responsive time of the caregivers when emergency situations arise in the elderly home. One of the main challenges of today's technology solutions is detection accuracy and timeliness of alerts. False alerts cause inconvenience to both the elderly and caregivers, whereas long delay may compromise the safety of the elderly.

Beyond the SHINESeniors project, iCity Lab is looking to explore several other avenues to support ageing-in-place through the use of technology. These include community monitoring efforts, such as in public spaces, so as to enhance the safety, liveability and accessibility of the elderly in the neighbourhood. In addition, the iCity Lab will also be focusing on the research efforts to improve pre-emptive care and intervention of the elderly, through long-term monitoring and data analytics of data gathered about the Activities of Daily Living (ADLs) of the elderly.

In addition, we are looking forward to work more closely with other stakeholders, to improve the care model, as well as to improve the outcome assessment of the system, so that it can be replicated across different towns in Singapore. We would like to explore looking at other aspects of ageing-in-place, such as from the cognitive, social and psychological aspects. We also intend to scale the testbed, while ensuring that the system is able to support the ever-growing number of elderly population.

5

CLOSING REMARKS

Ageing population is a reality that many countries around the world are facing. In the Singapore context, rapid ageing poses social, economic and fiscal challenges, requiring concerted efforts from both individuals and the society at large. The increasing demand for eldercare services, exacerbated by decreasing manpower to provide institutionalised care, calls for a transformation in the provision and delivery of care services.

A new paradigm of ageing is gaining traction, one that is harmonious with aspirations of the elderly, as it enables them to live independently in the safety and comforts of their own homes and communities. Known as "ageing-in-place", this model shifts the provision of care to the home and community where the elderly is living in. Ageing-in-place has the promise not just to alleviate the impending shortage of institutionalised care facilities and staff, but more importantly, to improve the elderly's quality of life as it empowers them to remain independent and in touch with their friends and loved ones.

Nonetheless, we must realise that the elderly, especially those staying alone at home, need to have access to timely care as and when the need arises. To reap the benefits of ageing-in-place, we need to seamlessly and efficiently link up the various providers of home and community care. Technology is indeed essential in this unprecedented undertaking; moreover, we advocate the use of technologies that understand and respect the uniqueness of every individual elderly, to enable the delivery of holistic and personalised care.

The technology platform consists of four main components. First is the In-home and Community Monitoring System that endeavours to collect data about the daily living patterns of the elderly and their environment. Second is the Home and Community Care Platform that seamlessly ingests, integrates and stores data from heterogeneous sources and external systems. Third is Data Analytics that aims to understand the unique profile of every elderly, and provide holistic and personalised care. Last but not the least, User Interfaces for information dissemination to the stakeholders and to enable caregivers to provide timely and appropriate care. Through this technology platform, care providers will be able to tailor care models to suit their specific needs. The platform can also support future models of care, enabling uberisation of care services and intervention, whereby the entire community is engaged in providing care for the elderly.

Ultimately, the success of technology-enabled aged care in general, and our vision of holistic and personalised care in particular, is contingent on the acceptance by the community volunteers and the elderly. Hence, as we continue to develop and testbed our platform, we work closely with volunteers and grassroots to continuously seek their feedback to improve the different aspects of the platform. With their help, we can reach out to the elderly, to enlighten them about the benefits of holistic and personalised ageing.

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About SMU-TCS iCity Lab

The SMU-TCS iCity Lab is a research facility set up through a partnership between TCS and SMU to develop industry standards and IT frameworks for the emerging intelligent city ("iCity") model of urban development. The partnership combines TCS' industry leading IT services expertise and culture of innovation with SMU's globally recognized excellence in research and education and for the world of business and management in both the public and private sectors.

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