An IoT-based Data Collection and Analytics Framework using Bluetooth Proximity Beacons

Background :

Tracking of public bus location requires a GPS device to be installed, and many bus operators in developing countries do not have such a solution in place to provide an accurate estimated time of arrival (ETA)

This project proposes an innovative IoT solution to track the location of buses to collect transportation data without requiring the deployment of GPS devices. It uses Bluetooth Low Energy (BLE) proximity beacon to track the journey of a bus by deploying an *Estimote* proximity beacon on the bus

Targets:

Bus operators in Johor (PAJ Bus) in Malaysia and School bus operator in Malang Indonesia

Benefit general public who commutes everyday by public transport

Speaker:

Sharul Kamal bin Abdul Rahim
Universiti Teknologi Malaysia (UTM)

An IoT-based Data Collection and Analytics Framework using Bluetooth Proximity Beacons

Project Members :

Members	Affiliation
Sharul Kamal bin Abdul Rahim (Project Leader), Abu Sahmah bin Md Supa'at, Jafri Bin Din, Mohd Adib bin Sarijari, Omar bin Abdul Aziz, Olakunle Elijah, Siti Fatimah Bte Ausordin, Muhammad Zairil bin Muhammad Nor	UTM, Malaysia
Sye Loong Keoh, Chee Kiat Seow, Qi Cao	UGS, Singapore
Somnuk Phon-Amnuaisuk, Md Saiful bin Haji Omar, Soon-Jiann Tan, Haji Idham Maswadi bin Haji Mashud	UTB, Brunei

Members	Affiliation
Achmad Basuki, Adhitya Bhawiyuga, Eko Setiawan, Agung Setia Budi	UB, Indonesia
Yung-Wey Chong, Mohd Najwadi Yusoff, Noor Farizah Binti Ibrahim	USM, Malaysia
Kok Chin Khor, Mau Luen Tham	UTAR, Malaysia

Project Duration :

June 2022 – May 2025 (2 years + 1 year Extension)

Project Budget:

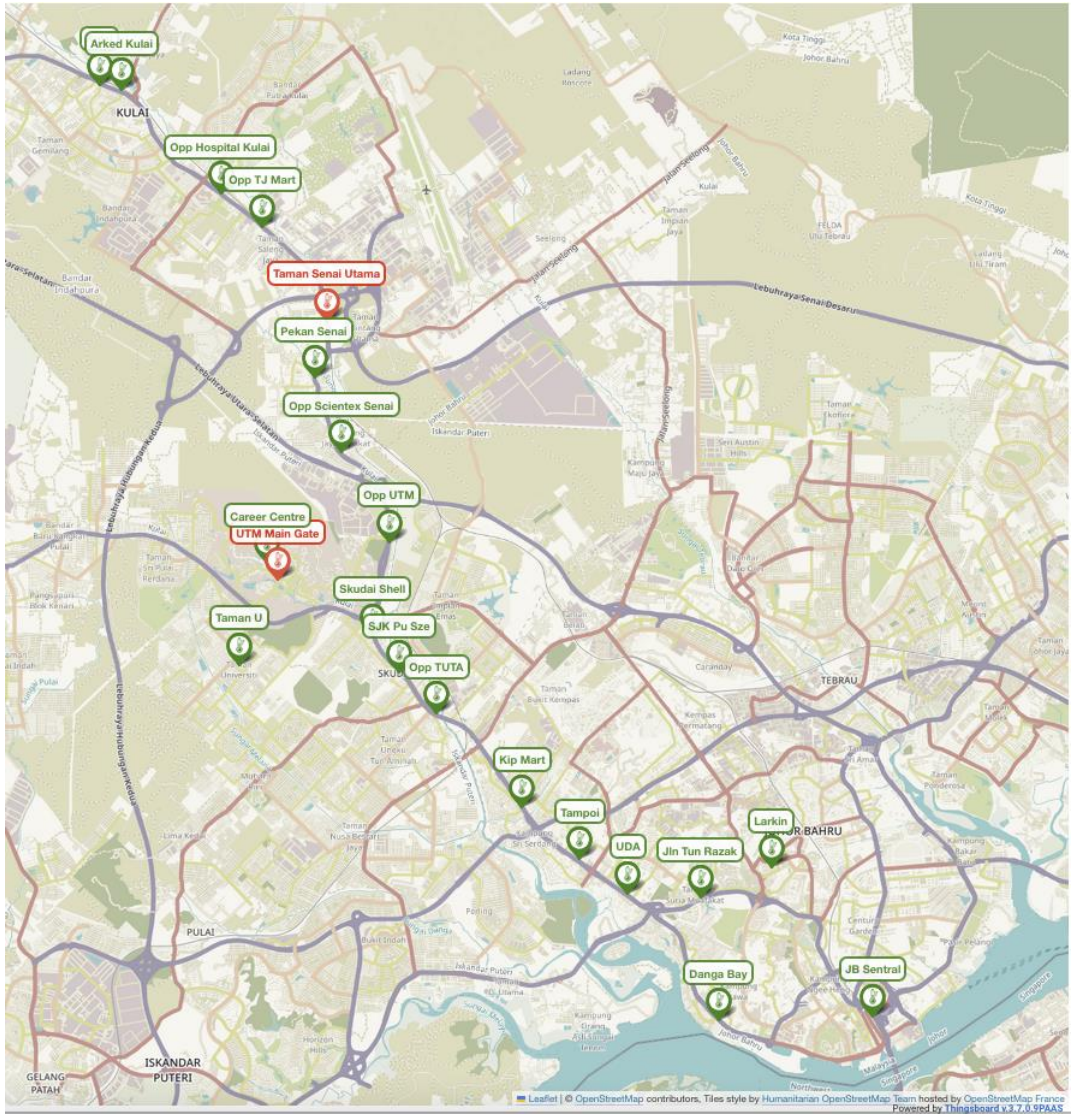
US$80,000

Project Activities: Improving the Reliability of the BLE Sensing System (UGS / UTM / UB)

1. Batteries for the sensing system have been deployed for over 1+ years, and many of them had degraded.

2. Several power outage have caused some batteries to be drained without re-charging. The team had to travel to the sites to replace the batteries.

3. An alternative approach to replace the battery with a 40,000 mAh powerbank is being tested in Johor.



Johor Deployment

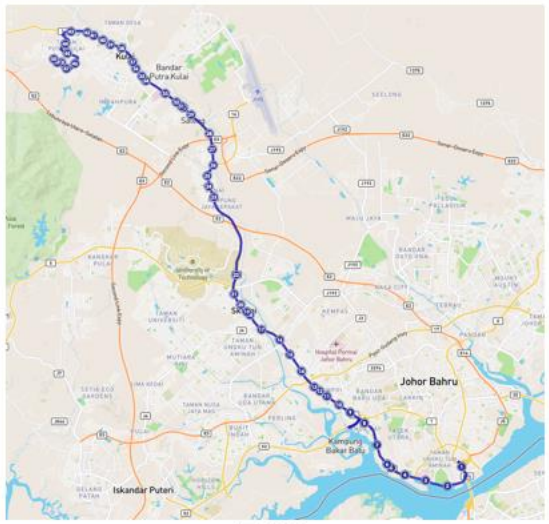
Source: ThingsBoard

Project Activities: Installation of Passenger Arrival Dashboard in Johor

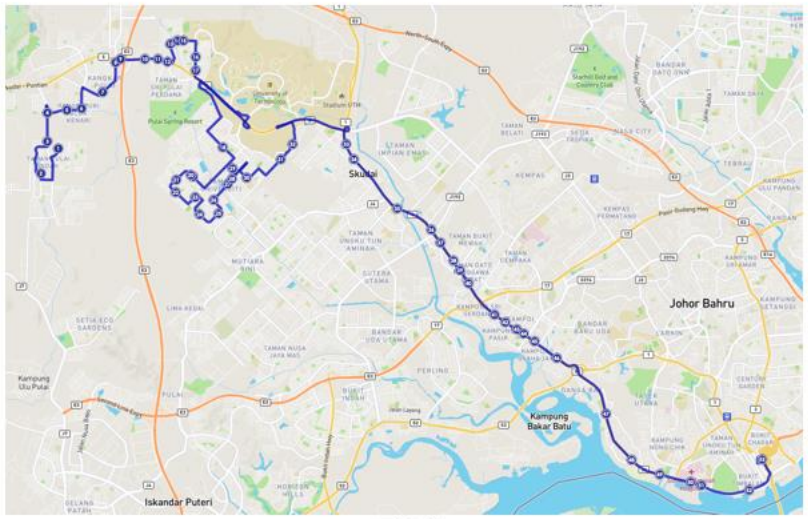
1. Developed bus arrival time dashboard's Interface for bus stop and bus terminal.

2. Extended collaboration with myBAS Johor to track two additional bus services: T30 and T31.

3. Install Passenger Information System Dashboard (PIDS) in Kulai, Senai and Larkin Sentral.



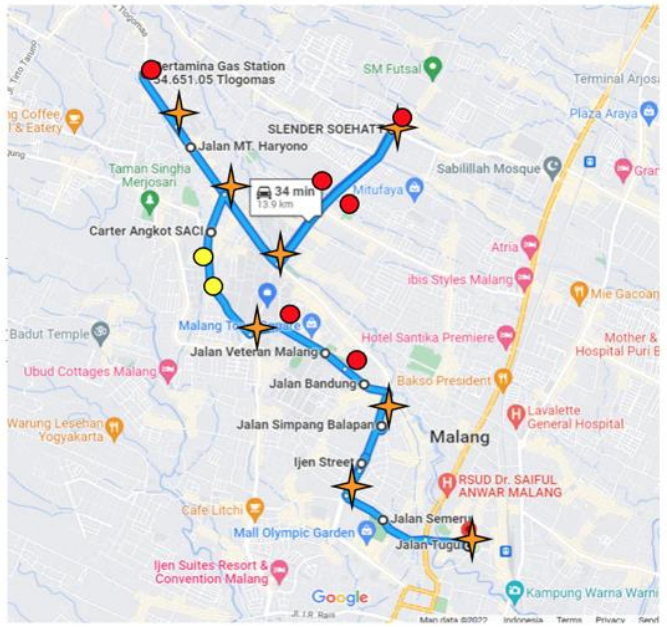
T30



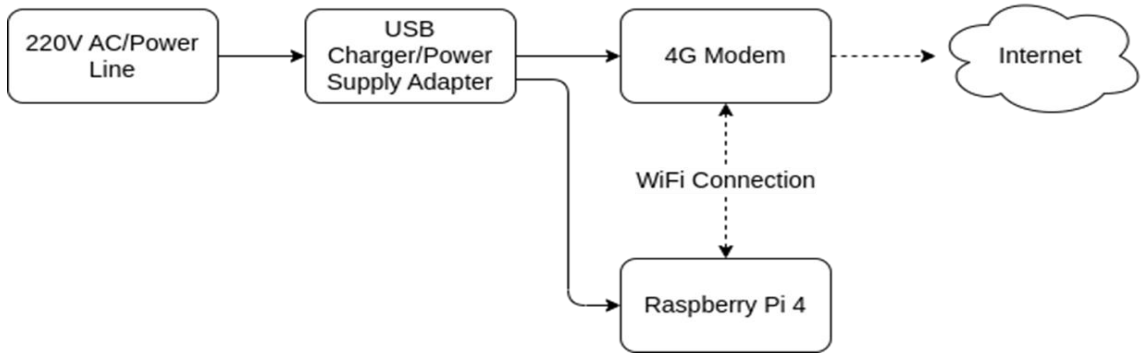
T31

Project Activities: Improving the Reliability of the BLE Sensing System (UGS / UTM / UB)

1. Malang's school bus system lacks real-time monitoring.
2. The map shows a typical bus route.
3. Inside metal box, we put Rpi 4 for detection and android phone for internet connection.
4. We use CCTV pole as source of electricity.
5. We put BLE Beacon Inside bus

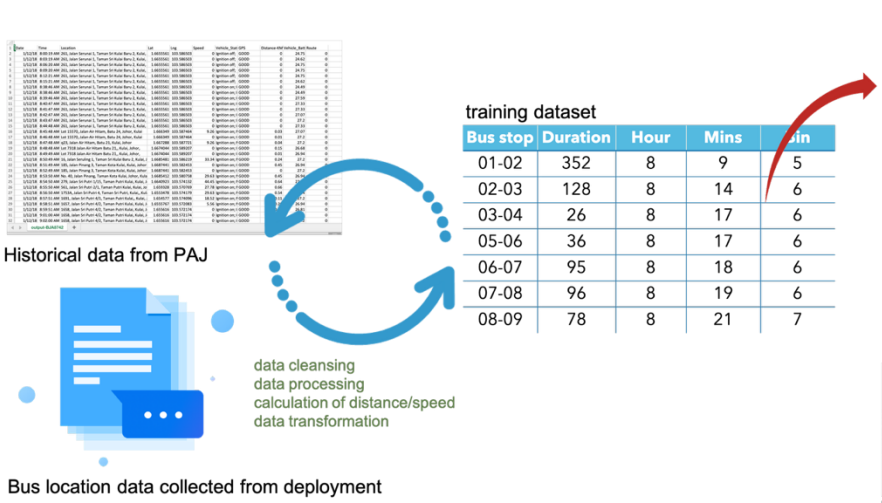


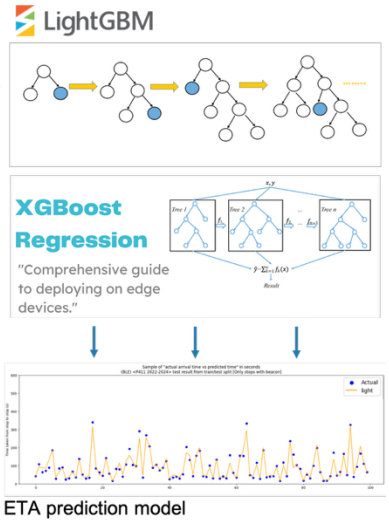
- Yellow Star = RSU (Installed On CCTV pole
- Red Dot = School Bus Stop & Blue line = Bus Route



R&D results: Johor Deployment (UGS/UTM/USM)

1. Raspberry Pi Zero and its battery charging system are deployed on 21 bus stops/terminals across three city councils (Johor Bahru, Iskandar Puteri and Kulai)
2. Bus Routes include:
   - BMJ (PAJ): P211, P411
   - BAS.MY (myBas/Causeway Link): T30, T31
3. A Journey Duration Models were trained using LightGBM and XGBoost based on the BLE location data collected, and deployed into Cloud.
   - LightGBM (MAE=11.49, MSE=376.38, RMSE=19.4, R^2=0.92)
   - XGBoost (MAE=12.70, MSE=437.14, RMSE=20.91, R^2=0.90)



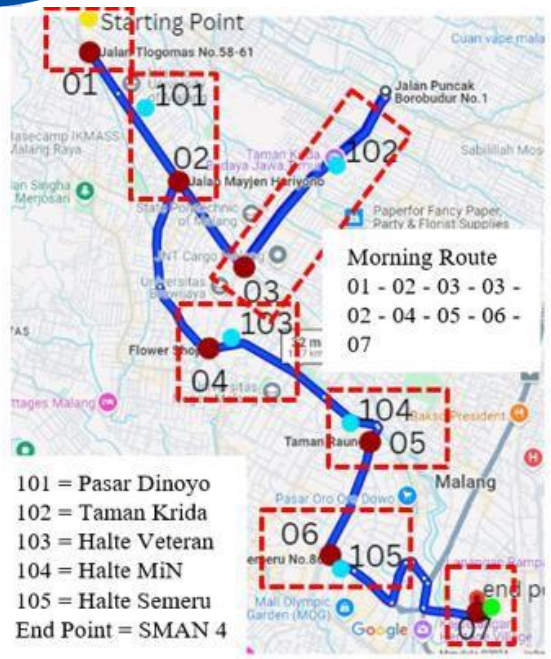


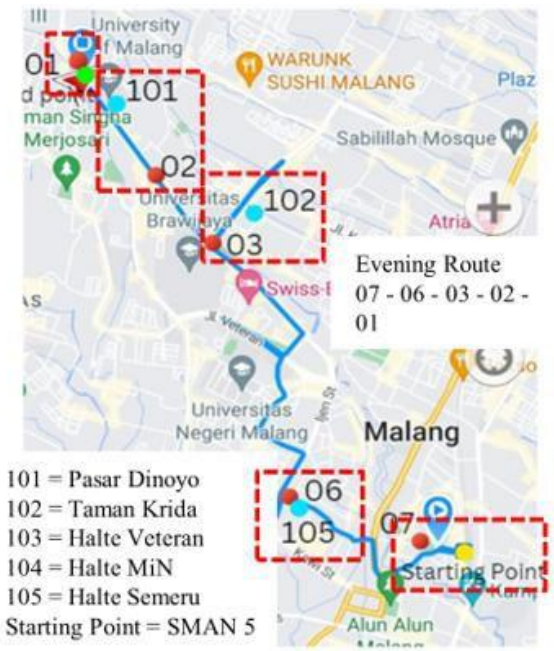
ETA prediction model

PIDS installed in Kulai since Dec'24

PIDS installed in Larkin since Nov'24

R&D results: Prediction of Bus ETA in Malang, Indonesia (USM/UB)





Model	Route	R^2	MAE	MSE	RMSE	Best Hyperparameters
Gradient Boosting	10	0.446	1.53	6.19	2.49	{'learning_rate': 0.01, 'max_depth': 3, 'n_estimators': 200, 'subsample': 0.8}
AdaBoost	10	0.456	1.46	6.08	2.47	{'learning_rate': 0.01, 'n_estimators': 50}
CatBoost	10	0.444	1.51	6.22	2.49	{'depth': 6, 'iterations': 300, 'learning_rate': 0.01}
XGBoost	10	0.445	1.53	6.20	2.49	{'learning_rate': 0.01, 'max_depth': 3, 'n_estimators': 200, 'subsample': 0.8}
LightGBM	10	0.460	1.44	6.04	2.46	{'learning_rate': 0.1, 'max_depth': 3, 'n_estimators': 50, 'num_leaves': 31}
Gradient Boosting	11	0.462	3.26	18.47	4.30	{'learning_rate': 0.1, 'max_depth': 3, 'n_estimators': 50, 'subsample': 0.8}
AdaBoost	11	0.475	3.24	18.05	4.25	{'learning_rate': 0.01, 'n_estimators': 50}
CatBoost	11	0.461	3.23	18.53	4.31	{'depth': 10, 'iterations': 500, 'learning_rate': 0.01}
XGBoost	11	0.459	3.27	18.58	4.31	{'learning_rate': 0.1, 'max_depth': 3, 'n_estimators': 50, 'subsample': 0.8}
LightGBM	11	0.457	3.29	18.67	4.32	{'learning_rate': 0.1, 'max_depth': 7, 'n_estimators': 50, 'num_leaves': 31}

Objective

Compare boosting models for predicting school bus arrival times.

Models Tested

Gradient Boosting, AdaBoost, CatBoost, XGBoost, LightGBM.

Key Findings

- LightGBM performed best for Route 10, with the lowest error rates (MAE: 1.44, RMSE: 2.46)
- AdaBoost was best for Route 11, achieving the highest R^2 (0.475) and lowest RMSE (4.25)

Challenges

- Higher variability in Route 11, requiring careful hyperparameter tuning.

127.0.0.1:5000

School Bus ETA Dashboard

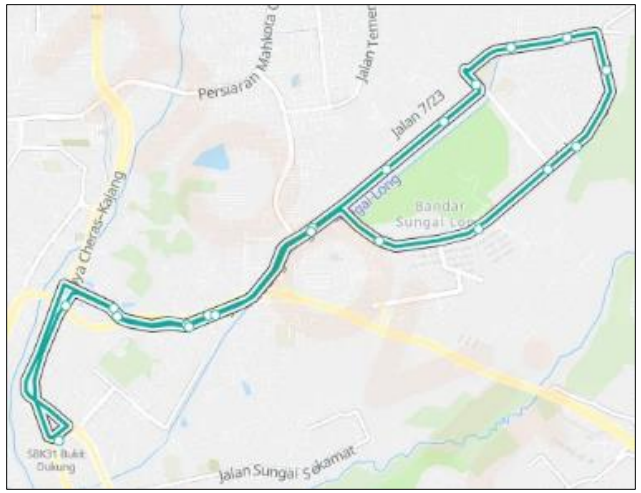
Route 10 Predictions

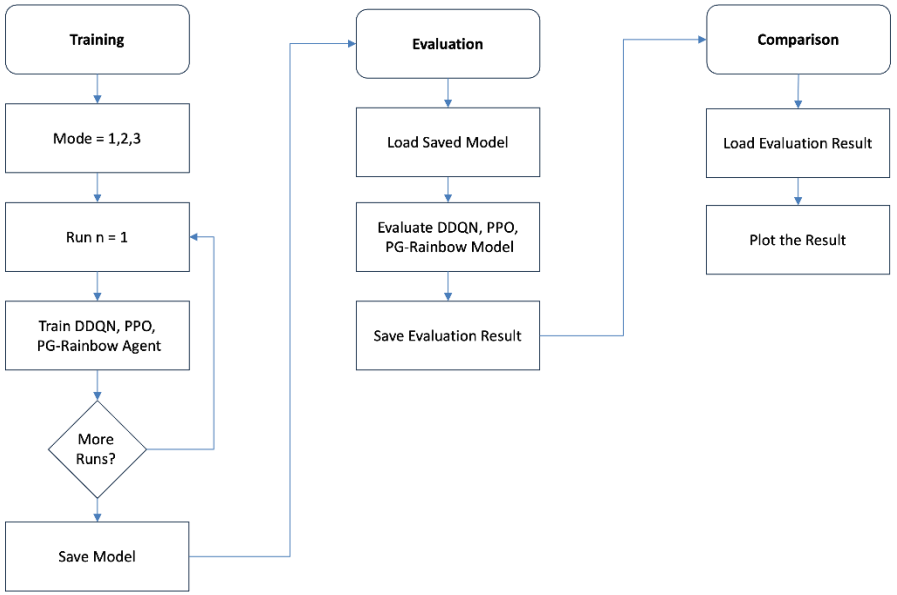
Current Stop	Next Stop	Predicted Time	Time Remaining	Confidence Interval
Pre Pasar Dinoyo 100	Pasar Dinoyo 101	20:10	1 minutes	±2 minutes
Pasar Dinoyo 101	Taman Krida 102	20:15	6 minutes	±2 minutes
Taman Krida 102	Pasar Dinoyo 101	20:21	13 minutes	±2 minutes
Pasar Dinoyo 101	Halte Veteran 103	20:26	17 minutes	±2 minutes
Halte Veteran 103	Halte MiN 104	20:35	26 minutes	±2 minutes
Halte MiN 104	Halte Semeru 105	20:37	28 minutes	±2 minutes
Halte Semeru 105	SMAN 4 106	20:39	30 minutes	±2 minutes

Route 11 Predictions

Current Stop	Next Stop	Predicted Time	Time Remaining	Confidence Interval
SMAN 5 107	Halte Semeru 108	20:26	17 minutes	±3 minutes
Halte Semeru 108	Taman Krida 111	20:34	25 minutes	±3 minutes
Taman Krida 111	Pasar Dinoyo 112	20:53	44 minutes	±3 minutes
Pasar Dinoyo 112	Pre Pasar Dinoyo 113	21:10	61 minutes	±3 minutes

R&D results: Bus Route Optimization using Deep Reinforcement Learning (UTAR)



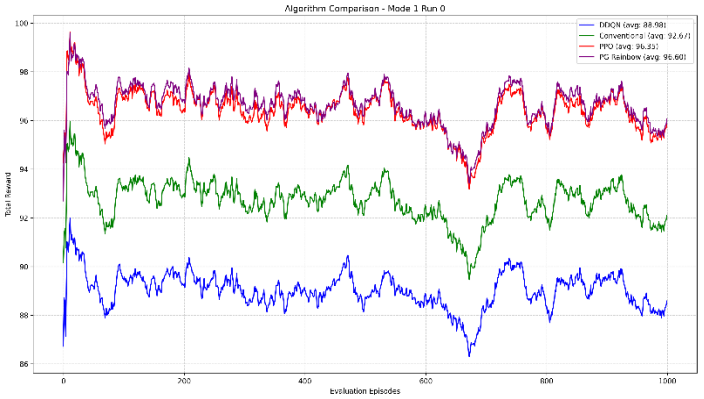


Algorithms		
Proximal Policy Optimization (PPO)	Double Deep Q Network (DDQN)	PG-Rainbow

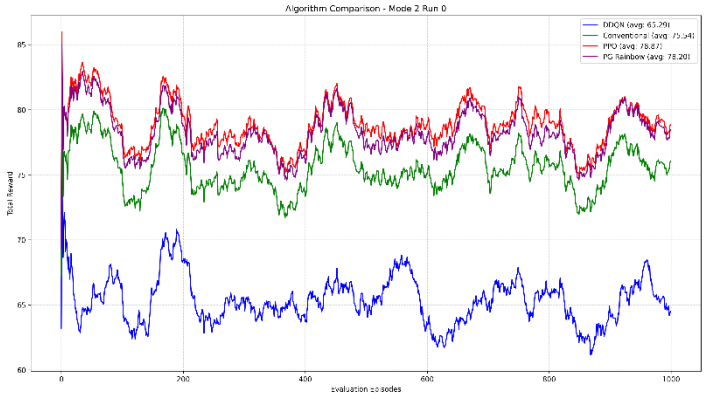
Table 1: Implemented Algorithms

Mode 1	Mode 2	Mode 3
Fixed Demand	Dynamic Demand	Random Demand

Table 2: Scenarios



(a)



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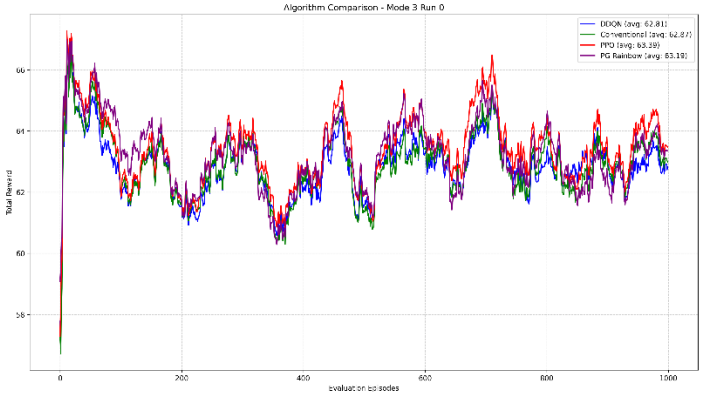

(c)

50-Step Moving Average Score. (a) Mode1 (b) Mode 2 (c) Mode 3

Scientific Contribution:

Presentations at International Conferences:

No:	Paper title:	Author names	Affiliation	Conference name:	The date of the conference	The venue of the conference
1.	Beamforming and Antenna Arrays for Smart City Communication Systems	Sharul Kamal Abdul Rahim, Sye-Loong Keoh	Universiti Teknology Malaysia, University of Glasgow	10TH Brunei International Conference On Engineering And Technology (BICET 2025)	20-22 Oct. 2025	Brunei
2.	An ANN-Based Prediction Model for Public Bus Journey Time	Yong Ting Lim, Sye Loong Keoh, Yung-Wey Chong, Noor Farizah Ibrahim, Sharul Kamal Abdul Rahim	University of Glasgow Singapore, Universiti Sains Malaysia, Universiti Teknology Malaysia	2024 International Conference on Artificial Intelligence in Information and Communication (ICAIIC)	19-22 Feb. 2024	Osaka, Japan
3.	Predicting Estimated Time of Arrival Using Boosting Models	Say-Hong Kam, Yung-Wey Chong, Noor Farizah Ibrahim, Sye-Loong Keoh, Somnuk Phon-Amnuaisuk, Sharul Kamal Abdul Rahim	Universiti Sains Malaysia, University of Glasgow Singapore, Universiti Teknology Brunei Universiti Teknology Malaysia	2024 International Conference on Artificial Intelligence in Information and Communication (ICAIIC)	19-22 February 2024	Osaka, Japan
4.	Antenna and Beamforming Network for 5G IoT Applications	Sharul Kamal Abdul Rahim, Sye-Loong Keoh	Universiti Teknology Malaysia, University of Glasgow	IEEE International Conference on Artificial Intelligent and Signal Processing, AISP 2024	26-27 Oct. 2024	Andhra Pradesh, India
5.	Non-GPS-based ETA Models Constructed from Historical Data and Traffic Contexts	S. Phon-Amnuaisuk, S.J Tan, K.C Khor, M.L. Tham, Y.W. Chong, S. Omar, N.F. Ibrahim, M.N, Yusoff, I. Mashud	Universiti Teknologi Brunei Universiti Tunku Abdul Rahman Universiti Sains Malaysia	8th International Conference on Business and Industrial Research (ICBIR 2023)	18-19 May, 2023	Bangkok, Thailand

Scientific Contribution:

Presentations at International Conferences:

No:	Paper title:	Author names	Affiliation	Conference name:	The date of the conference	The venue of the conference
6.	Towards Prediction of Bus Arrival Time using Multi-layer Perception (MLP) and MLP Regressor	X. Xu, S.L Keoh, C.K Seow, Q. Cao, S.K. Abdul Rahim	University of Glasgow Singapore Universiti Teknologi Malaysia	8th International Conference on Business and Industrial Research (ICBIR 2023)	18-19 May, 2023	Bangkok, Thailand
7.	Deep Reinforcement Learning Based Bus Stop-Skipping Strategy	M.L. Tham, B.S. Tay, K.C Khor, S. Phon-Amnuaisuk	Universiti Tunku Abdul Rahman Universiti Teknologi Brunei	38th International Technical Conference on Circuits, Systems, Computers and Communications	25-28 June, 2023	Jeju Island, South Korea
8.	Antenna and Beamforming Network for B5G/6G IoT Applications	Sharul Kamal Abdul Rahim, Sye-Loong Keoh	Universiti Teknology Malaysia, University of Glasgow	2023 International Conference on Multidisciplinary Applications of Information Technology (ICOMIT)	17-18 July, 2023	Solo, Indonesia

Scientific Contribution:

Published Journal Papers:

No:	Paper title:	Author names	Affiliation	Journal name:	The publisher of the Journal	The volume number and Pages
1.	Transforming urban mobility with internet of things: public bus fleet tracking using proximity-based bluetooth beacons	Olakunle Elijah, Sye Loong Keoh, Sharul Kamal Abdul Rahim, Chee Kiat Seow, Qi Cao, Mohammad Adib bin Sarijari, Noor Farizah Ibrahim, Achmad Basuki	Universiti Teknologi Malaysia, University of Glasgow, Universiti Sains Malaysia, Universitas Brawijaya	Frontiers in Internet of Things	Frontiers	Vol 2-2023
2.	Federated Learning for Intelligent Transportation System (ITS): Use Cases, Open Challenges and Opportunities	Yung-Wey Chong, Kok-Lim Alvin Yau, Noor Farizah Ibrahim, Sharul Kamal Bin Abdul Rahim, Sye Loong Keoh, Achmad Basuki	Universiti Sains Malaysia, Universiti Tunku Abdul Rahman, Universiti Teknologi Malaysia, University of Glasgow, Universitas Brawijaya	IEEE Intelligent Transport Systems Magazine	IEEE	Volume: 17, Issue: 3, May-June 2025

Societal Impact:

- Aims to improve the use of public transport systems in developing countries through the following:
  - Easy access to the bus departure and arrival data
  - Shorten the passenger waiting time if the ETA is known in advanced
  - Effective monitoring of the bus services from the operator's perspective

- With the increase usage of public transport, it will result in less carbon emission, and less traffic congestion

Conclusion:

- Great collaboration among the project members and other project stakeholders:
  - Field trials at Johor and Malang started, and data collection and data analysis.
  - UTM had organized a workshop to engage all the stakeholders, bus operators to present research work in 10-11 December 2025.
  - Journey prediction model established, showing feasibility of using the GPS and BLE dataset to predict journey duration between bus stops.
  - Display panel installation completed.
  - To integrate the system to MBJB monitoring system
  - To extent the system inside UTM

Future works:

- System Development:
  - Expand the system to other routes in Johor.
  - Expand the system to other cities in Malaysia and Indonesia
  - Expand the system to other ASEAN countries
  - Install the display panels in more bus stop.
  - Integrate the system with Johor Municipal Council, MBJB