Agency for Science, Technology and Research
SINGAPORE

E-WASTE COLLECTION AND RECYCLING BEHAVIOURS: AN AGENT-BASED MODEL FOR INTERVENTION ASSESSMENT IN SINGAPORE

Quoc Khanh Tran

Supervisor: Dr. Sun Yajuan

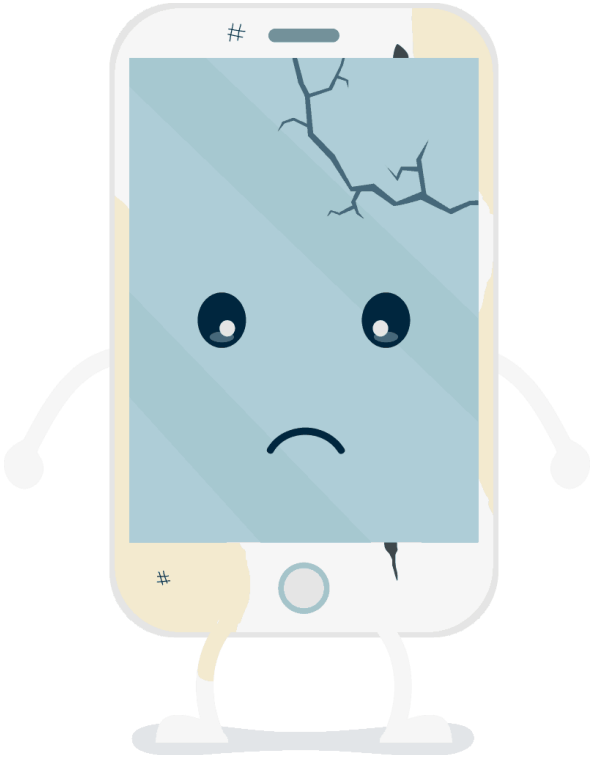
Agenda

Introduction

Research Problem

What would you do, if you had a no-longer-used smartphone?

60% of Singapore residents **do not know** or are **unsure** of how to recycle their electronic waste [1].



CREATING GROWTH, ENHANCING LIVES

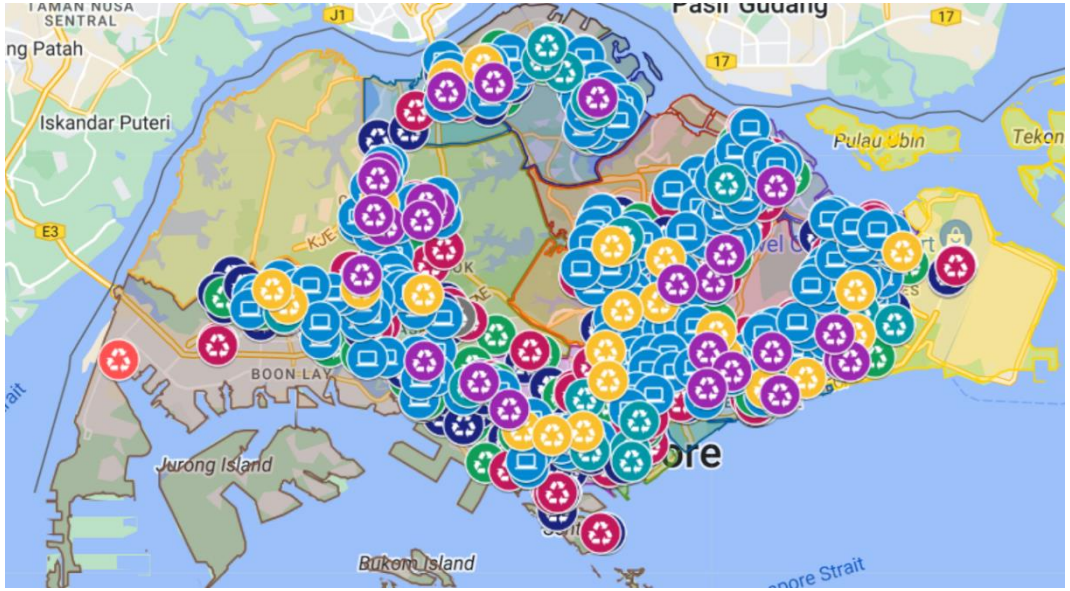
Research Problem

- Significant increase of electronic waste (e-waste) generation.
- **62 millions metric tons,** approximately 155,000 Boeing 747s, of e-waste was generated in 2022 globally [2].
- E-waste is:
  - Valuable raw material, e.g. gold, silver, and copper [3].
  - Environmentally hazardous [4].
- Only 22.3% were documented as formally recycled worldwide [5].
- Only 6% of 60,000 tonnes e-waste generated each year in Singapore are recycled [1].

→ **Model e-waste collection** to assess recycling interventions.

E-waste Management in Singapore

- **Extended Producer Responsibility** (EPR): producers are responsible for end-of-life products.
- **E-Bins** in public areas across Singapore to collect e-waste.



Locations of E-Bins in Singapore, information from National Environment Agency [9].

A 3-in-1 e-bin placed at Harvey Norman Millenia Walk. Photo from National Environment Agency [6].

CREATING GROWTH, ENHANCING LIVES

Modeling Methodology

Agent-Based Modeling (ABM)

- **Complex Adaptive System** (CAS) composes of multiple agents that adapt in response to environment.
- **Agent**: autonomous entity with unique characteristics and behaviours.
- **Emergence**: system-level phenomenon in CAS arises from agent interactions, unpredictable from individual components.

→ ABM is suitable for CAS, such as e-waste collection system.

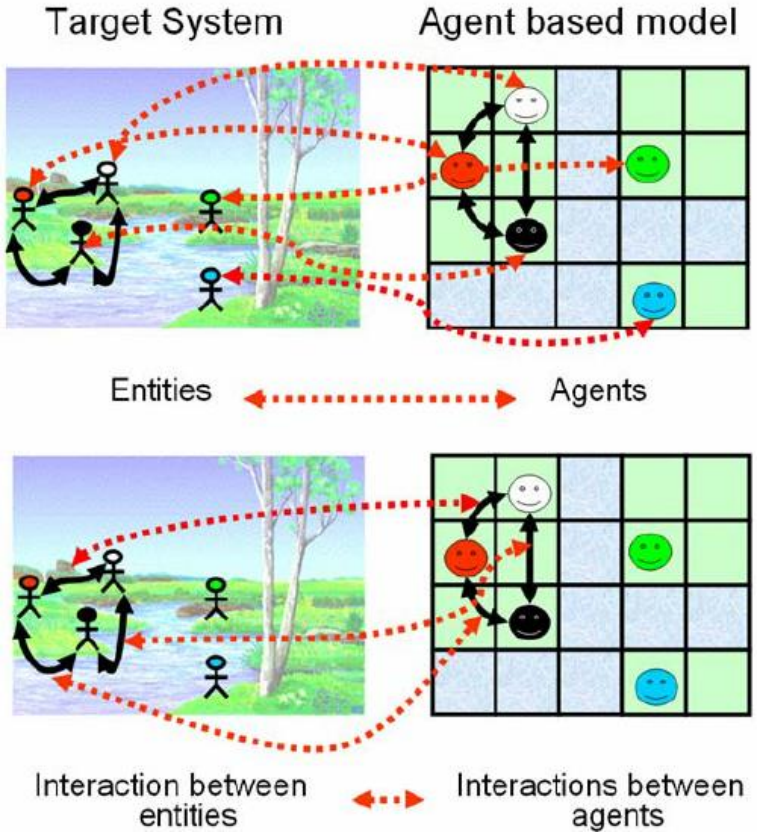
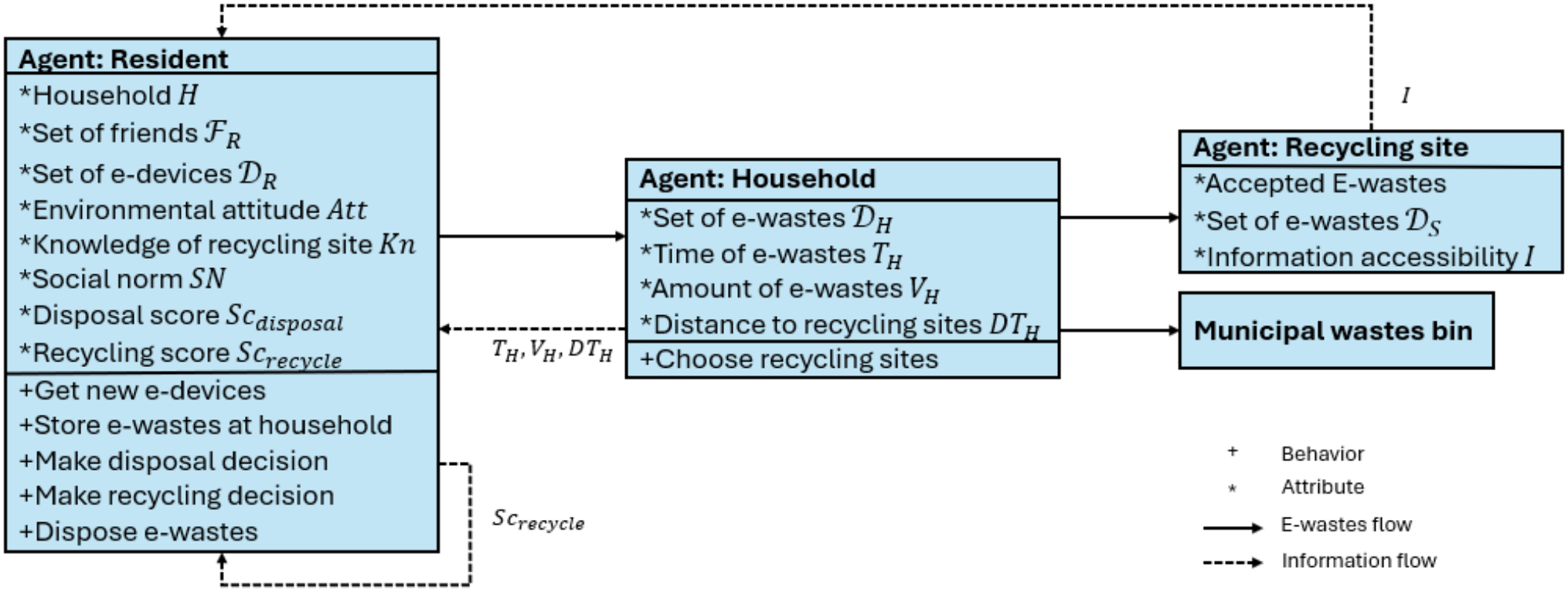


Illustration of Agent-Based Modeling. Figure extracted from Galán et al. [7].

Modeling Framework

- Agent-based model for e-waste collection and recycling behaviours.
- Agents in the model: **Resident**, **Household**, and **Recycle Site**.



Conceptual model of the agent-based model for e-waste collection and recycling behaviours.

Recycling Site and E-waste

- Types of e-wastes: ICT equipment (laptop, smartphone), household battery, bulb/lamp, large household appliance (refrigerator).
- Type of recycling sites: 3-in-1 Bin, Manned In-Store Counter, Battery & Bulb Bin, Battery-Only Bin, ALBA's Depot Drop-Off, and E waste Collection Drive

	ICT Equipment (laptop, smartphone)	Household Battery	Bulb/Lamp	Large Household Appliance (Refrigerator)
3-in-1 Bin	✓	✓	✓	
Manned In-Store Counter	✓	✓		
Battery & Bulb (BB) Bin		✓	✓	
Battery-Only Bin		✓		
ALBA's Depot Drop-off	✓	✓	✓	✓
E-waste Collection Drive	✓	✓	✓	✓

Recycling sites and their accepted types of e-wastes in our model.

Main Activities of Resident

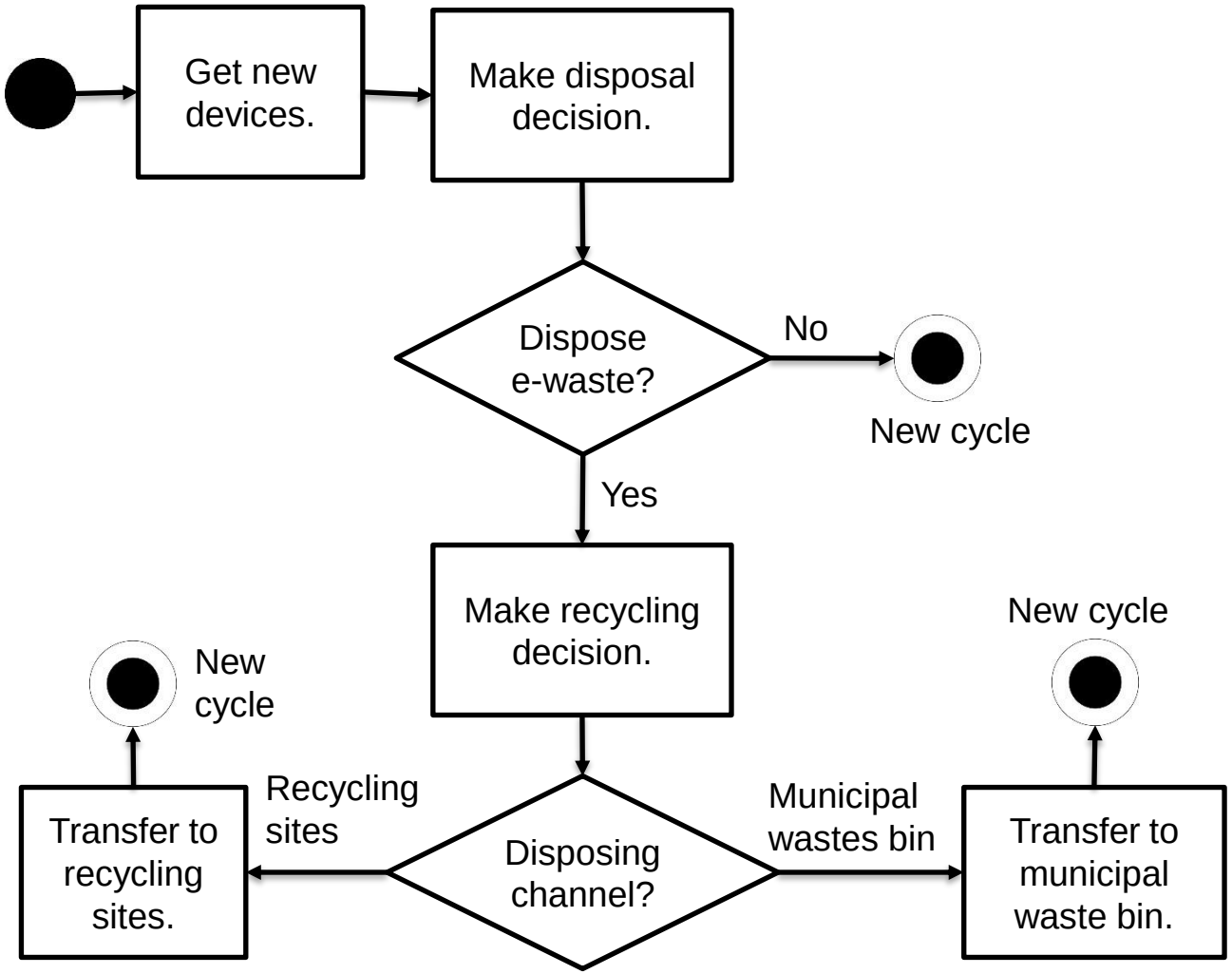
- **Disposal decision**: probability $P_{disposal}$.

$$S_{disposal} = \alpha_T \cdot T_{H_i} + \alpha_V \cdot V_{H_i} + \alpha_{DT} \cdot DT_{H_i}$$

$$P_{disposal} = \frac{S_{disposal} - S_{disposal_{min}}}{S_{disposal_{max}} - S_{disposal_{min}}}$$

- **Recycling decision**: thresholding $S_{recycle}$ to Very Bad, Bad, Good, Very Good behaviours.

$$S_{recycle} = \beta_{SN} \cdot SN + \beta_{Att} \cdot Att + \beta_{Kn} \cdot Kn + \beta_{DT} \cdot DT_{H_i}$$



Activity diagram of resident.

Recycling Indicators

- Averaged retention time of e-waste:

$$T_{avg} = \frac{\sum_{S \in \mathcal{S}} \sum_{D \in \mathcal{D}_S} t_D}{\sum_{S \in \mathcal{S}} |\mathcal{D}_S|}$$

- Recycling rate:

$$PCT_{recycled} = \frac{V_{recycled}}{V_{recycled} + V_{misplaced}}$$

Nearest Recycling Sites Assignment Intervention

- Promote e-waste recycling by **increasing convenience** associated with **proximity**.
- Recycling sites with minimal travelling distance are assigned.
- Scenarios: random choice and Nearest Recycling Sites Assignment.

$$\mathcal{S}_H^{nearest} = \arg\min_{\mathcal{S}_H \in O_H} \sum_{S \in \mathcal{S}_H} dist(S, H)$$

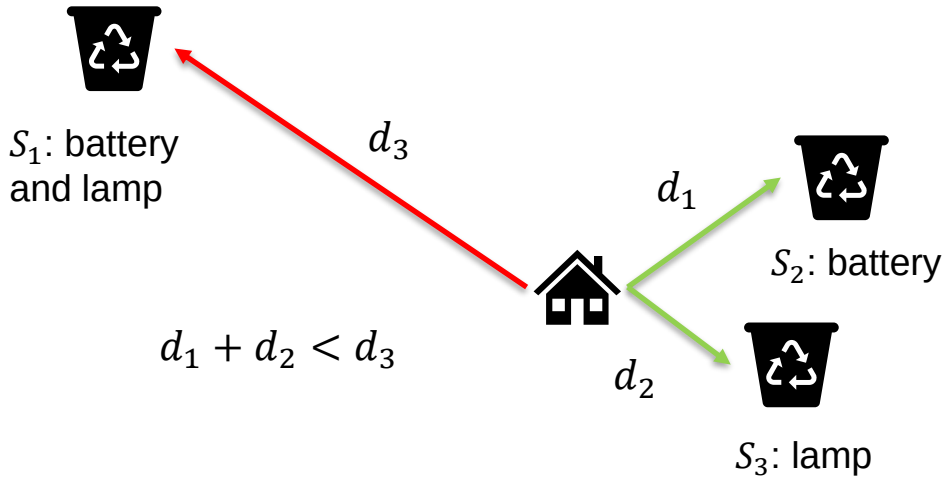


Illustration of Nearest Recycling Sites Assignment intervention. E-wastes at home: batteries and lamps. Assigned sites: $\mathcal{S}_H^{nearest} = (S_2, S_3)$

Recycling Information Campaign Intervention

- Promote e-waste recycling by **disseminating recycling knowledge**.
- Frequently organized events to increase resident's knowledge on proper recycling.
- Scenarios: annually, bi-annually, quarterly, and no events organization.

Recycle Right campaign run by NEA in January 2022. Photos from Mural Lingo [8].

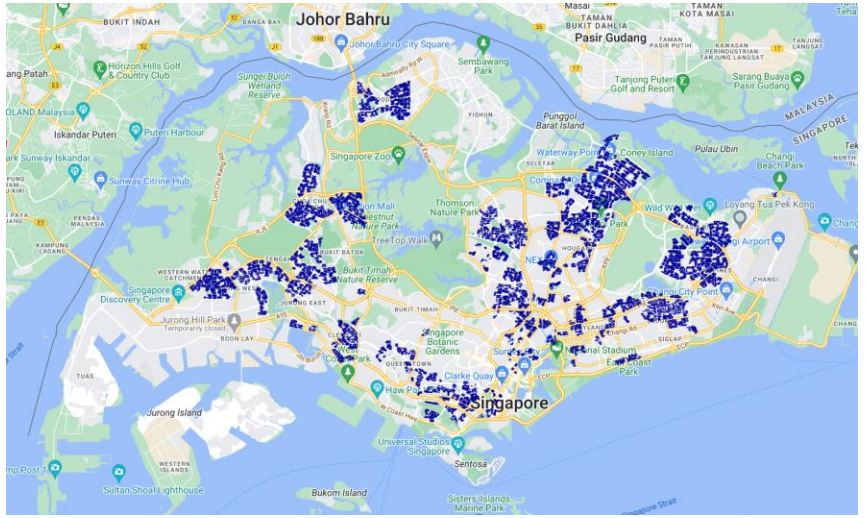
Do you remember that **60%** of Singapore residents **do not know** or are **unsure** of how to recycle their electronic waste?

Experiment Scenarios

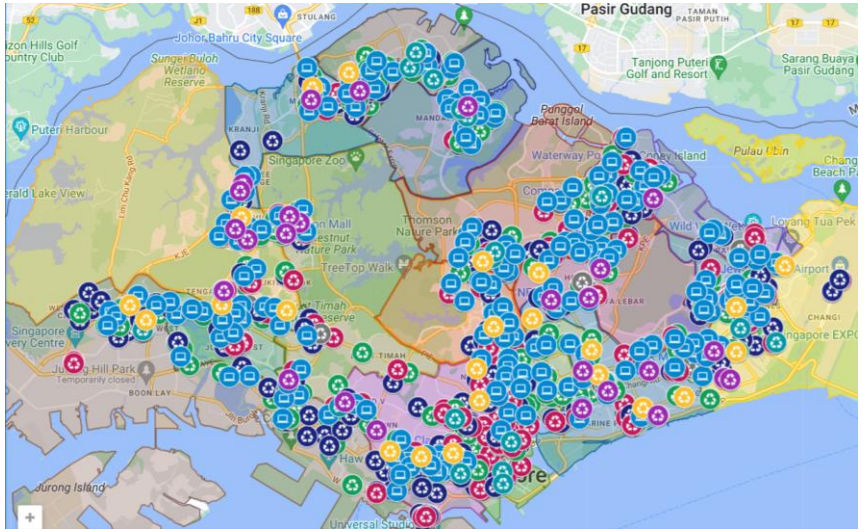
- **Baseline**: random sites assignment and no recycling information campaign.
- **Nearest Recycling Sites Assignment.**
- **Recycling Information Campaign**: annually, bi-annually, quarterly events.
- **Enhanced Scenario**: Nearest Recycling Sites Assignment and Recycling Information Campaign (bi-annual events).

Implementation Details

- GAMA Platform version 1.9.3.
- Data:
  - NEA recycling sites [9].
  - Housing & Development Board (HDB) geometric data [10].
  - HDB property information [11].
- More than 11,000 residents and 946 recycling sites.
- Simulation: 2080 cycles = 20 years, repeated 4 times.



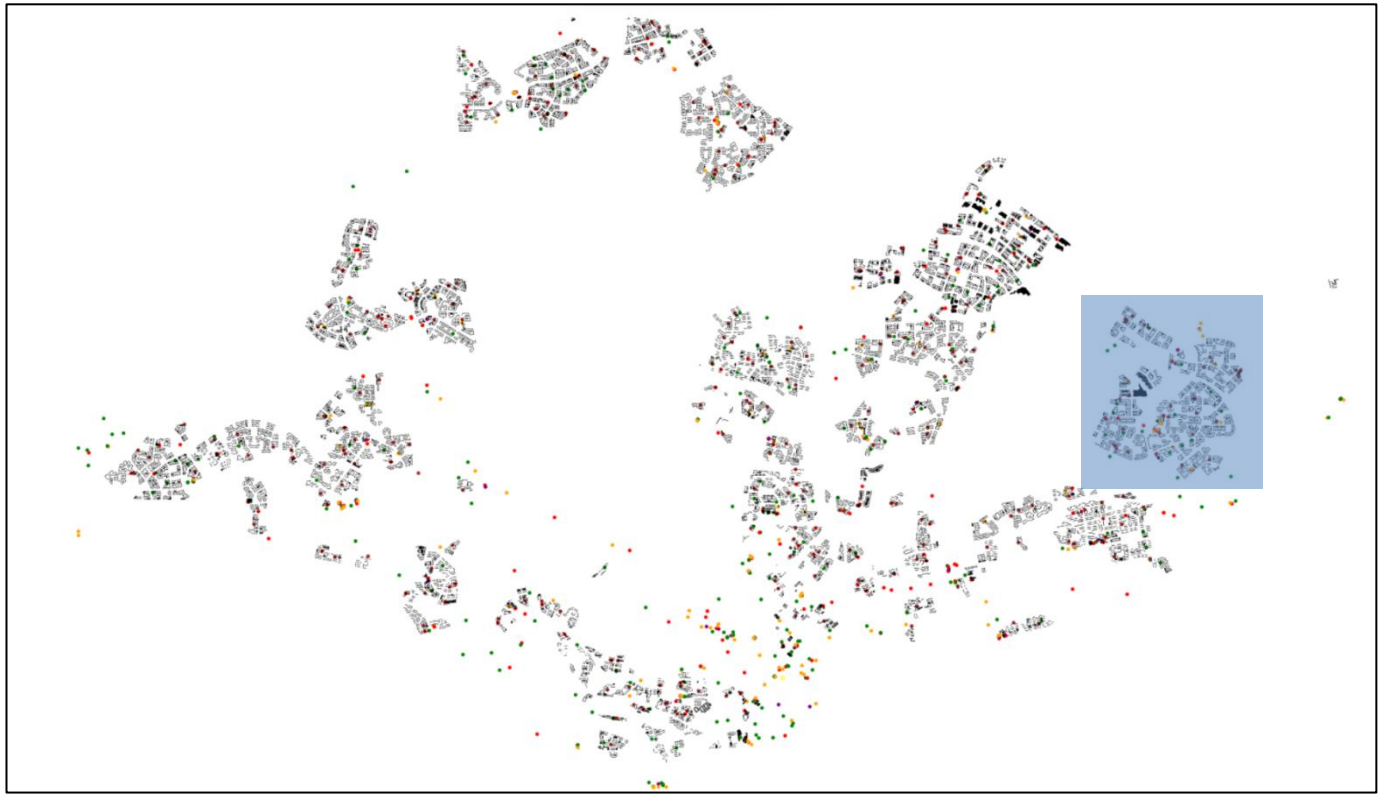
HDB geometric data.

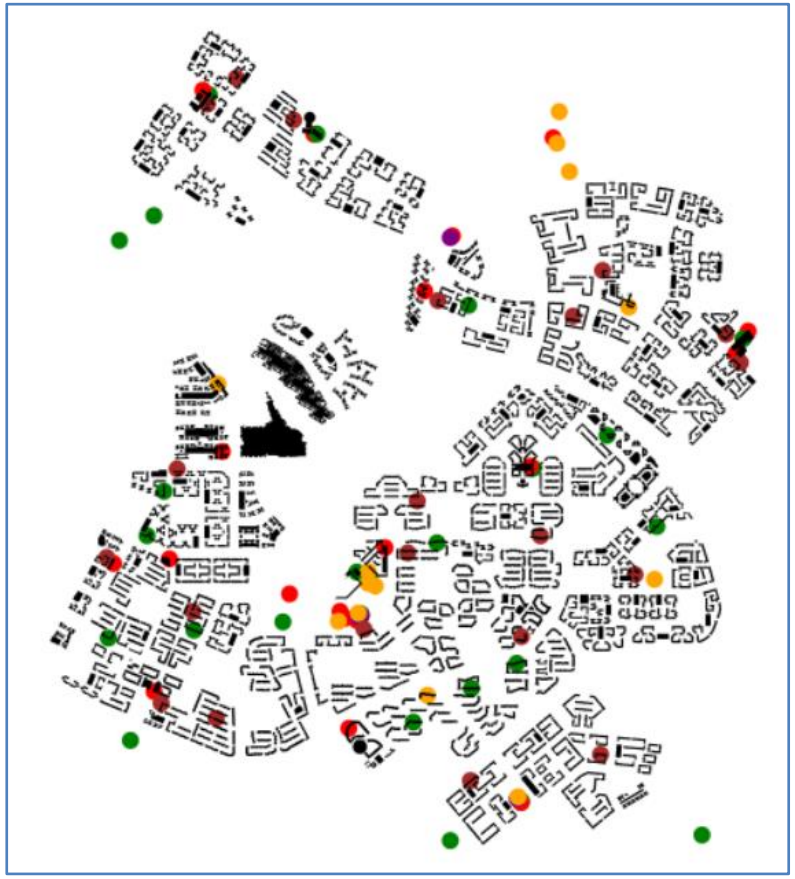


NEA recycling sites.

Experiment Results

Simulation Visualization



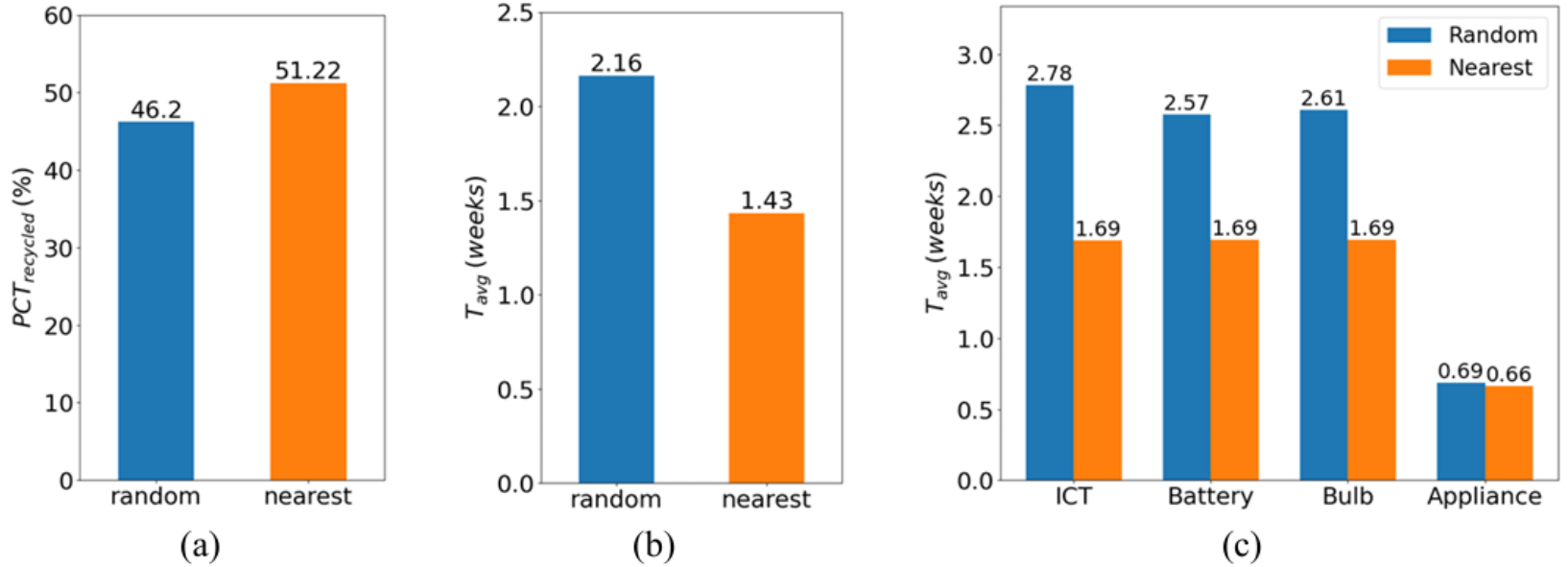


- 3-in-1 Bin
- Battery & Bulb (BB) Bin
- E-waste Collection Drive
- Battery-Only Bin
- Manned In-Store Counter
- ALBA's Depot Drop-off

Visualization of simulation. Colored dots represent recycling sites. Blocks are HDB buildings.

Nearest Recycling Sites Assignment Results

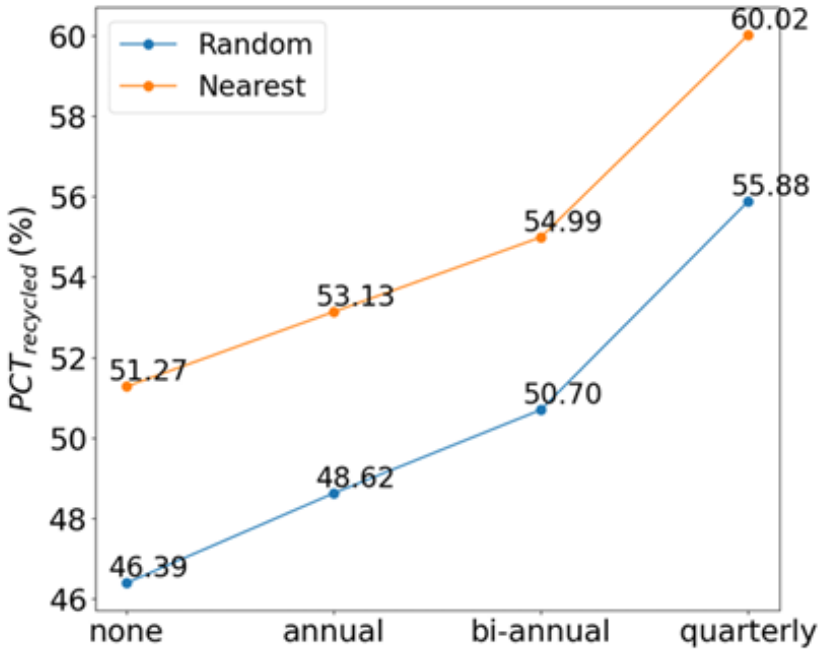
- Enhances recycling rate $PCT_{recycled}$ and reduces retention time T_{avg}.
- Small decrease of household appliances retention time T_{avg}: limited options for recycling.



Results of Nearest Recycling Sites Assignment: (a) recycling rate $PCT_{recycled}$; (b) average retention time T_{avg}; (c) average retention time by types of e-wastes.

Recycling Information Campaign and Enhanced Scenario Results

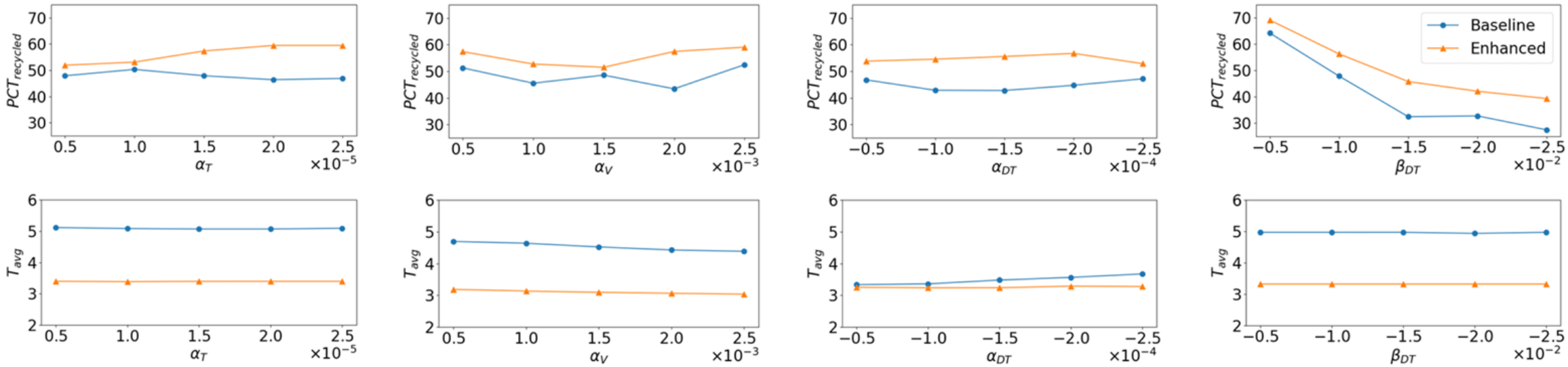
- Recycling Information Campaign: recycling rate $PCT_{recycled}$ increases proportionally to events organization frequency.
- Enhanced scenario (both interventions) further improves recycling rate.



Recycling Information Campaign result: recycling rate $PCT_{recycled}$ by campaign frequency.

Sensitivity Analysis – Are the Results Trustworthy?

- One-factor-at-a-time (OFAT) sensitivity analysis.
- Scenarios: baseline (no intervention) and enhanced (both interventions).
- Implementing interventions **constantly improves recycling**.



Results for sensitivity analysis. Baseline: no intervention is implemented. Enhanced: implementing both Nearest Recycling Sites Assignment and Recycling Information Campaign (bi-annual frequency).

Conclusion and Future Works

Conclusion

- Agent-based model to simulate e-waste collection system and recycling behaviours in Singapore.
- Quantitative assessment of interventions: Nearest Recycling Sites Assignment and Recycling Information Campaign.

→ Importance of knowledge dissemination and the convenience associated with proximity.

Future Works

- Exploration of other strategies: deposit refund schemes and incentive programs.
- Adaptation to other regions: region-specific data.

References

[1] National Environment Agency, Stakeholders sharing responsibility is key to building a sustainable e-waste management system: Nea study, available at: https://www.nea.gov.sg/media/news/news/index/stakeholders-sharing-responsibility-is-key-to-building-a-sustainable-e-waste-management-system-nea-study. (2019).

[2] B. Alves, Global e-waste generation 2010-2022, available at: https://www.statista.com/statistics/499891/projection-ewaste-generation-worldwide/. (2024).

[3] M. Shahabuddin, M. N. Uddin, J. Chowdhury, S. Ahmed, M. Uddin, M. Mofijur, M. Uddin, A review of the recent development, challenges, and opportunities of electronic waste (e-waste), International Journal of Environmental Science and Technology 20 (4) (2023) 4513–4520.

[4] I. Ilankoon, Y. Ghorbani, M. N. Chong, G. Herath, T. Moyo, J. Petersen, E-waste in the international context–a review of trade flows, regulations, hazards, waste management strategies and technologies for value recovery, Waste management 82 (2018) 258–275.

[5] B. Alves, Global e-waste management 2022, by method, available at: https://www.statista.com/statistics/1066948/share-of-electronic-waste-disposed-globally/. (2024).

[6] National Environment Agency, NEA And ALBA To Soft Launch E-Waste Recycling Bins Ahead Of Start Of E-Waste Management Scheme, available at: https://www.nea.gov.sg/media/news/news/index/nea-and-alba-to-soft-launch-e-waste-recycling-bins-ahead-of-start-of-e-waste-management-scheme. (2021).

References

[7] Galán JM, Izquierdo LR, Izquierdo SS, Santos JI, del Olmo R, López-Paredes A. Checking simulations: Detecting and avoiding errors and artefacts. Simulating Social Complexity: A Handbook. (2013) 95-116.

[8] Mural Lingo, Recycle Right Campaign, available at: https://www.behance.net/gallery/143384455/Recycle-Right-Campaign#moodboard. (2022).

[9] National Environmental Agency, E-waste recycling programmes for individuals/households, available at: https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/e-waste-management/where-to-recycle-e-waste. (2024).

[10] Data.gov.sg, HDB existing building, available at: https://beta.data.gov.sg/collections/2033/datasets/d_60a6c3d88483cf63d2063c93771a6aeb/view. (2024).

[11] Data.gov.sg, HDB property information, available at: https://beta.data.gov.sg/collections/150/datasets/d_17f5382f26140b1fdae0ba2ef6239d2f/view. (2024).

CREATING GROWTH, ENHANCING LIVES

Agency for Science, Technology and Research
SINGAPORE

THANK YOU

www.a-star.edu.sg