Math-for-industry
Education & Research Hub

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International Project Research-Workshop (I)

Malaysia – Japan Symposium on Mathematical and Statistical Modelling

Chief Editors : Zaiton Mat Isa, Arifah Bahar

Editors : Shariffah Suhaila Syed Jamaludin, Zaitul Marlizawati Zainuddin, Sharidan Shafie, Ahmad Fadillah Embong, Shaymaa Mustafa, Nur Arina Bazilah Aziz, Nik Zetti Amani Nik Faudzi, Mohamad Shahiir Saidin, Mohd Rashid Admon

九州大学マス・フォア・インダストリ研究所

MI Lecture Note Vol.105 : Kyushu University

FY2025 Joint Usage Research Program of Institute of Mathematics
for Industry, Kyushu University, Japan

International Project Research-Workshop (I)

Malaysia – Japan Symposium on Mathematical and Statistical Modelling

26 August 2025

**IMI Auditorium (W1-D-413), West Zone 1,
Ito Campus, Kyushu University, Japan**

broadcast live to

**UTM HELIxS, Universiti Teknologi Malaysia,
Johor Bahru, Malaysia**

Chief Editors:
Zaiton Mat Isa, Arifah Bahar

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Nik Zetti Amani Nik Faudzi, Mohamad Shahiir Saidin, Mohd Rashid Admon

About MI Lecture Note Series

The Math-for-Industry (MI) Lecture Note Series is the successor to the COE Lecture Notes, which were published for the 21st COE Program "Development of Dynamic Mathematics with High Functionality," sponsored by Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) from 2003 to 2007. The MI Lecture Note Series has published the notes of lectures organized under the following two programs: "Training Program for Ph.D. and New Master's Degree in Mathematics as Required by Industry," adopted as a Support Program for Improving Graduate School Education by MEXT from 2007 to 2009; and "Education-and-Research Hub for Mathematics-for-Industry," adopted as a Global COE Program by MEXT from 2008 to 2012.

In accordance with the establishment of the Institute of Mathematics for Industry (IMI) in April 2011 and the authorization of IMI's Joint Research Center for Advanced and Fundamental Mathematics-for-Industry as a MEXT Joint Usage / Research Center in April 2013, hereafter the MI Lecture Notes Series will publish lecture notes and proceedings by worldwide researchers of MI to contribute to the development of MI.

October 2025
Kenji Kajiwara
Director, Institute of Mathematics for Industry

FY2025 Joint Usage Research Program of Institute of Mathematics for Industry, Kyushu University, Japan

**International Project Research-Workshop (I)
Malaysia – Japan Symposium on Mathematical and Statistical Modelling**

MI Lecture Note Vol. 105, Institute of Mathematics for Industry, Kyushu University
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Chief Editors: Zaiton Mat Isa, Arifah Bahar
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Preface

The **Malaysia–Japan Symposium on Mathematical and Statistical Modelling**, held on **26 August 2025** at the IMI Auditorium, Kyushu University, Ito Campus, Japan, and broadcast live to UTM HELIxS, Universiti Teknologi Malaysia, Johor Bahru, Malaysia, marks yet another milestone in the enduring friendship and academic cooperation between Malaysia and Japan. For decades, the two nations have worked hand in hand in education, science and technology. This symposium is a further testament to the shared commitment to advancing knowledge for the benefit of societies.

Mathematical and statistical modelling extends beyond numbers and formulas. In today's world of global challenges, applied mathematics is a vital tool for understanding complex systems, guiding informed decisions, and tackling pressing challenges, whether in climate change, urban development issues, agriculture or industrial innovation.

This lecture note compiles the presentations delivered at the symposium, which accommodate both in-person and online participation. The event was jointly organized by the **UTM Centre for Industrial and Applied Mathematics (UTM-CIAM), Universiti Teknologi Malaysia**, and the **Institute of Mathematics for Industry (IMI), Kyushu University** under the framework of FY2025 Joint Usage Research Program of Institute of Mathematics for Industry, Kyushu University, Japan - International Project Research-Workshop. The symposium brought together academicians, researchers, industrial practitioners, and students from both countries to exchange insights, explore emerging methodologies, and strengthen academic ties.

The symposium began with remarks by Prof. Kenji Kajiwara, Director of IMI and Assoc. Prof. Dr. Arifah Bahar, Director of UTM-CIAM, who emphasized the role of mathematical and statistical modelling in bridging theoretical research and practical applications to address pressing societal and industrial challenges. This was followed by a virtual address from the **Ambassador of Malaysia to Japan, H.E. Dato' Shahril Effendi bin Abd Ghany**. In his speech, H.E. Ambassador Dato' applauded both the UTM-CIAM and the IMI, Kyushu University for initiating this inaugural symposium and expressed his hope that it would form the foundation for a long-term collaborative framework in areas of mathematical and statistical research, industrial applications, and innovation-driven problem solving. H.E. Ambassador Dato' also highlighted the importance of fostering academic exchanges and joint research projects between Malaysian and Japanese institutions, noting that such collaborations can contribute meaningfully to the development of advanced analytical solutions for both industry and society

The event was also attended by representatives Mr. Takashi Toyota from the **Ministry of Education, Culture, Sports, Science and Technology (MEXT)**, Mr. Sotaro Ito from the **Japan Science and Technology Agency (JST)**, and Ms Yumiko Hata from the **Ministry of Economy, Trade and Industry (METI)**.

The morning session featured contributed talks from the industrial sector. **Dr. Haifeng Chen, Department Head of NEC Laboratories America**, presented an AI-driven multi-agent simulation framework for carbon emissions modeling and optimization, highlighting the integration of artificial intelligence techniques with multi-modal prediction and swarm optimization to support carbon neutrality strategies. **Dr. Nurul Farahain Mohammad of Insulet Malaysia Sdn. Bhd.** discussed the role of advanced data analytics in modern manufacturing, illustrating how analytics can optimize operations, enhance decision-making, and improve overall efficiency in industrial systems.

In the afternoon, the symposium continued with invited talks and expert presentations. **Dr. Hideaki Yokomizo of WILLER, Inc.** introduced the application of AI-based Demand Responsive Transit (DRT) systems in Malaysia as a strategy to alleviate traffic congestion and environmental pressures associated with heavy reliance on private vehicles. **Associate Professor Dr. Zaitul Marlizawati Zainuddin of Universiti Teknologi Malaysia** presented her research on genetic algorithm–based optimization methods for location-routing problems in sustainable biomass supply chains. These sessions were followed by expert presentations that showcased the breadth of applications of mathematical and statistical modelling. **Associate Professor Dr. Atsushi Tero of Kyushu University** introduced common principles and applications of adaptive network theory, including results from collaborative projects with Malaysian researchers. **Associate Professor Dr. Shariffah Suhaila Syed Jamaludin of Universiti Teknologi Malaysia** presented a statistical framework for rainfall intensity and climate challenges in Malaysia, using advanced statistical approaches such as functional data analysis and copula models to improve flood risk prediction. **Dr. Zaiton Mat Isa of Universiti Teknologi Malaysia** ended the session with a presentation on advection–diffusion equations (ADE) and their applications to transport phenomena, including fumigation, heavy metal migration, and aerosol transmission.

The symposium concluded with reflections by Prof. Fumikazu Sato, Leader of the Division of Strategic Liaison, IMI, Kyushu University, and Prof. (Retired) Dr. Zainal Abdul Aziz, Director of MYHIMS Solutions PLT, Malaysia, who emphasized the growing role of mathematics as a platform for transnational collaboration. They highlighted the importance of strengthening research partnerships between the two nations and the relevance of mathematical and statistical modelling in addressing environmental, industrial, and societal challenges. A banquet held in the evening at Big Orange on the Ito Campus provided further opportunities for informal exchange and networking among participants.

Although organized as a one-day event, the symposium succeeded in bringing together a wide spectrum of expertise from academia, industry, and government, stimulating dialogue and collaboration across disciplines and borders. It is our sincere hope that the symposium will serve as a foundation for future Malaysia–Japan initiatives in mathematical and statistical modelling, enabling the co-creation of knowledge and innovative solutions with meaningful global impact.

Chief Editors: Zaiton Mat Isa, Arifah Bahar

November 2025

Contents

Organizing Committee

MALAYSIA

POSITION	NAME
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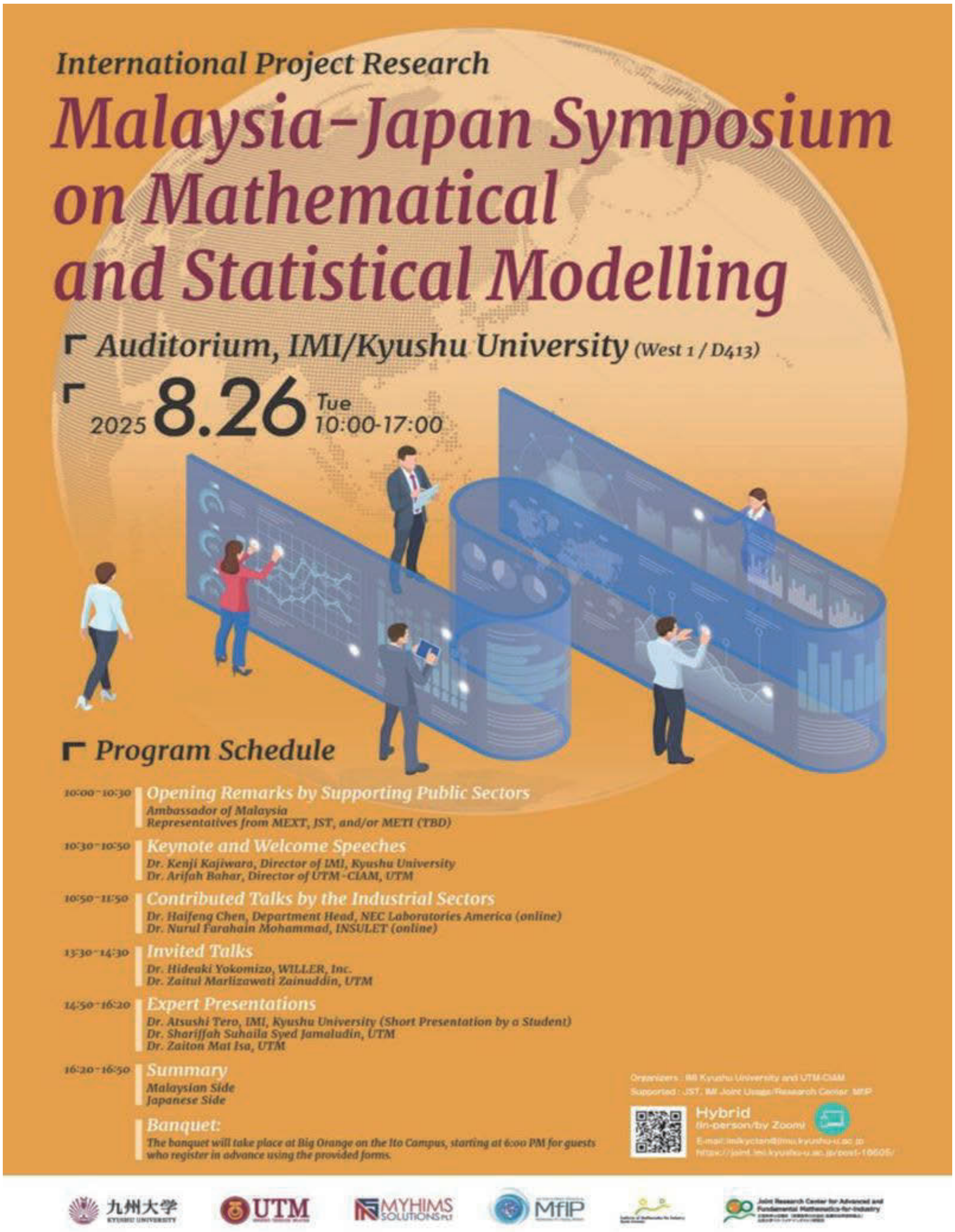
	Takako Iida

Poster


International Project Research
Malaysia-Japan Symposium on Mathematical and Statistical Modelling
Auditorium, IMI/Kyushu University (West 1 / D413)
2025 8.26 Tue 10:00-17:00
Program Schedule
10:00-10:30 Opening Remarks by Supporting Public Sectors
Ambassador of Malaysia
Representatives from MEXT, JST, and/or METI (TBD)
10:30-10:50 Keynote and Welcome Speeches
Dr. Kenji Kajiwara, Director of IMI, Kyushu University
Dr. Arifah Bahar, Director of UTM-CIAM, UTM
10:50-11:50 Contributed Talks by the Industrial Sectors
Dr. Haifeng Chen, Department Head, NEC Laboratories America (online)
Dr. Nurul Farahain Mohammad, INSULET (online)
13:30-14:30 Invited Talks
Dr. Hideaki Yokomizo, WILLER, Inc.
Dr. Zaitul Marlizawati Zainuddin, UTM
14:50-16:20 Expert Presentations
Dr. Atsushi Tero, IMI, Kyushu University (Short Presentation by a Student)
Dr. Shariffah Suhaila Syed Jamaludin, UTM
Dr. Zaiton Mat Isa, UTM
16:20-16:50 Summary
Malaysian Side
Japanese Side
Banquet:
The banquet will take place at Big Orange on the Ito Campus, starting at 6:00 PM for guests who register in advance using the provided forms.
Hybrid
(in-person/by Zoom)
九州大学
KYUSHU UNIVERSITY
UTM
MYHIMS SOLUTIONS
MfIP
Joint Research Center for Advanced and Fundamental Mathematics-for-Industry

Program Schedule

Thursday 26th, August 2025

10:00 – 10:30 ***Opening Remarks***
Ambassador of Malaysia
Ministry of Education, Culture, Sports, Science and Technology (MEXT)
Japan Science & Technology Agency (JST)

10:30 – 10:50 ***Keynote and Welcome Speeches***

- Dr. Kenji Kajiwara, Director of Institute of Mathematics in Industry (IMI), Kyushu University.
- Dr. Arifah Bahar, Director of UTM-Centre for Industrial and Applied Mathematics (UTM-CIAM), Universiti Teknologi Malaysia.

10:50 – 11:50 ***Contributed Talk by the Industrial Sectors***
Dr. Haifeng Chen
Department Head, NEC Laboratories America
Title: AI-driven Multi-Agent Simulation for Accurate Carbon Emissions Modeling & Optimization

11:50 – 13:30 **Lunch break**

13:30 – 14:30 ***Invited talks***

- Dr. Hideaki Yokomizo
  Director and Executive Office, DWILLER, Inc.
  Title : Solving urban traffic issues in Malaysia by AI-based Demand Responsive Transit
- Dr. Zaitul Marlizawati Zainuddin
  Research Fellow, UTM-Centre for Industrial and Applied Mathematics (UTM-CIAM)
  Title : Genetic Algorithm-Based Optimization of Location-Routing Problems for a Sustainable Biomass Supply Chain

14:30 – 14:50 **Break**

14:50 – 16:20 ***Expert presentations***

- Dr. Atsushi Tero
  Institute of Mathematics in Industry, Kyushu university
  Title : Common principles and applications of adaptive network theory using mathematical models
- Dr. Shariffah Suhaila Syed Jamaludin,
  Universiti Teknologi Malaysia
  Moderator: Nur Syafiqah
  Title : A Statistical Data-Driven Framework for Understanding Rainfall Intensity and Climate Challenges in Malaysia
- Dr. Zaiton Mat Isa,
  Universiti Teknologi Malaysia
  Moderator: Noraini
  Title : Advection-Diffusion Equations (ADE) in Modeling Transport Phenomena

16:20 – 16:50 ***Summary***
Malaysian side
Japanese side

List of Participants

NO.	NAME	AFFILIATION
1	Ahmad Fadillah Embong	Universiti Teknologi Malaysia
2	Amidora Idris	Universiti Teknologi Malaysia
3	Anati Ali	Universiti Teknologi Malaysia
4	Aneesa Sofea Abdul Rahim	Universiti Teknologi Malaysia
5	Aniza Binti Akaram	Universiti Teknologi Malaysia
6	Arifah Bahar	Universiti Teknologi Malaysia
7	Azizi Rosli	Universiti Teknologi Malaysia
8	Faradiba So'aib	Universiti Teknologi Malaysia
9	Farah Nur Atiqah Nor Azhar	Universiti Teknologi Malaysia
10	Fuaada Mohd Siam	Universiti Teknologi Malaysia
11	Haliza Abd Rahman	Universiti Teknologi Malaysia
12	Han Nee Yong	Universiti Teknologi Malaysia
13	Inessya Fam Enn Xii	Universiti Teknologi Malaysia
14	Intan Diyana Munir	Universiti Teknologi Malaysia
15	Lim Xiao Qin	Universiti Teknologi Malaysia
16	Mohd Rashid Admon	Universiti Teknologi Malaysia
17	Mohd Shazaril Mohd Zain	Universiti Teknologi Malaysia
18	Muhamad Hanis Mohd Nasir	Universiti Teknologi Malaysia
19	Muhammad Fauzee Hamdan	Universiti Teknologi Malaysia
20	Nik Zetti Amani Binti Nik Faudzi	Universiti Teknologi Malaysia
21	Noorehan Yaacob	Universiti Teknologi Malaysia
22	Noraini Binti Hasan	Universiti Teknologi Malaysia
23	Norhaiza Binti Ahmad	Universiti Teknologi Malaysia
24	Norsyahida Zulkifli	Universiti Teknologi Malaysia
25	Nur Arina Bazilah Kamisan	Universiti Teknologi Malaysia
26	Nur Husna Amierah Mohd Zaperi	Universiti Teknologi Malaysia
27	Nur Shafiqah Najwa Binti Mohd Fairuz	Universiti Teknologi Malaysia
28	Nur Syazwin Mansor	Universiti Teknologi Malaysia
29	Nurfazira Natasha Murad	Universiti Teknologi Malaysia
30	Nurul Aini Jaafar	Universiti Teknologi Malaysia
31	Nurul Syafiqa	Universiti Teknologi Malaysia
32	Purani Kunasegaran	Universiti Teknologi Malaysia
33	Sharidan Shafie	Universiti Teknologi Malaysia
34	Shariffah Suhaila Syed Jamaludin	Universiti Teknologi Malaysia
35	Shaymaa M H Darwish	Universiti Teknologi Malaysia
36	Siti Farahiyah Ismail	Universiti Teknologi Malaysia
37	Suzarina Ahmed Sukri	Universiti Teknologi Malaysia
38	Wan Rohaizad Wan Ibrahim	Universiti Teknologi Malaysia
39	Xin Rui Tan	Universiti Teknologi Malaysia
40	Yeou Jiann Lim	Universiti Teknologi Malaysia
41	Yuli Sudriani	Universiti Teknologi Malaysia
42	Zainal Aziz	Universiti Teknologi Malaysia
43	Zaiton Binti Mat Isa	Universiti Teknologi Malaysia

44	Zaitul Marlizawati Binti Zainuddin	Universiti Teknologi Malaysia
45	Zhi Xin Chong	Universiti Teknologi Malaysia
46	Ziou Hon Wu	Universiti Teknologi Malaysia
47	Zuhaila Ismail	Universiti Teknologi Malaysia
48	Zulkepli Majid	Universiti Teknologi Malaysia
49	Hani Suraya Tajudin	Universiti Kebangsaan Malaysia
50	Nuraddeen Gafai Sayyadi	Umaru Musa Yar'adua University Katsina
51	Ummi Munirah Syuhada Mohamad Zan	Universiti Islam Selangor (UIS)
52	Amirah Hazwani Roslin	Universiti Malaysia Pahang Al-Sultan Abdullah
53	Nur Hidayah Azmidi	Universiti Malaysia Pahang Al-Sultan Abdullah
54	Intan Martina Md Ghani	Universiti Malaysia Terengganu
55	Koon Sang Wong	Universiti Malaysia Terengganu
56	Intekhab Husain	Universiti Sains Malaysia
57	Mohd Mahayaudin Mansor	Universiti Teknologi Mara
58	Tian Hwee Lim	University Of Reading Malaysia
59	Nurul Tasnim Abdul Latiff	Universiti Teknologi Malaysia
60	Mohd Farizzal	Unknown
61	Kan Sakamoto	Hosei University
62	Nurul Farahain Binti Mohammad	Insulet Malaysia Sdn. Bhd.
63	Sotaro Ito	Japan Science and Technology Agency
64	Tae Fujishima	Japan Science and Technology Agency
65	Abdullah Gul Rayan	Kabul University
66	Masataka Kanki	Kansai University
67	Muhammad Ayaz	Kohat University of Science and Technology
68	Hinano Tachibana	Kumamoto University
69	Atsushi Tero	Kyushu University
70	Daisuke Tagami	Kyushu University
71	Dong Liang	Kyushu University
72	Fumikazu Sato	Kyushu University
73	Harada Kentaro	Kyushu University
74	Haruka Suga	Kyushu University
75	Hidetaka Arimura	Kyushu University
76	Hien Nguyen	Kyushu University
77	Ichiyo Yotsuji	Kyushu University
78	Junki Omae	Kyushu University
79	Kaname Matsue	Kyushu University
80	Katsunari Fujishima	Kyushu University
81	Kazuhiro Minami	Kyushu University
82	Kei Hirose	Kyushu University
83	Kenji Kajiwara	Kyushu University
84	Kota Hisakado	Kyushu University
85	Kota Nishi	Kyushu University
86	Masayo Hirose	Kyushu University
87	Miki Nagasawa	Kyushu University
88	Motoki Masada	Kyushu University

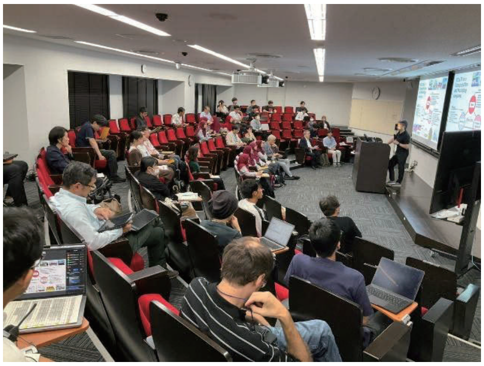
89	Muhammad Solihin	Kyushu University
90	Pierluigi Cesana	Kyushu University
91	Ryota Hagihara	Kyushu University
92	Satoru Tokuda	Kyushu University
93	Seiko Sasaguri	Kyushu University
94	Shotaro Kaneko	Kyushu University
95	Shuhei Muroya	Kyushu University
96	Taichi Hosotani	Kyushu University
97	Taiga Kadowaki	Kyushu University
98	Takako Iida	Kyushu University
99	Tomoki Kojima	Kyushu University
100	Tomomi Ebara	Kyushu University
101	Tomoyuki Shirai	Kyushu University
102	Toshiki Usui	Kyushu University
103	Yasuhiro Ishitsuka	Kyushu University
104	Yoshihiro Mizoguchi	Kyushu University
105	Yudai Sakihara	Kyushu University
106	Yuko Yokoo	Kyushu University
107	Yusuke Fujiyoshi	Kyushu University
108	Yuto Tanabe	Kyushu University
109	Syarifah Zyurina Nordin	Malaysia-Japan International Institute of Technology (MJIIT)
110	Takashi Toyota	MEXT
111	Yuka Watabe	MEXT
112	Yuki Serizawa	Ministry Of Education， Culture， Sports Science and Technology - Japan
113	Mariya Sadiki	Mohammed V University
114	Fihi Hiba	Moulay Ismail University
115	Watanabe Sawaki	NEc Corporation
116	Sunaga Kazuhisa	NEc Corporation
117	Gen Motoyoshi	NEc Corporation
118	Haifeng Chen	NEc Laboratories America
119	Shinji Sato	None
120	Nicolo' Briatico	Politecnico Di Torino
121	Thodsaporn Kumduang	Rajamangala University of Technology Rattanakosin
122	Sherief Hashima	RIKEN-AIP/Kyushu University
123	Mohamad Faizal Ishak	Solid Waste and Public Cleansing Management Corporation (Swcorp)
124	Zohaib Hassan Sain	Superior University
125	Hideaki Yokomizo	Willer, Inc.
126	Kunio Tanabe	The Institute of Statistical Mathematics & Waseda University

Event Photos

Opening remarks by Ambassador of Malaysia to Japan, H.E. Dato' Shahril Effendi Abd Ghany

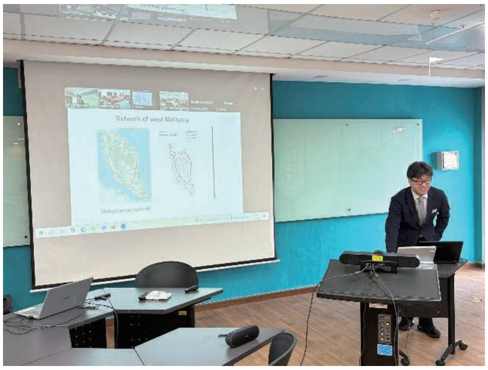
Seated (L–R): Dr. Hideaki Yokomizo (WILLER Inc.), Mr. Sotaro Ito (JST), Mr. Takashi Toyota (MEXT), Assoc. Prof. Dr. Arifah Bahar (UTM-CIAM), Prof. Kenji Kajiwara (IMI).
Standing (back, L–R): Assoc. Prof. Dr. Zaitul Marlizawati Zainuddin, Assoc. Prof. Dr. Shariffah Suhaila Syed Jamaludin, Dr. Zaiton Mat Isa (UTM-CIAM Fellows).

Malaysia–Japan Symposium on Mathematical & Statistical Modelling held at Kyushu University, Japan, with live telecast to UTM Johor Bahru



Participation in Kyushu University, Japan

Participation in UTM Johor Bahru, Malaysia



Presentation by Assoc. Prof. Dr. Atsushi Taro in Universiti Teknologi Malaysia.

Presentation by Nurul Farahain Mohammad from Insulet Malaysia Sdn. Bhd.

Concluding remark from Malaysia by Dr. Zainal Abdul Aziz

Token of appreciation from both UTM-CIAM and IMI

AI-Driven Multi-Agent Simulation for Accurate Carbon Emissions Modeling and Optimization

Haifeng Chen
NEC. US, Department Head

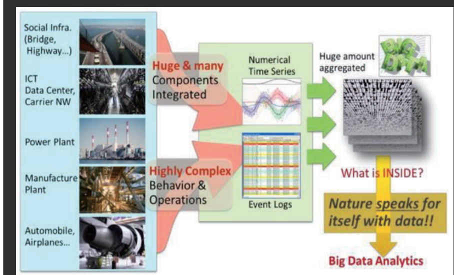
The talk presents the development of a multi-agent simulator designed to model carbon emissions and support global sustainability efforts. The simulator includes three core components: agents, resources, and topology. Advanced AI techniques are also incorporated to enhance the simulator's capabilities, including a multi-modal time series prediction method for accurate energy cost forecasting and a swarm optimization algorithm to identify optimal strategies for achieving carbon neutrality. By integrating AI and simulation, organizations can model carbon emission processes, conduct "what-if" analyses, and develop actionable strategies to reduce emissions and accelerate progress toward carbon neutrality goals.

Orchestrating a brighter world NEC

MOGI: Complex System Simulation and Modeling
MOGI: 複雑系システムのシミュレーションとモデリング

Haifeng Chen
NEC Labs America
Princeton, New Jersey, USA

Complex System Management



- A shortage of domain experts in industries
- Finding insights from time series data requires different technology and skills.
  - if derived insights are correct and actionable, they will have a real impact on the business
- The real impact comes from analyzing the data to derive system insight
  - Separate the signal from the noise
  - Uncover the global structure from local observations
  - Disentangle the heterogeneity in dynamics

- Understand **system complexity** by data analysis & mining;
- **Model system properties** by combing first principles & data inference;

Big insights are more important than big data

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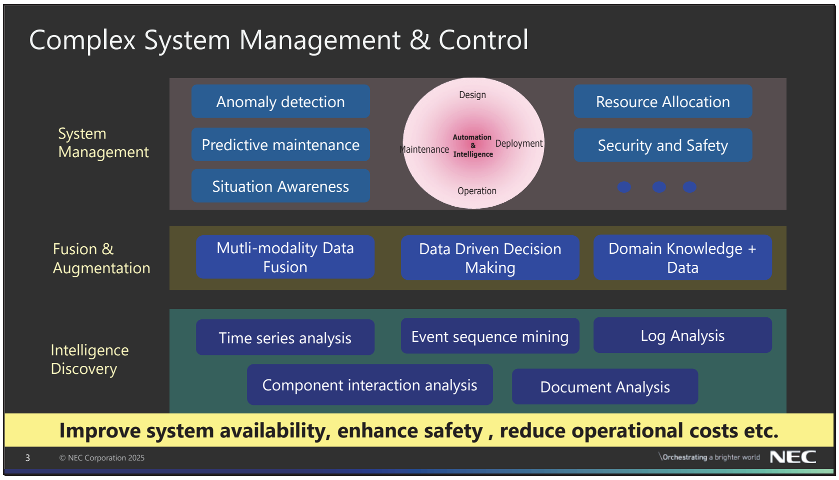
Complex System Management & Control
System Management
Anomaly detection
Predictive maintenance
Situation Awareness
Design
Automation & Intelligence
Maintenance
Deployment
Operation
Resource Allocation
Security and Safety
Fusion & Augmentation
Mutli-modality Data Fusion
Data Driven Decision Making
Domain Knowledge + Data
Intelligence Discovery
Time series analysis
Event sequence mining
Log Analysis
Component interaction analysis
Document Analysis
Improve system availability, enhance safety , reduce operational costs etc.
3
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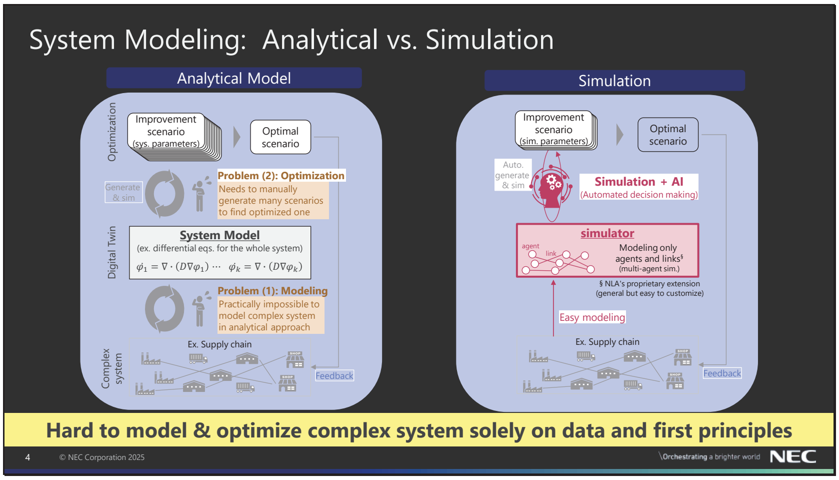
System Modeling: Analytical vs. Simulation
Analytical Model
Optimization
Improvement scenario (sys. parameters)
Optimal scenario
Generate & sim
Problem (2): Optimization
Needs to manually generate many scenarios to find optimized one
Digital Twin
System Model
(ex. differential eqs. for the whole system)
$\phi_1 = \nabla \cdot (D\nabla\phi_1) \cdots \quad \phi_k = \nabla \cdot (D\nabla\phi_k)$
Problem (1): Modeling
Practically impossible to model complex system in analytical approach
Ex. Supply chain
Complex system
Feedback
Simulation
Improvement scenario (sim. parameters)
Optimal scenario
Auto. generate & sim
Simulation + AI
(Automated decision making)
simulator
agent
link
Modeling only agents and links§
(multi-agent sim.)
§ NLA's proprietary extension
(general but easy to customize)
Easy modeling
Ex. Supply chain
Feedback
Hard to model & optimize complex system solely on data and first principles
4
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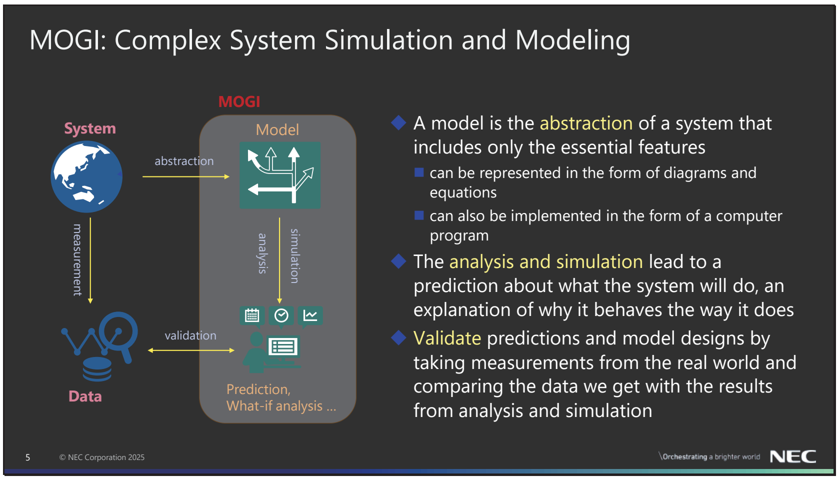
MOGI: Complex System Simulation and Modeling
MOGI
System
Model
abstraction
measurement
analysis
simulation
validation
Data
Prediction,
What-if analysis ...
A model is the abstraction of a system that includes only the essential features
can be represented in the form of diagrams and equations
can also be implemented in the form of a computer program
The analysis and simulation lead to a prediction about what the system will do, an explanation of why it behaves the way it does
Validate predictions and model designs by taking measurements from the real world and comparing the data we get with the results from analysis and simulation
5
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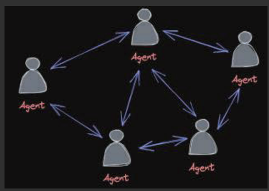
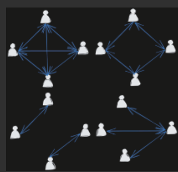
Multi-Agent Modelling



- Each agent is a persistent actor with its own decision-making processes and behaviors.
  - has some state and interacts with other agents
  - mutually modifying each other's states
- The components of an agent-based model are
  - A collection of agents and their states
  - Rules governing the interactions of the agents
  - The environment within which they live
- Interaction among agents is the central point of the simulation
  - agents perceive their environment, take actions based on their internal states, and exchange information with other agents.

Topology & Resources: Interaction between Agents

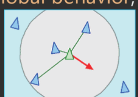
- Static or dynamic topology: each agent interacts with its neighbors
  - Agent interactions can range from cooperative to competitive and involve communication, resource sharing, negotiation, and conflict resolution.
  - Determine the overall behavior and outcomes of the system.
- We model the Resource Flow between agents for their interactions.
  - Link is responsible for transporting resources.
  - Transporting cost (time/money/distance) is supported for both resource-to-target and target-to-resource
  - The agent can assign priority to links to make a refined strategy.



- As the number of agents increases, even simple interaction rules between local agents can produce complex and coordinated global behaviors.
  - New emergent properties and behaviors that were not present in smaller groups of agents

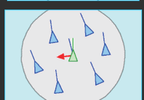
Example: Swarm Intelligence

- The state of each agent includes its position, velocity, and orientation.
- Simple interaction rules between agents lead to the emergence of "intelligent" global behavior, unknown to the individual.



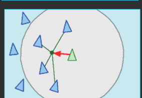
Separation rule

The agent maintains a reasonable amount of distance between itself and any nearby agents



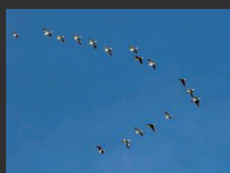
Alignment rule

The agent changes its position to correspond with the average alignment of other nearby agents.



Cohesion rule

The agent moves towards the average position of other nearby agents.



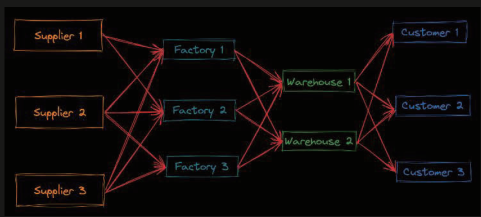
- No centralized control structure dictating how individual agents should behave
- can be used for direct control and stabilization of teams of simple unmanned ground vehicles (UGV)

Market Opportunities

Manufacturing	Social Impact	Defense
Optimize production processes, reduce waste, and improve quality control. Model a production line and identify bottlenecks or inefficiencies.	Model the behavior of individuals in a social network, including how they interact and influence one another. Understand how ideas and behaviors spread through a network. Design interventions to influence social change.	Simulate military operations and training exercises, e.g., a battlefield scenario to train soldiers on how to respond to different situations.

Finance	Transportation	Environmental
Model financial markets, test investment strategies, and manage risk, e.g., model the performance of a portfolio of investments under different market scenarios.	Model traffic patterns, test transportation infrastructure, and optimize logistics, e.g., simulate traffic flow and identify areas where traffic congestion is likely to occur.	Model the behavior of different actors such as farmers, factories, and policymakers. Understand how different policies and management strategies affect the environment. Design interventions to promote sustainable development.

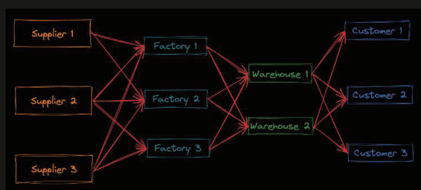
Case Study: Supply Chain Management



- Material supplier: location differences, dynamic prices, renewable energy, ...
- Factory: different manufacturing capacities; purchase of raw materials from different sources; transportation cost to warehouses; different prices for the product...
- Warehouse: storage cost; purchasing capacity in its location;
- Customers: uncertainty in demand at each season; economic factors

Understand the Complexity through Simulation

- Simulation & Modeling answers various "what-if" questions, given the uncertainties in each component
  - variations in customer demand; transportation costs and delays between factory to warehouse; market price change for the products; capacity change and the quality of product change in each plant; raw material supply changes
- Discover emerging behaviors; identify and mitigate potential disruptions or inefficiencies
  - impact of potential disease, wars, ...



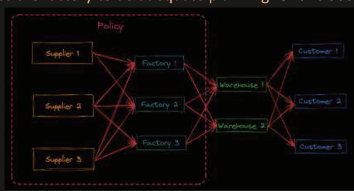
MOGI Simulation

Supply Chain: Supplier | Product Transmission | Location

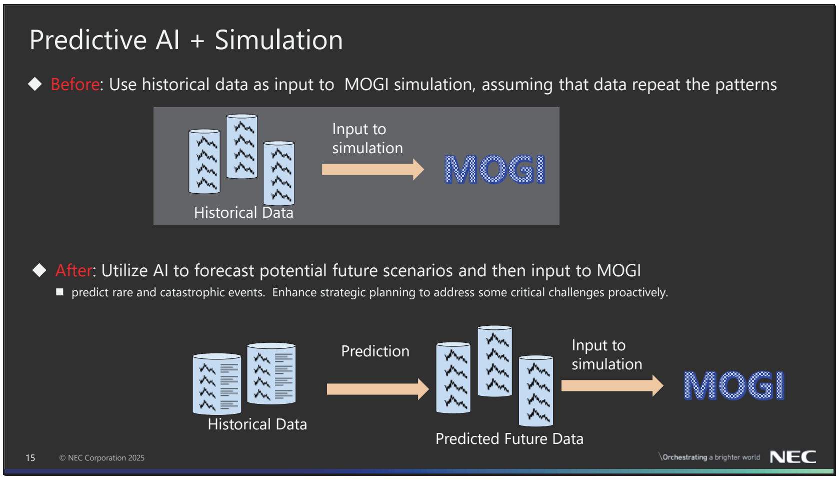
MOGI Simulation component: Agent | Resource Flow | Geographical Location topology

Policy for Environmental Sustainability and Carbon Neutrality

- The government will issue a number of different policies to regulate factories' manufacturing.
  - Achieve the balance between market demand and environmental sustainability
  - Simulation tool helps the government to evaluate the effectiveness of each policy before it is issued
- the objective of the factory has a double end: meet the environmental sustainability and carbon neutrality regulations while maintaining efficient supply chain operations.
  - Simulation tool help helps the factory to do adequate planning for this dual purpose.



Integrating AI with Simulation


Predictive AI + Simulation
Before: Use historical data as input to MOGI simulation, assuming that data repeat the patterns
Input to simulation
MOGI
Historical Data
After: Utilize AI to forecast potential future scenarios and then input to MOGI
predict rare and catastrophic events. Enhance strategic planning to address some critical challenges proactively.
Prediction
Input to simulation
MOGI
Historical Data
Predicted Future Data
15
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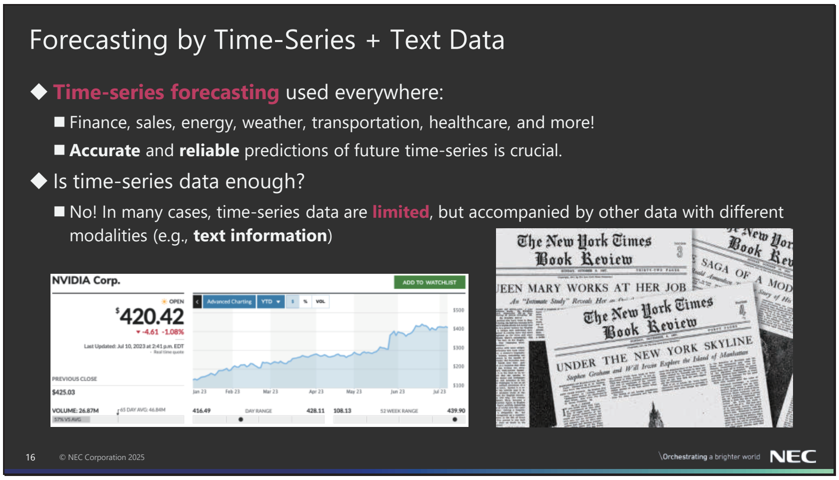
Forecasting by Time-Series + Text Data
Time-series forecasting used everywhere:
Finance, sales, energy, weather, transportation, healthcare, and more!
Accurate and reliable predictions of future time-series is crucial.
Is time-series data enough?
No! In many cases, time-series data are limited, but accompanied by other data with different modalities (e.g., text information)
NVIDIA Corp.
$420.42
The New York Times Book Review
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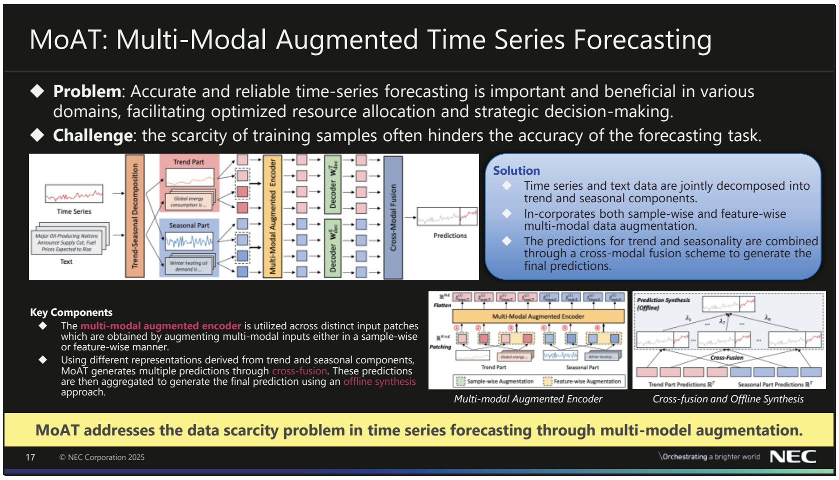
MoAT: Multi-Modal Augmented Time Series Forecasting
Problem: Accurate and reliable time-series forecasting is important and beneficial in various domains, facilitating optimized resource allocation and strategic decision-making.
Challenge: the scarcity of training samples often hinders the accuracy of the forecasting task.
Time Series
Text
Trend-Seasonal Decomposition
Trend Part
Seasonal Part
Multi-Modal Augmented Encoder
Cross-Modal Fusion
Predictions
Solution
Time series and text data are jointly decomposed into trend and seasonal components.
In-corporates both sample-wise and feature-wise multi-modal data augmentation.
The predictions for trend and seasonality are combined through a cross-modal fusion scheme to generate the final predictions.
Key Components
The multi-modal augmented encoder is utilized across distinct input patches which are obtained by augmenting multi-modal inputs either in a sample-wise or feature-wise manner.
Using different representations derived from trend and seasonal components, MoAT generates multiple predictions through cross-fusion. These predictions are then aggregated to generate the final prediction using an offline synthesis approach.
Multi-modal Augmented Encoder
Cross-fusion and Offline Synthesis
MoAT addresses the data scarcity problem in time series forecasting through multi-model augmentation.
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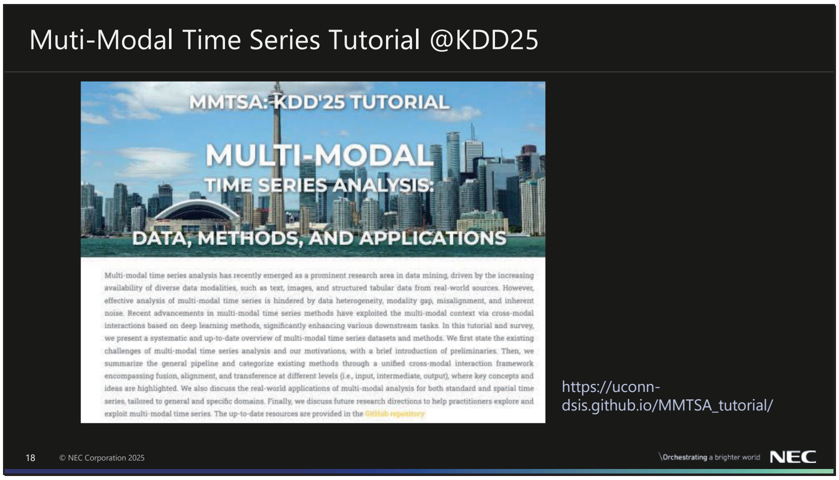

Muti-Modal Time Series Tutorial @KDD25
MMTSA: KDD'25 TUTORIAL
MULTI-MODAL
TIME SERIES ANALYSIS:
DATA, METHODS, AND APPLICATIONS
Multi-modal time series analysis has recently emerged as a prominent research area in data mining, driven by the increasing availability of diverse data modalities, such as text, images, and structured tabular data from real-world sources. However, effective analysis of multi-modal time series is hindered by data heterogeneity, modality gap, misalignment, and inherent noise. Recent advancements in multi-modal time series methods have exploited the multi-modal context via cross-modal interactions based on deep learning methods, significantly enhancing various downstream tasks. In this tutorial and survey, we present a systematic and up-to-date overview of multi-modal time series datasets and methods. We first state the existing challenges of multi-modal time series analysis and our motivations, with a brief introduction of preliminaries. Then, we summarize the general pipeline and categorize existing methods through a unified cross-modal interaction framework encompassing fusion, alignment, and transference at different levels (i.e., input, intermediate, output), where key concepts and ideas are highlighted. We also discuss the real-world applications of multi-modal analysis for both standard and spatial time series, tailored to general and specific domains. Finally, we discuss future research directions to help practitioners explore and exploit multi-modal time series. The up-to-date resources are provided in the GitHub repository
https://uconn-dsis.github.io/MMTSA_tutorial/
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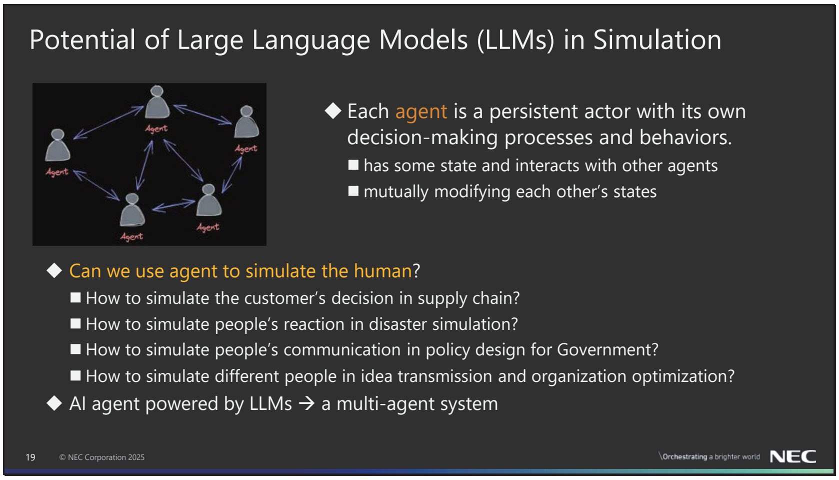

Potential of Large Language Models (LLMs) in Simulation
Agent
Agent
Agent
Agent
Agent
◆ Each agent is a persistent actor with its own decision-making processes and behaviors.
■ has some state and interacts with other agents
■ mutually modifying each other's states
◆ Can we use agent to simulate the human?
■ How to simulate the customer's decision in supply chain?
■ How to simulate people's reaction in disaster simulation?
■ How to simulate people's communication in policy design for Government?
■ How to simulate different people in idea transmission and organization optimization?
◆ AI agent powered by LLMs → a multi-agent system
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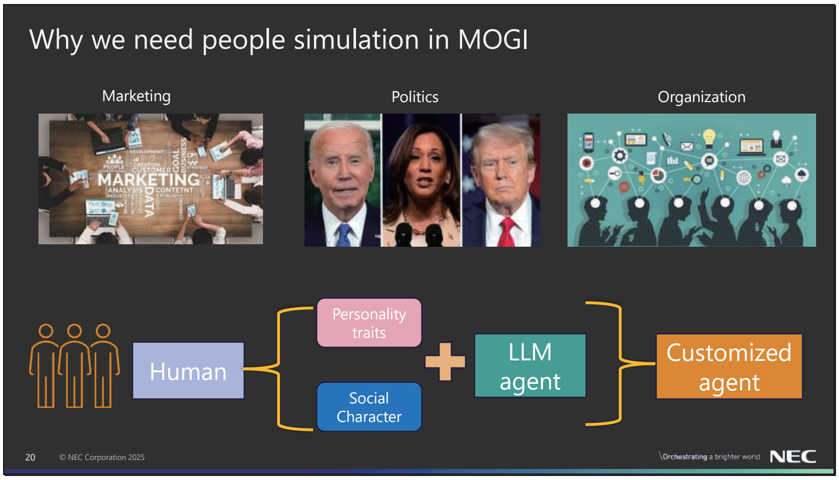

Why we need people simulation in MOGI
Marketing
Politics
Organization
MARKETING
Human
Personality traits
Social Character
LLM agent
Customized agent
20
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Personality from Real People

- Questionaries of Big Five personalities.
- Extract from social media.

- Methodology: prompt engineering.

Take-Aways

- The increasing complexity of real-world systems requires a cost-effective and efficient way to test, optimize, and improve their processes.
  - Simulation enables the exploration of multiple scenarios and what-if analysis.
  - Users can gain insight into the impact of different factors and variables on the system or process being modeled.
- We need tools to test scenarios that would be too dangerous or difficult to test in the real world.
  - Emergency situations, military operations, or complex engineering designs.
- The integration of AI and simulation provides promising future for complex system understanding and management

Simulation identifies and solves problems before they occur in real-world scenarios.

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NEC creates the social values of safety, security, fairness and efficiency to promote a more sustainable world where everyone has the chance to reach their full potential.

From Data to Decisions: The Role of Analytics in Modern Manufacturing

Nurul Farahain Mohammad

Insulet Malaysia Sdn. Bhd.

In today's manufacturing world, data is key to driving production and efficiency. This study will explore how data analytics is transforming the manufacturing industry. We will discuss the role of data analytics in enabling the visibility of material inventory, monitoring Overall Equipment Effectiveness (OEE), identify issues through scrap analysis and statistical process control. Additionally, the challenges of implementing data analytics projects and the skills and expertise required to leverage data effectively will be addressed.

From Data to Decisions: The Role of Analytics in Modern Manufacturing

Ts. Dr. Nurul Farahain Mohammad

Senior Analytics Engineer Insulet Malaysia Sdn. Bhd.

Malaysia - Japan Symposium on Mathematical and Statistical Modelling 26 August 2025

Insulet

About Insulet

Insulet ("Insulet" or "the Company") is an innovative medical device company focused on improving the lives of people with diabetes and other conditions through its proprietary Omnipod® platform.

The Omnipod platform provides a unique alternative to traditional insulin delivery methods. A simple, wearable, tubeless design allows the disposable Omnipod device ("Pod") to deliver up to three days of continuous insulin without requiring users to see or handle a needle.

In addition to enhancing diabetes management, **Insulet tailors the Omnipod product platform for subcutaneous delivery of non-insulin drugs across other therapeutic areas.** At Insulet, ingenuity meets a commitment to access, customer-centric operations, and high-quality products. Omnipod products are available in 25 countries around the world, reflecting Insulet's significant role in expanding the global adoption of insulin pump therapy.

Insulet's flagship Omnipod 5 Automated Insulin Delivery (AID) System integrates with a continuous glucose monitor (CGM) to automatically manage blood sugar levels, eliminating the need for multiple daily injections or fingersticks. Users can control this intuitive system via a compatible smartphone or the Omnipod 5 Controller.

Founded in 2000 and headquartered in Acton, Massachusetts, Insulet is a publicly traded company listed on the Nasdaq (PODD). We operate globally with offices in the United States (U.S.), Australia, Canada, China, France, Germany, Malaysia, Mexico, Netherlands, United Arab Emirates (U.A.E.), and the United Kingdom (U.K.). Our state-of-the-art manufacturing facilities are located in Massachusetts, China, and Malaysia.

OUR MISSION

To improve the lives of people with diabetes.

OUR VISION

We create innovative technology that allows people with diabetes globally to enjoy simplicity, freedom, and healthier lives.

OUR PRODUCTS

The Omnipod platform offers continuous insulin delivery, providing all the benefits of insulin pump therapy without compromise and eliminating the need for external tubing required with conventional pumps.

The Omnipod platform's innovative, proprietary design and differentiated features offer those with insulin-dependent diabetes unprecedented freedom, comfort, and ease in managing their condition. Pod Therapy is an innovative, intuitive kind of insulin management method — a customizable alternative to traditional insulin pumps and multiple daily injections. The wearable, insulin-filled Pod includes a small, flexible cannula that inserts automatically with the push of a button. The Pod delivers personalized doses of insulin into your body based on the set and variable rates that you program into a handheld Personal Diabetes Manager (PDM), or Omnipod 5 App on the Controller or compatible smartphone.

For more information on our products and expanding accessibility, please see the Value, Affordability, and Accessibility section of this report and the Insulet website.

Omnipod provides all the benefits of insulin pump therapy in a unique way. The primary components of our Pod therapy are:

1

POD

The tubeless, waterproof Pod provides automated, virtually pain-free insertion and can be worn in multiple locations to deliver precise, personalized insulin doses for up to three days.

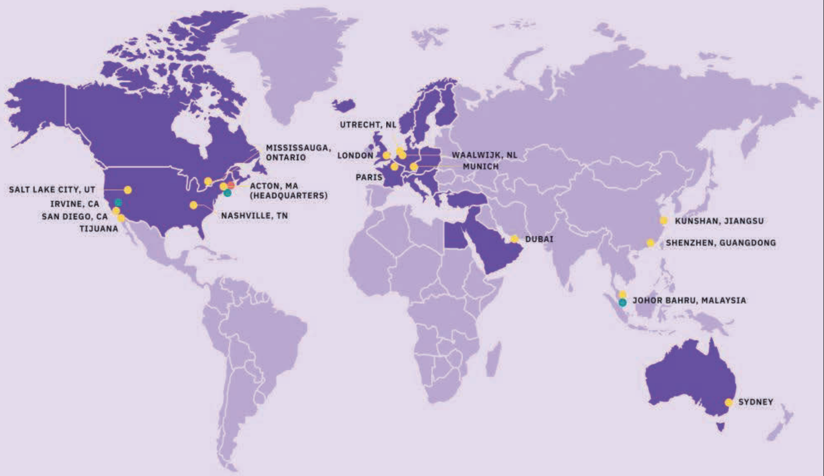
2

PERSONAL DIABETES MANAGER (PDM) OR CONTROLLER

The handheld Controller wirelessly programs the Pod with the user's personalized insulin instructions and monitors Pod operation.

LOCATIONS

We currently have offices in 11 countries, with products available in 25 countries spanning North America, Europe, the Middle East, and Asia Pacific. Every day, we actively work to expand access and reach more customers worldwide.



Introduction

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Abstract

In today's manufacturing world, data is key to driving production and efficiency. This study will explore how data analytics is transforming the manufacturing industry. We will discuss the role of data analytics in enabling the visibility of material inventory, monitoring Overall Equipment Effectiveness (OEE), identify issues through scrap analysis and statistical process control. Additionally, the challenges of implementing data analytics projects and the skills and

expertise required to leverage data effectively will be addressed.

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Modern Manufacturing

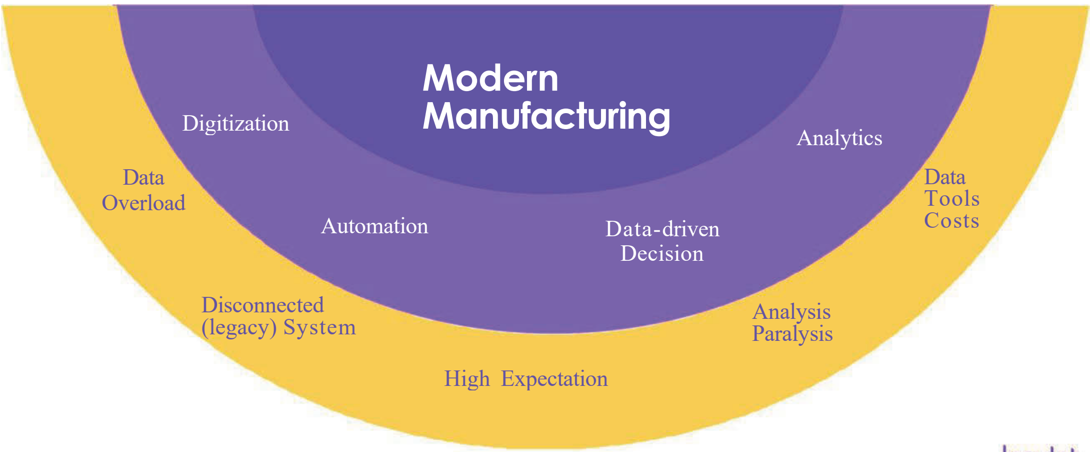
Modern manufacturing is defined as a **transformation process** involving materials, processes, and systems. It integrates traditional and newly developed manufacturing techniques, with a strong **emphasis** on **quantitative analysis,** electronics manufacturing, and sustainability. It reflects the shift toward **IR 4.0**, where **automation, data exchange,** and smart technologies are central. (Groover, 2020).

Modern manufacturing **embraces big data analytics** to optimize processes, reduce costs, and enhance production efficiency. (Luciano, 2024).

Groover, M. P. (2020). *Fundamentals of Modern Manufacturing: Materials, Processes, and Systems*. John Wiley & Sons.

Luciano, S. (2024). Data-driven Manufacturing: The Role of Big Data Analytics in Enhancing Production Efficiency. *Industrial Engineering & Management*, 13(5).

Modern Manufacturing



Manufacturing Analytics

Manufacturing analytics refers to the **systematic analysis of data** generated from manufacturing processes, equipment, and enterprise systems to support **data-driven decision making**. These programs aim to improve **productivity**, optimize **yield,** enable predictive **maintenance**, and support product **re-engineering**.

Emphasizes the **integration of internal data** (from MES, ERP, sensors, automation systems) and **external data** (from supply networks, customers, and regulatory bodies) to enhance operational **performance** (Ismail et al., 2019).

Ismail, A., Truong, H.-L., & Kastner, W. (2019). Manufacturing process data analysis pipelines: a requirements analysis and survey. *Journal of Big Data*, 6(1).

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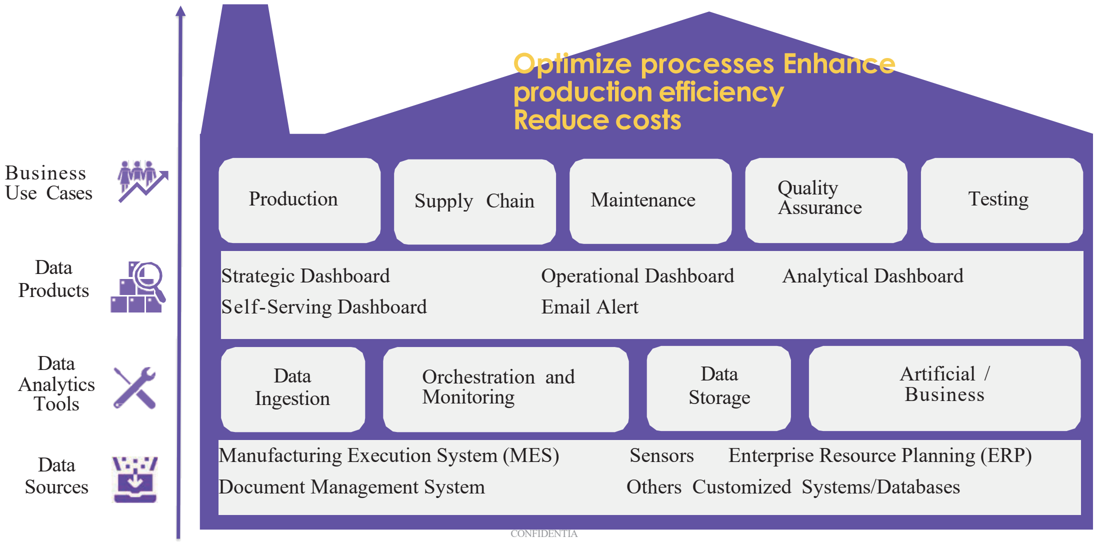
Manufacturing Analytics



Material Inventory

Use Case

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Material Inventory

Use Case Description

Managing the movement of materials from the warehouse to the production area to ensure timely replenishment and minimize production downtime.

Business Challenges

- Address bottlenecks in the movement of materials from warehouse to production.
- Production downtime due to incomplete material transport to the production areas.
- Lack of visibility on material inventory levels and status.

How Analytics Solution Helps?

- Provides visibility of the material inventory at each stages and their status via real-time operational dashboard.
- Identify and notify responsible personnel when materials are not replenished within a defined time threshold via automated email alerts .

Implementation

- Data source is from Manufacturing Execution System (MES) containers.
- Collaborate with stakeholders to define logic for categorizing urgency of material replenishment.
- Develop live dashboard using TIBCO Spotfire.
- Implement job orchestration and email alerts using Databricks.

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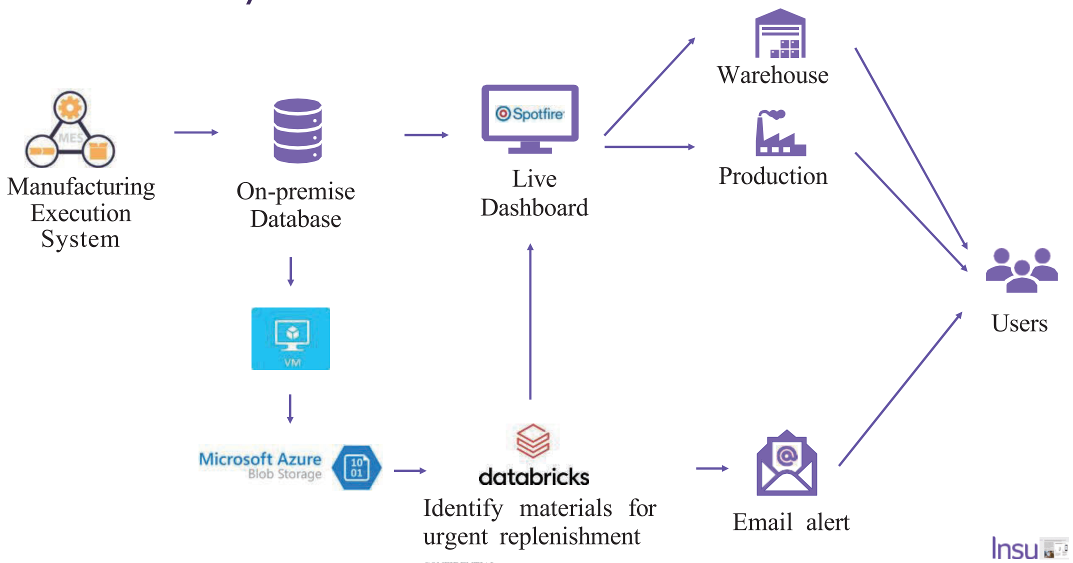
Material Inventory *Flow*



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Material Inventory *Categorization*

Color legend	Blue	Green	Yellow	Red
Rule 1: Quantity vs threshold	N/A	Quantity > Threshold	Quantity < Threshold	Quantity < Threshold
Rule 2: Time duration	N/A	N/A	≤ X hours	> X hour
Rule 3: Movement	Ready to collect any movement (MES Operation is Transit Area)	N/A	N/A	N/A

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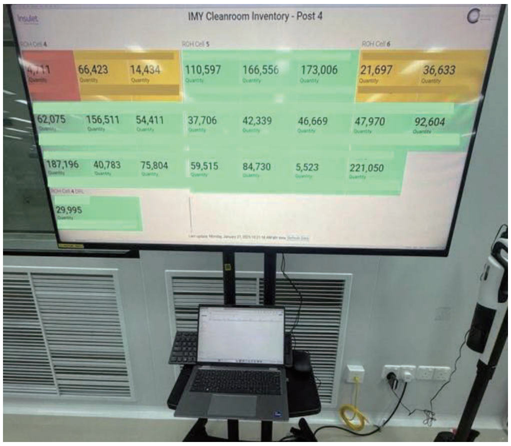
Material Inventory *Live Dashboard*



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Overall Equipment Effectiveness (OEE)

Use Case

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Overall Equipment Effectiveness (OEE)

Use Case Description

Measure of how well a manufacturing equipment is utilized compared to its full potential, during the periods when it is scheduled to run. An OEE of 100% means that only good parts are produced (100% quality), at the maximum speed (100% performance), and without interruption (100% availability).

Business Challenges

- Monitoring of performance of each machines at all processes.
- Time consuming data processing, analysis and report preparation due to the volume of data.

How Analytics Solution Helps?

- Provides monitoring of performance of each machines at all processes via analytical dashboard.
- Automated and consistent report that can save engineers' time so that they can focus on solving issues, finding opportunities for improvement and

Implementation

- Data source is from Manufacturing Execution System (MES).
- Collaborate with stakeholders to define logic for each metrics.
- Develop reporting dashboard using TIBCO Spotfire.
- Implement job orchestration using Databricks.

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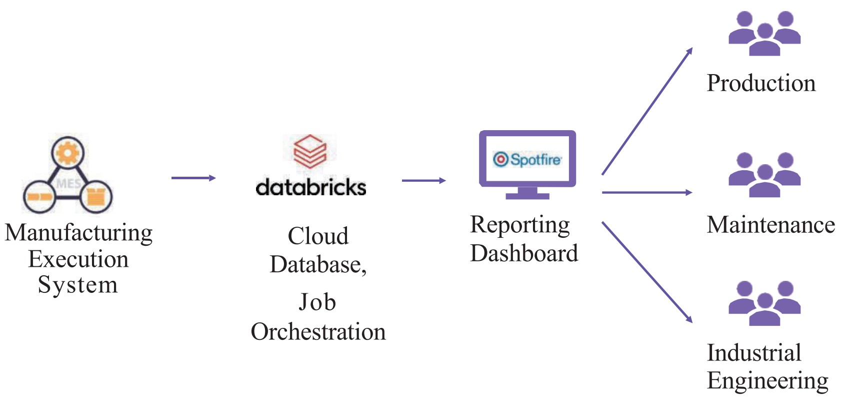
Overall Equipment Effectiveness (OEE) *Flow*



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Overall Equipment Effectiveness (OEE) *Formula*

$$Availability = \frac{\sigma\ Plan\ Hour - \sigma\ Unplan\ Downtime}{\sigma\ Plan\ Hour} \times 100$$

$$Performance = \frac{(\sigma\ Input\ ) \times Cycle\ Time}{(\sigma\ Plan\ Hour - \sigma\ Unplan\ Downtime)} \times 100$$

$$Quality = \frac{\sigma\ Output}{\sigma\ Input} \times 100$$

$$OEE = Availability \times Performance \times Quality$$

σ subject to daily, weekly, monthly, quarterly and yearly

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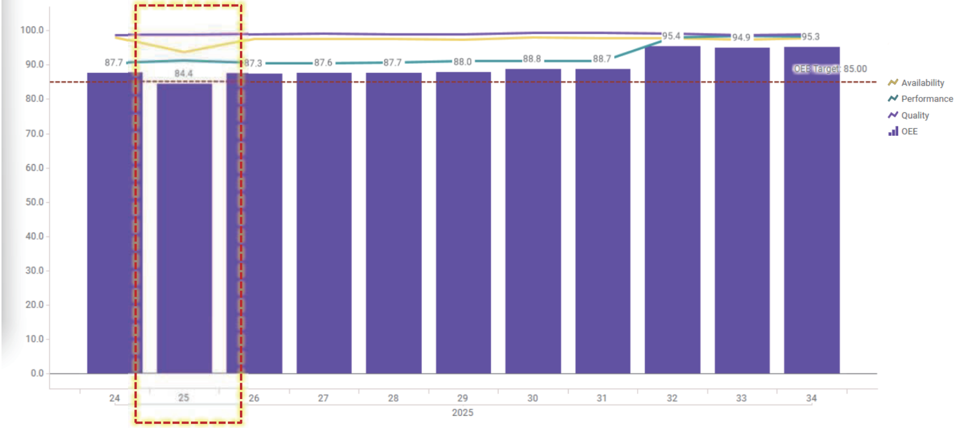
Overall Equipment Effectiveness (OEE) *Chart*

Availability, Performance, Quality, OEE per Year, Week



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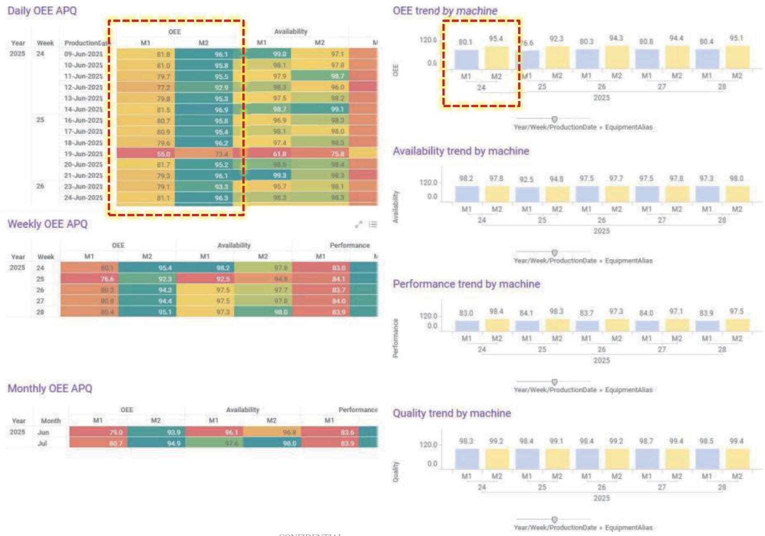
Overall Equipment Effectiveness (OEE) *Chart*



Scrap Analysis

Use Case

Scrap Analysis

Use Case Description

Analyze production scrap data to identify root causes, quantify losses, and uncover patterns that can guide process improvements and reduce waste.

Business Challenges

- High volume of scrap leading to increased production costs and reduced efficiency.
- Limited visibility into scrap trends across production lines, shifts, or material types.
- Difficulty in pinpointing root causes due to fragmented or inconsistent data.

How Analytics Solution Helps?

- Visualize scrap trends by product, line, shift, and reject codes for monitoring via dashboards.
- Statistical analysis and pattern detection to help identify recurring issues and potential root causes.
- Enables data-driven decision-making for process optimization and waste reduction.

Implementation

- Data source is from Manufacturing Execution System (MES).
- Collaborate with stakeholders to define logic for each metrics.
- Develop analytics dashboard using TIBCO Spotfire for trend analysis and drill down.
- Use Databricks for data processing. May be extended to drift detection.

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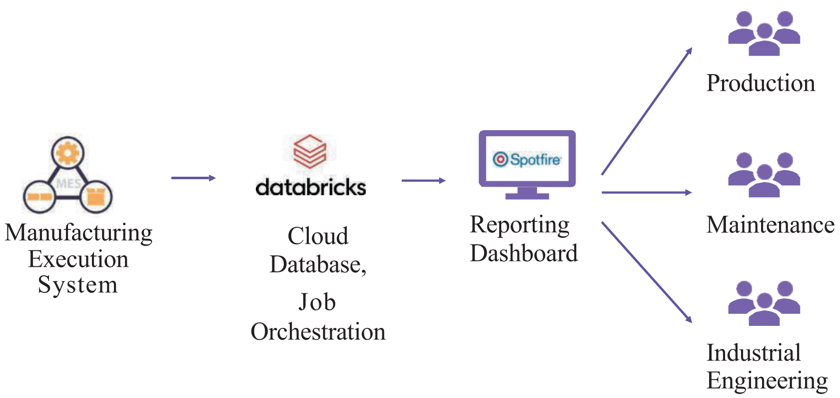
Scrap Analysis *Flow*



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Scrap Analysis *Formula*

$$\text{Yield} = \frac{Good\ parts}{Total\ parts} \times 100$$

$$\text{Defect Parts Per Million} = \frac{Defective\ parts}{Total\ parts} \times 1,000,000$$

$$\text{Scrap Cost} = \sigma_{Reject\ type}(Component\ quantity\ \times Component\ cost)$$

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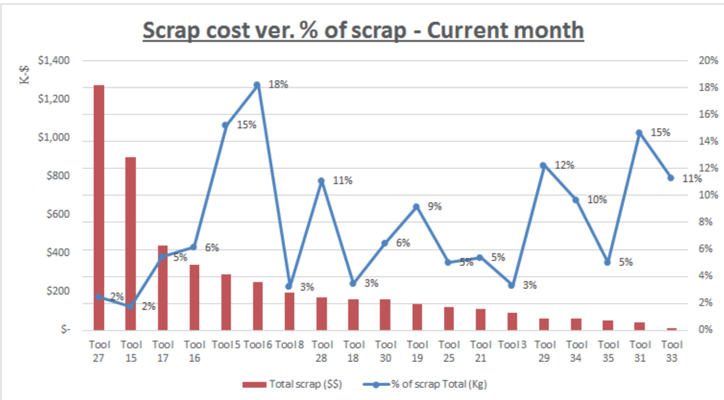
Scrap Analysis *Chart*



Source: https://theplanningmaster.com/scrap-kpi/

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Statistical Process Control

Use Case

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Statistical Process Control

Use Case Description

Monitor and control inspection and testing processes using statistical techniques to ensure outputs remain within defined specification limits and maintain consistent quality.

Business Challenges

- Manual tracking of inspection/test results is time-consuming and error-prone.
- Lack of early warning signals for processes drifting out of control.
- Difficulty in identifying trends or shifts before defects occur.

How Analytics Solution Helps?

- Monitor process stability with control charts via analytics dashboard.
- Automated detection of rule violations to flag out-of-control conditions.
- Enables proactive quality control by identifying trends, shifts, and anomalies early.

Implementation

- Data source can be from Manufacturing Execution System (MES) or Standard Testing Data Format (STDF) files.
- Collaborate with quality team to define define specification limits and control charts.
- Develop analytics dashboard using TIBCO Spotfire.
- Implement job orchestration using Databricks.

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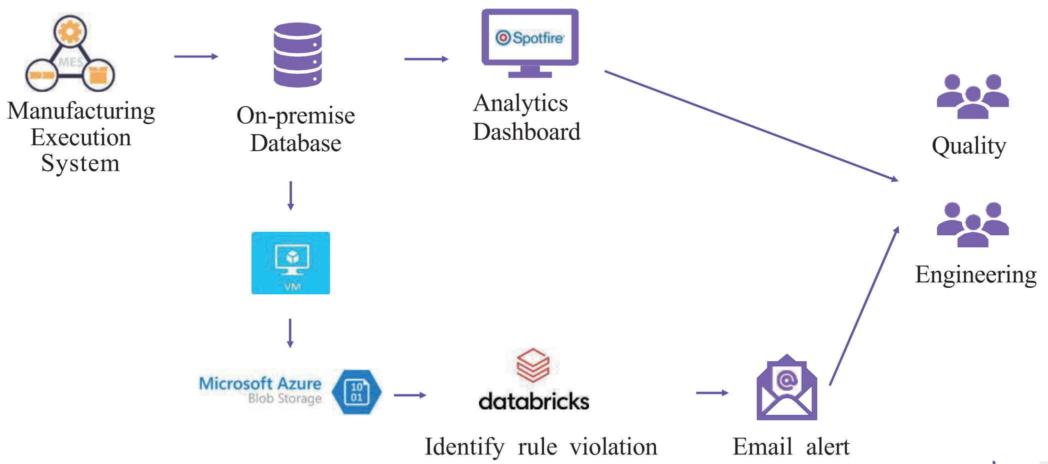
Statistical Process Control *Flow*



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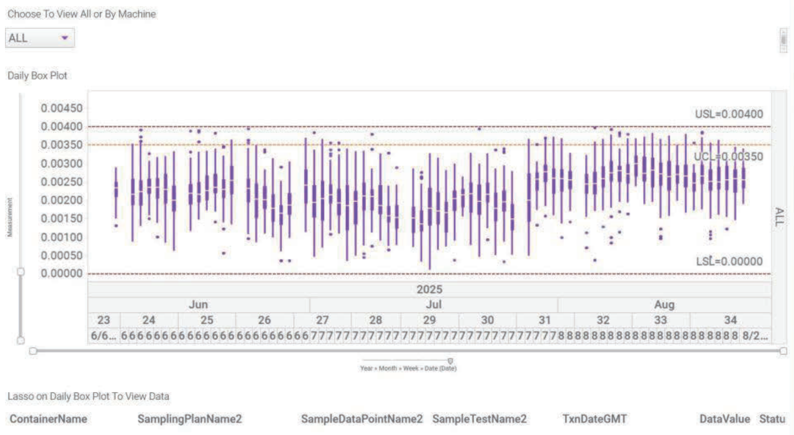
Statistical Process Control *Metric*

Metric	What It Measures	Goal	Std Dev Used
Pp	Process spread vs spec limits	> 1.5	Population
Ppk	Centering of process	> 1.33 (ideal > 1.67)	Population
Cp	Potential capability	> 1.5	Sample
Cpk	Centering of potential capability	> 1.33	Sample

30 CONFIDENTIAL

Statistical Process Control Charts

Box plot: Visualize distribution of measurements and identifying outliers



31

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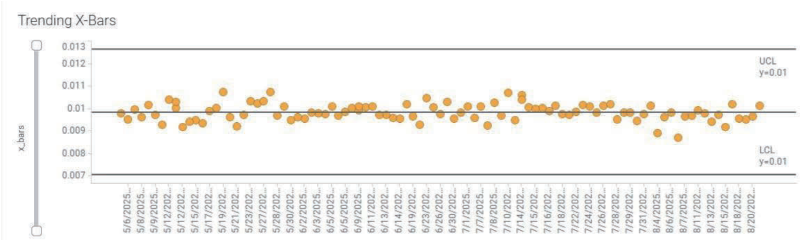
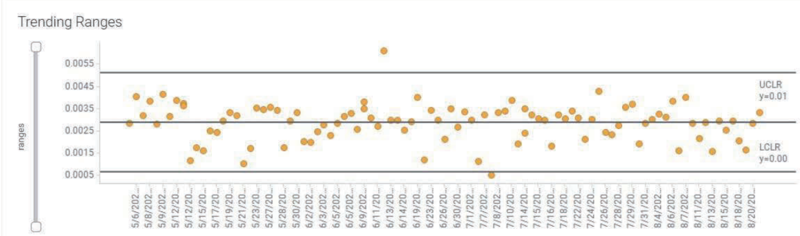
Statistical Process Control Charts

X-bar Chart: Tracks subgroup averages over time



R Chart: Tracks subgroup ranges over time



32

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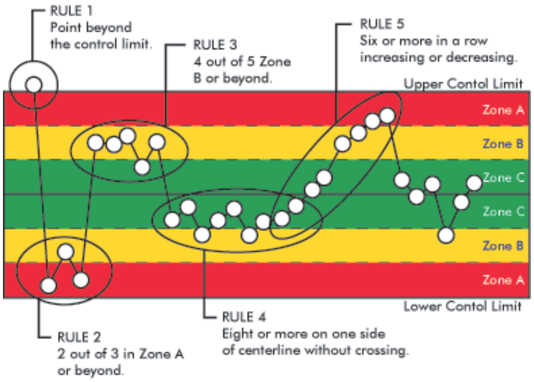
Statistical Process Control *Detection Rules*



Source: https://www.infinityqs.com/sites/infinityqs.com/files/images/Western_Electric.gif

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Challenges and Skills Required

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Challenges of implementing data analytics projects

- Data quality
- Data governance and ownership
- Stakeholder management
- Consistent metrics and analytics
- Real-time integration
- Trade off between most correct and business values

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Skills and expertise required to leverage data effectively

- Domain knowledge
- Communication & Collaboration
- Data Analysis & Statistics
- Programming
- Data Engineering
- Data Visualization
- Cloud & Big Data Technologies
- Curiosity & Continuous Learning

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Insulet

Thank You

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Solving urban traffic issues in Malaysia by AI-based Demand Responsive Transist

Hideaki Yokomizo
WILLER, Inc.

Urban transportation in Malaysia is overly reliant on private vehicles, resulting in traffic congestion, traffic accidents, and environmental issues. WILLER group is collaborating with public transportation operators such as Rapid KL to provide AI-based DRT (Demand Responsive Transport), developed and operated in Japan, as the last/first mile transportation to MRT/LRT stations, aiming to address these issues. This presentation will introduce this initiative.

Presentation at **Malaysia-Japan Symposium on Mathematical and Statistical Modelling**

Solving Urban Traffic Issues in Malaysia by AI-based Demand Responsive Transit

2025.8.26

HIDEAKI YOKOMIZO WILLER, INC.

WILLER

CONTENTS

1. Introduction
   - WILLER
   - Demand Responsive Transit（DRT）
   - Projects in Japan
2. DRT in Malaysia
   - Transportation issues in KL
   - DRTs by Rapid KL
   - Our trials
3. Future potential

1

Presenter Hideaki Yokomizo

Director and Executive Officer, WILLER, Inc.

Ph.D.
(Interdisciplinary Information Science)

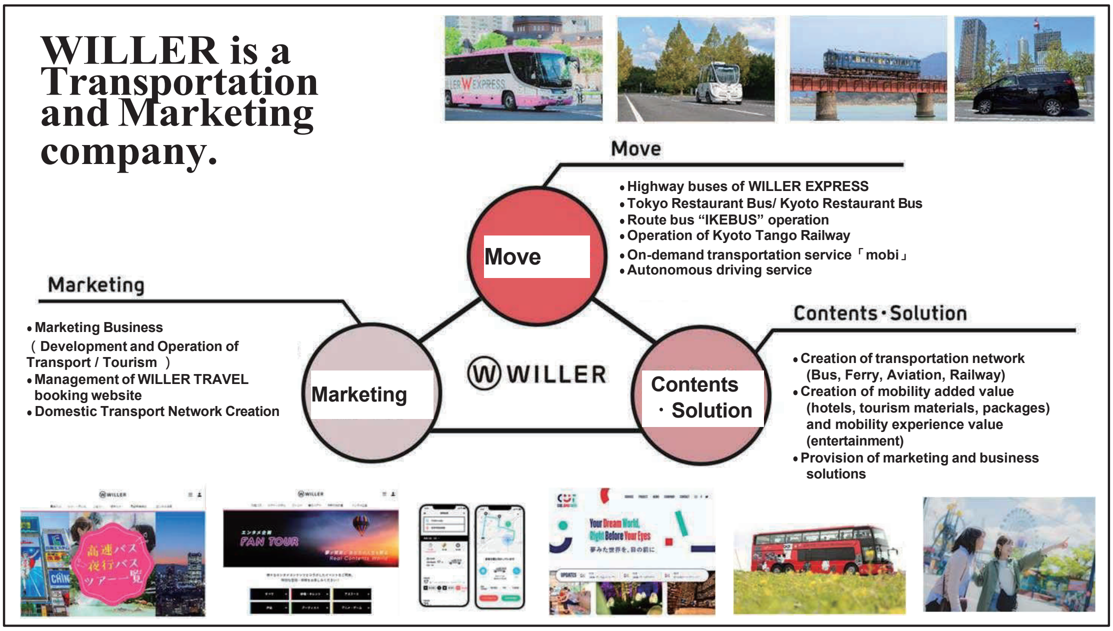
- University of Tokyo
- Research on MaaS (Mobility as a Service)

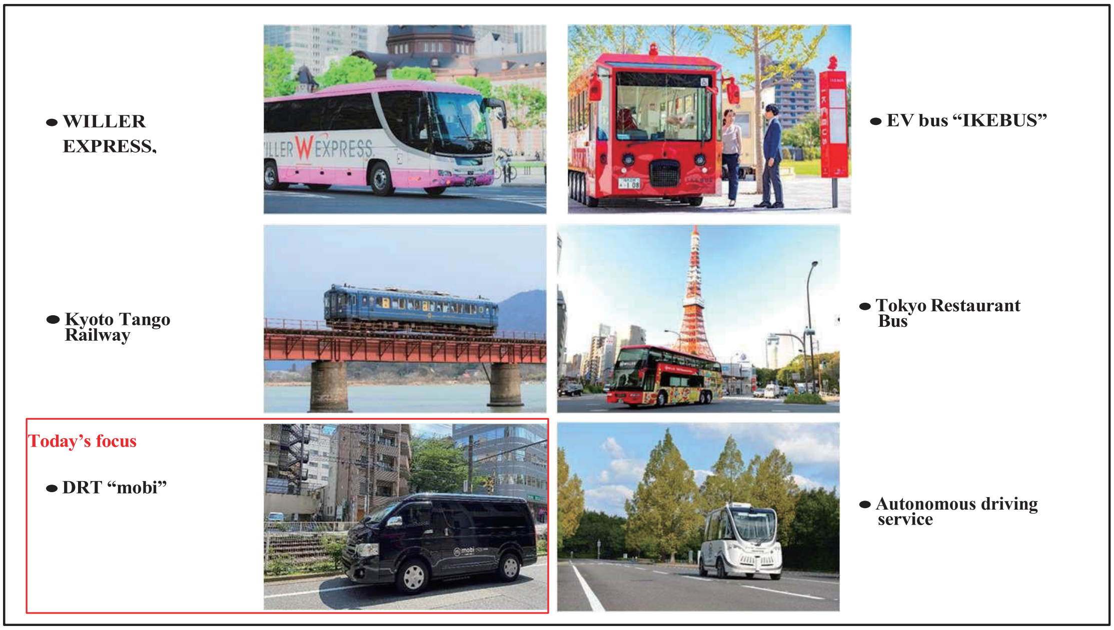
2

CONTENTS

1. Introduction
    - WILLER
    - Demand Responsive Transit（DRT）
    - Projects in Japan
2. DRT in Malaysia
    - Transportation issues in KL
    - DRTs by Rapid KL
    - Our trials
3. Future potential

3


WILLER is a Transportation and Marketing company.
Move
• Highway buses of WILLER EXPRESS
• Tokyo Restaurant Bus/ Kyoto Restaurant Bus
• Route bus "IKEBUS" operation
• Operation of Kyoto Tango Railway
• On-demand transportation service「mobi」
• Autonomous driving service
Move
Marketing
• Marketing Business
（Development and Operation of Transport / Tourism ）
• Management of WILLER TRAVEL booking website
• Domestic Transport Network Creation
Marketing
WILLER
Contents・Solution
Contents ・Solution
• Creation of transportation network (Bus, Ferry, Aviation, Railway)
• Creation of mobility added value (hotels, tourism materials, packages) and mobility experience value (entertainment)
• Provision of marketing and business solutions
高速バス 夜行バス ツアー一覧
FAN TOUR


• WILLER EXPRESS,
• EV bus "IKEBUS"
• Kyoto Tango Railway
• Tokyo Restaurant Bus
Today's focus
• DRT "mobi"
• Autonomous driving service

Why DRT in Japan?

Socio-economic changes are driving the shift to DRT in rural areas.

Aging population

Declining birthrate

Driver shortage transportation

Decrease of public

Fixed route and scheduled Bus

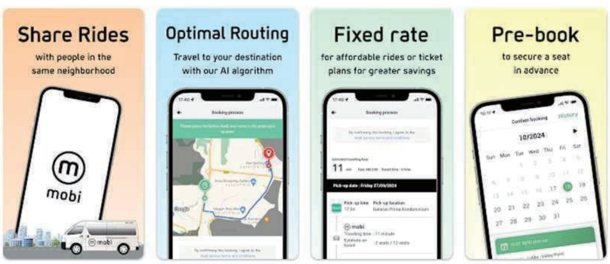
Demand Responsive Transit

Source: Chino City

6

Mobi: Our DRT service

Launched the AI-based Demand Responsive Transit service in 2021.

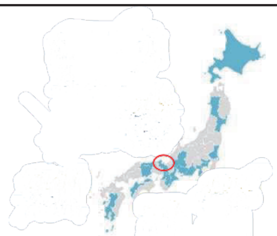


7

Mobi: Area Coverage in Japan

- Operating in 17 areas (as of August 2025)
- Partnering with local taxi providers

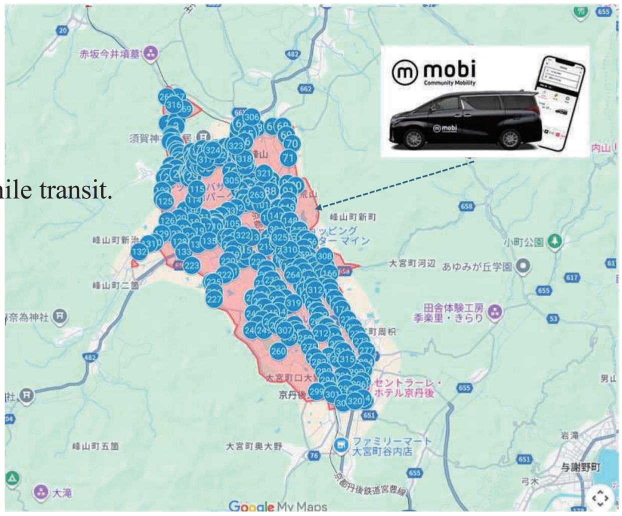
Mobi: A case in point (Kyo-tango City）

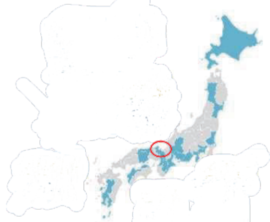


- WILLER runs KTR (local railway line) in Northern part of Kyoto.
- Bus lines from/to railway stations diminishing.

9

Mobi: A case in point (Kyo-tango City）





- Introduced DRT to enhance the last/first mile transit.
- More than 300 virtual stops in the area.

10

CONTENTS

1. Introduction
   - WILLER
   - Demand Responsive Transit（DRT）
   - Projects in Japan
2. DRT in Malaysia
   - Transportation issues in KL
   - DRTs by Rapid KL
   - Our trials
3. Future potential

11

Transportation issues in KL

Kuala Lumpur faces several persistent transportation challenges.

- Severe traffic congestion
- High private vehicle ownership
- Inefficient bus services
- Lack of Last-Mile connectivity from public transport
- …and more.

Picture: Malaymail（16 Feb 2023）

12

Transportation issues in KL

Kuala Lumpur faces several persistent transportation challenges.

1. **Severe Traffic Congestion**
- **High Private Vehicle Ownership:** passenger cars often making up 50% to 60% of total vehicles on the road.
- **Inadequate Road Capacity**
- **Inefficient Bus Services:** often get stuck in the same traffic jams as private cars, leading to unpredictable schedules and long travel times.

2. **Lack of Public Transport Integration and Connectivity**
- **Last-Mile Connectivity:** A major deterrent for public transport use is the difficulty of getting from a station to one's final destination.
- **Disjointed Systems:** MRT, LRT, Monorail, buses are not always well-integrated.
- **Inaccessible Stations:** Some stations are poorly located in areas with low population density, while others are difficult to access due to surrounding gated communities, private properties, or major expressways.

13

Grab in Malaysia

Grab-car has high usage in Malaysia.

- Grab's mobility segment: 25.3M MTU (Monthly Transacting Users) in 2024
- Malaysia's share in total revenue: 30%
- Estimated MTU in Malaysia: 7.4M
- Estimated pen rate of the ride-hailing in Malaysia: 28%*

Source: Grab Investor Relations; *Digital News Asia

DRT by Rapid KL

Rapid KL is expanding DRT as the last-mile connectivity to stations.

New fleet of 320 vans to boost Rapid KL On-Demand service

THE Rapid KL On-Demand service will be expanded with the addition of 320 new vans by June, at a cost of RM55mil.

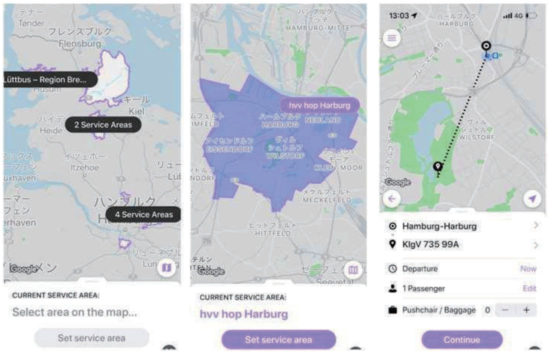
This is to improve first-mile and last-mile connectivity and encourage greater public transport use.

The vans will have designated seats for persons with disabilities. (Right) The open-payment system allows users to pay using debit and credit cards. — Photos: Bernama

Source: The Star (12 May 2025)

A case in Europe: DRT in Hamburg

HVV (Transport Authority in Hamburg) provides DRT to users from/to suburban stations, at the cost of 2 Euro per ride.

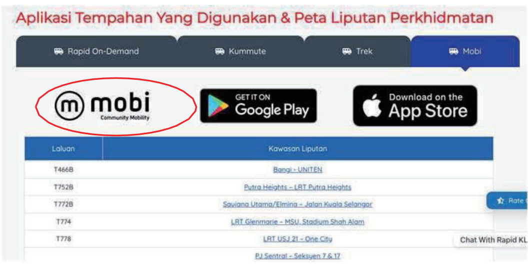


Source: hvv HP: https://vhhbus.de/hop/

16

Mobi in KL: Partnering with Rapid KL

WILLER has partnered with Rapid KL to launch and expand DRT.

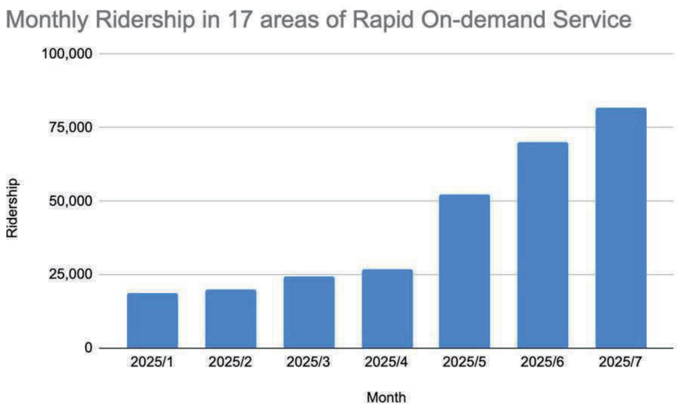


Source: myrapid.com.my

17

Mobi in KL: Ridership of Rapid KL project

Our ridership has been steadily increasing.

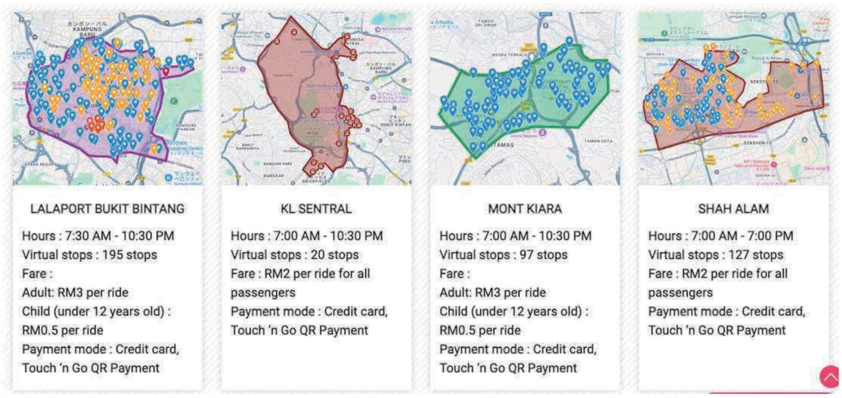


Source: WILLER

18

Mobi in KL: New Project

Launched 4 new areas with "mobi" original apps and transportation service in August.



Source: https://mobi.badanbascoach.com.my/

19

Mobi in KL: “Global South Project” funded by METI Japan

The new project in KL is funded by METI Japan to enhance the economic cooperation with ASEAN countries.

Source: METI; https://gs-hojo-web.jp/index.html (Japanese)

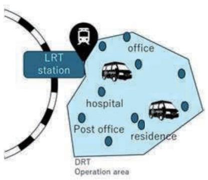
20

Mobi in KL: New Project’s Scope

The new project is to enhance the multi-modal connectivity.

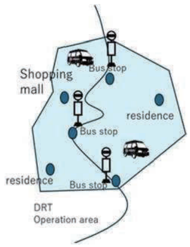
Case 1 : LRT × DRT

By utilizing DRT for the first and last mile to the LRT lines, we aim to establish a transportation infrastructure that allows commuters and students to travel without the need for a private car.



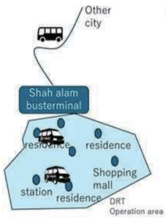
Case 2 : Citybus × DRT

Display city buses real-time availability on the app, and improve user convenience by showing both the main city buses and the DRT, which serves as a feeder, in a single app for city travel.



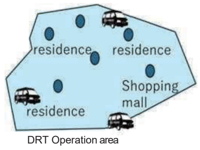
Case 3 : Intercity Bus × DRT

Connecting the Seksyen 17 Bus Terminal to the city and other mode of public transport to meet the demand for middle mile connectivity throughout the country.



Case 4 : New connectivity points

Introduce DRT in areas without public transportation services and collect public transportation usage data.

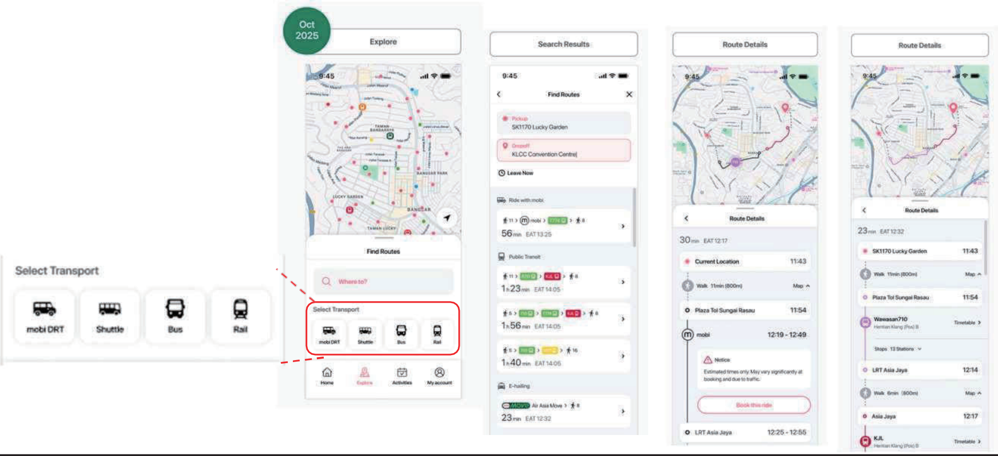


21

Mobi in KL: The multi-modal MaaS apps

Our new apps is to provide the integrated multi-modal journey planning and booking.

Preliminary design of new app



22

Mobi in KL: New Project in action

New "mobi" car

Customer's voice

Driver training

Launch campaign

23

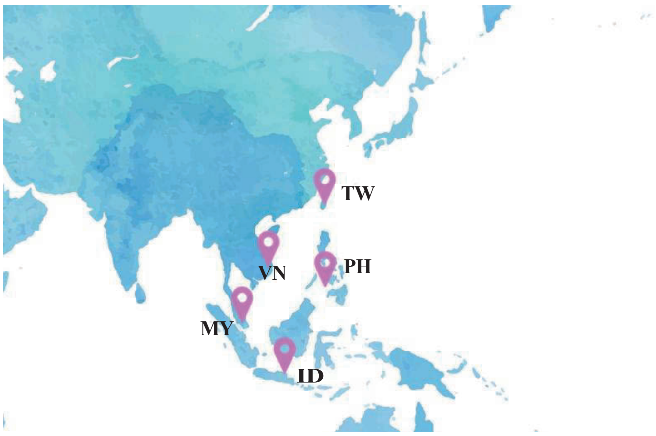
CONTENTS

1. Introduction
    - WILLER
    - Demand Responsive Transit（DRT）
    - Projects in Japan
2. DRT in Malaysia
    - Transportation issues in KL
    - DRTs by Rapid KL
    - Our trials
3. Future potential

24

Introduction to ASEAN countries

We aim to bring “mobi” and our solutions to other ASEAN countries.



25

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WILLER, Inc.

- https://www.willer.co.jp/ (Corporate site in Japanese)
- https://willers.com.sg/ (Corporate site in English)
- https://willer-travel.com/en/ （B2C site in English)
- https://mobi.badanbascoach.com.my/ (mobi site in Malaysia）

Genetic Algorithm-Based Optimization of Location-Routing problems for a Sustainable Biomass Supply Chain

Zaitul Marlizawati Zainuddin
Universiti Teknologi Malaysia (UTM)

Addressing location-routing problems (LRP) is crucial for sustainability in the biomass supply chain (BSC). This study applies a Genetic Algorithm (GA) with automated mutation selection and elite child strategies to solve the LRP. The approach promotes sustainable logistics and provides valuable insights for stakeholders.

References

[1] Foo, F. Y., Zainuddin, Z. M., & Pheng, H. S. (2024). Optimizing Palm Oil Biomass Supply Chain Logistics through Multi-Objective Location-Routing Model. Malaysian Journal of Fundamental and Applied Sciences, 20(2): 247 – 265. https://doi.org/10.11113/mjfas.v20n2.3085
[2] Foo, F. Y, Zainuddin, Z. M. & Hang, S. P. (2024). Palm Oil Biomass Supply Chain Multi-Objective Two-Echelon Location-Routing Optimization. Malaysian Journal of Mathematical Sciences, 18(4): 867- 901. https://doi.org/10.47836/mjms.18.4.12
[3] Foo, F. Y, Zainuddin, Z. M. & Hang, S. P. (2025). Optimizing palm oil biomass collection: genetic algorithm approaches in solving location-routing problem. Journal of Quality Measurement and Analysis, 21(2): 2025, 277-288. https://doi.org/10.17576/jqma.2102.2025.18

Malaysia-Japan Symposium on
Mathematical and Statistical Modelling,
Auditorium IMI/Kyushu University

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Genetic Algorithm-Based Optimization of Location-Routing Problems for a Sustainable Biomass Supply Chain

ZAITUL MARLIZAWATI ZAINUDDIN

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Presentation Outline

1 Problem Formulation

- Introduction & Motivation

2 Proposed Genetic Algorithm (GA) Solution Method

- Basic Procedure
- Proposed Procedure
- Chromosome Constructions
- Order Crossover
- Automated Mutation Operator Selection (AMS) Strategy
- Elite Child Population (EC) Strategy

3 Research Insights

- Inspection framework & Measurements
- Results for 1-LRP, 2-LRP, 2-SLRP

2

1 Problem Formulation

Introduction & Motivation

Biomass energy (biofuels)	As the world transitions toward sustainable energy systems, biomass energy derived from **agricultural waste** has emerged as **a promising solution** due to • **abundant availability** • potential to **address waste disposal challenges**.
Complex decision-making problems	However, the biomass energy industry faces complex **decision-making** problems, particularly in • **resource allocation**, • **facility siting**, • biomass collection **routing**, and • satisfying the **sustainability goals.**
An efficient biomass supply chain (BSC)	These challenges have intensified the need for an efficient biomass supply chain (BSC), where logistical optimization plays a critical role.
Motivation	To address the BSC challenges by optimizing the network and supporting Malaysia's clean energy and sustainability commitments.

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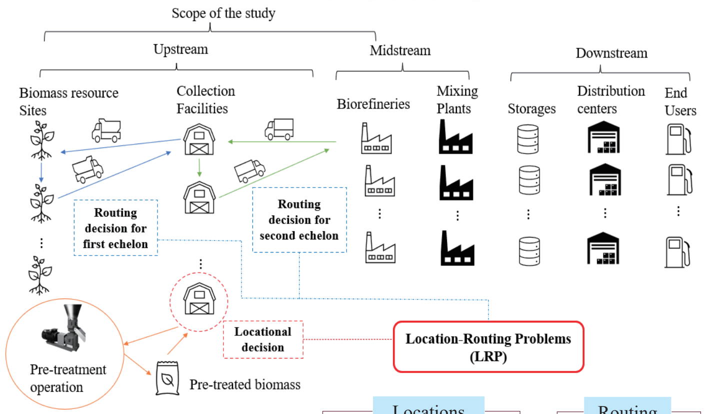
3

1 Problem Formulation

Introduction & Motivation

Atashbar et al. (2018): the most appealing area for research | resemble those in the petroleum industry



Locations | Routing

Sustainability: Social: local community (population) | Economic: Cost | Environmental: CO_2

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4

2 Genetic Algorithm (GA) Solution Method

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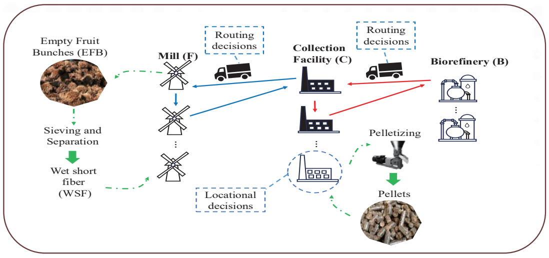
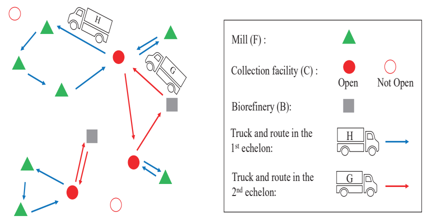
Multi-Objective Two-Echelon Location-Routing Problem (2-LRP)





(a) Open collection facilities can serve multiple mills, whereas each mill can only be associated with a single open collection facility.
(b) Several collection facilities can fulfill the demand of a given biorefinery, with each open collection facility being restricted to a single biorefinery assignment.
(c) Within the first echelon, the vehicle routing commences at an open collection facility and ends at the same facility after covering the assigned mills. Notably, no direct paths exist between collection facilities, and each mill must be visited exactly once.
(d) In the second echelon, truck routes initiate from a biorefinery and return to the same biorefinery after visiting the designated collection facilities. No flow is permitted between biorefineries. Visitation is solely restricted to open collection facilities, and each facility must be visited only once.

5

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2 Proposed Mixed Integer Programming (MIP) model

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Model Formulation

6

OBJECTIVE FUNCTIONS

Total Cost minimization

$$f_1 = \sum_{i\in C} f_i^{EC} z_i + \sum_{i\in C} f_i^{PC} q_i^C + \sum_{i\in F\cup C}\sum_{j\in F\cup C}\sum_{h\in H} v_h^H d_{ij}^F x_{ijh} + \sum_{i\in C\cup B}\sum_{j\in C\cup B}\sum_{g\in G} v_g^G d_{ij}^S y_{ijg} \quad (1)$$

Total Population minimization

$$f_2 = \sum_{i\in C} Pop_i z_i \quad (2)$$

Total CO_2 minimization

$$f_3 = \sum_{i\in C}\sum_{j\in F}\sum_{h\in H}\gamma^{FE} d_{ij}^F x_{ijh} + \sum_{i\in B}\sum_{j\in C}\sum_{g\in G}\gamma^{GE} d_{ij}^S y_{ijg} + \sum_{i\in F}\sum_{j\in F\cup C}\sum_{h\in H}\gamma^{FL} d_{ij}^F LP_{ijh}^F + \sum_{i\in C}\sum_{j\in C\cup B}\sum_{g\in G}\gamma^{GL} d_{ij}^S LP_{ijg}^S \quad (3)$$

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CONSTRAINTS

The first echelon constraints

Routing constraints

$$\sum_{j\in F\cup C}\sum_{h\in H} x_{ijh} = 1, \quad \forall i\epsilon F \tag{4}$$

$$\sum_{i\epsilon F\cup C} x_{ijh} = \sum_{i\epsilon F\cup C} x_{jih}, \quad \forall j\epsilon F\cup C, \forall h \in H \tag{5}$$

$$\sum_{i\epsilon F}\sum_{j\epsilon C} x_{ijh} \le 1, \ \forall h \in H \tag{6}$$

$$x_{ijh} = 0, \ \forall i,j \in F\cup C, \ i = j, \ \forall h \in H \tag{7}$$

$$\sum_{h\epsilon H} x_{ijh} = 0, \quad \forall i,j \in C \tag{8}$$

Routing and locational decision constraint

$$\sum_{j\epsilon F}\sum_{h\epsilon H} x_{ijh} \ge z_i, \ \forall i \in C \tag{9}$$

Assignment (mill to facility) and collection facility capacity (locational decision) constraint

$$\sum_{i\epsilon F} q_i^F \alpha_{ij} \le t_j^c z_j, \ \forall j \in C \tag{10}$$

Subtour elimination constraints

$$\sum_{h\epsilon H} x_{jih} \le \alpha_{ij}, \forall i \in F, \ \forall j \in C \tag{11}$$

$$\sum_{h\epsilon H} x_{jih} \le \alpha_{ij}, \forall i \in F, \ \forall j \in C \tag{12}$$

$$\sum_{h\epsilon H} x_{ijh} + \alpha_{ik} + \sum_{m\epsilon C, m\neq k} \alpha_{jm} \le 2, \ \forall i,j \in F, \forall k \in C \tag{13}$$

Vehicle loading and vehicle capacity constraints

$$\sum_{j\epsilon F\cup C}\sum_{h\epsilon H} LP_{ijh}^F - \sum_{j\epsilon F\cup C}\sum_{h\epsilon H} LP_{jih}^F = q_i^F, \forall i \in F \tag{14}$$

$$LP_{ijh}^F \le c_h^H x_{ijh}, \forall i,j \in F\cup C, i \neq j, \forall h \in H \tag{15}$$

$$\sum_{j\epsilon F}\sum_{h\epsilon H} LP_{jih}^F = \sum_{j\epsilon F} \alpha_{ji} q_j^F, \forall i \in C \tag{16}$$

$$LP_{ijh}^F \le (c_h^H - q_j^F) x_{ijh}, \forall i \in F\cup C, \forall j \in F, \forall h \in H \tag{17}$$

$$LP_{ijh}^F \ge q_i^F x_{ijh}, \forall i \in F, \forall j \in F\cup C, \forall h \in H \tag{18}$$

$$\sum_{j\epsilon F} LP_{ijh}^F = 0, \forall i \in C, \forall h \in H \tag{19}$$

Collected biomass quantity and pretreated biomass production constraints

$$q_j^C = \sum_{i\epsilon F}\sum_{h\epsilon H} LP_{ijh}^F, \ \forall j \in C \tag{20}$$

$$q_j^{CP} = \theta^p q_j^C, \quad \forall j \in C \tag{21}$$

CONSTRAINTS

The second echelon constraints

Routing and locational decision constraints

$$\sum_{j\epsilon C\cup B}\sum_{g\epsilon G} y_{ijg} = z_i, \ \forall i \in C \tag{22}$$

$$y_{ijg} \le z_j, \forall i \in B, \forall j \in C, \forall g \in G \tag{23}$$

Routing constraint

$$\sum_{g\epsilon G}\sum_{j\epsilon C} y_{ijg} \ge 1, \forall i \in B \tag{24}$$

$$\sum_{j\epsilon C\cup B} y_{ijg} = \sum_{j\epsilon C\cup B} y_{jig}, \forall i \in B\cup C, \forall g \in G \tag{25}$$

$$\sum_{i\epsilon B}\sum_{j\epsilon C} y_{ijg} \le 1, \forall g \in G \tag{26}$$

$$y_{ijg} = 0, \forall i,j \in B\cup C, i = j, \forall g \in G \tag{27}$$

$$\sum_{g\epsilon G} y_{ijg} = 0, \ \forall i,j \in B \tag{28}$$

Locational decision, assignment (facility to biorefinery) and biorefinery capacity constraints

$$\sum_{j\epsilon B} \beta_{ij} = z_i, \forall i \in C \tag{29}$$

$$\sum_{i\epsilon C} q_i^{CP} \beta_{ij} \le t_j^B, \forall j \in B \tag{30}$$

Subtour elimination constraints

$$\sum_{g\epsilon G} y_{ijg} \le \beta_{ij}, \forall i \in C, \ \forall j \in B \tag{31}$$

$$\sum_{g\epsilon G} y_{jig} \le \beta_{ij}, \forall i \in C, \ \forall j \in B \tag{32}$$

$$\sum_{g\epsilon G} y_{ijg} + \beta_{ik} + \sum_{m\epsilon B, m\neq k} \beta_{jm} \le 2, \ \forall i,j \in C, \forall k \in B \tag{33}$$

Vehicle loading and vehicle capacity constraints

$$\sum_{j\epsilon C\cup B}\sum_{g\epsilon G} LP_{ijg}^S - \sum_{j\epsilon C\cup B}\sum_{g\epsilon G} LP_{jig}^S = q_i^{CP}, \forall i \in C \tag{34}$$

$$LP_{ijg}^S \le c_g^G y_{ijg}, \forall i,j \in C\cup B, i \neq j, \forall g \in G \tag{35}$$

$$LP_{ijg}^S \le (c_g^G - q_j^{CP}) y_{ijg}, \forall i \in C\cup B, \forall j \in C, \forall g \in G \tag{36}$$

$$LP_{ijg}^S \ge q_i^{CP} y_{ijg}, \forall i \in C, \forall j \in C\cup B, \forall g \in G \tag{37}$$

$$\sum_{j\epsilon C} LP_{ijg}^S = 0, \forall i \in B, \forall g \in G \tag{38}$$

Collected pretreated biomass quantity and demand constraints

$$q_j^B = \sum_{i\epsilon C}\sum_{g\epsilon G} LP_{ijg}^S, \ \forall j \in B \tag{39}$$

$$q_j^B \ge D_j^B, \forall j \in B \tag{40}$$

CONSTRAINTS

Non-negativity (decision variable) constraints

$$z_i \in \{0, 1\}, \forall i \in C \quad (41)$$

$$\alpha_{ij} \in \{0, 1\}, \forall i \in F, \forall j \in C \quad (42)$$

$$\beta_{ij} \in \{0, 1\}, \forall i \in C, \forall j \in B \quad (43)$$

$$x_{ijh} \in \{0, 1\}, \forall i, j \in F \cup C, \forall h \in H \quad (44)$$

$$y_{ijg} \in \{0, 1\}, \forall i, j \in C \cup B, \forall g \in G \quad (45)$$

$$LP^F_{ijh} \geq 0, \ \forall i, j \in F \cup C, \forall h \in H \quad (46)$$

$$LP^S_{ijg} \geq 0, \quad \forall i, j \in C \cup B, \forall g \in G \quad (47)$$

$$q^C_j \geq 0, \forall j \in C \quad (48)$$

$$q^{CP}_j \geq 0, \forall j \in C \quad (49)$$

The MINLP model was solved by GAMS with DICOPT optimizer.

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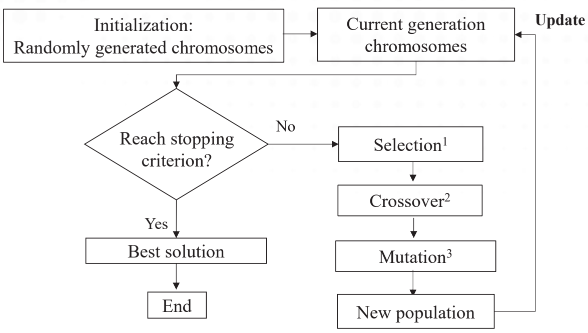
Basic GA Procedure



1) Selection operators include: (a) Roulette Wheel Selection, (b) Tournament Selection, (c) Ranking Selection, and (d) Elitism. The GA procedure **will use (a), (b), or (c), with or without (d).**
2) Crossover operators include: (a) One-point, (b) Two-point, (c) Uniform, (d) Order, and (e) Partially Mapped Crossover (PMX). The GA **will use any of these**, though (a)–(c) are most common for binary chromosomes.
3) Mutation operators include: (a) Bit-flip (binary chromosomes), (b) Insertion, (c) Swap, and (d) Inversion. The GA **may use one or a combination, with combinations applied randomly during execution.**

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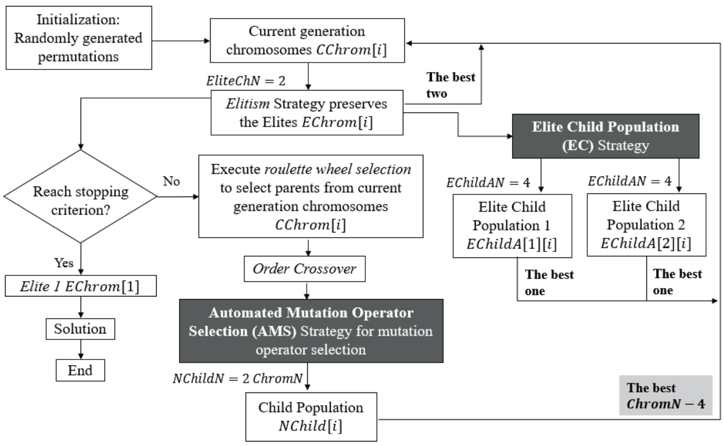
Proposed Procedure:
AMSEC Genetic Algorithm (AMSEC_GA)



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Chromosome Constructions

- Computational experiments were carried out on a test case involving **nine mills, five potential collection facilities, and two biorefineries.**

String of mill (F) nodes — String of candidate facility (C) nodes

	F1	F3	F4	F7	F8	F9	F6	F2	F5	C11	C13	C10	C12	C14
q^F	4.9421	7.1885	8.087	7.1885	8.9856	5.3914	6.2899	8.9856	3.145					

$t^c = 25$

- The chromosome construction process starts with string permutations of mill (F) and facility (C) nodes.
- These **nodes** include **data on biomass quantity** (q^F) and **facility capacity** (t^c).
- The permutation is later **encoded into a chromosome** considering **vehicle capacity, locational decisions, and route assignments.**
- The chromosome is then **decoded into a feasible LRP solution** for **fitness function (objective function) evaluation.**

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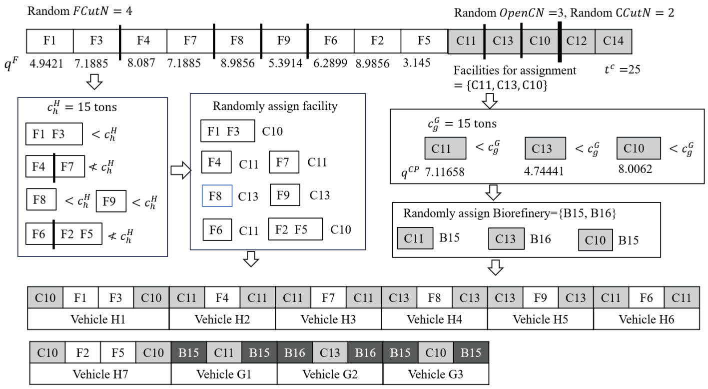
Chromosome Constructions



An example of the 2-LRP chromosome

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Genetic Algorithm (GA)

- maintains a constant population size of $ChromN$
- genetic operators are applied to create a new child population of size $NChildN$
- *elitism* strategy is used to preserve $EliteChN$ =2 elites

Elite Child Population (EC) Strategy

$ChromN$ of next generation

$$= EliteChN + {}^{EChildAN}_{ECP1}C_1^{Best} + {}^{EChildAN}_{ECP2}C_1^{Best} + {}^{NChildN}C_{best\ ChromN-4}$$

$$= 2 + 1 + 1 + {}^{NChildN}C^{Best}_{ChromN-4}$$

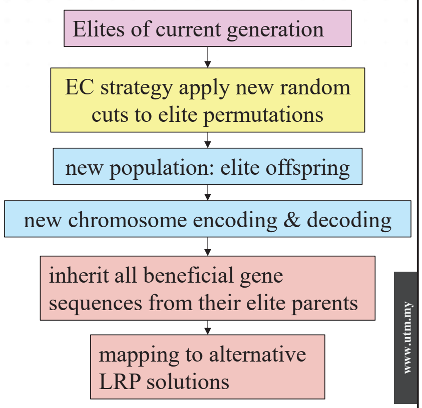
$$= 4 + {}^{NChildN}C^{Best}_{ChromN-4}$$

where $EliteChN$ = number of elites from the current population

${}^{NChildN}C^{Best}_{ChromN-4}$ = the best ($ChromN$ − 4) out of $NChildN$ offspring from the child population

${}^{EChildAN}_{ECP1}C_1^{Best}$ = The best offspring from elite child population 1 with size $EChildAN$

${}^{EChildAN}_{ECP2}C_1^{Best}$ = The best offspring from elite child population 2 with size $EChildAN$



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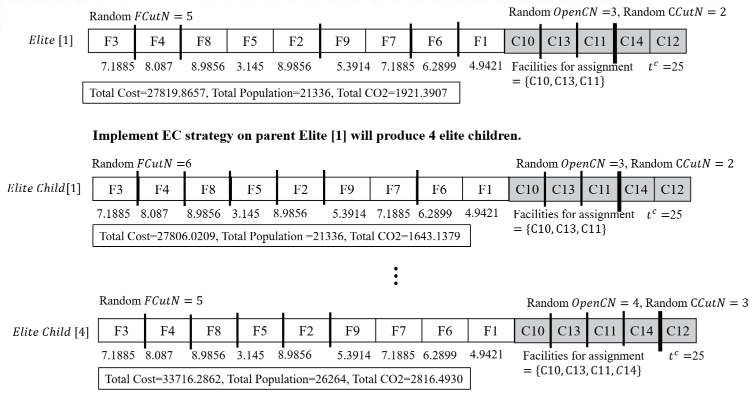
Elite Child Population (EC) Strategy



- new cuts initiate a fresh encoding and decoding process, leading to distinct LRP solutions.
- The best individual from this elite child population is then selected for inclusion in the next generation.

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2 Genetic Algorithm (GA) Solution Method

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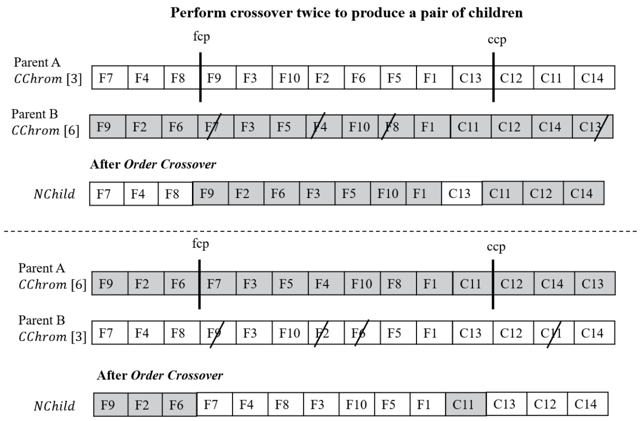
16

Order Crossover

An adaptation of Reeves' (1995) algorithm, originally designed for simple permutation-based chromosomes, has been developed to address LRP structures.



An example of the execution of Order Crossover

Reeves, C. R. (1995). A genetic algorithm for flowshop sequencing. *Computers and Operations Research*, *22*(1), 5 – 13. https://doi.org/10.1016/0305-0548(93)E0014-K

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17

Automated Mutation Operator Selection (AMS) Strategy

Guide the choice of mutation operator
↓
Monitors the generation count
↓
A predefined order of preference that aligns with the termination criteria
↓
Enhance solution diversity

Insertion	minimal alteration
Swap	increased alteration
String Inversion	high exploration

insert one

1	6	2	5	4	3

After INSERTION mutation

1	5	6	2	4	3

Swap Two

2	6	1	4	5	3

After SWAP mutation

2	3	1	4	5	6

1	3	4	5	2	6

After STRING INVERSION mutation

1	2	5	4	3	6

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2 Genetic Algorithm (GA) Solution Method

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18

Automated Mutation Operator Selection (AMS) Strategy

AMS strategy for $MaxGen$ criterion

let $MaxGen$ = maximum generations (iterations), then $GenBY1 = ceil\left(\frac{1}{3}MaxGen\right)$, $GenBY2 = ceil\left(\frac{2}{3}MaxGen\right)$

Domain	Mutation Operator
$[1,\ GenBY1]$	Insertion
$(GenBY1, GenBY2]$	Swap
$(GenBY2, MaxGen]$	String Inversion

the *insertion* mutation operator is used due to its minimal impact on the chromosome structure.

the *swap* mutation operator is applied to introduce moderate changes.

the string inversion operator is employed to increase exploration and help escape local optima.

AMS strategy for $RepeatN$ and $MaxGen$ criteria

let $RepeatN$ = elite solution repeats for N consecutive generations, then $RepBY1 = ceil\left(\frac{1}{3}RepeatN\right)$, $RepBY2 = ceil\left(\frac{2}{3}RepeatN\right)$

*Note: the $MaxGen$ criterion serves as a default condition, and the algorithm stops when either criterion is met.

$MaxGen$ Criterion (Domain)	$RepeatN$ Criterion (Domain)	Mutation Operator
$[1, GenBY1]$	$[1, RepBY1]$	Insertion
	$(RepBY1, RepBY2]$	Swap
	$(RepBY2, RepeatN]$	String Inversion
$(GenBY1, GenBY2]$	$[1, RepBY1]$	Swap
	$(RepBY1, RepeatN]$	String Inversion
$(GenBY2, MaxGen]$	$[1, RepeatN]$	String Inversion

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Inspection framework:

1. Test CR-MR pairs

Parameter Settings
Fixed Setting: $ChromN = 20, NChildN = 40, MaxGen = 400$
Varied Setting:
$CR = \{0.7, 0.8, 0.9\}$, $MR = \{0.05, 0.1, 0.15, 0.2\}$

2. Test $ChromN$ and $MaxGen$

Parameter Settings
Fixed Setting: CR-MR pair from previous stage
Varied Setting:
$ChromN = \{20, 30, 40\}$, $NChildN = 2ChromN$
$MaxGen = \{200, 400, 600, 800, 1000\}$

3. Test $RepeatN$

Parameter Settings
Fixed Setting: CR-MR pair, $ChromN$, and $MaxGen$ from previous stages
Varied Setting:
$RepeatN = \{50, 100, 150, 200, 250\}$

Measurements:

- Percentage Error (PE) is used to measure the difference between the best GA trial value and the GAMS value.
- Since the objectives involve minimization,
  - positive PE indicates that the GA solution is higher than the GAMS solution, meaning the GAMS solution is better.
  - Vice versa, negative PE show that the GA solutions are better.

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Results for 2-LRP :

Percentage Error (PE) of Overall Best Trial Value (%)				
2-LRP	Stopping criterion	Total Cost	Total Population	Total CO_2
Multi-objective optimization	$MaxGen$	-0.5196	0.0000	-27.6580
	$RepeatN$	-0.5196	0.0000	-29.2933

The best combination of parameter settings is CR=0.8, MR=0.05, $ChromN$=20, $MaxGen$ = 400 and $RepeatN$ =250.

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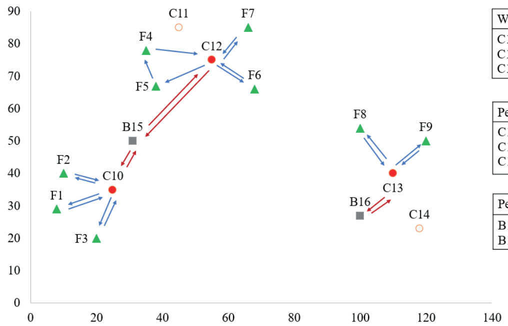
21

Results for 2-LRP :

Best trial output

Mf	1st echelon
Multi-objective	Assignment, allocation and production decisions C10: F1, F2, F3, (allocation, production) = (21.1162, 6.96835) C12: F4, F5, F6, F7 (24.7104, 8.15443) C13: F8, F9, (14.377, 4.74441) Routing decisions and loads $C10 \xrightarrow{0} F1 \xrightarrow{4.9421} C10$, $C10 \xrightarrow{0} F2 \xrightarrow{8.9856} C10$, $C10 \xrightarrow{0} F3 \xrightarrow{7.1885} C10$ $C12 \xrightarrow{0} F5 \xrightarrow{3.145} F4 \xrightarrow{11.232} C12$, $C12 \xrightarrow{0} F6 \xrightarrow{6.2899} C12$, $C12 \xrightarrow{0} F7 \xrightarrow{7.1885} C12$ $C13 \xrightarrow{0} F8 \xrightarrow{8.9856} C13$, $C13 \xrightarrow{0} F9 \xrightarrow{5.3914} C13$ **2nd echelon** Assignment and allocation decisions B15: C10, C12, allocation = (15.1228) B16: C13, (4.74441) Routing decisions and loads $B15 \xrightarrow{0} C10 \xrightarrow{6.96835} B15$, $B15 \xrightarrow{0} C12 \xrightarrow{8.15443} B15$, $B16 \xrightarrow{0} C13 \xrightarrow{4.74441} B16$ Total Cost = 27548.290, Total Population = 17435, Total CO2= 760.196 **Computational Time: 0.63525 minutes**



WSF allocation decisions
C10: 21.1162 C12: 14.377 C13: 14.377

Pellets produced
C10: 6.96835 C12: 8.15443 C13: 4.74441

Pellets allocation decisions
B15: 15.1228 B16: 4.74441

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22

Comparison of AMSEC_GA average computation time and GAMS computational time

Research Problems	Average computational time of AMSEC_GA (minutes)		Computational time of GAMS (minutes)
	Stopping criterion		
	MaxGen	*RepeatN*	
2-LRP	2.2394	0.4192	7.9234

Result findings

The proposed AMS and EC strategies enhance the GA's search capabilities.

Effectively manages the multi-objective optimization

- Outperform GAMS for cost & CO_2 optimization
- GA works as well as GAMS for population optimization

The computational time of AMSEC_GA is generally faster than GAMS.

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4 Research Insights

Suggestions and Recommendation

Suggestions and recommendations which are believed to be worthwhile for future investigation:

- (a) Relax the single-visit assumption, as there may be scenarios where the quantity of biomass at a location exceeds a truck's capacity, making multiple visits necessary.
- (b) Consider a heterogeneous fleet of vehicles, as different locations may require trucks with varying capacities where some needing smaller vehicles and others larger ones.
- (c) Extend the proposed GA to solve LRP with time windows, as the mills (resource sites) and facilities may not operate 24 hours a day
- (d) Incorporate stochastic elements into the proposed GA to account for uncertainties in biomass availability and demand.

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23

List of Publications

Foo, F. Y., Zainuddin, Z. M., & Pheng, H. S. (2024). Optimizing Palm Oil Biomass Supply Chain Logistics through Multi-Objective Location-Routing Model. Malaysian Journal of Fundamental and Applied Sciences, 20(2): 247 – 265. https://doi.org/10.11113/mjfas.v20n2.3085 (WOS, Q4, IF: 0.8; Indexed by Scopus)

Foo, F. Y, Zainuddin, Z. M. & Hang, S. P. (2024). Palm Oil Biomass Supply Chain Multi-Objective Two-Echelon Location-Routing Optimization. Malaysian Journal of Mathematical Sciences, 18(4): 867-901. https://doi.org/10.47836/mjms.18.4.12 (WOS, Q3, IF=0.5; Indexed by Scopus)

Foo, F. Y, Zainuddin, Z. M. & Hang, S. P. (2025). Optimizing palm oil biomass collection: genetic algorithm approaches in solving location-routing problem. Journal of Quality Measurement and Analysis, 21(2): 2025, 277-288. https://doi.org/10.17576/jqma.2102.2025.18 (WOS, Q4, IF=0.3; Indexed by Scopus)

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24


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Common principles and applications of adaptive network theory using mathematical models

Atsushi Tero

Kyushu University

Human distribution networks are an important topic that bring great benefits to society. We must balance various objectives, such as the cost of creating and maintaining the network, transportation efficiency, and robustness against accidents. On the other hand, in addition to humans, ants and mold also form networks. The human body also has a vascular network, the formation and maintenance of which is an important factor for health. In order to understand these and to form and maintain them in good condition, it is important to construct mathematical models. In this presentation, I will introduce a mathematical model of how true slime molds solve mazes that I have created so far. The presenter will then present the results of numerical calculations on Malaysia’s transportation network. In addition, the presenter’s laboratory students will present the results of a joint research project on vascular networks conducted with Malaysian researchers.

Malaysia-Japan Symposium on
Mathematical and Statistical Modelling
26/Aug./2025

Common principles and applications of adaptive network theory using mathematical models

Atsushi Tero (Kyushu University)

Co-worker Supervisor: Ryo Kobayashi (Hiroshima University)

Co-worker Experimentalist: Toshiyuki Nakagaki (Hokkaido University)

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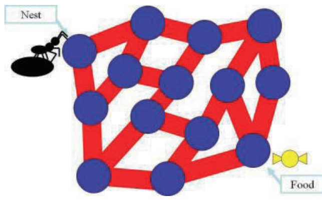
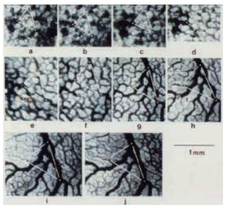
transportation networks of living organisms

Railway

Ant trail

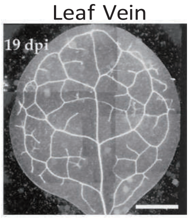


Blood vessel



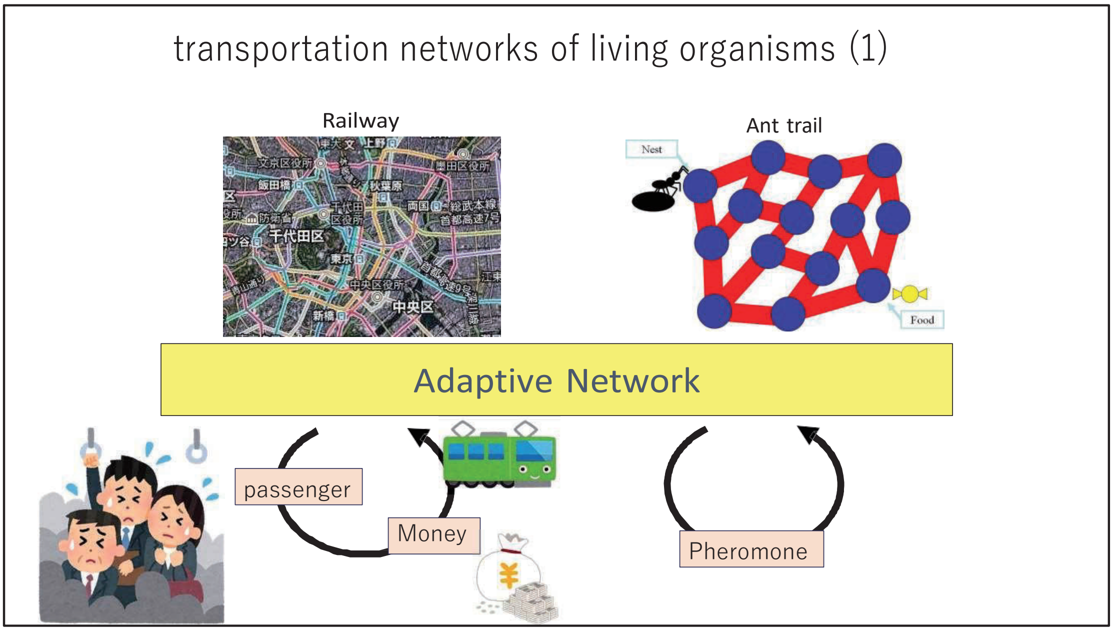
Thanks to H. Honda

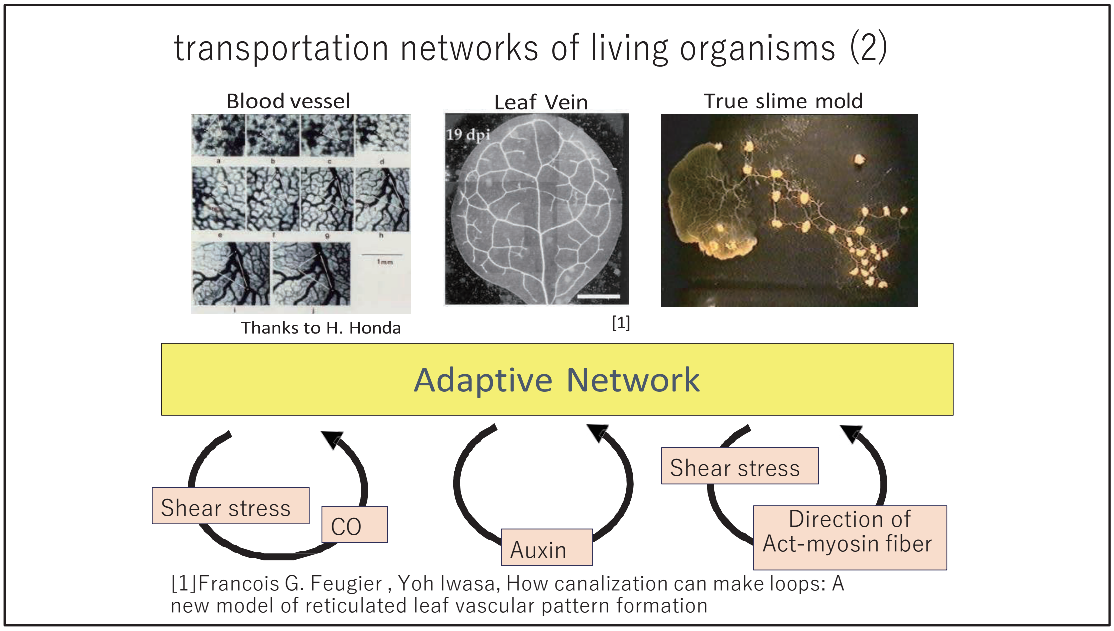
Leaf Vein



[1]

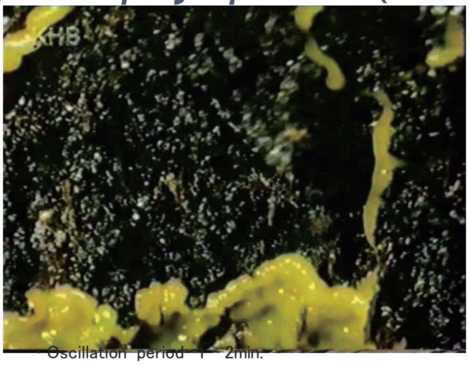
[1]Francois G. Feugier , Yoh Iwasa, How canalization can make loops: A new model of reticulated leaf vascular pattern formation


transportation networks of living organisms (1)
Railway
Ant trail
Nest
Food
Adaptive Network
passenger
Money
Pheromone


transportation networks of living organisms (2)
Blood vessel
Leaf Vein
True slime mold
19 dpi
Thanks to H. Honda
[1]
Adaptive Network
Shear stress
CO
Auxin
Shear stress
Direction of
Act-myosin fiber
[1]Francois G. Feugier , Yoh Iwasa, How canalization can make loops: A
new model of reticulated leaf vascular pattern formation

True Slime Mold(真正粘菌)

Physarum polycephalum（モジホコリ）



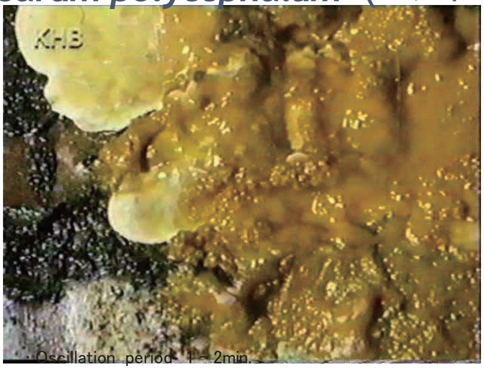
・Oscillation period 1 ~ 2min.
・It gather to flood source (Oat Flake)
・Single cell (multi-core)
・Free for “cut and paste”
・Living at dark and humid environment

Slime mold in Studio Ghibli

Nausicaä of the Valley of the Wind

True Slime Mold(真正粘菌)

Physarum polycephalum（モジホコリ）



・Oscillation period 1～2min.
・It gather to flood source (Oat Flake)
・Single cell (multi-core)
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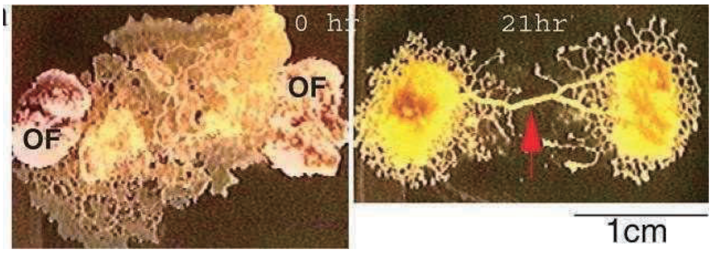
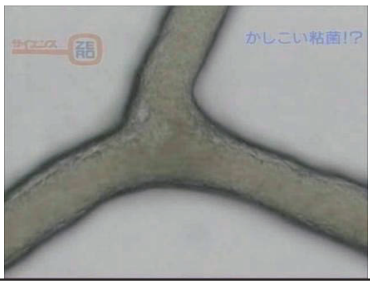
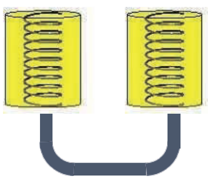
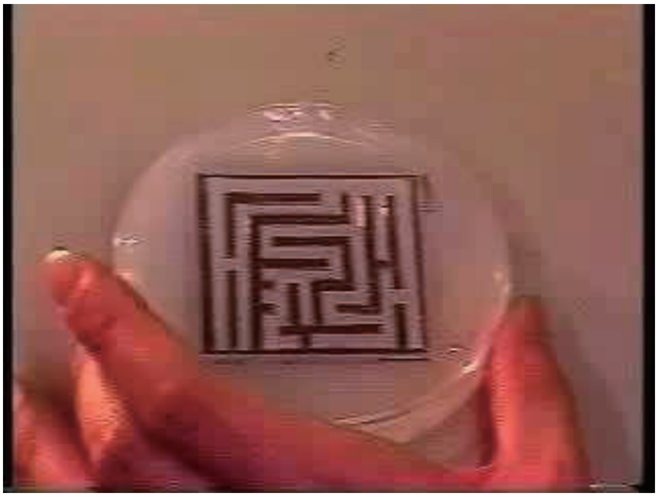
Physarum polycephalum





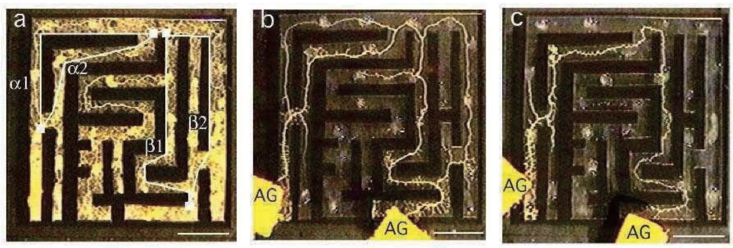


Solving ma/e by slime mold



Toshiyuki Nakagaki (Hokkaido University)

Solving ma/e by slime mold



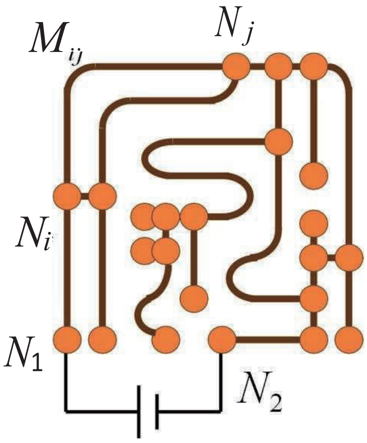
Why can slime mold solve the ma/e!?

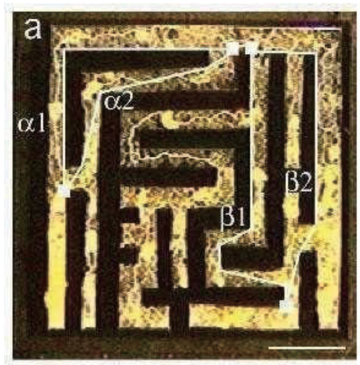
(Solving ma/e needs global information. Slime don't have the brain and have only local information)

1、Physarum OsCillates near the food
2、Sol flow throw the network
3、High used way grows more.

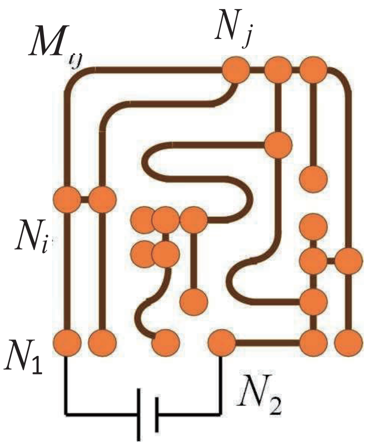
Make mathematical model and calculate with computer!!

Mathematical modeling





Mathematical modeling



N_i $p_i(t)$ pressure

N_1 N_2 Connecting with food

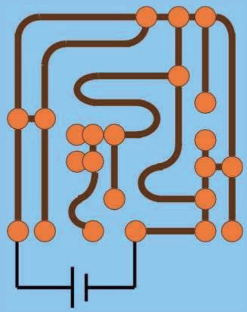
M_{ij}

L_{ij} length

$D_{ij}(t)$ width (conductivity)

$Q_{ij}(t)$ Flow amount

Model equations



$$Q_{ij} = \frac{D_{ij}}{L_{ij}}(p_i - p_j)$$

Ohm's Law

$$\sum_i Q_{ij} + I_j(t) = 0$$

Kirchhoff's 1st Law

Model equations

Tube growth rule

High flow more, growth more

Tube Growth Eq.

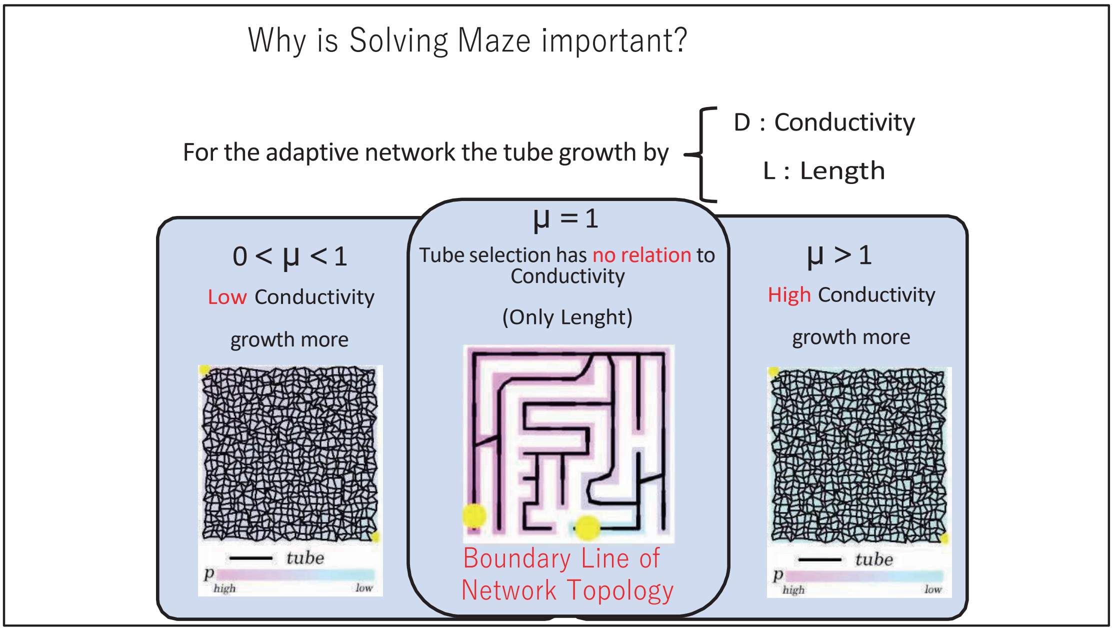
$$\frac{d}{dt}D_{ij} = f(|Q_{ij}|) - rD_{ij}$$

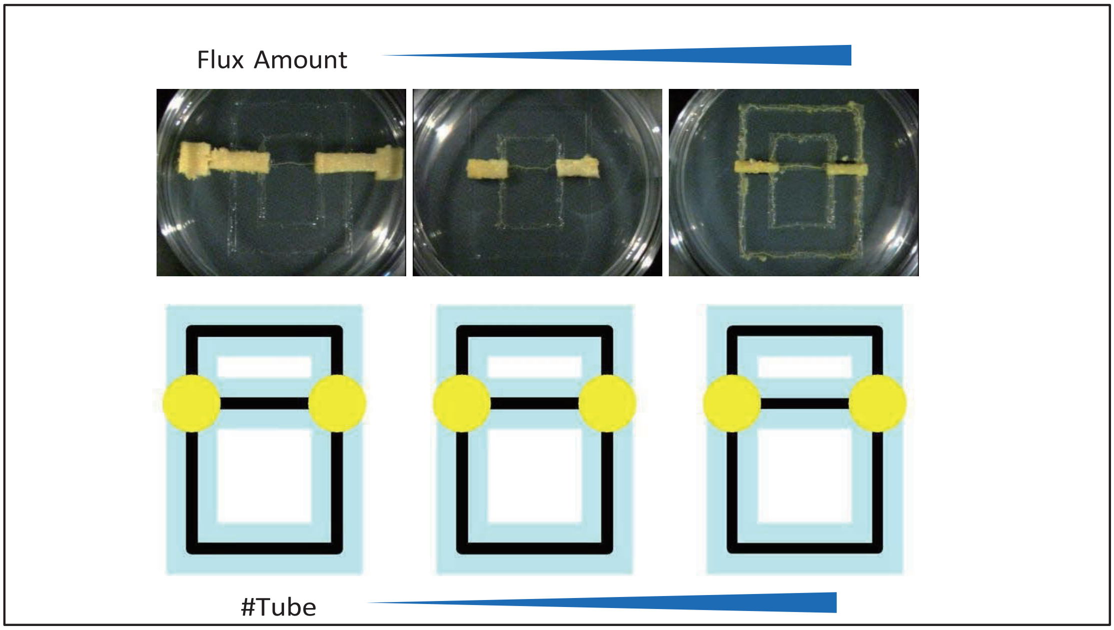
$$f(0) = 0$$

Tube Growth Eq.

$$\frac{d}{dt}D_{ij} = |Q_{ij}|^{\mu} - rD_{ij}$$

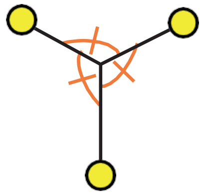
Positive feedback parameter

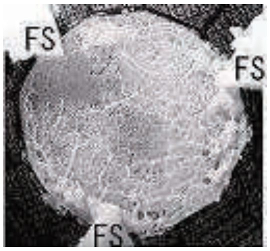

Why is Solving Maze important?
For the adaptive network the tube growth by
D : Conductivity
L : Length
0 < μ < 1
Low Conductivity
growth more
tube
p
high
low
μ = 1
Tube selection has no relation to Conductivity
(Only Lenght)
Boundary Line of Network Topology
μ > 1
High Conductivity
growth more
tube
p
high
low


Flux Amount
#Tube

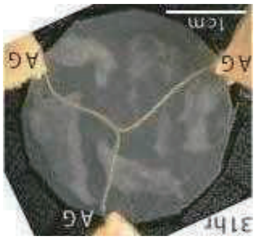
Minimum Steiner Tree Problem

Shortest network connecting with all points
NP-hard problem
(The calculation time increases exponentially
when the network size increases.)





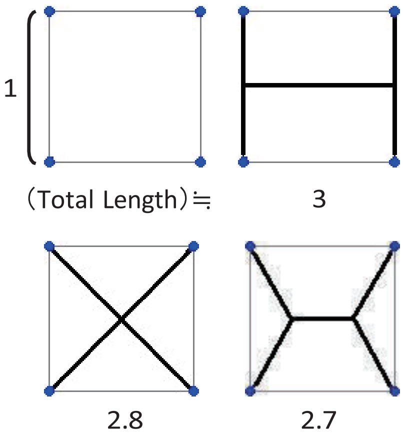
Initial condition

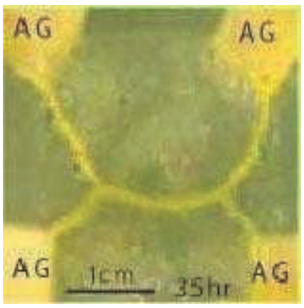


Final state

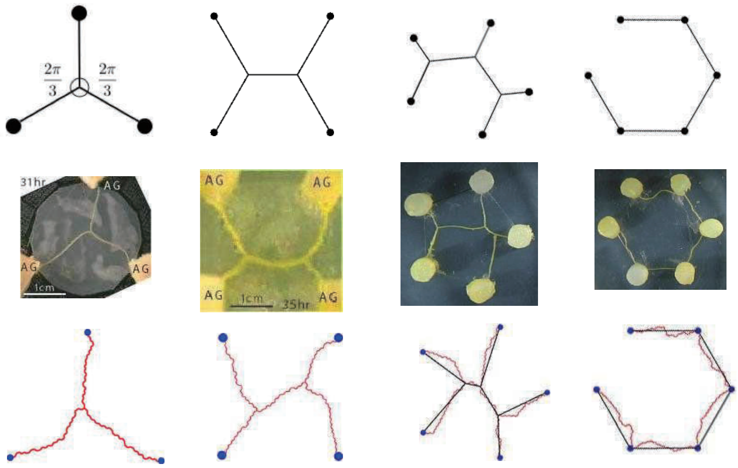
Minimum Steiner Tree Problem

What is the shortest network connecting with 4 points?

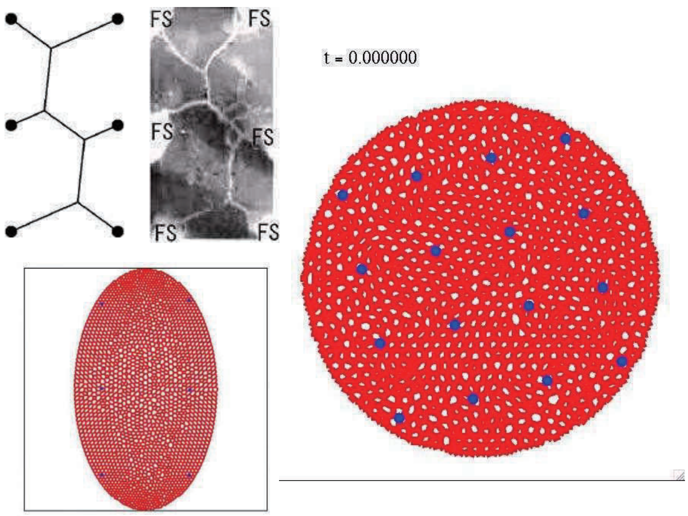




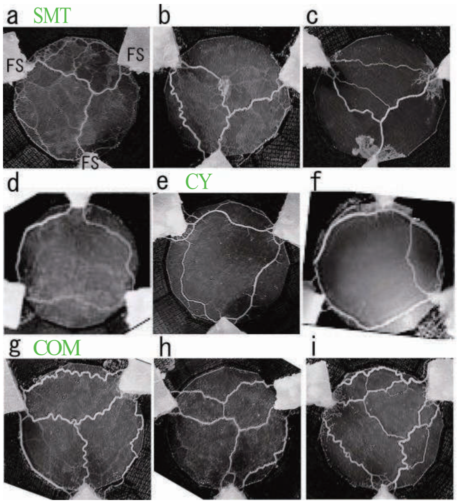
Minimum Steiner Tree Problem $f(q) = |q|^{\mu}$

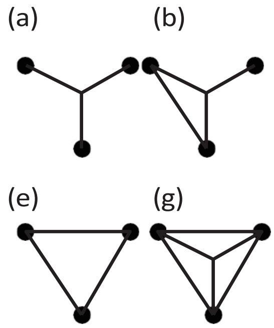


The shortest network



The optimal network for 3 points





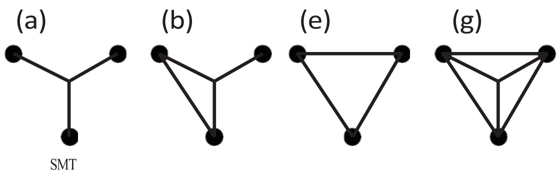
30 hours after
Food application

To estimate the network

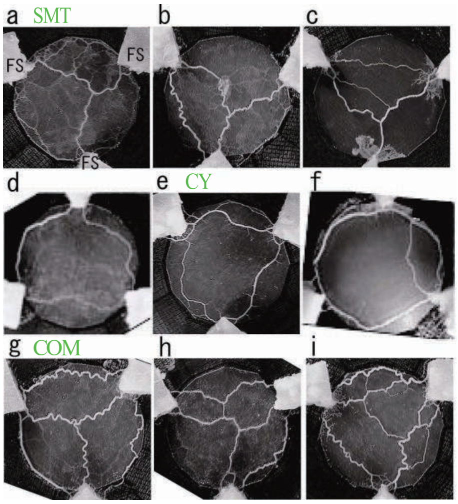
TL---total length of the network, normalized to SMT

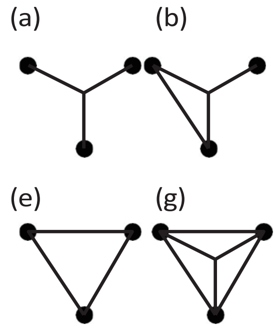
FT_N---Fault Tolerance (the probability of keeping coupled network when the network is broken randomly. It describes network robustness.)

FT_1	0.00	0.79	1.00	1.00
FT_2	0.00	0.23	0.33	1.00
TL	1.00	1.58	1.72	2.58



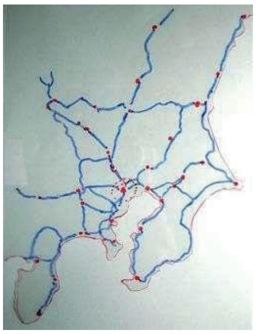
The optimal network for 3 points

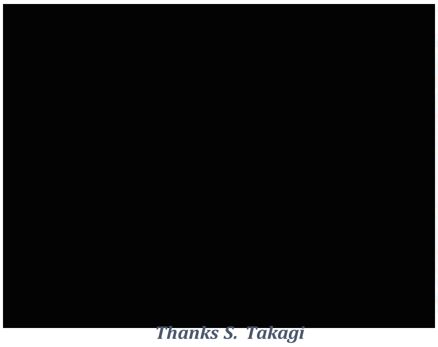


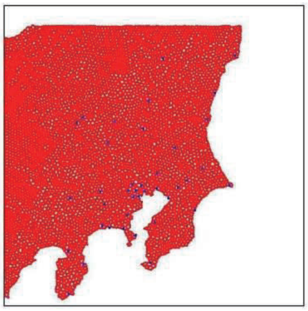


30 hours after
Food application

For real network problem







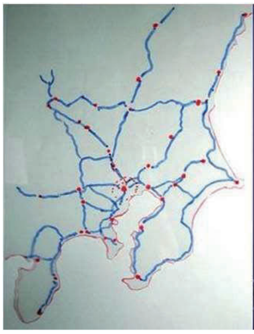
Thanks S. Takagi

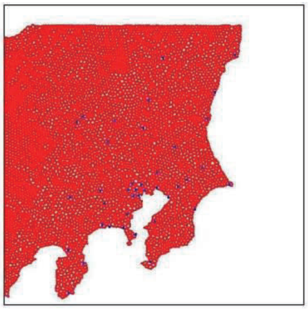
Human Answer **Physarum Answer** **Simulation Answer**

1. The railway/tube with a lot of passenger/flow grows more.
   The railway/tube without passenger/flow will be closed.
2. The smaller total length is better
3. They need network robustness.

A. Tero, et al. **Science** 2010

For real network problem





Thanks S. Takagi

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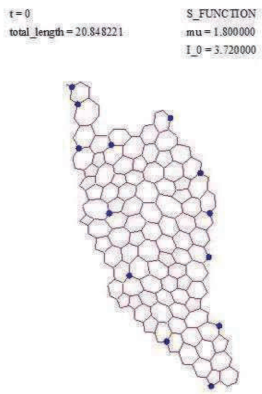
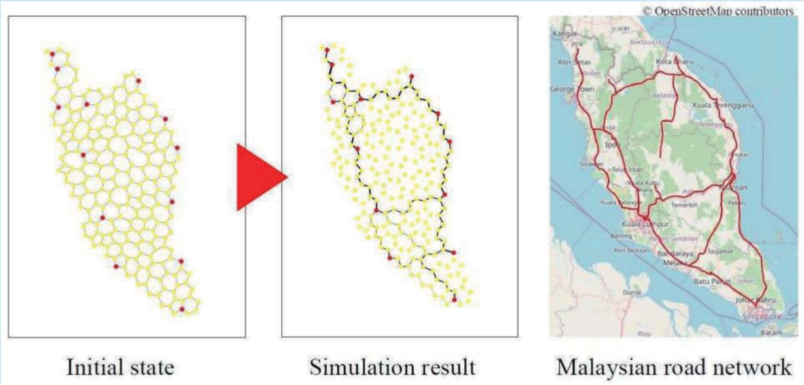
A. Tero, et al. **Science** 2010

Network of west Malaysia

Malaysian road network



Highway Network in West Malaysia with Ant Algorithm

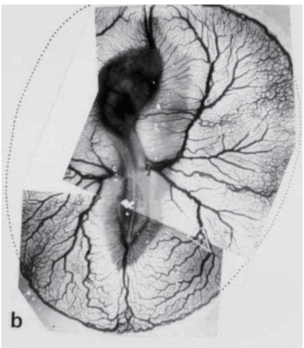


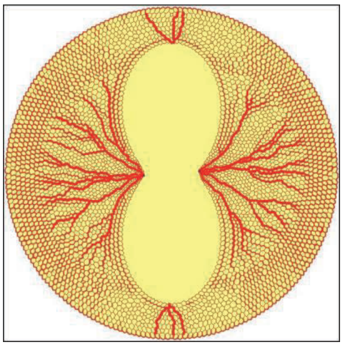
Kazuhiro Minami, Atsushi Tero @FMFI 2025

Math & biology suggest robust and efficient network

3. To blood vessels

Vascular network in quail embryos
(My supervisor result)





Initial state

capillaries

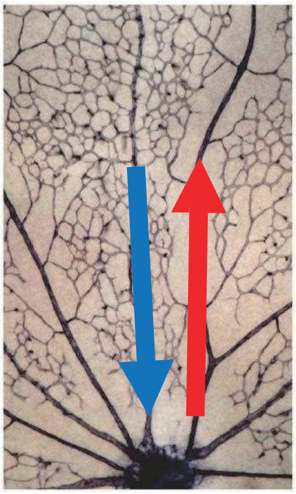
High pressure link grows to artery

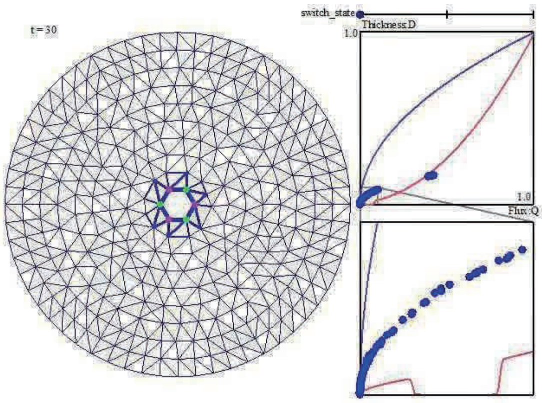
Low pressure link grows to vein

Capillaries does not stable

By Ryo Kobayashi, Hisao Honda
Calculated by Kenji Yumiki

Retinal vascular network





By Uemura, Miura
Calculated by Atsushi Tero

4. Blood Vessel with Stenoses
Joint research with
Universiti Teknologi Malaysia

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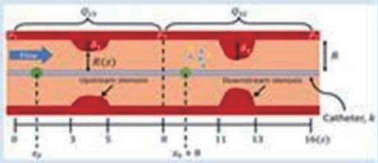
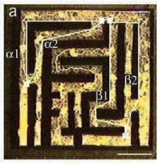
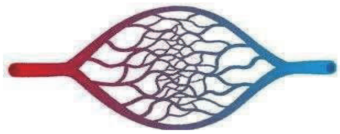


Haruka Suga, Intan Diyana,
Atsushi Tero @FMFI 2026, In preparation
Contributing to medical care
by reducing calculation time

Ms. Suga
よろしく
お願いします。

Comparison
Slime net. and blood net.



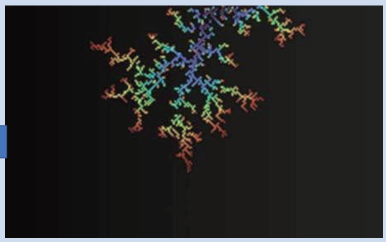


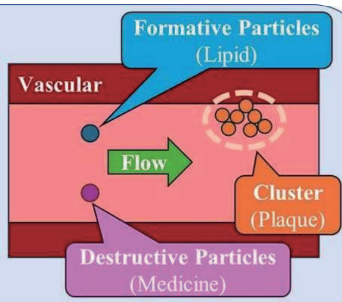
Flow	$Q_{ij} = \frac{D_{ij}}{L_{ij}}(p_i - p_j)$	⇐	Navier-Stokes equations $\frac{D\boldsymbol{v}}{Dt} = \frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v}\cdot\nabla)\boldsymbol{v} = \frac{1}{\rho}\operatorname{div}\boldsymbol{\sigma} + \boldsymbol{g}$ (By Malaysia Team)
Interaction	$\sum_i Q_{ij} = 0$		
Network growth	$\frac{d}{dt}D_{ij} = f(\lvert Q_{ij}\rvert) - rD_{ij}$	⇐	$\frac{d\delta}{dt} = -\frac{1}{d(R-\delta Q)}$

Stochastic < − > Deterministic Model

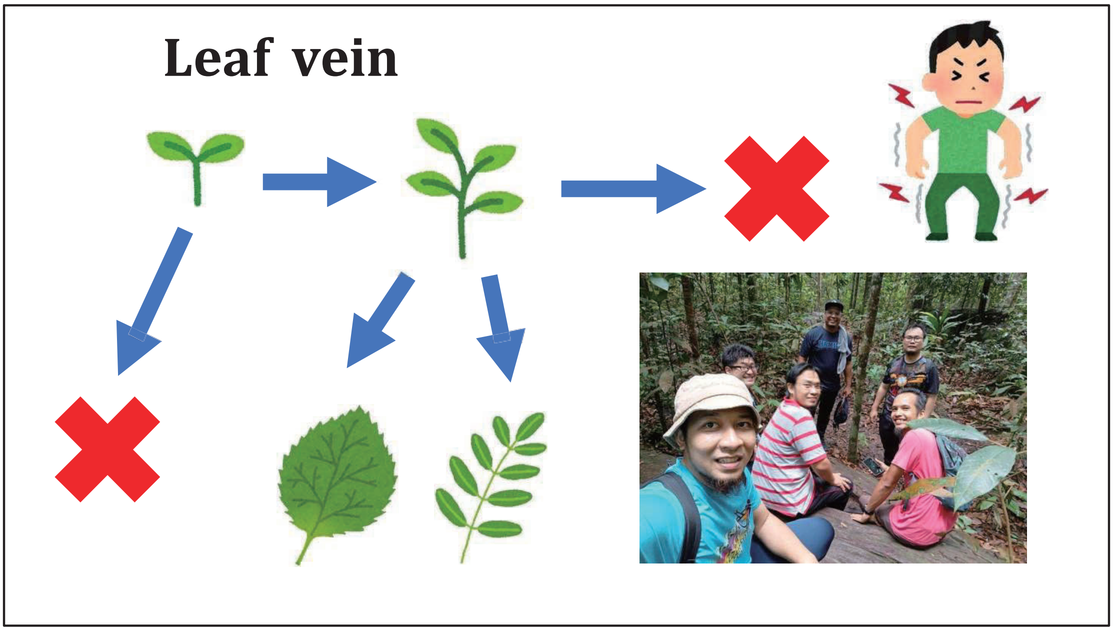
Network Growth (Breaking stenosis) eq.

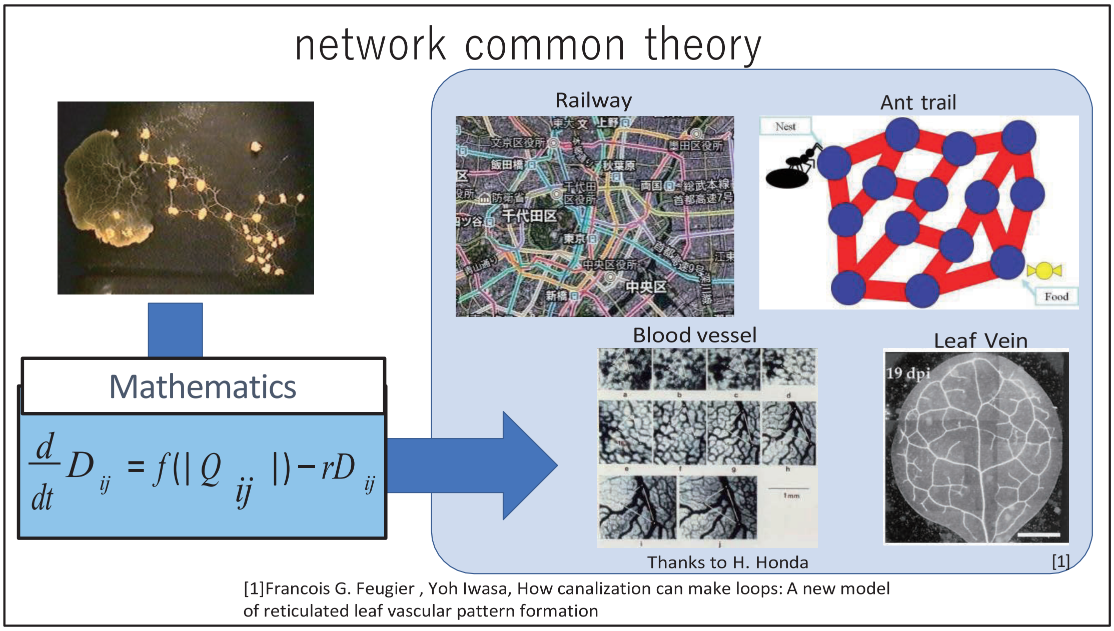
$$\frac{d\delta}{dt} = -\frac{1}{d(R-\delta Q)}$$





Taiga Kadowaki, Atsushi Tero @FMFI 2026


Leaf vein


network common theory
Railway
Ant trail
Nest
Food
Mathematics
$\frac{d}{dt}D_{ij} = f(|Q_{ij}|) - rD_{ij}$
Blood vessel
Leaf Vein
19 dpi
Thanks to H. Honda
[1]
[1]Francois G. Feugier , Yoh Iwasa, How canalization can make loops: A new model of reticulated leaf vascular pattern formation

Summary

True slime molds can solve mazes.

This is not only interesting, but it is also useful for connecting various networks.

It is power of Mathematics

My stay in Malaysia will help study adaptive networks.

Mathematics can connect the networks of

Kyushu University and Universiti Teknologi Malaysia.

A Statistical Data-Driven Framework for Understanding Rainfall Intensity and Climate Challenges in Malaysia

Shariffah Suhaila Syed Jamaludin

Universiti Teknologi Malaysia (UTM)

This study examines advanced statistical methods, including distribution fitting, functional data analysis (FDA), and copula models, to enhance understanding and modeling of Malaysia's increasing flood risks driven by extreme rainfall and climate change. It emphasizes the importance of capturing the temporal structure, interdependencies, and boundedness of wet days to improve flood prediction and resilience planning.

UTM UNIVERSITI TEKNOLOGI MALAYSIA

A Statistical Data-Driven Framework for Understanding Rainfall Intensity and Climate Challenges in Malaysia

SHARIFFAH SUHAILA SYED JAMALUDIN

RESEARCH FELLOW
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DEPARTMENT OF MATHEMATICAL SCIENCESFAC ULTY OF SCIENCE
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suhailasj@utm.my

Innovating Solutions

Introduction

Major Climate Change Challenges

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Flooding & Rainfall Extremes

- Flash floods fr equently occur s in urban areas due to intense rainfall a nd poor drainage
- Monsoon flooding affecting both east and west Malaysia

Rising Temperatures & Heatwaves

- Temperatures rose by 0.14–0.25 ˚C per decade.
- Increase the number of heatwaves occurring annually
- Urban heat island effects in major cities

Sea Level Rise & Coastal Erosions

- Coastal erosion affecting beaches and infrastructure

IPCC (2021) (The Sixth Assessment Report (AR6))

Air Pollution & Seasonal Haze

severely affects air quality

Deforestration & Land Use Changes

Habitat loss, biodiversity decline, and disrupted hydrological cycles are increasing flood and landslide risk.

Health Impacts: Vector-Borne Diseases & Heat Stress

Climate shifts increase the incidence of dengue, malaria, and other vector- borne diseases.

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Major Flood Events

- Malaysia faced an escalating climate crisis more than two decades ago.

18 December 2006- 13 January 2007

Caused: Torrential rainfall (extreme and heavy rainfall that occurs for a short time)associated with Typhoon Utor.

Affected Areas: Primarily Johor

Impacts: Over 100,000 people evacuated in Johor; 18 deaths.

Damage: Infrastructure damage, road closures, economic loss (USD 395 million)

Exposed weaknesses in flood forecasting and early-warning systems.

Flood in Kota Tinggi, Johor 2006

Introduction

Major Flood Events

December 2014- January 2015

Labeled as the worst floods in decades for the East Coast.

Caused: Prolonged heavy rain in the Northeast Monsoon, intensified by strong Borneo Vortex

Affected Areas: East coast states (Kelantan, Terengganu, Pahang)

Impacts: Over 500,000 people affected, at least 21 deaths; floodwaters up to 4 m.

Estimated damage: USD 560 million

Raised urgent calls for river basin management and sustainable land-use planning.

Flood in Kelantan 2014

Source: Shamsuddin J et al. 2016

Source: Ahmad et al. 2025

2021-2022

Major Flood Events

Introduction

UTM

December 2021 – January 2022

Caused: Tropical Depression (weakest form of Tropical cyclones) 29W + extreme rainfall during NEM monsoon

Affected areas: Selangor (Shah Alam, Klang), Negeri Sembilan, Kuala Lumpur.

Impacts: Approximately 70,000 victims evacuated daily, 54 killed

Estimated damage: USD 4.8 billion

Demonstrated rising urban flood risk

2024

November-December 2024

Caused: Intense Northeast Monsoon events compounded by extreme rainfall episodes.

Affected areas: 25 districts in seven Malaysian states

Impacts: 137,410 people were affected.

Estimated damage: USD 224 million

Reinforces the trend of increasingly frequent and

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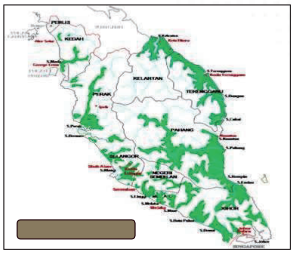
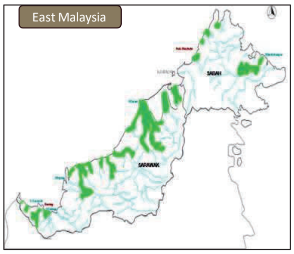
FLOOD PRONE AREAS IN MALAYSIA





Government Initiatives

UTM

National Flood Mitigation Plan (2023-2030)

Flood Relief & Preparedness Budget

SMART Tunnel (Storm Water Management & Road Tunnel)

Designed to divert floodwaters from Kuala Lumpur City Centre

Disaster Coordination

NADMA (National Disaster Management Agency)

SMART (Special Malaysia Rescue Team)

Evacuation & Shelter Readiness

Prepare Evacuation Center

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The Statistical Challenges

Problem Statement

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1. Boundedness Effect → 2. Temporal Complexity → 3. Dependency Measure

1. "Wet days are not randomly distributed and are not independent. They cluster, they have memory, they create patterns."

2. How do rainfall patterns evolve throughout the day, season, and year?

3. When volume increases, does duration always decrease? How do multiple variables interact during rain/flood events?

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Boundedness Effect

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Issue: Rainfall events are not independent.
The distribution of rainfall amounts should be considered separately according to the number of adjoining wet days; 0,1,2.

010 → **Solitary Wet Days**

$X_{t-1} = 0,\ X_t = 1,\ X_{t+1} = 0$

Class 0

Convective rainfall
High intensity but short duration

011, 110 → Wet days bounded on one side by a wet day and on the other side, bounded by a dry day

$X_{t-1} = 0,\ X_t = 1,\ X_{t+1} = 1$

$X_{t-1} = 1,\ X_t = 1,\ X_{t+1} = 0$

Class 1

Start or end of wet spell
Occur particularly during the inter-monsoon

111 → Wet days bounded on both sides by a wet day.

$X_{t-1} = 1,\ X_t = 1,\ X_{t+1} = 1$

Class 2

Northeast Monsoon season, prolonged and heavier rainfall

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Methodology

3 sets of rainfall data

All rainfall classes grouped → Solitary wet days (Class 0) are fitted separately from the other two classes (Classes 1 and 2). → Each rainfall class is fitted separately

Fitting Distribution

Gamma → Weibull → Lognormal → Mixed exponential → Skew Normal → Kappa

Kolmogorov Smirnov Test → **Akaike Information Criterion** → **Loglikelihood Ratio Test**

- Kolmogorov Smirnov Test: To determine the significant differences between each pair of rainfall classes.
- Akaike Information Criterion: AIC = $-2 \log L + 2k$
- Loglikelihood Ratio Test: To determine the significant difference in AIC between three classes

Suhaila and Jemain, Journal of Hydrology 2009.(368): 17-25. Investigating the impacts of adjoining wet days on the distribution of daily rainfall amounts in Peninsular Malaysia.

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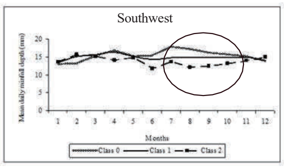
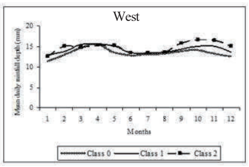
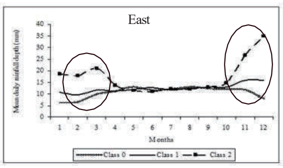
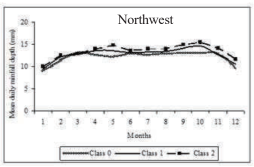
Percentage of months showing significant ($p < 0.05$) differences between distributions of rainfall classified according to the number of adjoining wet days.

Region	East	Southwest	West	Northwest
Classes 0 and 1	17	14	7	9
Classes 1 and 2	38	38	25	19
Classes 0 and 2	51	49	28	28

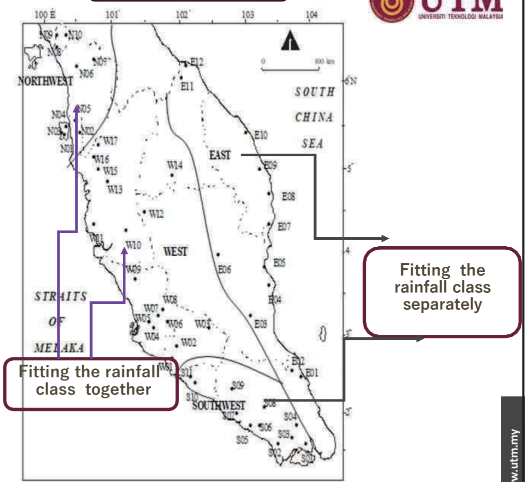








50 stations



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Summary 1

- May **overestimate Class 0 (Solitary Wet Days)** and **underestimate** Class 2
- Leads to **distortion in simulation outputs**, affecting the reliability of predictions.
- Misclassification can bias the statistical distribution of rainfall in models, leading to poor decision-making in sectors like flood forecasting, climate modeling, and agriculture.

Innovating Solutions

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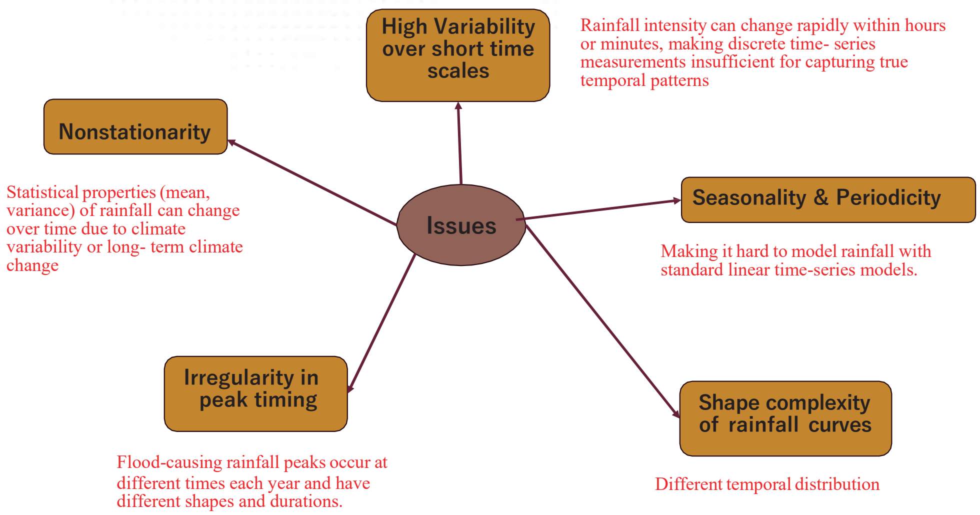
Rainfall Temporal Complexity



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Functional Data Analysis

Functional Data Analysis treats rainfall data as continuous curves (functions) rather than discrete points. This allows the entire temporal pattern to be modeled, smoothed, and compared. FDA treats the whole curve as a single entity.

- Smoothing with basis functions reduces noise while maintaining temporal features
- **The Fourier basis can explicitly capture periodic components**
- **Functional Principal Component Analysis (FPCA)** detects changing dominant modes over time.
- Phase–amplitude separation and curve registration align peaks before analysis.
- FDA captures full curve shapes, enabling classification or clustering of different rainfall patterns.
- FDA can handle irregular sampling and interpolate missing observations smoothly.

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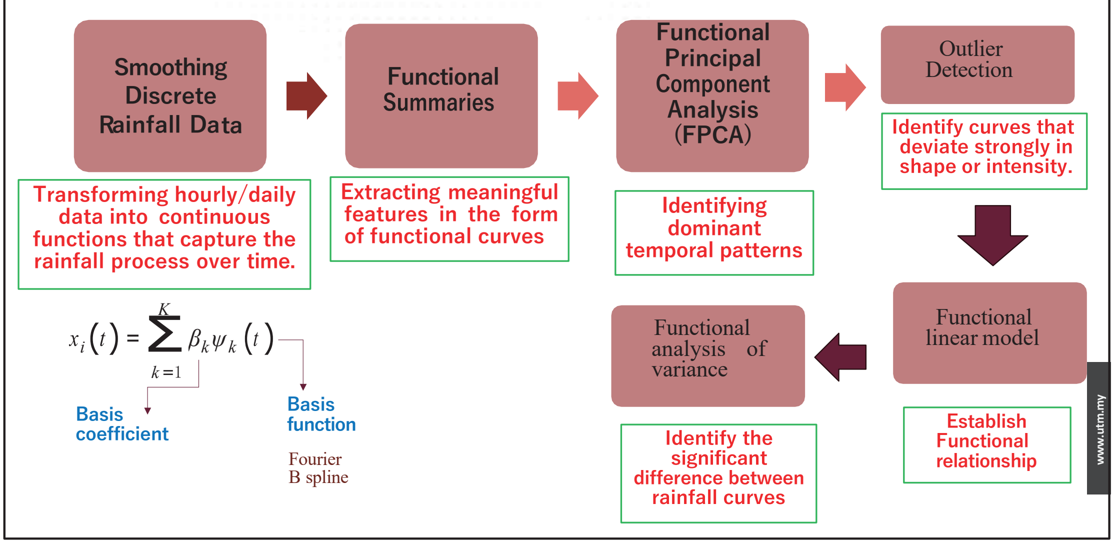
FDA Framework



Reconstructing flow data through basis functions

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- Daily flow 1980-2014, from Sg. Kelantan (Jam. Guillemard) with station code SF5721442 .
- Situated at Kelantan River Basin with the northern latitude of 5°45N and eastern longitude of 102°09′E.

$$\mathbf{Y}_i = \left(y_i(t_1), \ldots, y_i(t_T)\right)', i = 1, 2, \ldots, n, j = 1, 2, \ldots, T,$$

- n is the number of years
- $y_i(t_j)$ – flow measured at the day-t_j of the i-th year. T=365 days
- The discrete observed data are converted into the smoothing curves as temporal functions with a base period of T and k basis functions.
- Choice of k can be justified to capture the flow variation.

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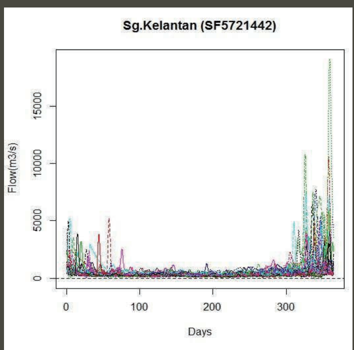
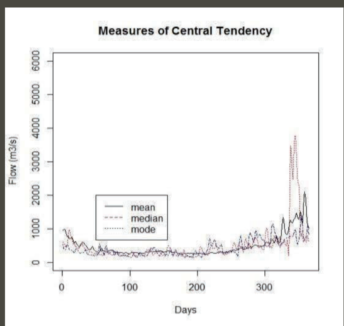
Smoothing flow curves

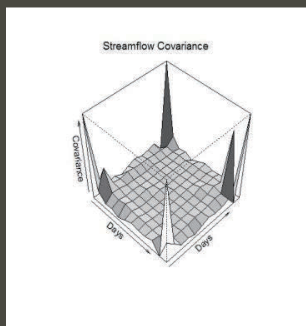


- The smooth representation of flow data is done with a 365-day base period and selected k basis functions, which are chosen based on the quality of smoothing and a high percentage of explained variance.

Summary of functional data



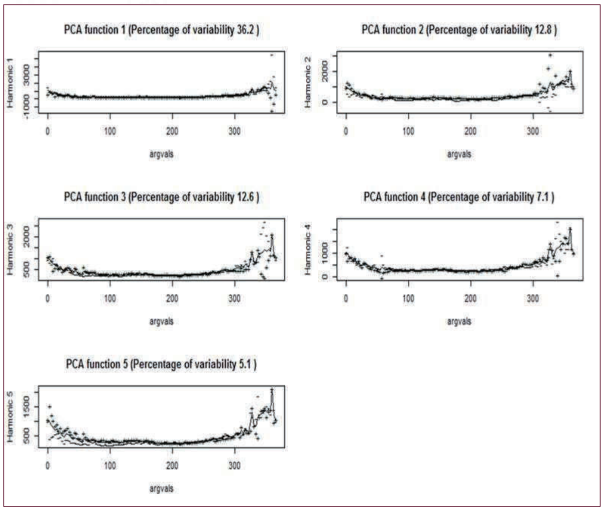
- The maximum flow occurs in the middle of November up to early January (North East Monsoon flow)



- The highest variability occurs approximately between (Nov-Jan)
- This period corresponds approximately to the highest flows

Functional Principal Component Analysis

- ❑ 73.8% of streamflow variability, showing that the **dominant driver is the seasonal monsoon flood regime**
- ❑ Captures the **overall seasonal streamflow regime**, especially the **magnitude of peak flows at year-end**
  - ❑ PC1 (36%) → General wet-season intensity (flood magnitude).
- ❑ PC2–PC3 (~25%) → Shape and timing of the hydrograph (flood duration, onset, persistence).
- ❑ PC4–PC5 (~12%) → Extreme and anomalous events (flash floods, unusual peaks).



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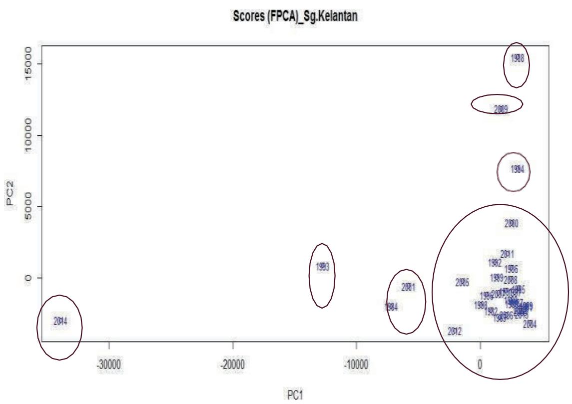
FUNCTIONAL PCA



- Based on scores of FPCA, the curves can be classified into several clusters. Different magnitude and shape of the curves.

May consider having the same flow pattern

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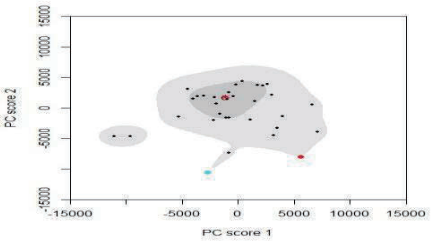
Functional Outliers

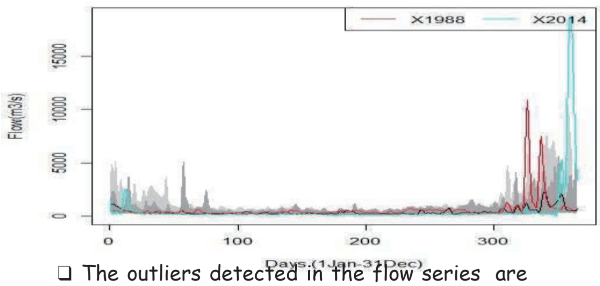
Bivariate HDR plot



Individual functional curves based on 99% coverage probability

The dark grey regions show the 'bag'.
The light grey regions display the fence.
All points outside the regions were identified as outliers.

Functional high-density region (HDR) plot



- The outliers detected in the flow series are those curves that represent 1988 and 2014.
  - Referring to the flood history of Sg Kelantan River Basin, the year 2014 is one of the worst floods that occurred and caused major destruction to the state of Kelantan.

Functional Analysis of Variance (ANOVA)

Compare mean rainfall functions across multiple climate categories and identify when during the time such differences were most pronounced.

$$\text{Rain}_{mg}(t) = \mu(t) + \alpha_g(t) + s_{mg}(t).$$

- $\mu(t)$: grand mean function — indicates the average rainfall profile across the studied stations of Peninsular Malaysia
- α_g are the specific effects on rainfall of being in group g
- $s_{mg}(t)$: the unexplained variation specific to the m-th rainfall station within climate group g

$$\sum_{g=1}^{5} \alpha_g(t) = 0$$

$$\text{Rain}_{mg}(t) = \sum_{j=1}^{6} z_{(mg)j}\beta_j(t) + s_{mg}(t),$$

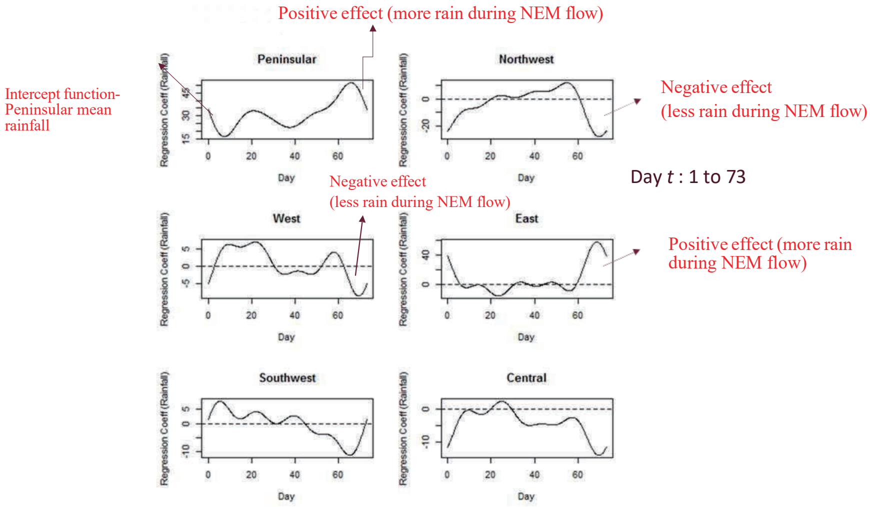
Functional response: $\text{Rain}_{mg}(t)$

Represent either 0 or 1: $z_{(mg)j}$

Regression Coefficients: $\beta_j(t)$

Region effects for the rainfall functions via the functional ANOVA

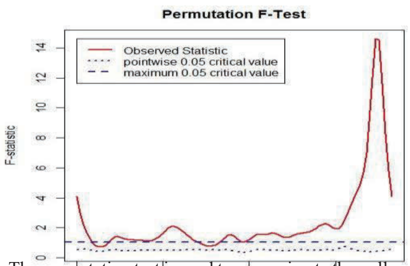
α_g



Day t : 1 to 73

Statistical test of no effect of geographical region on the rainfall profile

Comparison all five regions



The permutation test is used to approximate the null distribution of the test statistic and to obtain an estimated critical value for the test

- The differences are statistically significant at certain time intervals in the year.
- The study demonstrates that Peninsular Malaysia regions have distinct rainfall temporal structures that are best captured using functional representations rather than aggregate statistics.

Why Dependency Matters?

Issues

Rainfall and flood characteristics are highly correlated and not univariate.

→ Traditional univariate analysis fail to capture joint behaviors.

→ Traditional Multivariate statistics have some limitations in dealing with cases with different marginal distributions that need to be the same type, normally distributed, or independent.

→ Copulas allow us to model the joint behavior of different features of random variables.

Able to capture the nonlinear & tail dependencies

Copula

A copula is a multivariate cumulative distribution function (CDF) with uniform marginals on the interval [0,1].

$$C : [0, 1]^d \rightarrow [0, 1].$$

Sklar's Theorem

$$H(x_1, x_2, \ldots, x_d) = C(F_1(x_1), F_2(x_2), \ldots, F_d(x_d)).$$

Let H be a joint cumulative distribution function with marginals $F_1, F_2, \ldots F_d$
Then, there exists a Copula C such that for all real numbers $x_1, x_2, \ldots, x_d$.
If the marginals $F_1, F_2, \ldots F_d$ are continuous, the copula C is unique.

If C is a Copula and $F_1, F_2, \ldots F_d$ are distribution functions, then the function H is a multivariate distributions with marginals $F_1, F_2, \ldots F_d$.

COPULA FAMILIES

Elliptical Copulas

Gaussian

(No tail dependence)

Student T

(Upper & lower tail dependence)

Archimedean Copulas

Clayton (Lower Tail Dependence)

Gumbel (Upper Tail Dependence)

Frank (Symmetric)

Joe (Strong upper tail)

Extreme Value Copulas

Gumbel Hougaard Galambos

Other Copulas

Farlie-Gumbel-Morgenstern (FGM)

Plackett

Ali-Mikhail-Haq

BB Families

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Capturing Dependencies in Rainfall /Flood Characteristics

Bivariate Copula → Trivariate Copula → Vine Copula

$$H_{X,Y}(x,y) = C[F_X(x), F_Y(y)] = C(u_1,u_2).$$

$$C(u_1,u_2,u_3) = C_2[C_1(u_1,u_2), u_3].$$

- ❖ Breaks high-dimensional dependence into a sequence of bivariate copulas.
- ❖ Allows modeling different types of dependencies between pairs of variables.

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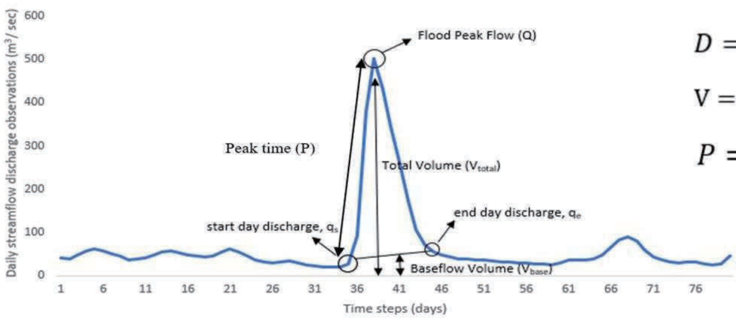
Study Area

FLOOD HYDROGRAPH



$$D = q_e - q_s$$

$$V = V_{total} - V_{base}$$

$$P = q_d - q_s$$

Figure 2 : Flood hydrograph showing flood characteristics.

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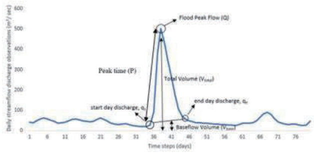
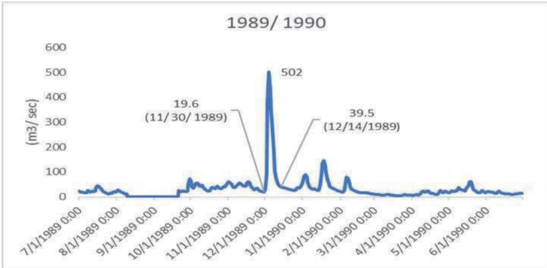
FLOOD HYDROGRAPH CALCULATION





$$D = q_e - q_s$$

$$V = V_{total} - V_{base}$$

$$V = \sum_{i=e}^{s} q_j - \frac{D}{2}(q_s + q_e),$$

$$P = q_d - q_s$$

N. A. Jafry, J. Suhaila1,F. Yusof, S. R. M. Nor,· N. E. Alias, L. Shahid. Joint probabilistic assessments of four-dimensional flood characteristics using the vine copula-based methodology
https://doi.org/10.1007/s12665-024-11743-7

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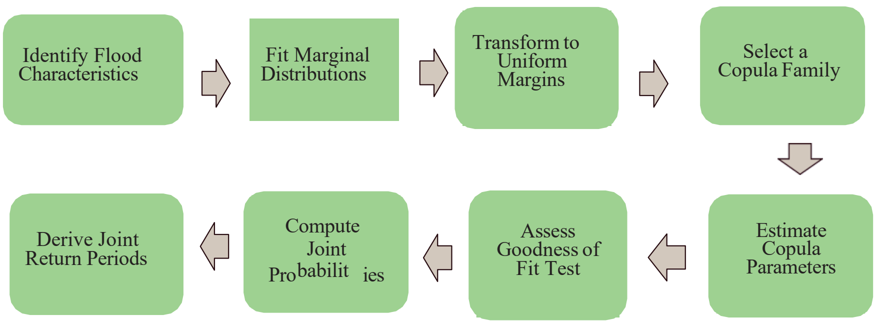
Copula Implementation for Flood Characteristics



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Flood Risk Estimation

The return period (also called recurrence interval) of an event is the average time between occurrences of an event of at least a given magnitude.

The return period T is calculated as

$$T = \frac{\mu}{P(X \geq x_T)} = \frac{1}{p}$$

$$P(X \geq x_T) = p = \frac{1}{T}$$

$$F_X(x_T) = 1 - p = 1 - \frac{1}{T}$$

$$x_T = F_X^{-1}\left(1 - \frac{1}{T}\right)$$

μ mean inter-arrival duration between two consecutive episodes

Univariate Return Period

Lognormal-3P - peak flow & peak time
Weibull-3P – volume
Generalized Extreme Value - duration.

The analysis reveals distinct characteristics for different return periods.

T=10-year (10% probability of occurrence annually)

Estimated flood parameters Peak flow (Q) - 337.04 m³/s Volume-2797.05 m³
Duration: 28 days, and peak time exceeding 13 days

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Bivariate Copula

Joint exceedance (AND) for two variables

Return period of both events happening **together** in the same occurrence.

$$P_{AND} = P(X_1 > x_1, X_2 > x_2)$$
$$= 1 - F_1(x_1) - F_2(x_2) + C(\mu_1, u_2)$$
$$= 1 - F_1(x_1) - F_2(x_2) + C(F_1(x_1), F_2(x_2))$$

$$T = \frac{1}{P_{AND}}$$

Joint exceedance (OR) for two variables

Return period of at least one event exceeding its threshold.

$$P_{OR} = P(X_1 > x_1 \text{ or } X_2 > x_2)$$
$$= 1 - C(\mu_1, \mu_2)$$
$$= 1 - C(F_1(x_1), F_2(x_2))$$

$$T = \frac{1}{P_{OR}}$$

T= 10-year return period

$P(X_Q > 337.04, X_V > 2797.05) = 0.06993$
$P(X_Q > 337.04 \text{ or } X_V > 2797.05) = 0.13004$
$P(X_Q > 337.04, X_D > 14) = 0.02162$
$P(X_Q > 337.04 \text{ or } X_D > 14) = 0.17825$

$T_{Q,VAND}$ = 14.30 years.
$T_{Q,VOR}$ = 7.69 years.
$T_{Q,DAND}$=46.26 years.
$T_{Q,DOR}$ = 5.61 years.

A flood event where **both the peak discharge exceeds 337.04 m³/s AND the volume exceeds 2797.05 m³** is expected to occur, on average, **once every 14.3 years**. Rare event (Small probability).

Return period for OR is shorter with a larger probability.

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Summary

Flood Risk Management

AND return periods help design critical infrastructure (dams) for compound worst-case floods.

OR return periods help with preparedness planning and insurance assessment, the likelihood of damaging floods.

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Conclusion

Boundedness Effect
Rainfall and flood extremes are naturally bounded by physical limits, and ignoring this can bias risk estimation.
By incorporating boundedness, more realistic estimates of extreme rainfall are obtained, preventing over- or under-design of infrastructure (e.g., dams, drainage).

Temporal Complexity
Rainfall exhibits strong seasonality, inter-annual variability, and long-term shifts (e.g., ENSO, climate change).
Functional Data Analysis (FDA) allows authorities to track evolving rainfall patterns and detect anomalies more effectively than traditional methods. This helps anticipate shifts in flood timing, duration, and intensity.

Copula Rainfall Modelling
Flood risk depends on multiple characteristics simultaneously (e.g., rainfall intensity, volume, duration).
Copula-based models capture the dependence structure between these variables, providing joint return periods that are more informative than univariate approaches.

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THANK YOU

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Advection-Diffusion Equations (ADE) in Modeling Transport Phenomena

Zaiton Mat Isa
Universiti Teknologi Malaysia (UTM)

This talk explores the versatility of advection-diffusion equations (ADE) in modeling transport phenomena. Applications include fumigation in grain storage, heavy metal migration in soil and indoor disease transmission.

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ADVECTION-DIFFUSION EQUATIONS (ADE) IN MODELING TRANSPORT PHENOMENA

ABSTRACT: This talk explores the versatility of advection-diffusion equations (ADE) in modeling transport phenomena. Applications include fumigation in grain storage, heavy metal migration in soil and indoor disease transmission.

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OUTLINE

- DEFINITION
- BACKGROUND
- DERIVATION OF ADE
- GENERAL MATHEMATICAL MODEL
- APPLICATION

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DEFINITION

DIFFUSION

Diffusion is the process where particles spread from regions of higher concentration to regions of lower concentration.

ADVECTION

Advection refers to the transport of a substance by the bulk motion of the fluid.

REACTION

Reaction is the process where the concentration of a substance changes due to chemical transformations or other internal interactions within the system.

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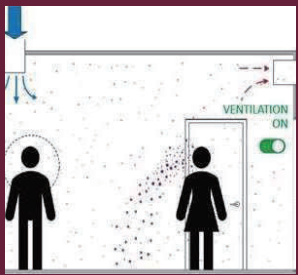
BACKGROUND

01 GRAIN FUMIGATION

02 HEAVY METAL IN SOIL



03 INDOOR DISEASE TRANSMISSION

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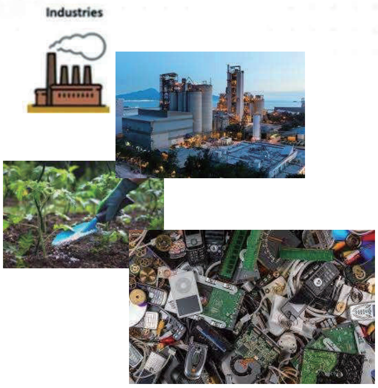
BACKGROUND –grain fumigation

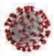
- In grain industry, after harvesting, the grain will be stored in storage/silo
- Stored grain often contains insects that can damage the quality of the product
- To control these pests, one of the method is fumigation
- This process involves pumping a toxic gas, into the silo/storage to kill the insects
- However failed fumigation has been reported, and the ineffective spatial phosphine distribution in the grain storage are one of the factors contributing to the failure

BACKGROUND –heavy metal migration in soil



- Heavy metals can enter soil from :
  - Industry
  - Agriculture – inorganic fertilizer
  - Electronic waste
- Once in the soil, they can move with water and slowly spread out.
- Effect
  - Can get in to crops - reduce agricultural productivity and overall crop quality – food safety
  - Poses risk to groundwater
  - Long term environmental effect

BACKGROUND – indoor disease transmission



- When infected individuals breathe, talk, or cough, they release tiny droplets into the air
- These droplets can float around and travel with the air in the room
- If the room has poor ventilation, the air becomes filled with more of these particles.
- This makes it easier for others to breathe them in and get sick.

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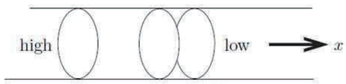
DERIVATION OF ADE

- Consider a circular tube with cross-sectional area, A representing the hollow section, which is filled with solute. It is presumed that bulk mixture remains stationary.



- Mass conservation:

{rate of change of mass} = {net rate of mass diffusing in and out of the tube}

- Rate of change of mass:

$$\{\text{rate of change of mass}\} = A\delta x \frac{\partial C}{\partial t}(x, t)$$

- The change in mass of solute as it diffuses down the tube over time

$$\{\text{Net rate of mass diffusing}\} = J(x, t)A - J(x + \Delta x, t)A$$

- Combining both equation

$$\frac{\partial C}{\partial t}(x, t) = -\left[\frac{J(x+\Delta x, t) - J(x, t)}{\delta x}\right]$$

as $\delta x \rightarrow 0$

$$\frac{\partial C}{\partial t} = -\frac{\partial J}{\partial x}$$

A – cross sectional area
J – mass flux of the solute

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DERIVATION OF ADE

- Fick's Law

$$J(x,t) = -D\frac{\partial C}{\partial x}(x,t)$$

- Substituting Fick's law into mass conservation

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}$$

- If Advection involve

$$J = J_d + J_a$$

- In the absence of diffusion, solute particles move at the same speed as the mixture

$$J_a = uA\delta t = u \cdot C$$

- Hence $J = uC - D\frac{\partial C}{\partial x}$
- Resulting in concentration equation

$$\frac{\partial C}{\partial t} + u\frac{\partial C}{\partial x} = D\frac{\partial^2 C}{\partial x^2}$$

D – diffusivity
J_d —mass flux due to diffusion
J_a - mass flux due to advection

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MATHEMATICAL MODEL OF ADE

$$\frac{\partial C}{\partial t} + \nabla \cdot (uC) = D\nabla^2 C + R$$

Reaction term

Advection term

Diffusion term

EXAMPLE OF REACTION TERM

$$R = -kC$$

- k is the **rate constant** that determines how fast the reaction occurs.
- C is the **concentration** of the substance involved in the reaction.

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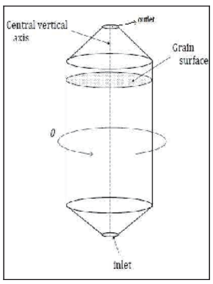
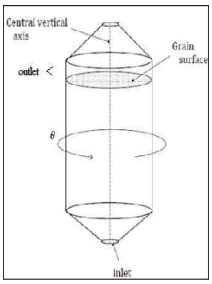
METHODOLOGY IN PRACTICE

01 Identification of governing equation → **02** Non-dimensionalization → **03** Implementation of Integral transformation → **04** Inverse Integral Transformation → **05** Numerical Simulation

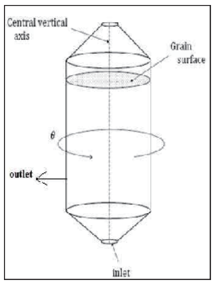
APPLICATION – grain fumigation



Case 1: Outlet at the top of the silo

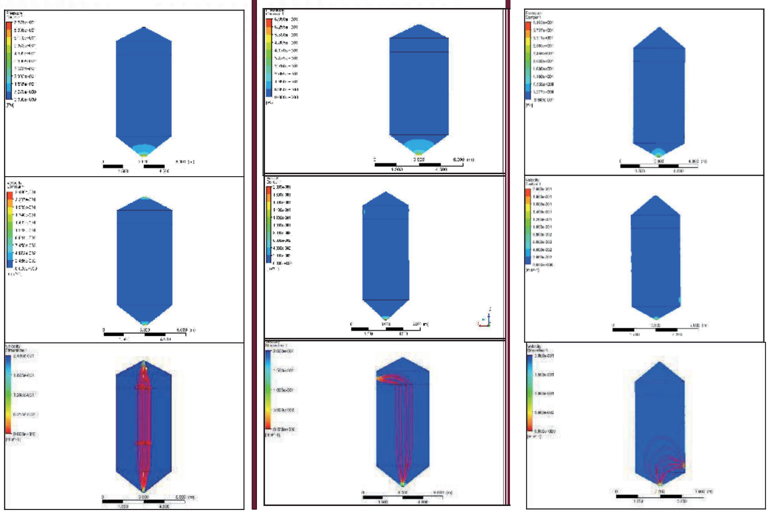


Case 2: Outlet at the above of the grain surface



Case 3: Outlet at the below of the grain surface

Case 1 Case 2 Case 3



- the gas flow towards the outlet regardless the position of the outlet.
- If outlet = leaks, the position of leaks in the silo significantly effects the fumigant distribution
- There is an insufficient dosage area at the top part of the silo if leaks are predominant located at the lower part of the silo

APPLICATION – Heavy metal transport in soil

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TWO-DIMENSIONAL HEAVY METAL TRANSPORT IN SOIL WITH ADSORPTION AND SOURCE TERM

PRESENTER: LIANGRUISHI

SUPERVISOR:DR ZAITON MAT ISA
CO-SUPERVISOR:DR SHAYMAA M.H. DARWISH

TRANSPORT OF HEAVY METAL WITH ADSORPTION AND DESORPTION

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Model Equation: $R\frac{\partial C}{\partial t} = D_x \frac{\partial^2 C}{\partial x^2} + D_y \frac{\partial^2 C}{\partial y^2} - u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} - \frac{\rho}{\theta}\frac{\partial S}{\partial t}$, while $\frac{\rho}{\theta}\frac{\partial S}{\partial t} = kC - k_1\frac{\partial C}{\partial t}$

Problem 1: Instantaneous emission

initial and boundary condition:

$$C(x,y,0) = C_i; \quad 0 \le x < +\infty, 0 \le y < +\infty$$

$$C(0,0,t) = \frac{m}{Q}\delta(t),$$

$$\frac{\partial C}{\partial x} = 0, \frac{\partial C}{\partial y} = 0; \quad x \to \infty, y \to \infty.$$

The analytical solution:

$$C(z,t) = \frac{mz\sqrt{A}}{2Q\sqrt{\pi D t^3}}\exp(\frac{Uz}{2D})\exp(-\frac{Az^2}{4Dt})\exp\left(\left(-\frac{U^2}{4AD} - \frac{k}{A}\right)t\right)$$
$$-\frac{C_i}{2}\exp((-\frac{k}{A})t)\exp(\frac{Uz}{2D}) \times \left(\exp\left(-z\sqrt{\frac{U^2}{4D^2}}\right)\operatorname{erfc}\left(\frac{z\sqrt{A}}{2\sqrt{Dt}} - \sqrt{\frac{U^2t}{4AD}}\right)\right.$$
$$\left.+\exp\left(z\sqrt{\frac{U^2}{4D^2}}\right)\operatorname{erfc}\left(\frac{z\sqrt{A}}{2\sqrt{Dt}} + \sqrt{\frac{U^2t}{4AD}}\right)\right) + C_i\exp((-\frac{k}{A})t).$$

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Problem 2: Exponential decay emission

Initial and boundary condition:

$$C(x,y,0) = C_i; \quad 0 \le x < +\infty, 0 \le y < +\infty$$

$$C(0,0,t) = C_0 e^{-\alpha t}$$

$$\frac{\partial C}{\partial x} = 0, \frac{\partial C}{\partial y} = 0; \quad x \to \infty, y \to \infty.$$

The analytical solution:

$$\begin{aligned}C(z,t) = {} & \frac{C_0}{2}\exp\left(\frac{Uz}{2D} - \alpha t\right)\left\{\exp\left(-z\sqrt{\frac{A}{D}}\sqrt{\frac{U^2}{4AD}+\frac{k}{A}-\alpha}\right)\operatorname{erfc}\left(\frac{z\sqrt{A}}{2\sqrt{Dt}}\right.\right.\\
& \left.-\sqrt{\left(\frac{U^2}{4AD}+\frac{k}{A}-\alpha\right)t}\right) + \exp\left(z\sqrt{\frac{A}{D}}\sqrt{\frac{U^2}{4AD}+\frac{k}{A}-\alpha}\right)\operatorname{erfc}\left(\frac{z\sqrt{A}}{2\sqrt{Dt}}\right.\\
& \left.\left.+\sqrt{\left(\frac{U^2}{4AD}+\frac{k}{A}-\alpha\right)t}\right)\right\} - \frac{C_i}{2}\exp\left((-\frac{k}{A})t + \frac{Uz}{2D}\right)\left(\exp\left(-z\sqrt{\frac{U^2}{4D^2}}\right)\right.\\
& \operatorname{erfc}\left(\frac{z\sqrt{A}}{2\sqrt{Dt}} - \sqrt{\frac{U^2 t}{4AD}}\right) + \exp\left(z\sqrt{\frac{U^2}{4D^2}}\right)\operatorname{erfc}\left.\left(\frac{z\sqrt{A}}{2\sqrt{Dt}} + \sqrt{\frac{U^2 t}{4AD}}\right)\right)\\
& + C_i \exp\left((-\frac{k}{A})t\right)\end{aligned}$$

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The concentration at different time for instantaneous boundary condition

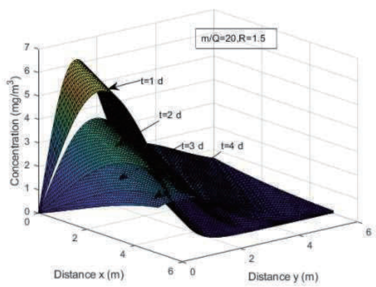

fig 3.1 Concentration profiles of heavy metals at different time for fixed m/Q=20 and R=1.5

The concentration at different time for exponential decay boundary condition

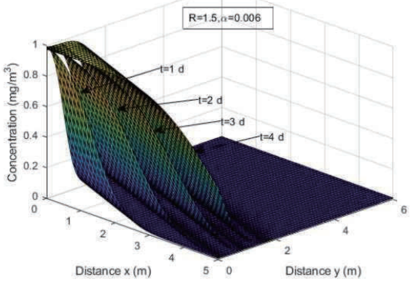

fig 3.2 Concentration profiles of heavy metal with exponential decay boundary condition at different time

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TRANSPORT OF HEAVY METAL WITH ADSORPTION,DESORPTION AND POINT SOURCE

Model equation : $R\frac{\partial C}{\partial t} = D_x\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} - u\frac{\partial C}{\partial x} - v\frac{\partial C}{\partial y} - \frac{\rho}{\theta}\frac{\partial S}{\partial t} + F,$ while $\frac{\rho}{\theta}\frac{\partial S}{\partial t} = kC(x,y,t) - k_x\frac{\partial C}{\partial x} - k_y\frac{\partial C}{\partial y}.$

Problem 3: Instantaneous point source

Initial and boundary condition:

$C(x, y, 0) = 0;\ 0 \le x < +\infty,\ 0 \le y < +\infty,$

$C(0, 0, t) = 0,$

$C(x, y, t) = 0;\ x \to +\infty,\ y \to +\infty$

point source:

$F = G(t)W(z),\ G = M\delta(t - t_0),\ W(z) = \frac{1}{\theta}\delta(z - z_0)$

The analytical solution

$$C(z,t) = \frac{M}{2\theta\sqrt{DR}}\exp\left(\frac{U(z-z_0)}{2D}\right)\frac{\exp\left(-\left(\frac{U^2}{4DR}+\frac{k}{R}\right)(t-t_0)\right)}{\sqrt{\pi(t-t_0)}} \times \left\{\exp\left(\frac{-R(z-z_0)^2}{4D(t-t_0)}\right) - \exp\left(\frac{-R(z+z_0)^2}{4D(t-t_0)}\right)\right\}.$$

The concentration at different time for instantaneous point source

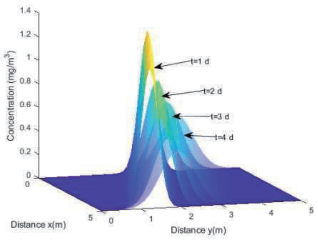


fig4.1 Concentration profiles of heavy metals at different time for fixed M/θ =1 and R=1.5 with instantaneous release source heavy metals is introduced at(2.5,2.5)

Problem 4: The exponential decay source

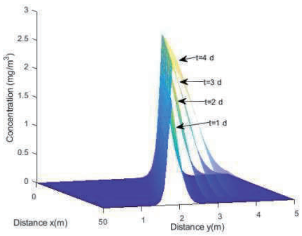
point source:

$$F = G(t)W(z),\ W(z) = \frac{1}{\theta}\delta(z - z_0),\ G(t) = g_0 e^{-\alpha t}$$

The concentration effects at different time

The analytical solution

$$C(z,t) = \int_0^t \frac{g_0}{2\theta\sqrt{DR}} \exp(-\alpha\zeta)\exp\left(\frac{U(z-z_0)}{2D}\right)\frac{\exp(-(\frac{U^2}{4DR}+\frac{k}{R})(t-\zeta))}{\sqrt{\pi(t-\zeta)}} \times \left\{\exp\left(\frac{-R(z-z_0)^2}{4D(t-\zeta)}\right) - \exp\left(\frac{-R(z+z_0)^2}{4D(t-\zeta)}\right)\right\} d\zeta$$



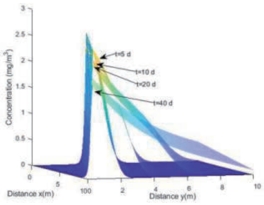


fig 4.4 Concentration profiles of heavy metals at different time for fixed g_0/θ=1 and R=1.5 with exponential decay release source heavy metals is introduced at (2.5,2.5) and α=0.01

TRANSPORT OF HEAVY METAL WITH ADSORPTION,DESORPTION AND LINE SOURCE

Problem 5: Instantaneous line source

The model equation, initial and boundary conditions are same as CH4, but the line source is:

$$F = G(t)W(z);$$

$$W(z) = M(H(z-c) - H(z-d))\ G(t) = \frac{1}{\theta}\delta(t - {}_0)$$

The analytical solution

$$C(z,t) = \frac{M}{2\theta\sqrt{DR}} \int_0^\infty \exp\left(\frac{U(z-\tau)}{2D}\right)\frac{(H(\tau-c)-H(\tau-d))\exp(-(\frac{U^2}{4DR}+\frac{k}{R})(t-t_0))}{\sqrt{\pi(t-t_0)}} \times \left\{\exp\left(\frac{-R(z-\tau)^2}{4D(t-t_0)}\right) - \exp\left(\frac{-R(z+\tau)^2}{4D(t-t_0)}\right)\right\} d\tau$$

The concentration at different time for instantaneous line source

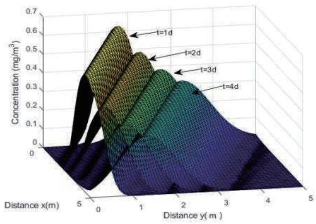


fig 5.1 Concentration profiles of heavy metals at different time for fixed M/θ=1 and R=1.5 with instantaneous release line source heavy metals

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Problem 6: Exponential decay line source

The line source is:

$$F = G(t)W(z);$$

$$W(z) = M(H(z-c) - H(z-d)),\ G(t) = g_0 e^{-\alpha t}$$

The analytical solution:

$$C(z,t) = \frac{g_0}{2\sqrt{DR}} \int_0^\infty \exp\left(\frac{U(z-\tau)}{2D}\right) \int_0^t \frac{\exp(-\alpha\zeta) M(H(\tau-c) - H(\tau-d)) \exp\left(-\left(\frac{U^2}{4DR} + \frac{k}{R}\right)(t-\zeta)\right)}{\sqrt{\pi(t-\zeta)}} \times \left\{\exp\left(\frac{-R(z-\tau)^2}{4D(t-\zeta)}\right) - \exp\left(\frac{-R(z+\tau)^2}{4D(t-\zeta)}\right)\right\} d\zeta\, d\tau$$

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The concentration at different time for exponential decay line source

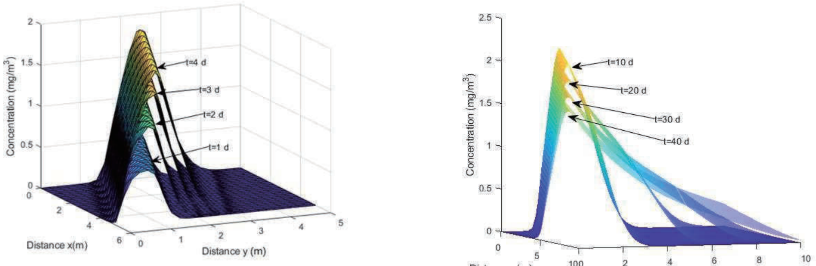
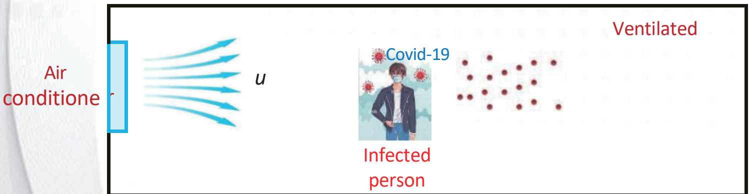


fig 5.1 Concentration profiles of heavy metals at different time for fixed R=1.5 with exponential decay release line source heavy metals

APPLICATION - Indoor transmission of covid-19

How does Covid-19 spread in an indoor space?



talking?
breathing?
Mask?
Without mask?

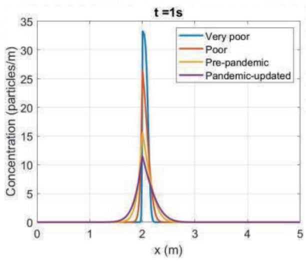
Advection-Diffusion Equation

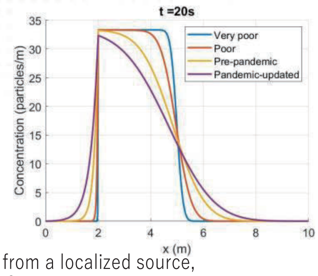
$$\frac{\partial C}{\partial t} = K\frac{\partial^2 C}{\partial x^2} - U\frac{\partial C}{\partial x} - \lambda C + R\delta(x - x_0)H(t - t_0)$$

$C(x, 0) = 0,\quad C(0, t) = 0,\quad C(\infty, t) = 0$

C – concentration
K – diffusion coefficient
u - velocity
λ – air exchange rate
R – rate of production of infectious particle

Turkyilmazoglu (2022)
Lau et al. (2020)





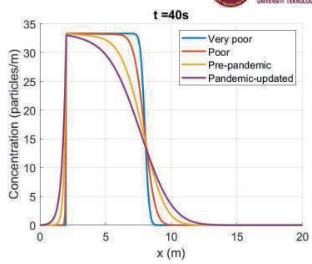
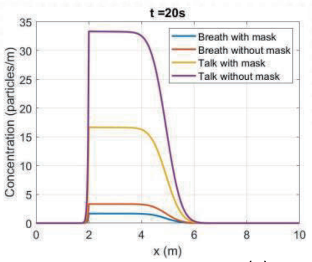


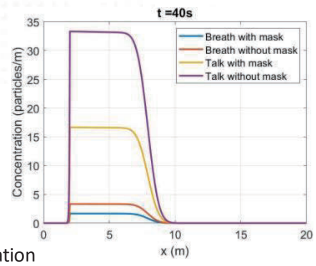
Fig. 1. Concentration of particles emitted from a localized source, talking without mask positioned at $x = 2$ m.

☑ The concentration spikes with very poor ventilation has the highest peak

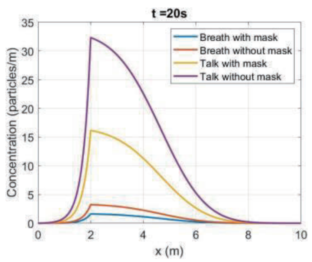
☑ As time increases, the particle concentrations begin to spread out from the source with the very poor ventilation still maintains the highest peak

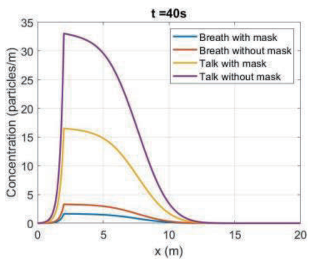
☑ The pandemic-updated ventilation scenario shows a low and broad concentration profile that spreads across a wide area





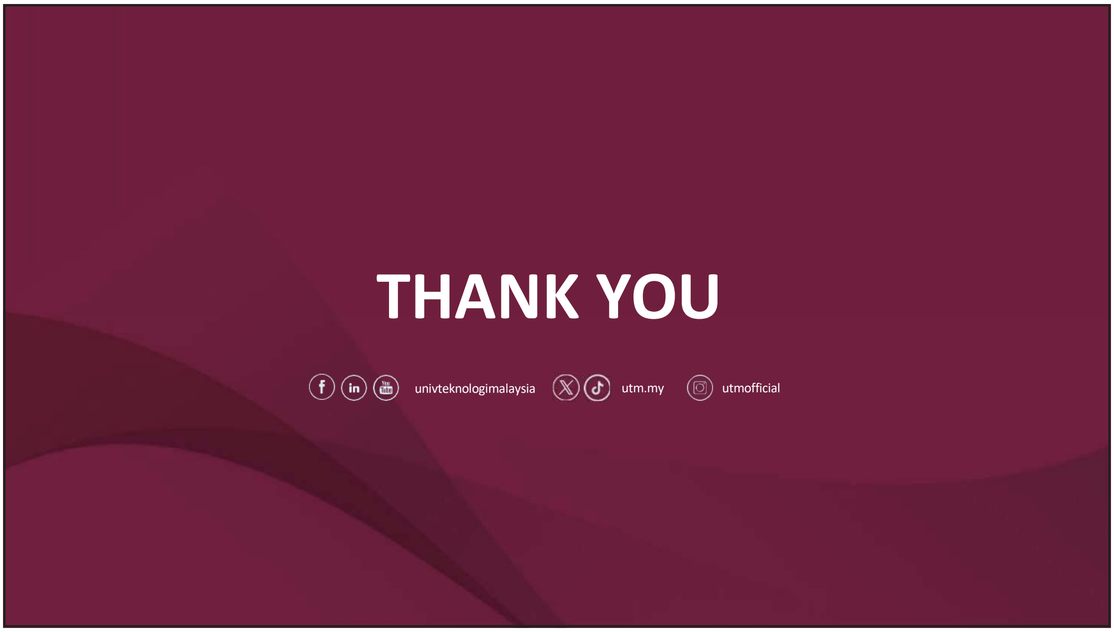
(a) Poor ventilation





(a) Pandemic-updated ventilation

- ☑ the highest concentration is observed when talking without a mask.
- ☑ over time, the particles disperse broader, but the poor ventilation continues to result in high concentrations near the source.
- ☑ In Pandemic-updated ventilation, the concentration drop faster
- ☑ breathing without a mask shows a lower concentration compared to talking with a mask,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MI レクチャーノートシリーズ刊行にあたり

本レクチャーノートシリーズは、文部科学省 21 世紀 COE プログラム「機能数理学の構築と展開」（H15-19 年度）において作成した COE Lecture Notes の続刊であり、文部科学省大学院教育改革支援プログラム「産業界が求める数学博士と新修士養成」（H19-21 年度）および、同グローバル COE プログラム「マス・フォア・インダストリ教育研究拠点」（H20-24 年度）において行われた講義の講義録として出版されてきた。平成 23 年 4 月のマス・フォア・インダストリ研究所（IMI）設立と平成 25 年 4 月の IMI の文部科学省共同利用・共同研究拠点として「産業数学の先進的･基礎的共同研究拠点」の認定を受け、今後、レクチャーノートは、マス・フォア・インダストリに関わる国内外の研究者による講義の講義録、会議録等として出版し、マス・フォア・インダストリの本格的な展開に資するものとする。

2022 年 10 月
マス・フォア・インダストリ研究所
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MI Lecture Note Vol.69	土橋　宜典 鍛治　静雄	Symposium MEIS2016: Mathematical Progress in Expressive Image Synthesis　82pages	October 24, 2016
MI Lecture Note Vol.70	Institute of Mathematics for Industry, Kyushu University	Forum “Math-for-Industry” 2016 “Agriculture as a metaphor for creativity in all human endeavors” 98pages	November 2, 2016
MI Lecture Note Vol.71	小磯　深幸 二宮　嘉行 山本　昌宏	Study Group Workshop 2016 Abstract, Lecture & Report　143pages	November 21, 2016

シリーズ既刊

Issue	Author／Editor	Title	Published
MI Lecture Note Vol.72	新井　朝雄 小嶋　　泉 廣島　文生	Mathematical quantum field theory and related topics　133pages	January 27, 2017
MI Lecture Note Vol.73	穴田　啓晃 Kirill Morozov 須賀　祐治 奥村　伸也 櫻井　幸一	Secret Sharing for Dependability, Usability and Security of Network Storage and Its Mathematical Modeling　211pages	March 15, 2017
MI Lecture Note Vol.74	QUISPEL, G. Reinout W. BADER, Philipp MCLAREN, David I. TAGAMI, Daisuke	IMI-La Trobe Joint Conference Geometric Numerical Integration and its Applications　71pages	March 31, 2017
MI Lecture Note Vol.75	手塚　　集 田上　大助 山本　昌宏	Study Group Workshop 2017 Abstract, Lecture & Report　118pages	October 20, 2017
MI Lecture Note Vol.76	宇田川誠一	Tzitzéica 方程式の有限間隙解に付随した極小曲面の構成理論 ―Tzitzéica 方程式の楕円関数解を出発点として―　68pages	August 4, 2017
MI Lecture Note Vol.77	松谷　茂樹 佐伯　　修 中川　淳一 田上　大助 上坂　正晃 Pierluigi Cesana 濵田　裕康	平成29年度　九州大学マス・フォア・インダストリ研究所 共同利用研究集会（I） 結晶の界面，転位，構造の数理　148pages	December 20, 2017
MI Lecture Note Vol.78	瀧澤　重志 小林　和博 佐藤憲一郎 斎藤　　努 清水　正明 間瀬　正啓 藤澤　克樹 神山　直之	平成29年度　九州大学マス・フォア・インダストリ研究所 プロジェクト研究　研究集会（I） 防災・避難計画の数理モデルの高度化と社会実装へ向けて 136pages	February 26, 2018
MI Lecture Note Vol.79	神山　直之 畔上　秀幸	平成29年度　AIMaP チュートリアル 最適化理論の基礎と応用　96pages	February 28, 2018
MI Lecture Note Vol.80	Kirill Morozov Hiroaki Anada Yuji Suga	IMI Workshop of the Joint Research Projects Cryptographic Technologies for Securing Network Storage and Their Mathematical Modeling　116pages	March 30, 2018
MI Lecture Note Vol.81	Tsuyoshi Takagi Masato Wakayama Keisuke Tanaka Noboru Kunihiro Kazufumi Kimoto Yasuhiko Ikematsu	IMI Workshop of the Joint Research Projects International Symposium on Mathematics, Quantum Theory, and Cryptography　246pages	September 25, 2019
MI Lecture Note Vol.82	池森　俊文	令和２年度　AIMaP チュートリアル 新型コロナウイルス感染症にかかわる諸問題の数理 145pages	March 22, 2021

シリーズ既刊

Issue	Author／Editor	Title	Published
MI Lecture Note Vol.83	早川健太郎 軸丸　芳揮 横須賀洋平 可香谷　隆 林　　和希 堺　　雄亮	シェル理論・膜理論への微分幾何学からのアプローチと その建築曲面設計への応用　49pages	July 28, 2021
MI Lecture Note Vol.84	Taketoshi Kawabe Yoshihiro Mizoguchi Junichi Kako Masakazu Mukai Yuji Yasui	SICE-JSAE-AIMaP Tutorial Advanced Automotive Control and Mathematics　110pages	December 27, 2021
MI Lecture Note Vol.85	Hiroaki Anada Yasuhiko Ikematsu Koji Nuida Satsuya Ohata Yuntao Wang	IMI Workshop of the Joint Usage Research Projects Exploring Mathematical and Practical Principles of Secure Computation and Secret Sharing　114pages	February 9, 2022
MI Lecture Note Vol.86	濱田　直希 穴井　宏和 梅田　裕平 千葉　一永 佐藤　寛之 能島　裕介 加葉田雄太朗 一木　俊助 早野　健太 佐伯　　修	2020年度採択分　九州大学マス・フォア・インダストリ研究所 共同利用研究集会 進化計算の数理　135pages	February 22, 2022
MI Lecture Note Vol.87	Osamu Saeki, Ho Tu Bao, Shizuo Kaji, Kenji Kajiwara, Nguyen Ha Nam, Ta Hai Tung, Melanie Roberts, Masato Wakayama, Le Minh Ha, Philip Broadbridge	Proceedings of Forum “Math-for-Industry” 2021 -Mathematics for Digital Economy-　122pages	March 28, 2022
MI Lecture Note Vol.88	Daniel PACKWOOD Pierluigi CESANA, Shigenori FUJIKAWA, Yasuhide FUKUMOTO, Petros SOFRONIS, Alex STAYKOV	Perspectives on Artificial Intelligence and Machine Learning in Materials Science, February 4-6, 2022　74pages	November 8, 2022

シリーズ既刊

Issue	Author／Editor	Title	Published
MI Lecture Note Vol.89	松谷　茂樹 落合　啓之 井上　和俊 小磯　深幸 佐伯　　修 白井　朋之 垂水　竜一 内藤　久資 中川　淳一 濵田　裕康 松江　　要 加葉田雄太朗	2022年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 材料科学における幾何と代数 III　356pages	December 7, 2022
MI Lecture Note Vol.90	中山　尚子 谷川　拓司 品野　勇治 近藤　正章 石原　　亨 鍛治　静雄 藤澤　克樹	2022年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 データ格付けサービス実現のための数理基盤の構築　58pages	December 12, 2022
MI Lecture Note Vol.91	Katsuki Fujisawa Shizuo Kaji Toru Ishihara Masaaki Kondo Yuji Shinano Takuji Tanigawa Naoko Nakayama	IMI Workshop of the Joint Usage Research Projects Construction of Mathematical Basis for Realizing Data Rating Service 610pages	December 27, 2022
MI Lecture Note Vol.92	丹田　　聡 三宮　　俊 廣島　文生	2022年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 時間・量子測定・準古典近似の理論と実験 ～古典論と量子論の境界～　150pages	Janualy 6, 2023
MI Lecture Note Vol.93	Philip Broadbridge Luke Bennetts Melanie Roberts Kenji Kajiwara	Proceedings of Forum “Math-for-Industry” 2022 -Mathematics of Public Health and Sustainability-　170pages	June 19, 2023
MI Lecture Note Vol.94	國廣　　昇 池松　泰彦 伊豆　哲也 穴田　啓晃 縫田　光司	2023年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 現代暗号に対する安全性解析・攻撃の数理　260pages	Janualy 11, 2024
MI Lecture Note Vol.96	澤田　茉伊	2023年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 デジタル化時代に求められる斜面防災の思考法　70pages	March 18, 2024

シリーズ既刊

Issue	Author／Editor	Title	Published
MI Lecture Note Vol.97	Shariffah Suhaila Syed Jamaludin Zaiton Mat Isa Nur Arina Bazilah Aziz Taufiq Khairi Ahmad Khairuddin Shaymaa M.H.Darwish Ahmad Razin Zainal Abidin Norhaiza Ahmad Zainal Abdul Aziz Hang See Pheng Mohd Ali Khameini Ahmad	International Project Research-Workshop (I) Proceedings of 4th Malaysia Mathematics in Industry Study Group (MMISG2023)　172pages	March 28, 2024
MI Lecture Note Vol.98	中澤　嵩	2024 年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 自動車性能の飛躍的向上を目指す Data-Driven 設計　92pages	January 30, 2025
MI Lecture Note Vol.99	Jacques Garrigue	2024 年度採択分 九州大学マス・フォア・インダストリ研究所 共同利用研究集会 コンピュータによる定理証明支援とその応用　308pages	March 17, 2025
MI Lecture Note Vol.100	Yutaka Jitsumatsu Masayoshi Ohashi Akio Hasegawa Katsutoshi Shinohara Shintaro Mori	IMI Workshop of the Joint Usage Research Projects Mathematics for Innovation in Information and Communication Technology 274pages	March 19, 2025
MI Lecture Note Vol.101	Makoto Ohsaki Yoshiki Jikumaru	IMI Workshop of the Joint Usage Research Projects Evolving Design and Discrete Differential Geometry:towards Mathematics Aided Geometric Design 528pages	October 1st, 2025
MI Lecture Note Vol.102	Keunsu Kim	Young Researchers and Students-Workshop (I) Topological Data Analysis and Industrial Mathematics 198 pages	December 22, 2025
MI Lecture Note Vol.103	Kulbir Ghuman Pierluigi Cesana, Kenji Kajiwara, Yu Kaneko Linh Thi Hoai Nguyen Daniel Packwood, Yasser Salah Eddine Bouchareb	International Project Research-Workshop (I) Advancing Materials Data, Design and Discovery 102 pages	December 26, 2025
MI Lecture Note Vol.104	Soon-Sun Kwon Minjung Gim Jae-Hun Jung	International Project Research-Workshop (I) orum “Math for Industry” 2025 - Challenge of Mathematics for Industry in the AI era – 444pages	January 5, 2026

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