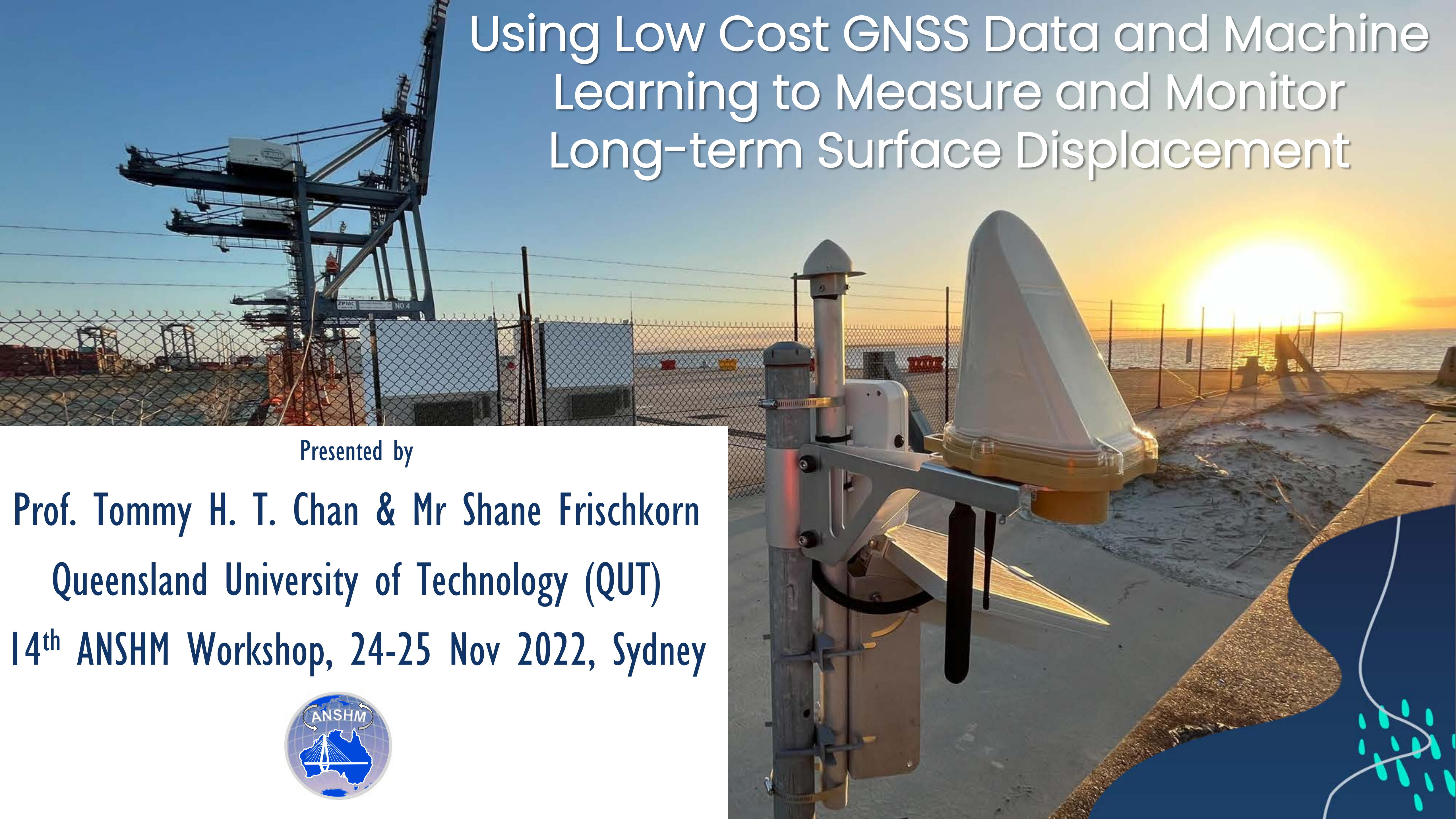
Using Low Cost GNSS Data and Machine Learning to Measure and Monitor Long-term Surface Displacement



Presented by

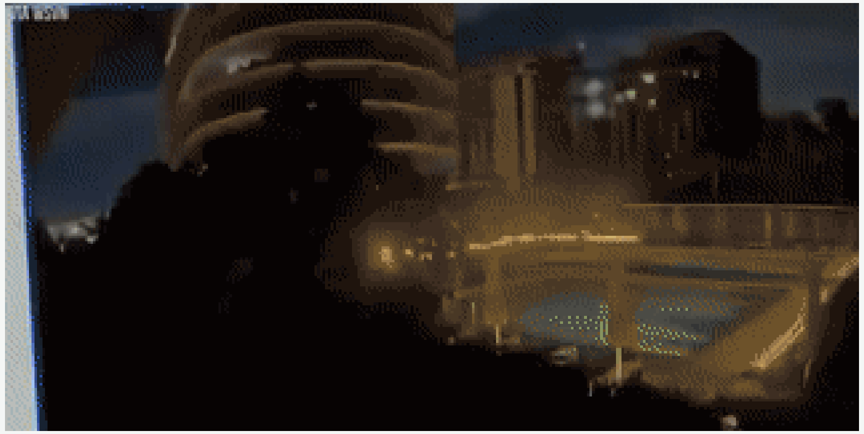
Prof. Tommy H. T. Chan & Mr Shane Frischkorn

Queensland University of Technology (QUT)

14th ANSHM Workshop, 24-25 Nov 2022, Sydney

why remote monitoring?

We face constant & invisible pressure



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Automated monitoring and analytics for settlements of geotechnical structures using Internet of GNSS Things

GNSS-IoT Sensor

- Affordable
- Compact & low power
- Hardware design with suitable technologies
- Configurable remotely
- Security
- Reliability
- Intelligence through additional sensing

GNSS-IoT Service Platform

- SaaS architecture
- Device management
- User management
- Data management and visualization
- Data analytics
- Device operation control

GNSS Data Processing

- GNSS data manipulation and QC
- Automated processing campaign creation and execution
- Service platform integration with log, status and results
- Advance GNSS ML algorithm

SHM in Settlement

- Settlement prediction from GNSS and geotechnical data
- ML-based stratigraphic correlation to predict settlement between sensor locations
- Back analysis to improve geotechnical data accuracy

Business Model

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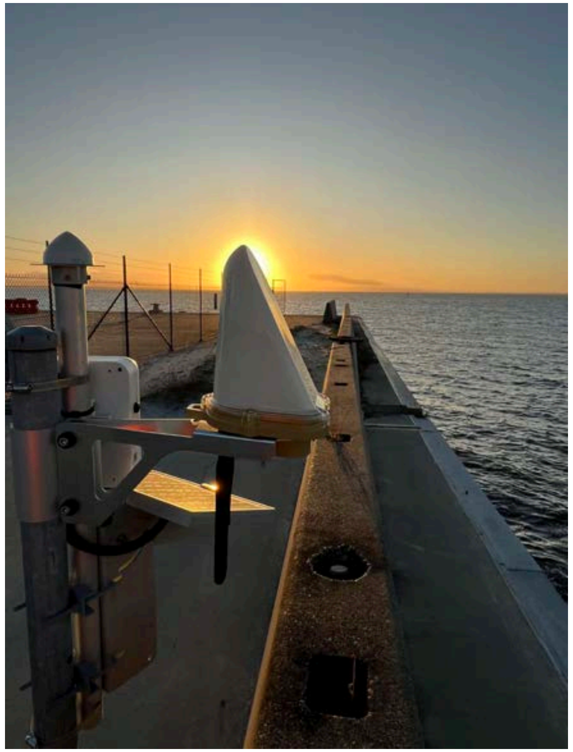
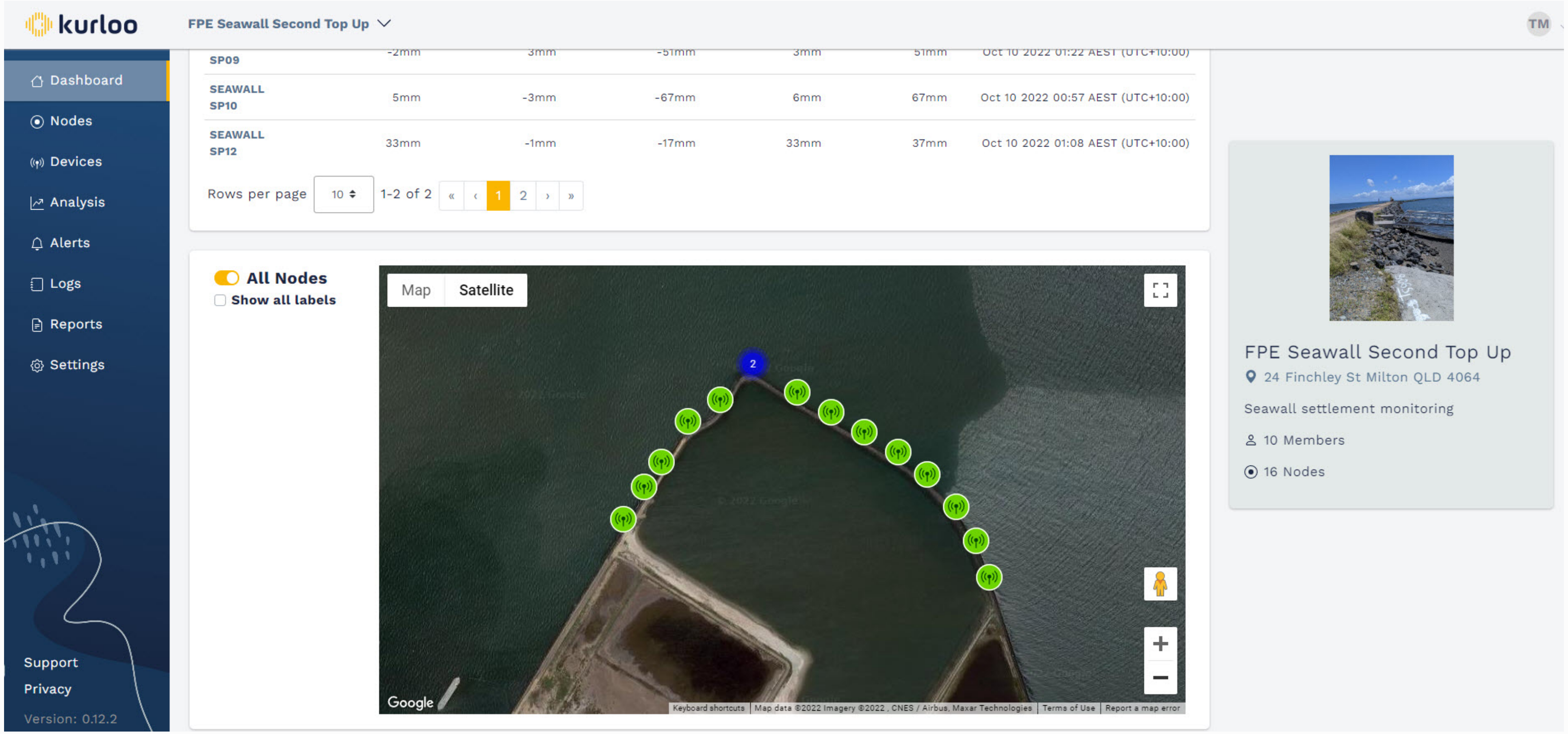
End to End displacement solution
Fully autonomous
Daily mm positioning
Solar powered
Cloud processing
Web based analysis software

kurloo

kurloo



Kurloo Nest


kurloo
FPE Seawall Second Top Up
TM
Dashboard
Nodes
Devices
Analysis
Alerts
Logs
Reports
Settings
Support
Privacy
Version: 0.12.2
SP09
SEAWALL SP10 5mm -3mm -67mm 6mm 67mm Oct 10 2022 00:57 AEST (UTC+10:00)
SEAWALL SP12 33mm -1mm -17mm 33mm 37mm Oct 10 2022 01:08 AEST (UTC+10:00)
Rows per page 10
1-2 of 2
All Nodes
Show all labels
Map
Satellite
Google
FPE Seawall Second Top Up
24 Finchley St Milton QLD 4064
Seawall settlement monitoring
10 Members
16 Nodes

PORT of BRISBANE
Here for the future

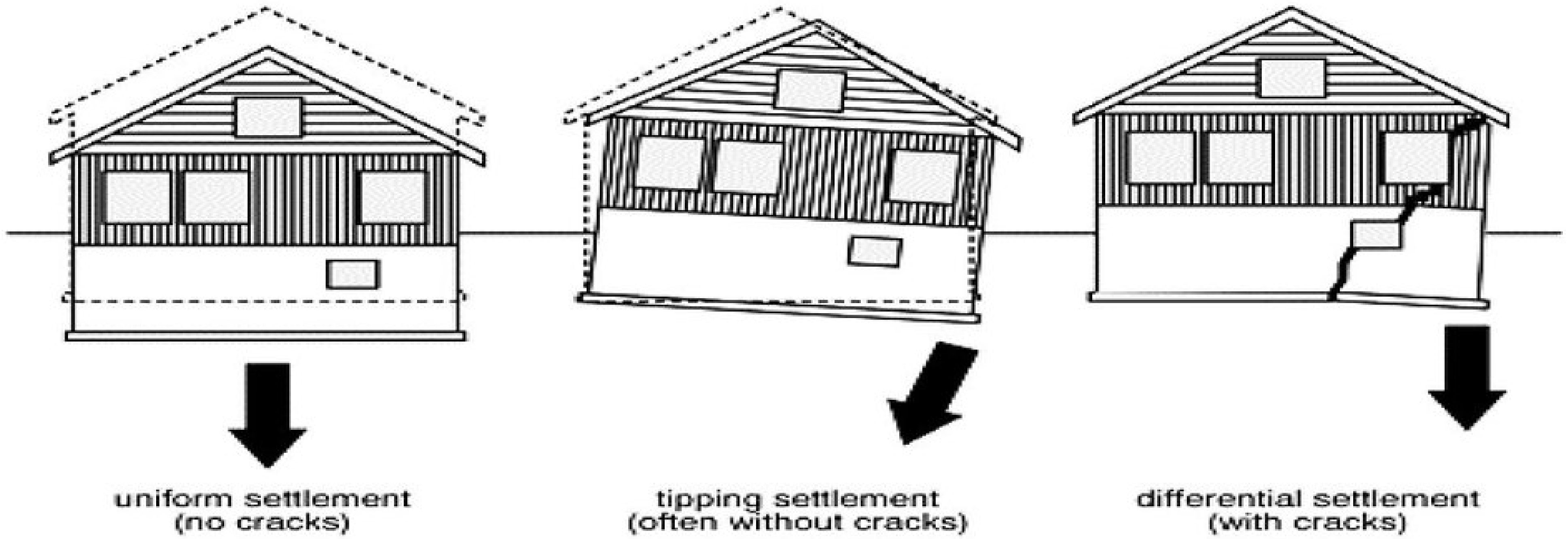
settlement: land reclamation

kurloo

Using GNSS Data and Machine Learning for Settlement Monitoring

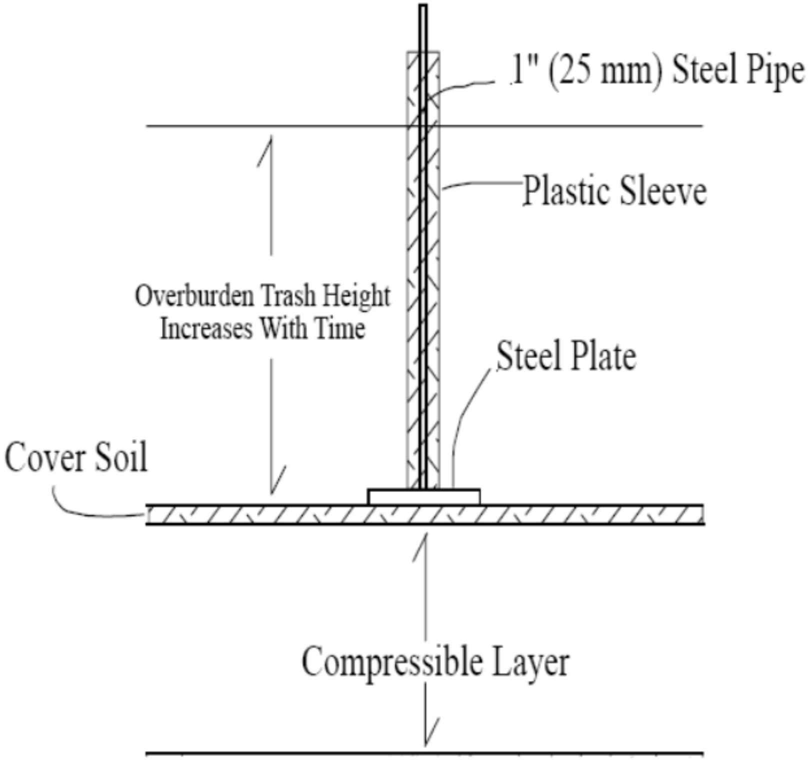
Settlement Importance

Figure 1 - Effects of Settlement on a Building

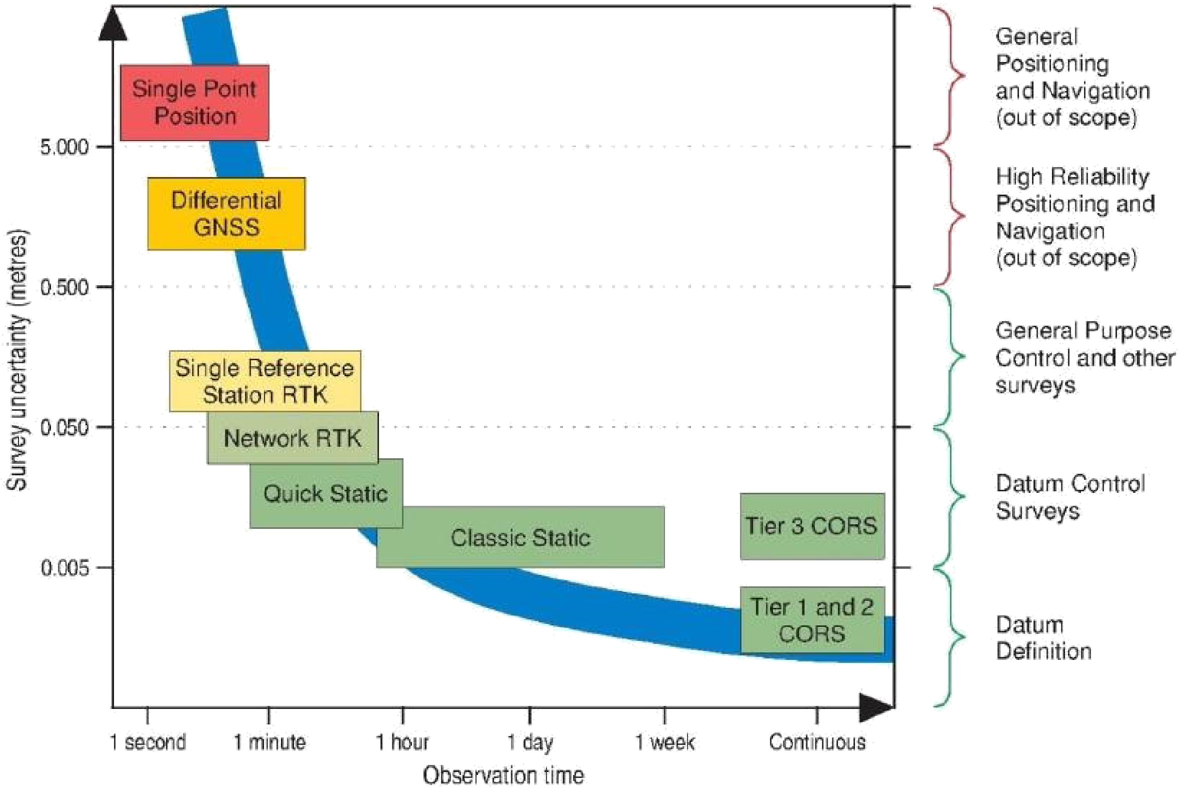


Source: American Society of Home Inspectors (ASHI)

Measuring Settlement



(Minnesota Department of Transportation, 2017)



(PCG, 2014)

Measuring Settlement with GNSS

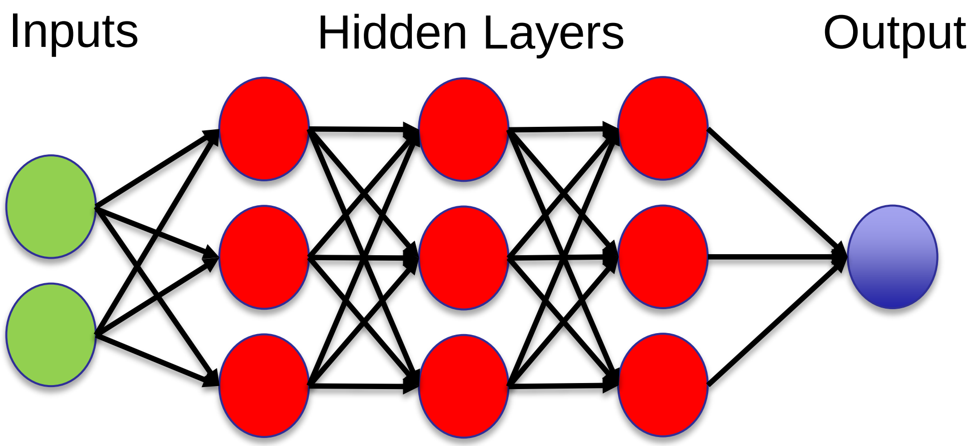
- Prior work
  - Davarpanah et al. (2016) used GNSS for monitoring tunnel induced settlement
    - Results comparable to expected results from numerical modelling
    - Not compared with survey measurements
  - Ganas et al. (2016) measured regional subsidence but only achieved vertical accuracy of ~20mm
  - Khomsin et al. (2019) processed GPS, GLONASS, and BeiDou signals simultaneously and achieved accuracies of 6mm vertically

- Knowledge gap: Can GNSS data be used successfully to monitor settlement?

Settlement Prediction

- Machine Learning Methods
  - Learn from existing data, and continually improve as new data is acquired
  - Agnostic methods, does not have explicit knowledge about problem space

- Can use various algorithms e.g.:
  - Neural network
  - Decision tree
  - Bayesian network



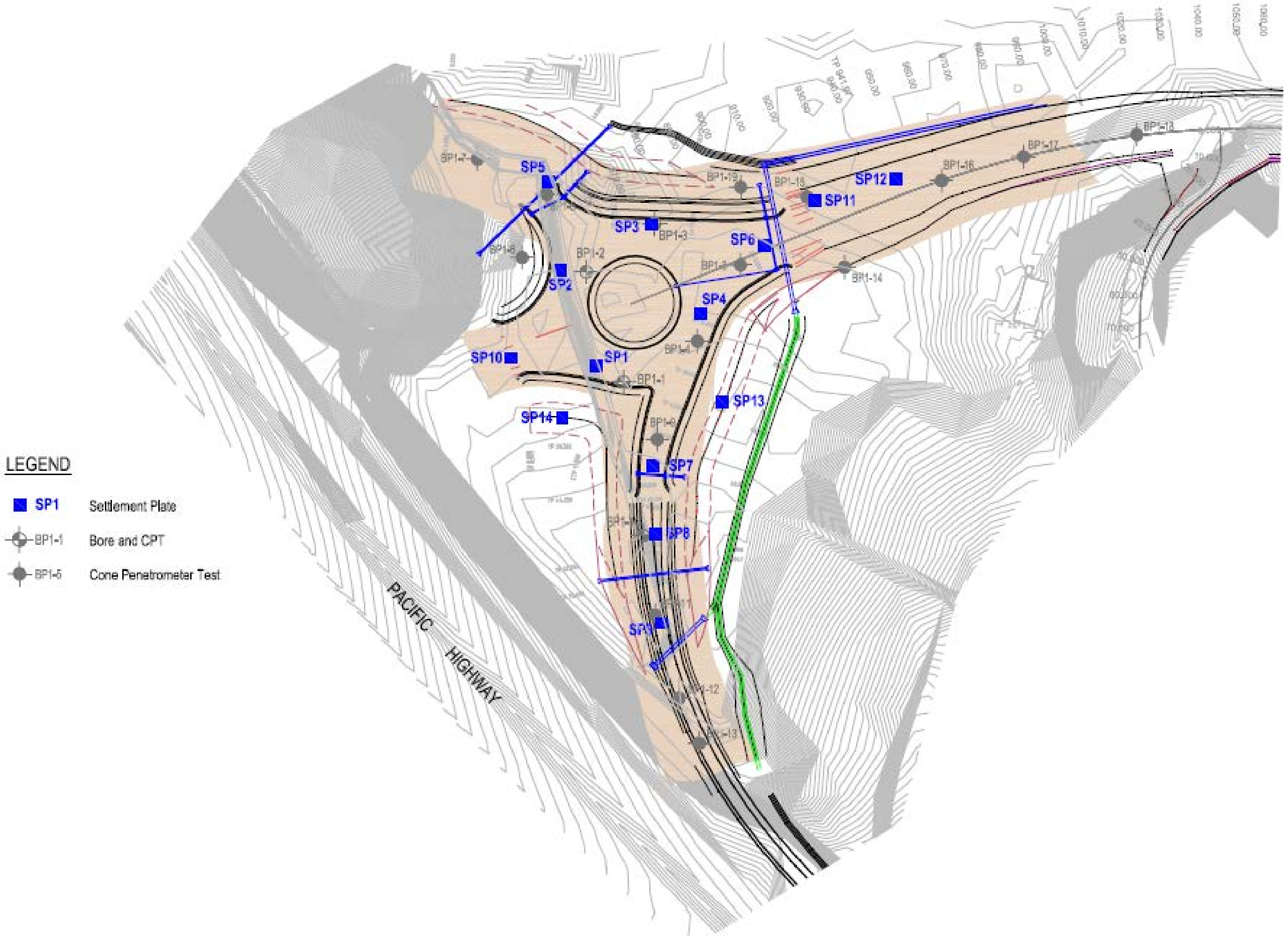
Artificial Neural Network Structure

Settlement Prediction

- Machine Learning Advantages
  - Does not require assumptions
  - Does not require explicit knowledge
  - Can easily be run on different sites with settlement problems

- Disadvantages
  - Dependent on the data it is trained on
  - Does not answer the question of why?, only what?

Input Variables

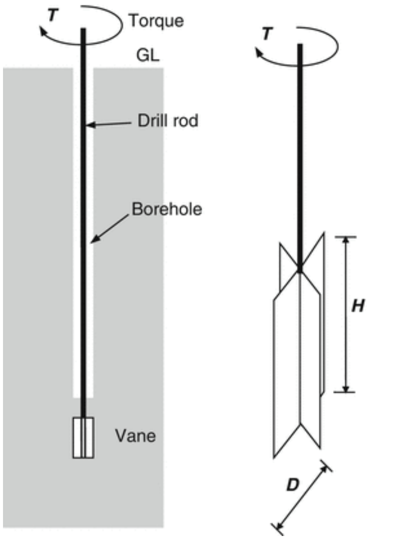


Anonymised settlement project map

Data Always Collected - Borehole

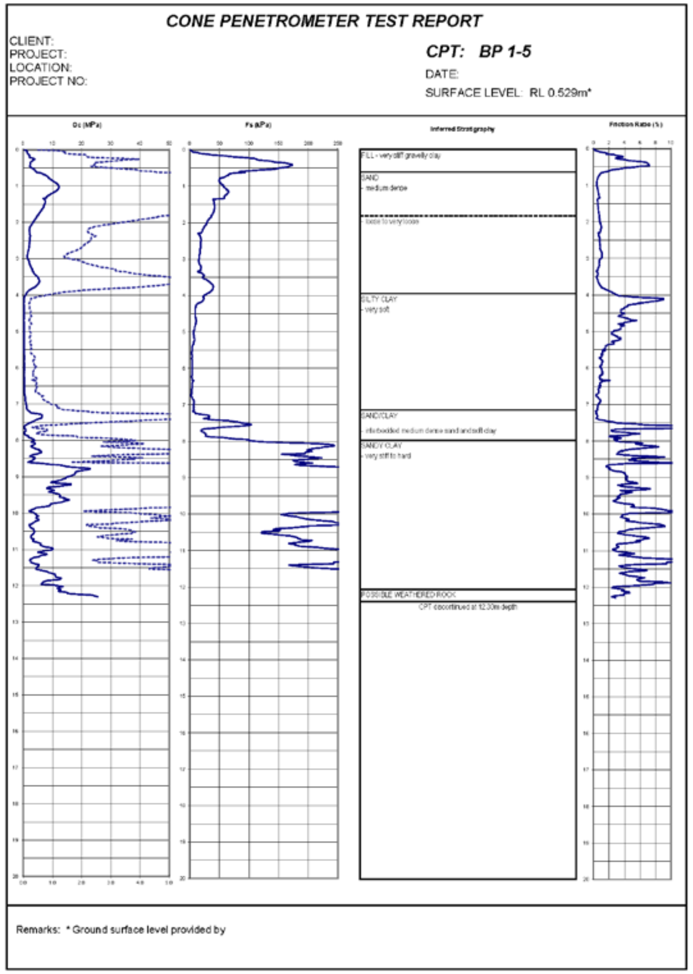
- Borehole Data:
  - Location
  - Stratigraphy (soil layer interface depth)
  - Soil/Lithological classification (USCS)
  - Vane shear strength (kPa)

Bore	Depth	USCS	VSS
BP1-1	3.8	CH	8
BP1-1	6.8	SC	16
BP1-1	8.3	CL	28



(Ameratunga et. al., 2016)

Data Always Collected – CPT/SPT



Digitised cone resistance data

	ID	Depth	Cone Resistance
0	BP1-1	-0.003	-0.272
1	BP1-1	0.0348	0.135
2	BP1-1	0.0786	0.544
3	BP1-1	0.0831	0.585
4	BP1-1	0.0861	0.612

Digitised sleeve friction data

	ID	Depth	Sleeve Friction
0	BP1-1	0.0008	3.83
1	BP1-1	0.1766	18.77
2	BP1-1	0.3323	45.25
3	BP1-1	0.4444	60.72
4	BP1-1	0.5542	54.17

Digitised friction ratio data

	ID	Depth	FR
0	BP1-1	0.0127	1.4613
1	BP1-1	0.0322	1.5987
2	BP1-1	0.0877	1.0248
3	BP1-1	0.1565	0.9003
4	BP1-1	0.3095	0.5389

Digitised inferred stratigraphy

ID	Start	End	Stratigraphy
BP1-1	0	0.8	Fill
BP1-1	0.8	1.25	Fill
BP1-1	1.25	2.4	Sand
BP1-1	2.4	3.45	Sandy Clay
BP1-1	3.45	7.5	Silty Clay

Optional Inputs

Pre-load height at settlement plate locations

Rainfall data

- Can be sourced from the BOM, or from a locally installed rain gauge if necessary

Tipping bucket rain gauge
(Acharya, 2017)

Challenges with Using Geotechnical Data

Averaged Input Data:

Settlement Plate	Soil Layer	Start Depth	End Depth	Friction Ratio	Local friction	Pore pressure	Tip resistance
CB9	1	0.0000	0.0662	0.2224	0.7170	0.0000	0.7478
	2	0.0662	0.1766	0.7781	0.6759	0.1174	0.5386
	3	0.1766	0.2097	0.6244	0.3204	0.1263	0.1206
	4	0.2097	1.0000	0.4730	0.2585	1.0000	0.1315
FF31	1	0.0000	0.0883	0.1993	0.9530	0.0021	1.0000
	2	0.0883	0.1479	0.4379	0.6597	0.0757	0.6121
	3	0.1479	0.2053	1.0000	0.1466	0.3013	0.0280
	4	0.2053	0.8698	0.5330	0.3119	0.8909	0.1214

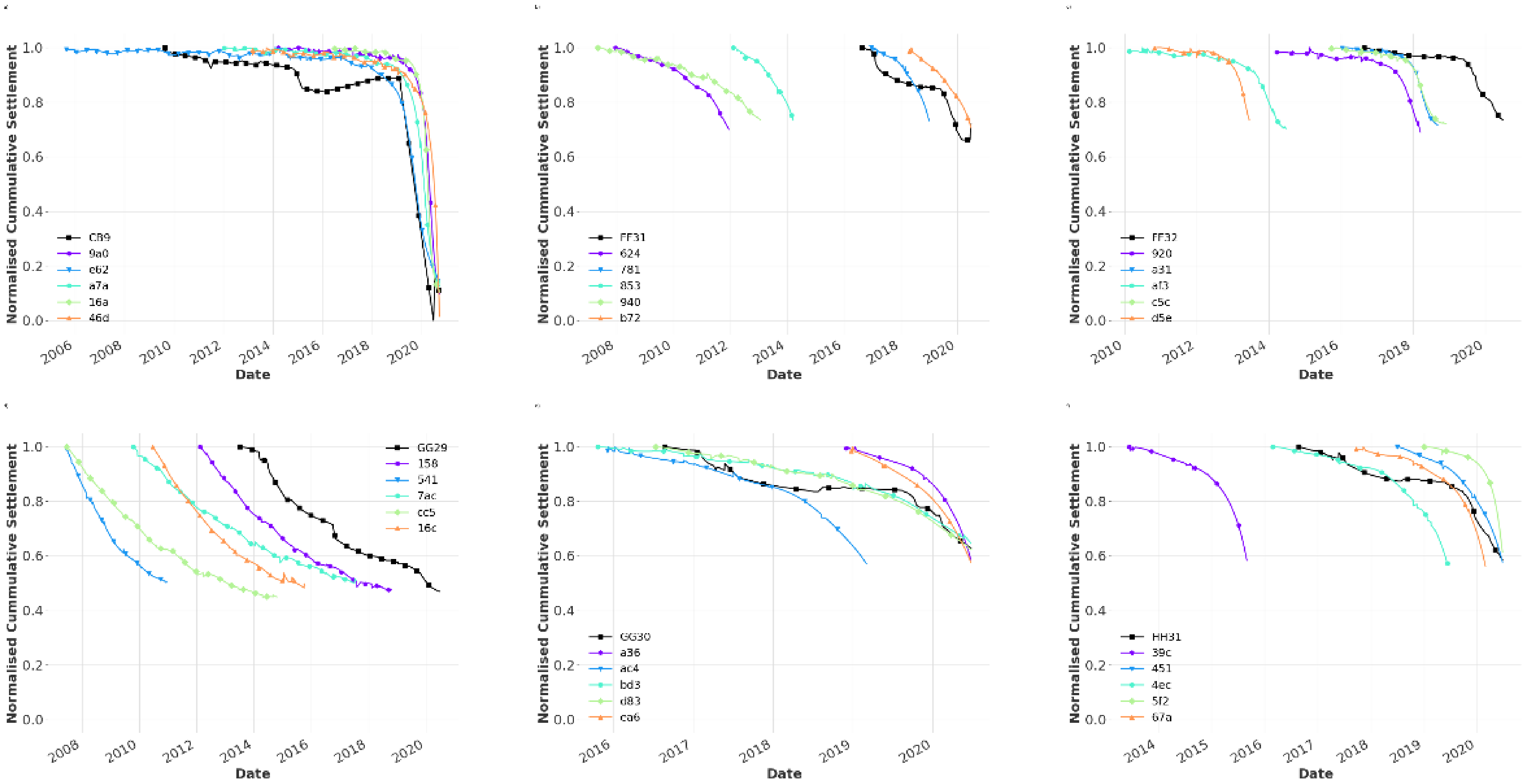
Input tensor y:

Settlement Amount	Settlement Time
5.293	11.11780822
1.662	3.835616438

Input tensor X:

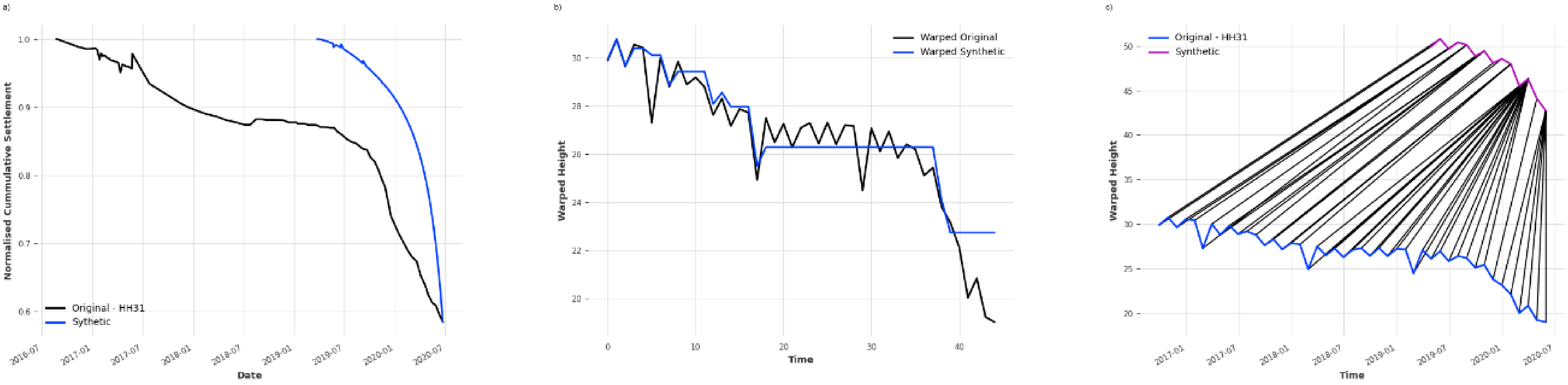
Settlement Plate	Start Depth 1	Start Depth 2	Start Depth 3	Start Depth 4	End Depth 1	End Depth 2	End Depth 3	End Depth 4	Friction Ratio 1	Friction Ratio 2	Friction Ratio 3	Friction Ratio 4	Local friction 1	Local friction 2	Local friction 3	Local friction 4	Pore pressure 1	Pore pressure 2	Pore pressure 3	Pore pressure 4	Tip resistance 1	Tip resistance 2	Tip resistance 3	Tip resistance 4
CB9	0.0000	0.0662	0.1766	0.2097	0.0662	0.1766	0.2097	1.0000	0.2224	0.7781	0.6244	0.4730	0.7170	0.6759	0.3204	0.2585	0.0000	0.1174	0.1263	1.0000	0.7478	0.5386	0.1206	0.1315
FF31	0.0000	0.0883	0.1479	0.2053	0.0883	0.1479	0.2053	0.8698	0.1993	0.4379	1.0000	0.5330	0.9530	0.6597	0.1466	0.3119	0.0021	0.0757	0.3013	0.8909	1.0000	0.6121	0.0280	0.1214

Lack of Data

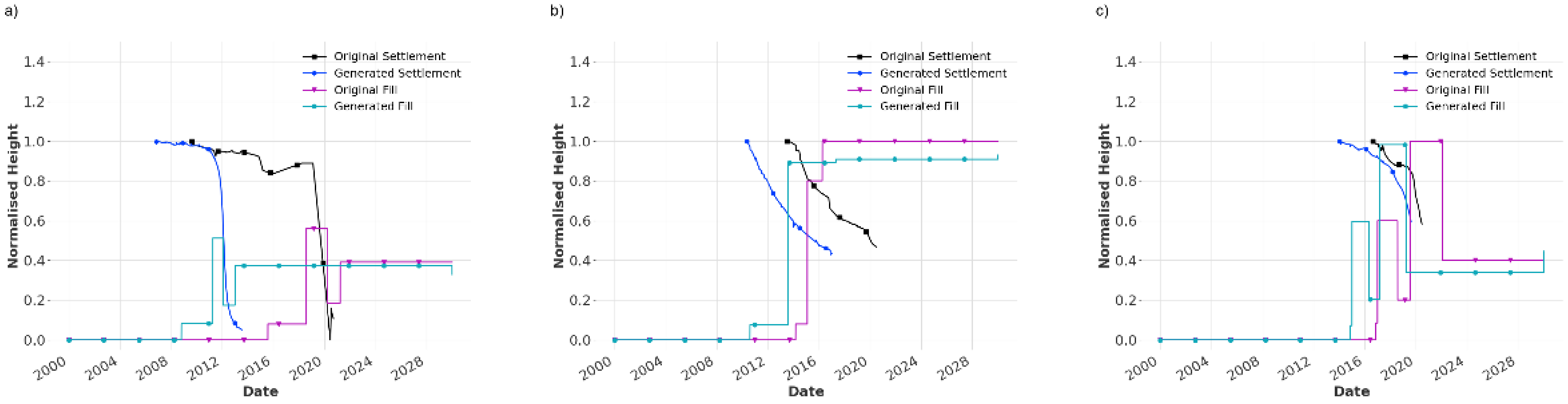


Normalised Cummulative Settlement
Date
CB9
9a0
e62
a7a
16a
46d
FF31
624
781
853
940
b72
FF32
920
a31
af3
c5c
d5e
GG29
158
541
7ac
cc5
16c
GG30
a36
ac4
bd3
d83
ca6
HH31
39c
451
4ec
5f2
67a

Synthetic Data – Dynamic Time Warping

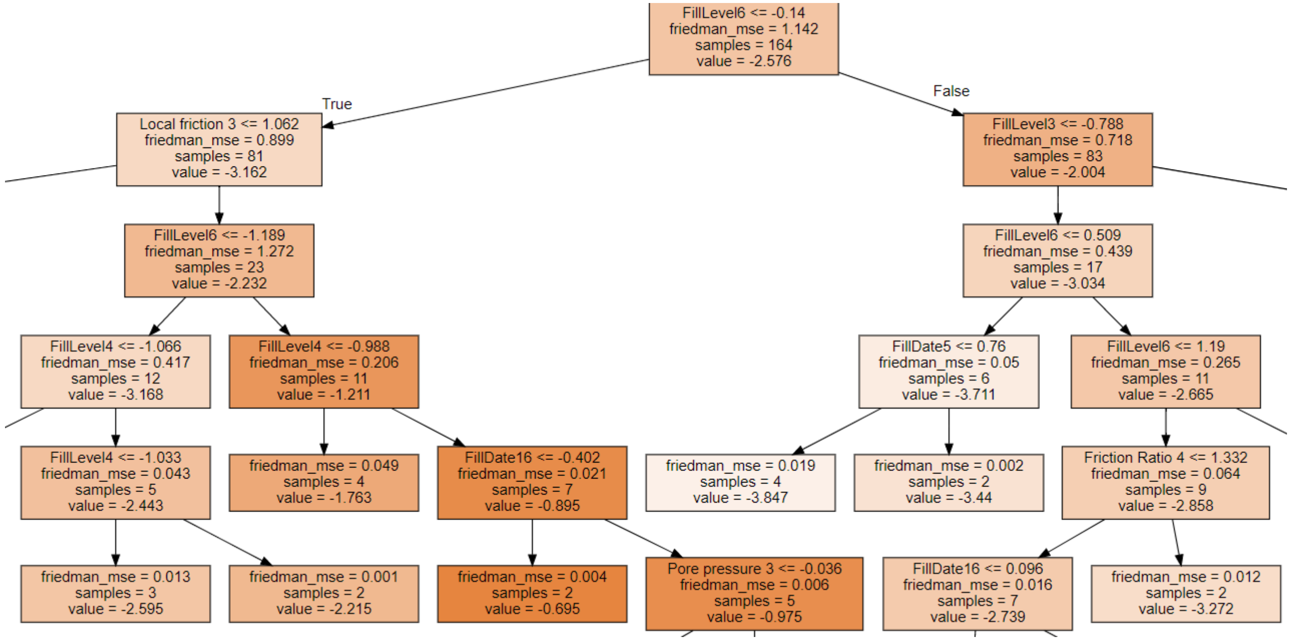


Synthetic Data

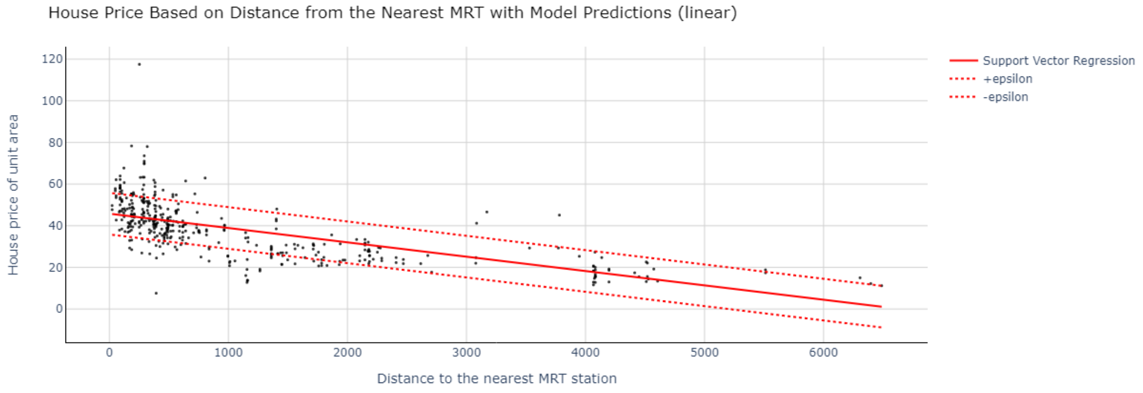


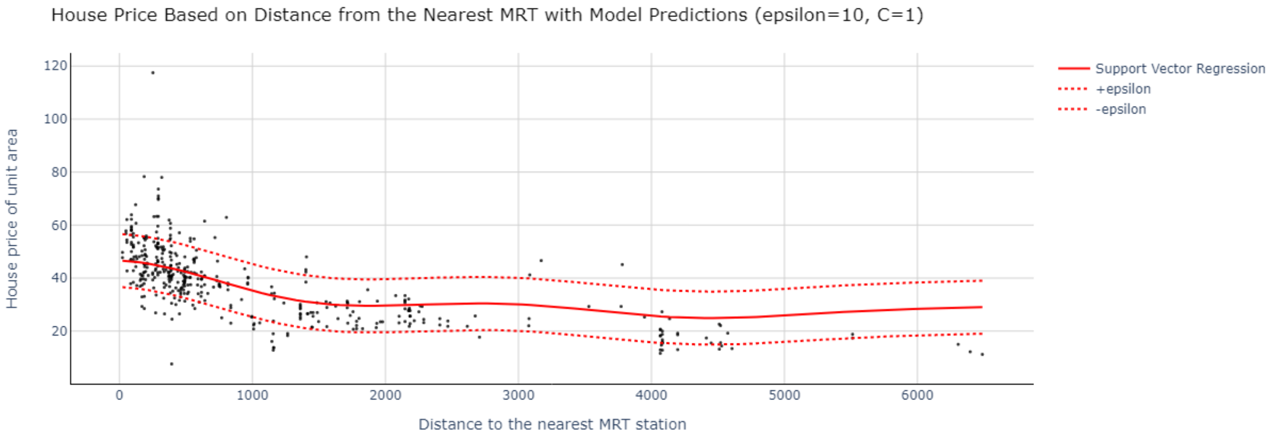
Determining the best model

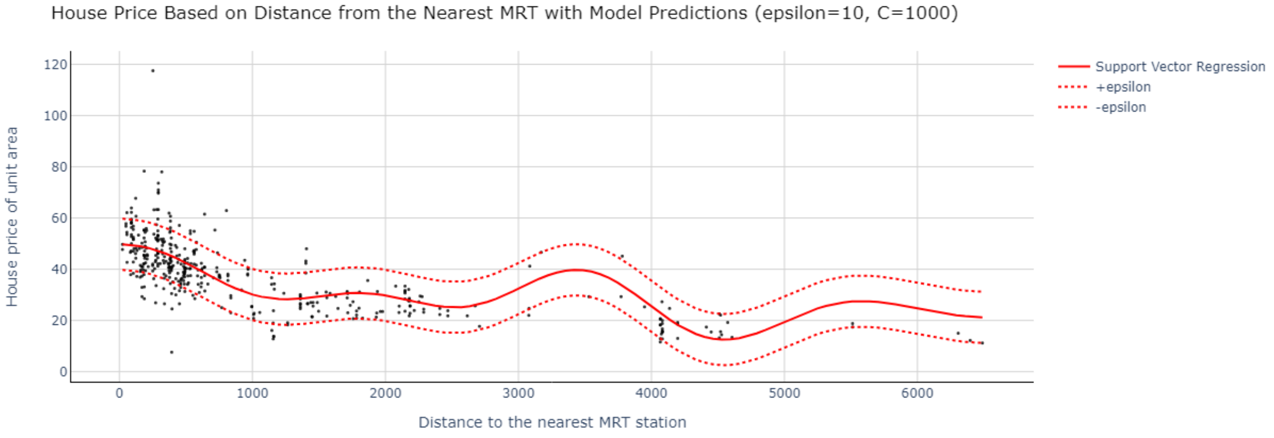
	Amount			Time	
	Single DT	Single SVR	Joint SVR	Single SVR	Joint SVR
MAPE	0.248648058	0.161120357	0.165235751	0.132609274	0.138715022
R2	0.885905768	0.866717378	0.868439693	0.840630768	0.836172834



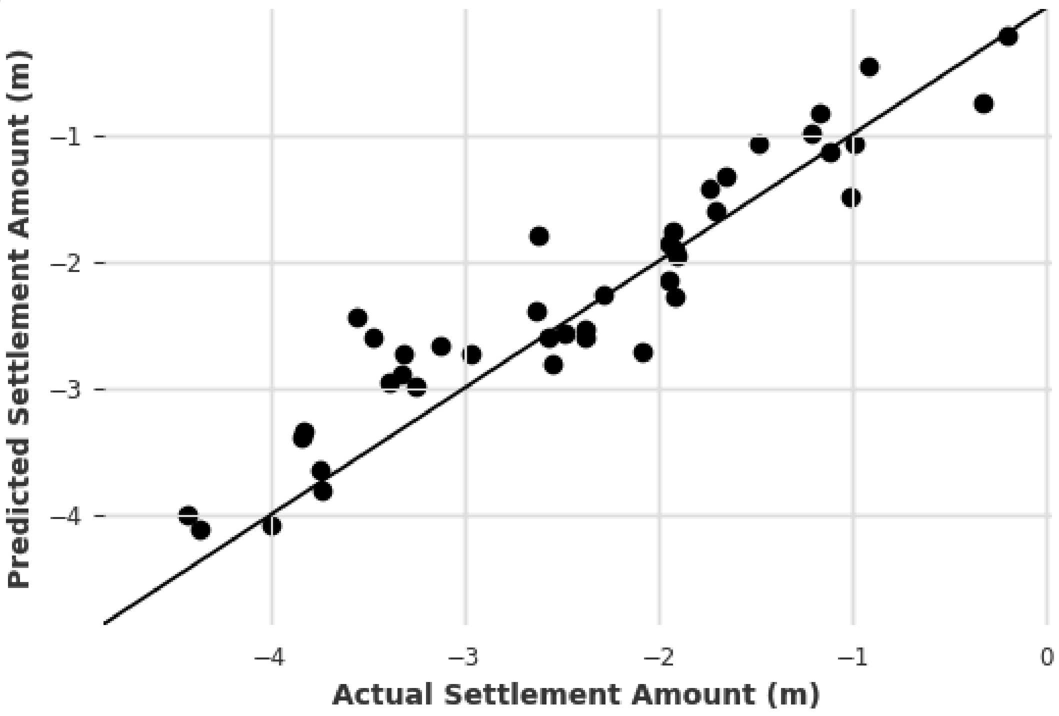
SVR Overview

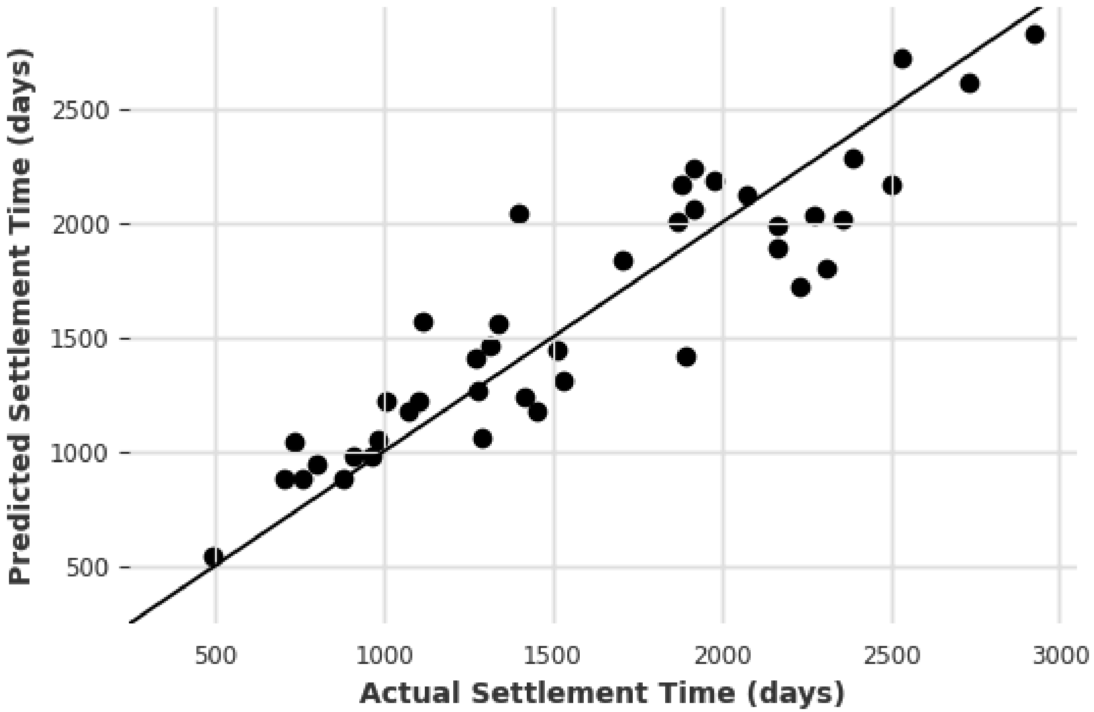






Settlement Prediction Results





Settlement amount prediction vs actual settlement
MAPE: 0.165
r^2: 0.868

Settlement time prediction vs actual settlement time
MAPE: 0.139
r^2: 0.836

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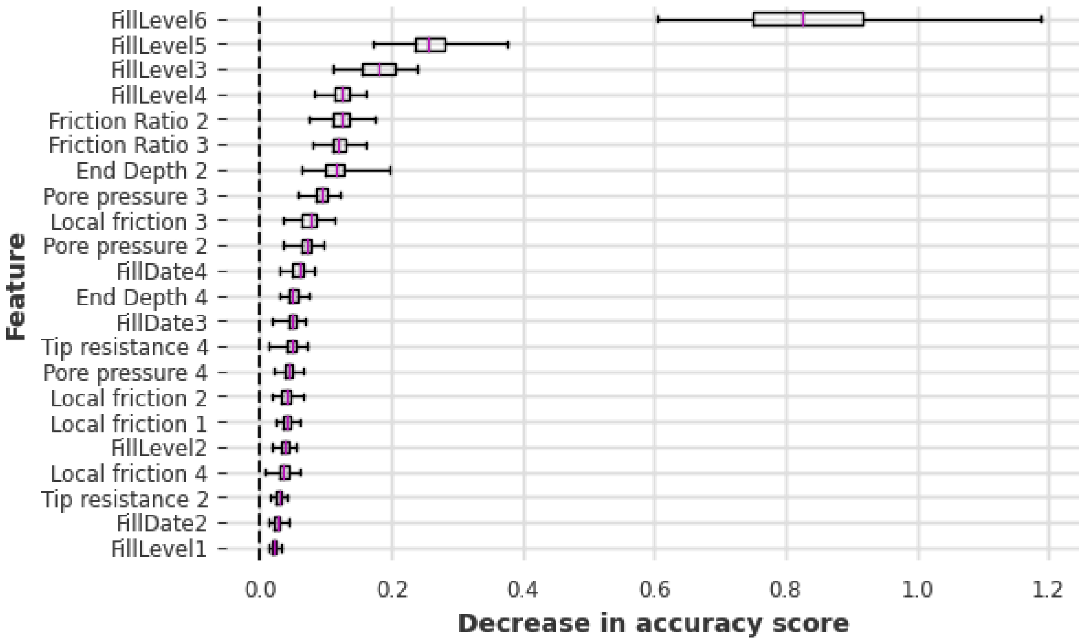
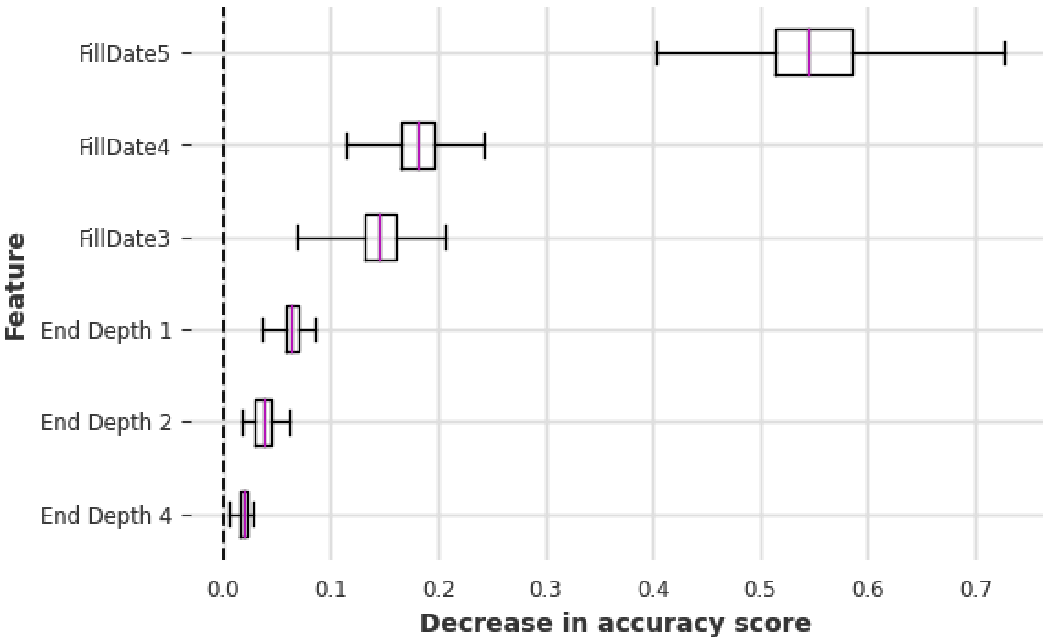
Feature Importance



Most Important features for predicting settlement amount



Most Important features for predicting settlement time

Future Work