Large-scale IoT Systems for Ageing-in-Place: Experiences and Lessons Learnt towards Sustainability

Hwee-Pink TAN, Ph.D.
Associate Professor of Information Systems (Practice)
Academic Director, SMU-TCS iCity Lab

15 August 2018
About the SMU-TCS iCity Lab

- Established in August 2011 to explore and pursue new research areas in **Smart Cities** to provide long-term competitive advantage to TCS
- /={intelligent, integrated, inclusive, innovative}

- Track record in executing large transformation projects for governments
- Digital reimagination with social media, mobile, big data analytics and IoT
- Focused on integrating computing, management and social science
- Multi-disciplinary expertise on smart city solutions
- State-of-the-art city campus in Singapore ideal for piloting solutions
iCity Lab’s research focus

Phase 1 (2011-2014) From thought leadership to smart aging
Citizen engagement and services aspects
Community with special needs

Application of IoT through social-behavioural lens
Partnership with key stakeholders
Deployments at scale with caregivers

Phase 3 (2017-2020) Citizen as a producer for resilient cities
Citizen as consumer and producer of services
Helping
Thinking
Doing
Meeting the needs of seniors living alone

Seniors living alone may rise to 83,000 by 2030

- Elderly living alone need community support to ensure their
  - Safety
  - Physical wellbeing
  - Social wellbeing

“Can non-intrusive technologies be used to better enable **person-centric community care** for me to age-in-place?”

- Mr Lim, 73yo, living alone, beneficiary

“Can the system **complement**, instead of burden, our team to provide targeted, as-needed and timely care for the elderly to age-in-place?”

- Ms Tan, 45yo, community caregiver, user & beneficiary
Data-driven Community Eldercare Platform

Community Dwelling Elderly

In-home sensing
Surveys and observations
DATA COLLECTION

Modular by design, extensibility by choice

Aging-related Policy Enablers

Data management
Analytics
INSIGHT & ACTION

Community Care Enablers

In- home sensing
Data management
Analytics
dashboard
OTT messaging
ENABLER

Technology Enablers
Needs of key ecosystem partners

“Can I maximize the **reliability** of the system and minimize the need for predictive maintenance?”
- Mr Ong, 43yo,
  - CTO, Tech4Elderly Pte Ltd

“Are our **HDB towns** sufficiently **age-friendly** where seniors living alone can remain physically, socially and mentally well and safe?”
- Ms Lee, 35yo,
  - Urban Planning Group,
  - Urban Redevelopment Authority

“Is there **evidence** that data-driven **community care** can **improve the wellbeing** of seniors living alone through both reactive and preventive care”
- Dr Ho, 50yo,
  - Ageing Planning Office,
  - Ministry of Health

“Is it **economically viable** and **useful** to have in-home monitoring technologies that can improve the safety and wellbeing of seniors living alone?”
- Mr Yap, 40yo,
  - Technology Research,
  - Housing Development Board
Over 200 elderly reached with ~90 ‘live’ homes

- Marine Parade (>36 months)
  - Reactive care for 48 elderly (help button & prolonged inactivity)
  - Preventive care for 48 elderly (social, cognitive and physical wellbeing)

- Bedok South (>12 months)
  - Care for 17 elderly for irregular medication patterns, help button and prolonged inactivity

- 5 estates (>12 months)
  - Reactive care for 50 elderly (help button & prolonged inactivity)
  - Preventive care (social wellbeing)

- Bukit Merah / Tampines / Bedok North (<12 months)
  - VWO/NOK care for 6 elderly
  - Call centre care for 22 elderly (Yellow Flag)

- Multiple estates (<2 months)
  - Identifying cognitive impairment among 48 elderly through passive sensing and wearables

# elderly beneficiaries (living alone)

- 2015
- 2016
- 2017
- 2018

Community partner

SMU Classification: Restricted
What our users & beneficiaries say?

“…For a layperson like me, it was easy to see and interpret. I didn’t have to ask too much questions for confirmation and we managed to save the senior.”

- Senior Case Worker 1, MontfortCare

“......from a new workers perspective, to be able to see all the information on the screen is very helpful and it’s very easy for people to respond.”

- Senior Case Worker 2, MontfortCare

“....one other things I thought this was good, it gives elderly some form of security to know that they are being monitored, specially those are frail, that they are not left alone in the community”

- Case Worker 2, THK Moral Society

“In general, I feel positive about the sensor system. If something happens to me, someone will know...”

- Elderly, Mdm Khoo, 77 – Marine Terrace

“I feel that it is beneficial for me as I am getting old too. I’m slightly more fragile and I think with age, it’s a bit harder to do certain things like heavy household chores. ....... it helps me feel a sense of security”

- Elderly, Mdm Teng, 88 – Bedok South
In-home unobtrusive monitoring system
Evolution of In-Home Monitoring System

Vendor A system
- Built in-house
- Proprietary comms standards
- 2G system
- No ack with help button

Vendor B system
- Proprietary gateway with off-the-shelf z-wave sensors
- Unused UI indicates power consumption

Open, reliable and extensible system
- Fully-based on off-the-shelf devices
- Open comms standards
- Extensible
- ACK with help button
- Full system monitoring

• Senior-centric design
  • Minimal disruption to their lives
  • Maximum dependability
Technology-enabled Personalized & Timely Reactive Community Care

- **Medication non-adherence**
- **Prolonged away duration**
- **Prolonged inactivity (Door)**
- **Prolonged inactivity @ home**

**Data analysis & anomaly detection**

**Help / friendship request**

**Provide timely care and intervention**

- **VWO/Call Centre/NOK**
- **Person-centric rules**
- **Anomaly-triggered Alert (Person-centric)**

**Community Care Model**

**Person-centric Response protocol**

**Care execution & evaluation**

- **Elderly Living Alone**
- **Community Volunteers**
- **Community Caregivers**
Prolonged inactivity / dwell time @ home

A period of prolonged inactivity at home / zonal dwell time can indicate trouble for the elderly resident.

When this duration exceeds a threshold, trigger an alert to caregivers.

Challenge: How to set the right alert threshold for different elderly with different daily routines.
Data-driven alert threshold personalization

**Methods**

- Exceedance-based Day/Night Threshold

**Historical Inactivity Data**

**Personalized Alert Threshold**

- **Aunty Tan**
  - Early 80s
  - High blood pressure, diabetes and high cholesterol
  - Stays home mostly
  - Frail, fall history
  - Socializes infrequently, with few visitors

- **Aunty Chan**
  - Daily exercise routine
  - Generally fit
  - Socializes frequently
Balancing needs of elderly and caregiver

<table>
<thead>
<tr>
<th></th>
<th>15 Sep – 31 Dec ‘15</th>
<th>1 Jan – 31 Dec ‘16</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daytime Threshold</strong></td>
<td>8 hours</td>
<td>5.7 hours</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nighttime Threshold</strong></td>
<td>8 hours</td>
<td>4.9 hours</td>
</tr>
<tr>
<td>(Average)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>False Alarm Rate Due to Threshold Exceedance</strong>*</td>
<td>5 False Alarms / 3.5 Months = 1.4 Per Month</td>
<td>63 False Alarms / 12 Months = 5.3 Per Month</td>
</tr>
<tr>
<td><strong>Overall False Alarm Rate</strong></td>
<td>43 False Alarms / 3.5 Months = 12.3 Per Month</td>
<td>121 False Alarms / 12 Months = 10.1 Per Month</td>
</tr>
</tbody>
</table>

Event of stress detected faster!

Within tolerable fatigue limit!
# Technology-enabled Personalized Reactive Community Care (Medication regularity)

<table>
<thead>
<tr>
<th>Zone</th>
<th>Marine Parade</th>
<th>Bedok South</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDB type</td>
<td>Rental</td>
<td>Rental</td>
</tr>
<tr>
<td>Total no of elderly</td>
<td>10</td>
<td>14</td>
</tr>
<tr>
<td>Senior profile</td>
<td>Generally healthy and socially active</td>
<td>Vulnerable and frequently admitted to hospital</td>
</tr>
<tr>
<td>#Medication types</td>
<td>4 to 10</td>
<td>1 to 15</td>
</tr>
<tr>
<td>Medication Intake frequency</td>
<td>1 to 3</td>
<td>1 to 4</td>
</tr>
<tr>
<td>Period</td>
<td>Jul 15 - Apr 16</td>
<td>Jul 16 - Feb 18</td>
</tr>
<tr>
<td>Caregiver</td>
<td>MontfortCare</td>
<td>Neighbours for Active Living</td>
</tr>
<tr>
<td>Study type</td>
<td>Observational</td>
<td>Interventional</td>
</tr>
</tbody>
</table>
Understanding elderlies’ needs & wellbeing

- Social-demographic profile, family support, financial status
- Physical health, mental health, medication, sleep patterns and quality, activities of daily living
- Social function, overall happiness and wellbeing, liveability, technology
- Routines and unusual events (hospitalization, faint spells, family visits etc)

Psychosocial Surveys & Regular Ground Observations
Care for Inferred Non-medications adherence

- Non-adherence leads to adverse health complications
- Existing solutions are costly and cannot be tailored to elderly’s habits
- Real-time monitoring allows for timely care and personalized intervention

~80% of elderly have no packing assistance

~60% of elderly store medication in plastic bags or containers

~87.5% of elderly are on daily medication

<table>
<thead>
<tr>
<th>Medication Daily Intake Frequency (n=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medication Packing Assistance (n=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No meds</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Medication Storage (n=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No meds</td>
</tr>
<tr>
<td>7-day pillbox</td>
</tr>
<tr>
<td>Medication box</td>
</tr>
<tr>
<td>ic bags or containers</td>
</tr>
<tr>
<td>Others</td>
</tr>
</tbody>
</table>

~60% of elderly store medication in plastic bags or containers

~87.5% of elderly are on daily medication

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<tr>
<td>3</td>
</tr>
<tr>
<td>4</td>
</tr>
</tbody>
</table>
User-centric approach to real-time monitoring

Existing Medication Packing Habits

Sensor-Enabled Medication Box

Legend:
- Gateway
- Motion Sensor
- Sensorized medication box
- Door Contact
- Help/friendship button
- Beacon
Irregular medication behavior is common

Very few elderly exhibit consistent medication behaviors
Data-driven care for irregular medication

Real-time monitoring data

Categorization of adhering vs non-adhering elderly

Community care and intervention
Evolution of Caregiver Notification Interface

Mobile app A
- Difficult to navigate from alert to resident activity
- OS and device dependent performance
- Missing alert delivery

Mobile app B
- Presents glut of unactionable information
- Primarily targeted at savvy users
- Plenty of user-configuration needed

Unified interface
- Inactivity, help/friendship, yellow flag and medication
- Context-rich alert
- Enables group collaboration and response

- Caregiver-centric design
  - Complements, instead of burdens
  - Ease of use, and when-needed use
Intervention improves medication regularity

Improved medication regularity after intervention in Sep 2016
(medication reconciliation)

Early 60s
- Polypharmacy
- Wheelchair-bound
- Live-in daughter is primary caregiver
Personalized Preventive Care to meet wellbeing needs

- Elderly Living Alone
- Community Caregiver

Activity level @ bedroom
Activity level @ kitchen
Activity level @ bathroom
Overall activity level @ home
Multi-modal Data analysis

Wellbeing indices
- Loneliness/Social Isolation
- Physical frailty
- Sleep Quality

Community Care Model
Refinements
Care execution & evaluation

Provide care and intervention

Personalized care plan

Poor / declining wellbeing level?

SMU Classification: Restricted

Going out
## Preventive Care (Social Isolation)

<table>
<thead>
<tr>
<th>Sensor-derived indices</th>
<th>Survey-derived features</th>
<th>Emotional loneliness</th>
<th>Social loneliness</th>
<th>Social network</th>
<th>Social Isolation Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average daily going out duration</td>
<td>-0.22 (0.144)</td>
<td>-0.38* (0.011)</td>
<td>0.31* (0.037)</td>
<td>-0.42* (0.005*)</td>
<td></td>
</tr>
<tr>
<td>Going out count</td>
<td>0.13 (0.392)</td>
<td>-0.10 (0.503)</td>
<td>-0.07 (0.656)</td>
<td>0.08 (0.606)</td>
<td></td>
</tr>
<tr>
<td>Napping duration</td>
<td>-0.08 (0.597)</td>
<td>0.32* (0.038)</td>
<td>-0.26 (0.101)</td>
<td>-0.05 (0.777)</td>
<td></td>
</tr>
<tr>
<td>Night time sleep duration</td>
<td>-0.12 (0.448)</td>
<td>0.24 (0.133)</td>
<td>-0.14 (0.373)</td>
<td>-0.16 (0.297)</td>
<td></td>
</tr>
<tr>
<td>Average time spent in the living room</td>
<td>0.31* (0.049)</td>
<td>-0.01 (0.973)</td>
<td>-0.23 (0.149)</td>
<td>0.17 (0.292)</td>
<td></td>
</tr>
<tr>
<td>Kitchen activity</td>
<td>-0.11 (0.48)</td>
<td>0.03 (0.854)</td>
<td>0.03 (0.852)</td>
<td>0.10 (0.508)</td>
<td></td>
</tr>
</tbody>
</table>

*P values are in parenthesis

**P ≈ 0.001, **P < 0.01, *P < 0.05

### Key Points
- **Away Duration, Napping Duration and Time Spent in the Living Room** are correlated with social isolation dimensions.

Effective socialising

- Chronic conditions do not predict socializing
- Elderly with high social network but still feels lonely needs attention
- Findings can provide useful recommendations for value-added personalized eldercare planning

Source: “Employing In-Home Sensor Technology to explore Elderly needs and Community Participation: Implications on Personalising Community Elder Care”, M. Huang et al, 8th APRU Population Aging Conference, Oct 2017, Singapore
Preventive Care (Early detection of frailty)

### Preventive Care (Early detection of frailty)

#### Robust vs Frail

<table>
<thead>
<tr>
<th>Robust</th>
<th>Frail</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Feature ranking (Logistic Regression)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Generic model</th>
<th>Daytime model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Away duration</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Napping duration</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Night time sleep duration</td>
<td>3</td>
<td>NA</td>
</tr>
<tr>
<td>Time spent in the bedroom</td>
<td>2</td>
<td>NA</td>
</tr>
<tr>
<td>Kitchen activity level</td>
<td>4</td>
<td>NA</td>
</tr>
<tr>
<td>Kitchen usage duration</td>
<td>7</td>
<td>NA</td>
</tr>
<tr>
<td>Transitions</td>
<td>6</td>
<td>NA</td>
</tr>
<tr>
<td>Time spent in the bedroom (daytime)</td>
<td>NA</td>
<td>3</td>
</tr>
<tr>
<td>Door open count (daytime)</td>
<td>NA</td>
<td>1</td>
</tr>
</tbody>
</table>

#### ROC curve (Generic vs Daytime Features)

**Source:** “Unobtrusive Detection of Frailty in Older Adults”, N. Goonawardene et. al., Human Aspects of IT for the Aged Population, July 2018
Preventive Care (Mild Cognitive Impairment)

Can information derived from in-home sensing differentiate cognitively healthy (HC) elderly from those with and mild cognitive impairment (MCI)?
Promising Preliminary Results

**Table 1: Baseline characteristics of participants**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>73.6 (4.3)</td>
</tr>
<tr>
<td>Education (years)</td>
<td>5.0 (4.0)</td>
</tr>
<tr>
<td>MMSE</td>
<td>26.5 (2.8)</td>
</tr>
<tr>
<td>MoCA</td>
<td>24.1 (4.3)</td>
</tr>
<tr>
<td>Baseline GDS</td>
<td>1.3 (1.1)</td>
</tr>
</tbody>
</table>

12 elderly with MCI, 5 with Healthy Cognition

![Healthy Cognition vs MCI](image)

**Figure 3**

**Incidents of forgetting personal effects (group)**

MCI participants also had
- More outings
- Longer total sleep duration
Detecting poor sleep quality in elderly

- **Feature extraction & model verification**
  1. Min. Activity level
  2. Xth % of activity levels and diff
  3. Std (activity level)
  4. Est sleep duration
  5. Est sleep efficiency

80% accuracy with 25% false positive

Source: “Identifying Elderly with Poor Sleep Quality using Unobtrusive In-home Sensors for Early Intervention”, X. Ma et. al., Submitted to GoodTechs 2018
<table>
<thead>
<tr>
<th>Year</th>
<th>2015</th>
<th>2018</th>
<th>2021</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMU-TCS iTech R&amp;D Team</td>
<td>1</td>
<td>10</td>
<td>1,000</td>
<td>10,000</td>
</tr>
<tr>
<td>SMU-TCS iTech Translation/commercialization Team</td>
<td>100</td>
<td>100</td>
<td>100,000</td>
<td>100,000</td>
</tr>
</tbody>
</table>

### Mechanism

- **Elderly segment**
  - ≥ 65yo living alone; 80/20%: Low/middle income, rental/purchased flat, community care
  - ≥ 50yo living alone; 60/40%: Low/middle income, rental/purchased flat, hybrid care

- **Key challenges**
  - Can non-intrusive in-home technologies keep the elderly safe, and physically, mentally and socially well?
  - Can technologies assist community (non-health) caregivers to provide as-needed care for elderly to age-in-place?
  - Can sustainable community sensing keep the elderly safe, and physically, mentally and socially well?
  - Can technologies assist integrated (health and non-health) community caregivers to provide as-needed care for elderly to age-in-place?

- **Capabilities demonstrated**
  - Usable, dependable and vendor-neutral system for detecting and responding to help / friendship requests, prolonged inactivity (home; main door; medication)
  - Multi-modal data analysis to early detect social isolation and cognitive impairment
  - Can AI be used for the system to extract more value for self-care that will result in improved wellbeing in fee-paying (middle-income) clients?

- **Partners**
  - MontfortCare
  - Health
  - CareLine
  - Neighbours for Active Living
  - ???
Thank you for your attention

Hwee-Pink TAN, Ph.D.

hptan@smu.edu.sg
icity.smu.edu.sg