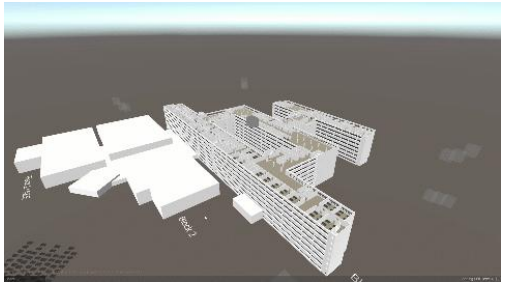


How Digital Twins Enable Real-Time Surveillance, Early Outbreak Detection & System-Level Innovation

Adj A/Prof Chow Weien
Chief Data & Digital Officer
Changi General Hospital, SingHealth

HealthTechX Asia
Innovate. Collaborate. Partner.

Nil conflicts of interest to declare

Scope

- Digital twins in healthcare
- Share how a hospital digital twin was designed and implemented for infectious disease surveillance “4D-Disease Outbreak Surveillance System (4D-DOSS)”
- Identify strategies for scaling and sustaining digital twins across hospitals and health systems

2

digital twin CONSORTIUM

On December 3, 2020, the Digital Twin Consortium released the definition of a digital twin.

The goal of the definition is to establish a foundation for the emerging industry and a launching pad for its future progress, driven by consensus among our members, the definition unifies industry stakeholders and speeds our members' time to market.

noun

A virtual replica or a digital copy of a real-life object or facility, synchronized at a specified frequency and fidelity.

What can a digital twin do?

- Transform business by accelerating holistic understanding, optimal decision-making, and effective action
- Use real-time and historical data to represent the past and present and simulate predicted futures.
- Motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems.

Digital Twins in Healthcare

npj | digital medicine

Review article

Published in partnership with Seoul National University Bundang Hospital

https://doi.org/10.1038/s41746-024-01073-0

Digital twins for health: a scoping review

Check for updates

Evangelia Katsoulakis[1,2], Qi Wang[3], Huanmei Wu[4], Leili Shahriyari[5], Richard Fletcher[6,7], Jinwei Liu[8], Luke Achenie[9], Hongfang Liu[10], Pamela Jackson[11], Ying Xiao[12], Tanveer Syeda-Mahmood[13], Richard Tuli[2] & Jun Deng[14]

HOME : HEALTHCARE IT : DIGITAL TWINS IN HEALTHCARE MARKET

Digital Twins in Healthcare Market: Growth, Size, Share, and Trends

Report Code
HIT 8675

Published in
May, 2025, By MarketsandMarkets™

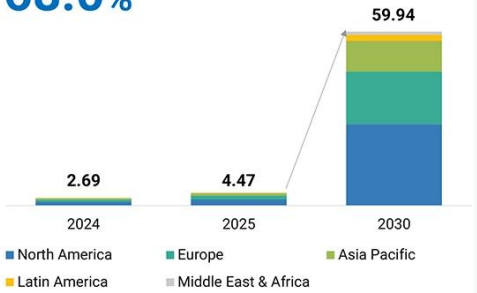
DIGITAL TWINS IN HEALTHCARE MARKET

Market Size, Dynamics, and Ecosystem

MARKETSANDMARKETS™

CAGR (2025–2030)

68.0%



MARKET SIZE (USD BILLION)

MARKET DYNAMICS (DRIVERS AND RESTRAINTS)

DRIVERS

- Increasing investments by public and private entities
- Growing applications of digital twins
- Technological advancements

RESTRAINTS

- Managing data quality, privacy issues, and high implementation costs

COMPANY EVALUATION MATRIX: KEY PLAYERS

ECOSYSTEM ANALYSIS

MANUFACTURERS | REGULATORY BODIES | END USERS

PHILIPS, ORACLE, U.S. FOOD & DRUG ADMINISTRATION, JOHNS HOPKINS MEDICINE, DASSAULT SYSTEMES, GOV.UK, Microsoft, IBM, EUROPEAN MEDICINES AGENCY, MAYO CLINIC, Atos

SingHealth

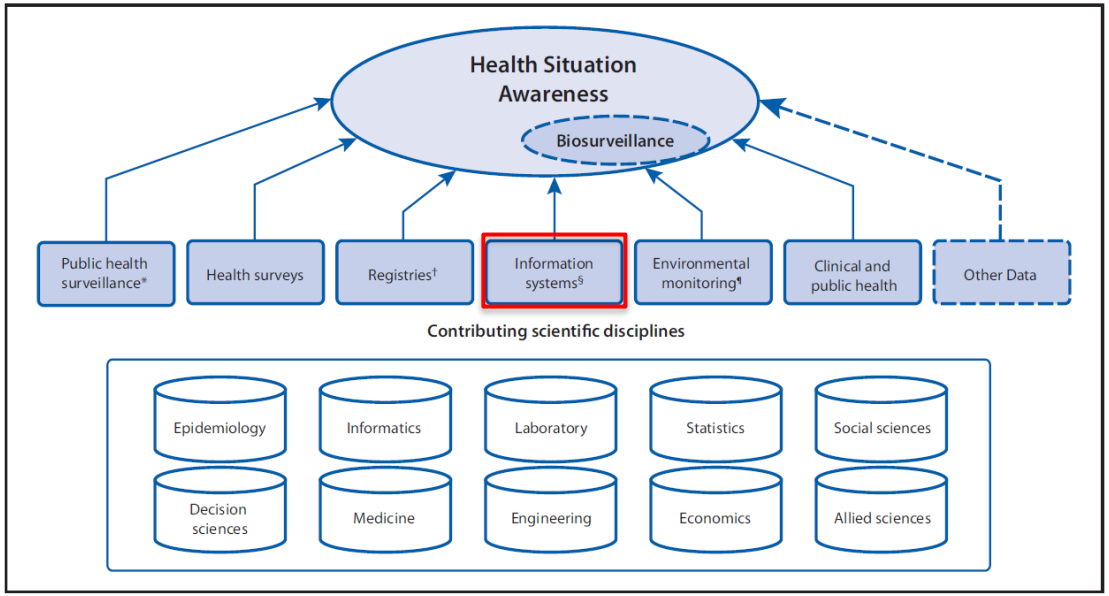
Fig. 1. 1851 Census addresses and building outlines and deaths from 1854 Cholera outbreak in Soho, Central London.
Source: 1:2500 County Series 1st Edition [TIFF geospatial data], Scale 1:2500, Tiles: lond-tq2880-1,lond-tq2881-1,lond-tq2980-1,lond-tq2981-1, Updated: November 30, 2010, Historic, Using: EDINA Historic Digimap Service, <https://digimap.edina.ac.uk>, Downloaded: 2019-11-29 13:40:24.579

What makes a good Surveillance System?

Public Health Surveillance in the United States: Evolution and Challenges*

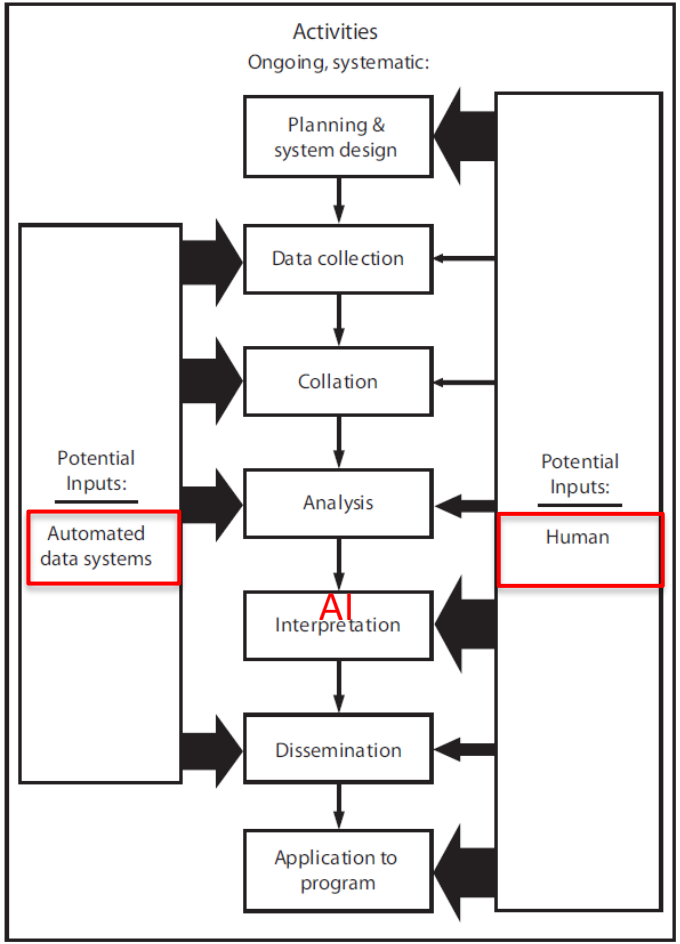
Stephen B. Thacker, MD[1], Judith R. Qualters, PhD[2], Lisa M. Lee, PhD[1]
[1] Office of Surveillance, Epidemiology and Laboratory Services, CDC
[2] National Center for Environmental Health, CDC

FIGURE 1. Various data feeds to support health situation awareness



* Systematic and continuous collection, analysis, and interpretation of data, closely integrated with the timely and coherent dissemination of the results and assessment to those who have the right to know so that action can be taken (Porta MA, Dictionary of Epidemiology, 5th Ed., Oxford University Press, 2008).
† Vital registration, cancer registries, and exposure registries.
§ Medical and laboratory records, criminal justice information, and Lexis-Nexis.
¶ Weather, climate change, and pollution.

FIGURE 4. Optimal balance of human and automated inputs into ongoing, systematic public health surveillance system activities*



* The size of the arrow indicates the relative human and automated inputs into each activity

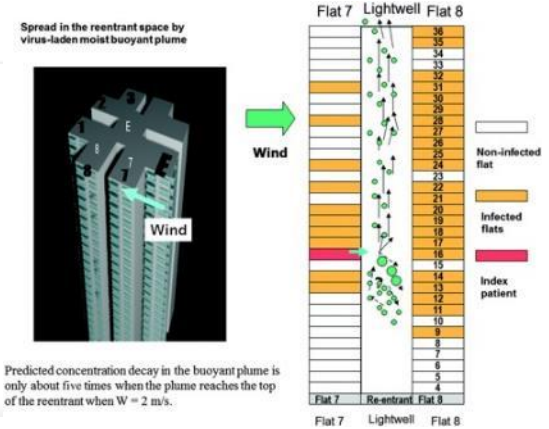
In Hong Kong Apartment Tower, SARS Virus Spread Through Plumbing

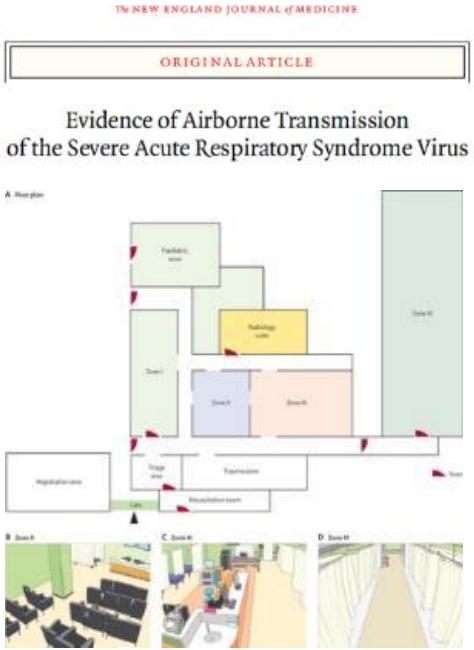
By **Rob Stein**
April 18, 2003

The SARS virus that infected hundreds of people in a 33-story Hong Kong apartment tower probably spread in part by traveling through bathroom drainpipes, officials said yesterday in what would be a disturbing new confirmation of the microbe's versatility.

The possible explanation for what has been one of the most baffling and worrisome outbreaks in the epidemic indicates that the virus can be transmitted in ways other than close person-to-person contact.

"The possibility that the virus could by aerosol move through a vertical pipe through other pipes . . . into the air and affect so many people, that's not comforting," said Klaus Stohr, who is leading the World Health Organization's





Geospatial tech touted as more crucial than ever amid pandemic

Yip Wai Yee Tech Correspondent

PUBLISHED SEP 10, 2020, 5:00 AM SGT

Geospatial technology (or location-based data tech) is more crucial than ever amid the pandemic, as it can be used to help contain the spread of Covid-19 through solutions such as crowd management applications.

This sentiment was shared by several speakers at the virtual launch of Singapore Geospatial Week+ yesterday, an event promoting the importance and growth of geospatial technology in Singapore and beyond.

Singapore Land Authority (SLA) acting chief executive Simon Ong said: "The importance of geospatial cannot be emphasised more, especially in today's environment."

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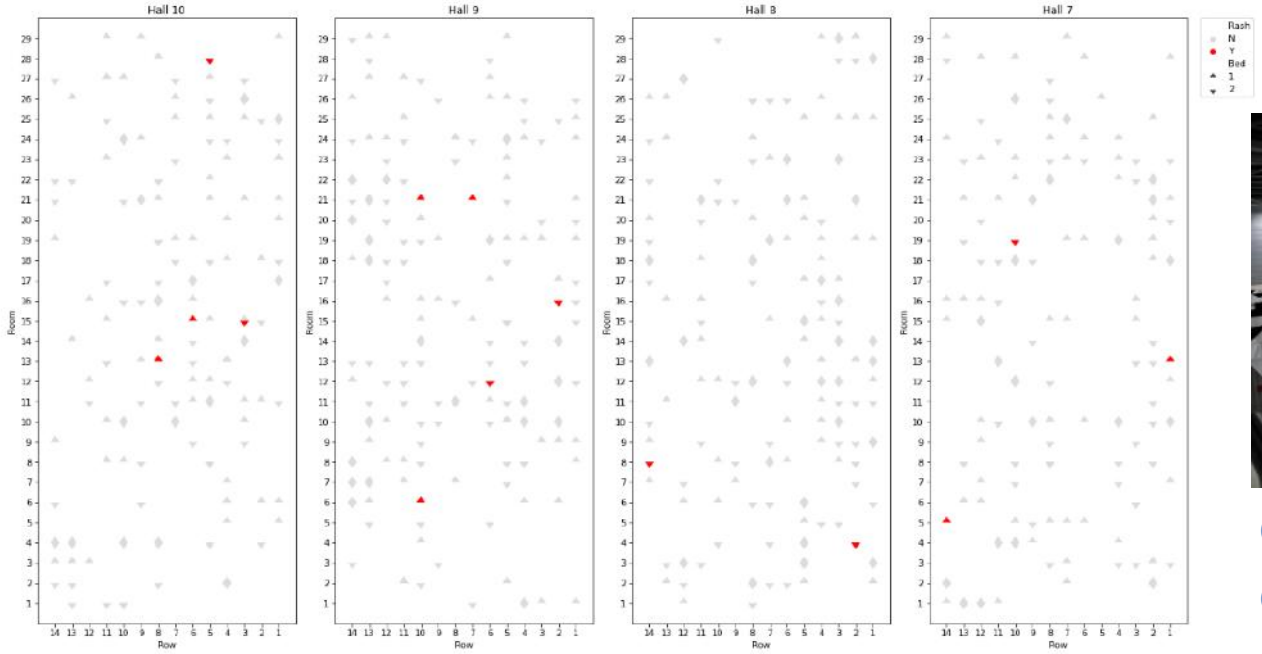
Project Origins (4D-DOSS)
4D-Disease Outbreak Surveillance System



Origins: COVID-19 Pandemic

Community Care Facility@EXPO

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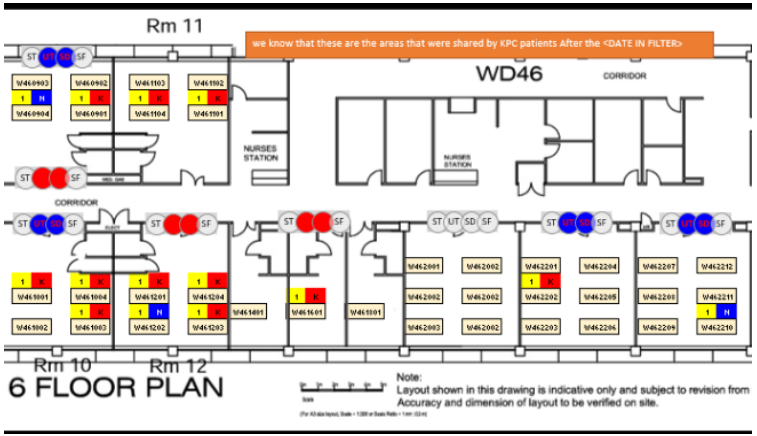
Project Context

▪ Hospitals have some capabilities for early detection of fast-moving outbreaks.

- Current outbreak analysis processes largely rely on manual extracts into Excel from data warehouse, which has a 24–36-hour latency.
- Patients move frequently and cross-infection risks quickly multiply and become challenging to track manually.
- Spatial relationships and distances are impossible to analyze algorithmically as no digital spatial version of the hospital exists.



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MALE	07/09/2020	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1	W752501_1
FEMALE	18/09/2020	W58A2001_1	W58A2001_1	W58A2001_1	W58A2001_1	W58A2001_1	W58A2001_1	W58A2001_1	W58A2001_1	SICU1001_1	SICU1001_1
MALE	21/09/2020	W64F1503_1	W730201_1	W730201_1	W730201_1	W730201_1					
FEMALE	28/09/2020					W45B1401_1	W45C2202_	W45C2202_	W752606_1	W752606_1	W752606_1
FEMALE	29/09/2020	W64F1702_(	W64F1702_(	W58A2001_(	W58A2001_(	W58A2001_(	W64F1702_1	W64F1702_1	W64F1702_1	W64F1702_1	W64F1702_1
MALE	01/10/2020	SICU0201_0	W58A2001_(	W58A2001_(	W58A2001_(	W58A2001_(	W58A2001_(	W58A2001_(	W58A2001_1	W58A2001_1	W58B1102_1
FEMALE	05/10/2020		W462407_0	W462407_0	W462407_0	W462407_0	W462407_0	W462407_0	W462407_0	W462407_0	W462407_0
MALE	06/10/2020	W64E2602_(	W64E2602_(	W64E2602_(	W64E2602_(	W64E2602_(	W64E2602_(	W64E2602_(	W58B0701_(	W58B0701_(	W58B0701_(
FEMALE	08/10/2020	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0	W11A0006_0
MALE	09/10/2020							W64C2103_(	W64C2103_(	W64C2103_(	
FEMALE	09/10/2020										
FEMALE	10/10/2020		SICU0501_0	SICU0501_0	SICU0501_0	SICU0501_0	SICU0501_0	W572201_0	W572201_0	W572201_0	W572201_0
FEMALE	10/10/2020						W762005_0	W762603_0	W762603_0	W762603_0	W762603_0
FEMALE	11/10/2020		W67190I_0	W67190I_0	W67190I_0	W53A110I_0	W53A110I_0	W55B1804_(	W55B1804_(	W53A2204_(	W53A2204_(
MALE	12/10/2020	W73A2610_(	W73A2610_(	W73A2610_(					W66190I_0	W66190I_0	
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FEMALE	13/10/2020						W43A2604_(	W43A2604_(	W43A2604_(	W43A2604_(	W43A2604_(
FEMALE	13/10/2020								W661005_0	W661005_0	W661005_0
FEMALE	13/10/2020								W572404_0	W572404_0	W572404_0
FEMALE	13/10/2020										
MALE	14/10/2020	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0	W562510_0
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MALE	15/10/2020	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(	W65A0302_(
MALE	15/10/2020									W73A2212_(	W73A2212_(
MALE	16/10/2020	W680801_0	W680801_0	W680801_0							
FEMALE	17/10/2020								W651003_0	W651003_0	W651003_0
MALE	17/10/2020								W771601_0	W771601_0	
MALE	18/10/2020	W751104_0	W752508_0	W752508_0	W752508_0	W752508_0	W752508_0	W752508_0	W752508_0	W752508_0	W752508_0
FEMALE	18/10/2020						W47A0904_(	W47A0904_(	W47A0904_(	W47A0904_(	W47A0904_(
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FEMALE	19/10/2020				W67170I_0	W67170I_0	W67170I_0	W67170I_0	W63B2202_(	W63B2202_(	W63B2202_(
MALE	20/10/2020										
MALE	20/10/2020									W762507_0	W762507_0

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W45C2202										
W58A2001		2	3	3	3	2	2	2		
W63B1303										
W63B1903										
W661101										
W752606										

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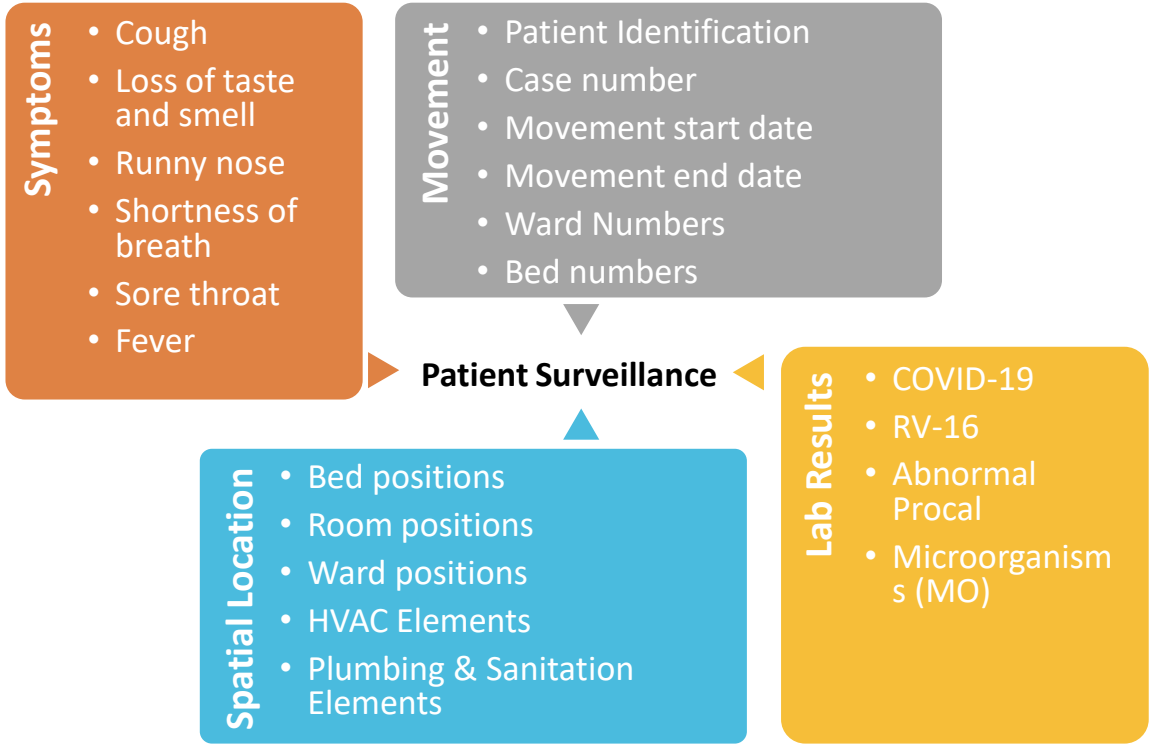
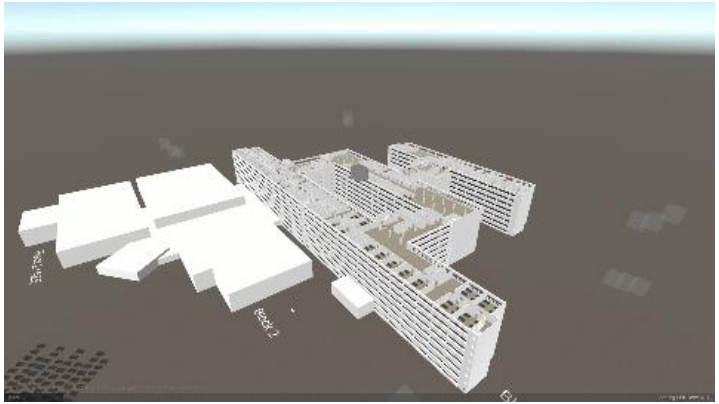
Patient Surveillance

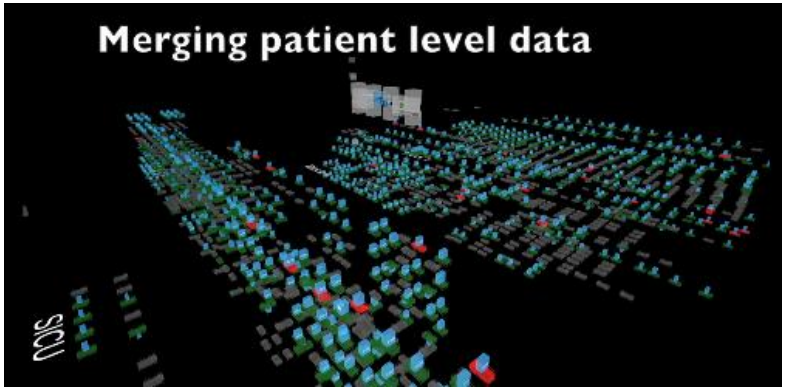
Patient surveillance now requires combination of data from multiple silos at a much faster speed



Original slide credit: Dr Jennifer Wong Tzu-Jung

Accurate digital replica of hospital's physical space





- Using anonymized data from eHints data warehouse, the hospital model has been populated with patient movement and disease data from several studies.

- The project demonstrated feasibility of ingesting, visualizing and analyzing disease spread over time and distance, and has detected clusters in historical ARI data.

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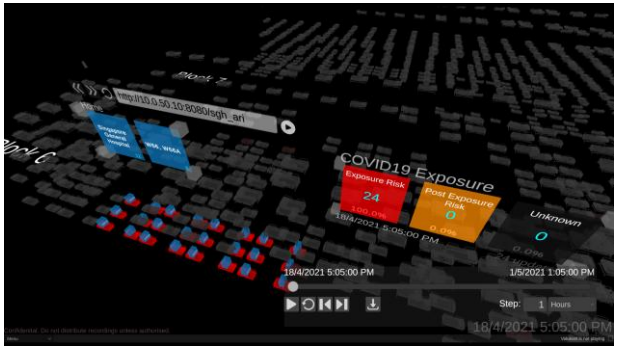
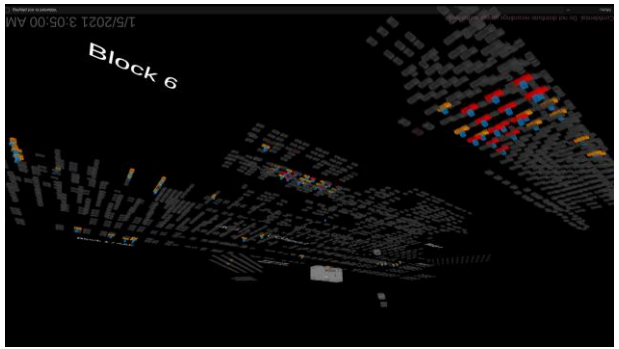
Advanced Exposure Risk Analysis

Test case with potential exposure event in April identified and ranked 200+ at risk patients

COVID 19 Potential Exposure Risk

17/4/2021 – 1/5/2021





- The algorithm leverages historical infection data patterns and real-time patient information to calculate risk scores, enabling early detection of potential outbreaks
- By incorporating spatial-temporal analysis and contact tracing patterns, the system can identify high-risk areas and potential transmission pathways
- Allows clinical staff to implement targeted containment measures promptly.

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4D-DOSS

* eHints Interface
* BMS Interface
* EMR Interface

* Common Infrastructure
* Active Directory
* Exchange/email

- The 4D-DOSS system incorporates detailed infrastructure and automated patient level data flow to represent persons across space and time.
- Designed to overlay the operational and clinical workflows.
- Visual representation of integrated healthcare data enables analytics to drive inference which can prompt targeted interventions.
- Allows development of risk prediction analytics based on variables such as distance, ventilation, patient movement and clinical parameters

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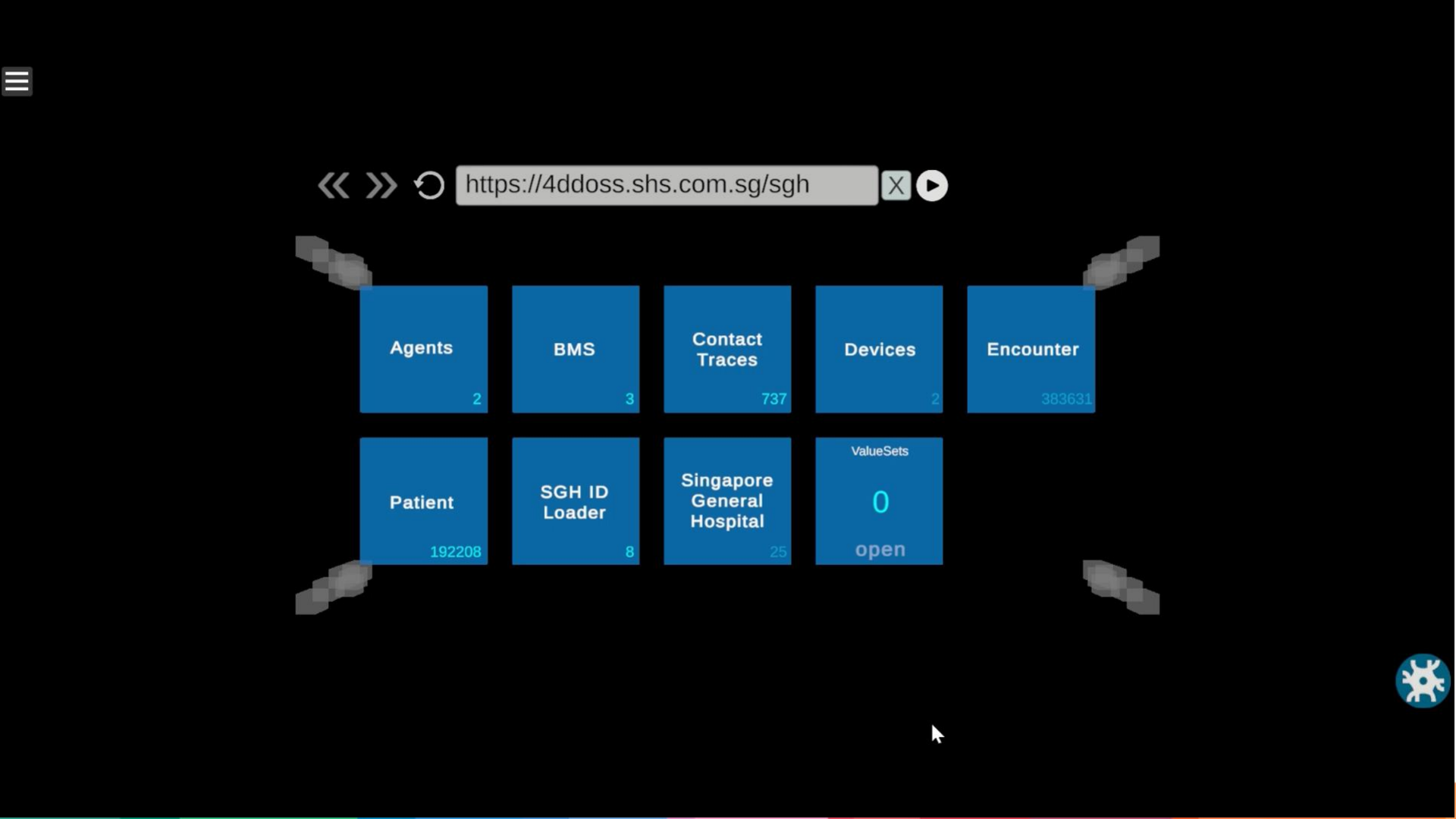
https://4ddoss.shs.com.sg/sgh
Agents
2
BMS
3
Contact Traces
737
Devices
2
Encounter
383631
Patient
192208
SGH ID Loader
8
Singapore General Hospital
25
ValueSets
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open


Center
Global
0.1
20
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Digital Twin Maturity model

Unity

LEVEL 1

Virtual Twin

The Level 1 twin is a physically accurate realistic digital representation of an asset, facility, or product that emulates its real-world counterpart

Keywords

- Spatial awareness
- Interaction
- Experience
- Collaboration

LEVEL 2

Connected Twin

The Level 2 twin integrates real-time and right-time data to provide insights into the performance of an asset at specific points in time.

Keywords

- Real-time data
- Monitoring and reporting
- IoT

LEVEL 3

Predictive Twin

The Level 3 twin leverages data to predict the outcomes and problems for the operations of complex facilities and equipment.

Keywords

- Analytics
- Decision-assist
- Predictive maintenance

LEVEL 4

Prescriptive Twin

The Level 4 twin leverages advanced modeling and real-time simulation for potential future scenarios as well as prescriptive analytics and recommendations.

Keywords

- What-if simulation
- Machine learning
- Intelligent recommendations
- Process optimization

LEVEL 5

Autonomous Twin

The Level 5 twin uses multiple real-time data feeds to learn and make decisions to correct issues automatically and enable predictive and prescriptive analytics.

Keywords

- Autonomous action
- Artificial Intelligence

Each Stage Unlocks New Use Cases

Unity

LEVEL 1

Virtual Twin

- Design Reviews
- Product Configuration
- XR Training & Guidance
- Master Planning
- Navigation
- Ecommerce Expenses
- Ect.

LEVEL 2

Connected Twin

- Facilities Maintenance
- Real-time Operations
- Remote Operations
- Smart Factories
- Asset Location Tracking
- Ect.

LEVEL 3

Predictive Twin

- What-if Analysis
- Robotics Simulation
- Dynamic Training
- Routing Optimization
- Simulation Visualization
- Synthetic Data Generation
- Etc.

LEVEL 4

Prescriptive Twin

- System Optimization
- Real-time Process Monitoring
- Robotics
- Advanced Decision Support
- ML Agent Training
- Ect.

LEVEL 5

Autonomous Twin

- Lights-out Smart Factory
- Dynamic Routing Optimization
- Autonomous Process Control
- Real-time Energy & Emissions Control
- Ect.

Lessons Learnt & Challenges

axomem

Received funding and support from various agencies (Government DPC, Ministry of Health, Design SG, internal Innovation and Research grants)

Identification of a unique use case

Clinical versus operational use case (moving beyond visualization to intelligence)

Trans-disciplinary team collaboration

Infection prevention control team, data scientists, operations team, microbiologist, systems integrator (Synapxe)

Digital innovation

"Thinking out of the box"

Data source systems

Data warehouse, mapping of data fields, lab information system (LIS), bed management system (BMS)

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Digital Twin Capabilities

Process Optimization	Enhancing efficiency through workflow and resource analysis
Real-time Monitoring	Continuous tracking of patient and system status
Simulation and Scenario Analysis	Modelling scenarios to predict healthcare outcomes
Predictive Analytics	Forecasting future states using real-time data analytics

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The Cognitive Digital Twin: A New Nervous System for Hospital Monitoring

Cognitive Digital Twin Architecture

Tier 3: Cloud (Aggregated Intelligence)

Frontier models analyze de-identified data to optimize the entire hospital fleet's intelligence.

Layers 1 & 2: Deliberative Reasoning

AI agents use clinical context and LLMs to evaluate complex patient behaviors and workflows.

Tier 2: Local Data Center (Reasoning)

GPU servers handle complex LLM deliberation and Vision Language Model (VLM) scene interpretation.

Tier 1: Edge (Real-Time Perception)

NVIDIA Jetson Thor hardware processes 30+ camers streams with sub-50ms latency per frame.

Layer 0: Hardwired Safety Reflexes

Deterministic, sub-100ms response rules for safety-critical events like falls or seizures.

Current Status Quo	Cognitive Digital Twin (CDT)
Monitoring Frequency: **Every 1–2 hours (Periodic)**	Monitoring Frequency: **Every second, every shift (Continuous)**
Knowledge Growth: **Individual/Forgets**	Knowledge Growth: **Collective/Permanent**
Response Nature: **Reactive (Alarms)**	Response Nature: **Proactive (Contextual Reasoning)**

Publications & Scientific Presentations

ORIGINAL ARTICLE

MAYO CLINIC PROCEEDINGS: DIGITAL HEALTH

MAYO CLINIC

Three-Dimensional Disease Outbreak Surveillance System in a Tertiary Hospital in Singapore: A Proof of Concept

Indumathi Venkatachalam, FRACP; Edwin Philip Conceicao, BSc; Jean Xiang Ying Sim, MRCP; Sean Douglas Whiteley, BIT; Esther Xing Wei Lee, PhD; Hui San Lim, BE; Joseph Kin Meng Cheong, BE; Shalvi Arora, BSc; Andrew Hao Sen Fang, MMed; and Weien Chow, MRCP

Journal of Hospital Infection
Available online 27 September 2023
In Press, Journal Pre-proof

The cost-effectiveness of a real-time spatiotemporal mapping surveillance system for meticillin-resistant *Staphylococcus aureus* prevention

新保集团运用数码孪生科技预测及更早干预传染病暴发

Boston
Oct. 11-15, 2023

IDWeek
www.idweek.org

For attributable mortality, length of stay, healthcare costs of methicillin-resistant Staphylococcus aureus infections in SG

Background

Infections caused by methicillin-resistant *Staphylococcus aureus* (MRSA) are known to compromise patient outcomes and increase healthcare costs. Previous evidence on the prolongation of length of stay due to MRSA infections in Singapore is limited by methodology, including time-dependent bias. We used a multistate model to estimate the expected attributable mortality, length of stay, and healthcare costs of MRSA infections in Singapore.

Results

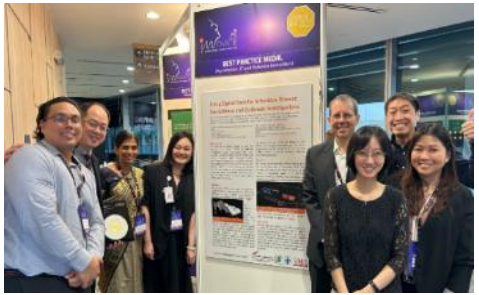
We matched 752 patients with MRSA infections to 2,256 patients without MRSA infections. The most common MRSA infections were skin and soft tissue infections (44.5%) and bacteraemia (18.9%). From the multistate model, the excess length of stay of a MRSA infection was 3.02 days (95% CI, 1.90 – 4.13 days). This translated to an excess healthcare cost of $594,128 (95% CI, $375,111–$813,144) per 100,000 admissions. MRSA skin and soft tissue infections had the longest length of excess stay (3.98 days; 95% CI, 2.50 – 5.46 days) and contributed most to health-care costs ($348,788 per 100,000 admissions; 95% CI, $219,099 – $478,476).

Healthcare IT News TOPICS RESOURCES REGIONS MORE

HIMSS BUILD THE FOUNDATION FOR HEALTH AI. Get Started

SingHealth scaling digital twin project beyond disease outbreak monitoring

Digital twins are now being applied for resource optimisation and healthcare facilities planning.



For methicillin-resistant Staphylococcus aureus prevention

Background

Methicillin-resistant *Staphylococcus aureus* (MRSA) surveillance and cluster detection involves time intensive processes in Singapore hospitals. Hence, there is substantial lag between outbreak occurrence and intervention. 4D-Disease Outbreak Surveillance System (4D-DOSS) is a real-time spatiotemporal mapping surveillance system that is under development and has potential to promptly detect MRSA clusters. We assessed projected costs and outcomes of adopting 4D-DOSS for MRSA surveillance in a Singapore tertiary hospital.

Results

The changes to costs and outcomes from adopting 4D-DOSS over 10 years were -$1,006,889 ± 3,781,728 and 45 ±127 life-years respectively. At a willingness-to-pay of $45,000/life-year saved, 4D-DOSS had 70% chance of being cost-effective. In a less optimistic scenario analysis where effectiveness of 4D-DOSS in preventing MRSA transmission was halved, 4D-DOSS had 66% chance of being cost-effective. If the 10-year implementation cost exceeded $3.0M, 4D-DOSS was unlikely to be cost-effective (Fig 2). Value of information analysis showed that uncertainty in bed-day costs contributed most to model uncertainty.

Acknowledgements

National University Hospital

Tengah General and Community Hospital

Woodlands Health
National Healthcare Group

NHG Health

Eastern General Hospital
SingHealth

5D-DOSS

"fifth" dimension is to track the dynamic flow and interaction between patients across the 3D space across time (with AI)