RISK ASSESSMENT OF RAILWAY TRACKS IN FLOODPLAIN AREA USING DIGITAL SURFACE MODEL AND COMPUTER VISION

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Abstract: Monsoon region, which Thailand is situated in, experiences frequent heavy rainfall, leading to recurring flooding problems. This is one of the serious natural disasters that cause significant damage to Thailand's Infrastructure. Furthermore, human activities, such as the construction of railway tracks that obstruct the flow of water, and the inadequate natural drainage system also contribute to the problem. In order to analyze the area-based risk factors that cause railway track flooding, 5 major factors, including average total rainfall in rainy season, waterway density, land use, slope, and elevation must be considered. The study utilizes computer vision techniques such as Digital Surface Model (DSM) and flooding simulation to illustrate the topography of the flood-prone area and the right of way of railway tracks. A Digital Surface Model (DSM) is used to illustrate the topography of the flood-prone area and right of way of railway tracks. A comprehensive map showing the likelihood of railway track flooding in the area can be generated via the digital surface model and flooding simulation. Moreover, the results from these techniques can help identify the railway tracks damage, track structure, and surrounding areas due to the influences of different flooding conditions. The outcome of this study will provide a robust flood risk management process that can effectively prevent railway track's damages from natural disasters by utilizing computer vision technology to improve flood modeling accuracy.

Keywords: Digital Surface Model, Disaster risk, Flood, Railway tracks, Computer vision

1. INTRODUCTION

Railway track flooding is a common occurrence in Thailand, especially during the monsoon season when heavy rainfalls lead to flash floods and river overflows which cause extensive damage to railway infrastructure up to 1.3 billion THB (SRT Annual Report, 2017). Flooding of railway tracks disrupts transportation and poses a significant risk to the safety of railway rolling stocks along with passengers and personnel. With the increasing frequency and intensity of extreme weather events due to climate change, railway infrastructure in monsoon regions is facing greater challenges to maintain operational efficiency and safety in long term.

The issue of railway track flooding in Thailand is closely related to the country's floodplains. Western and Southern Thailand's geography are characterized by a network of rivers, which overflow their banks during the monsoon season, leading to extensive flooding (W. Jomwinya, 2017). The railway tracks, which run closely to the rivers, are often located in low-lying areas that are prone to flooding. When floodwaters rise, the tracks and fields become submerged, making the area unpassable.

Moreover, flooded tracks can cause the soil beneath them to erode, wash the ballast away, leading to mud pumping and destabilization of the track bed and compromising the safety of the trains passing over them. This has led to a growing need for effective flood mitigation strategies and better disaster and extreme event management plans to minimize the impact of flooding on railway transportation. In this context, understanding the risk and prediction of railway track flooding in the regions, as well as exploring potential modelling solutions, are crucial for ensuring the predictability, reliability, and resilience of railway infrastructure.

The area that we selected is the floodplain area in the Amphoe Meung Phetchaburi, Phetchaburi Province. The area between the Nong Pla Lai Station and Phetchaburi Station since area of interest had repeated flood over the course of 11 years from GISTDA data. (GISTDA Thailand Flood Monitoring System, 2023) The area, shown below in satellite imagery in Figure 1, is floodplain with some discharge network, land use of paddy fields, elevation between 0 – 10 meters.

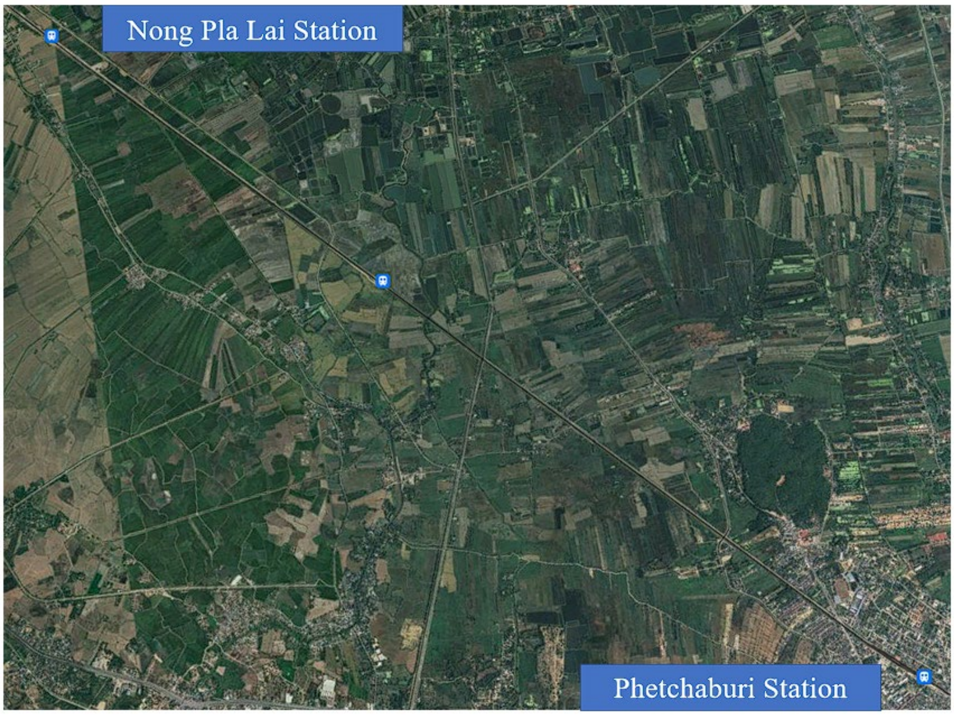


Figure 1. Satellite image of area of interest

2. METHOD

2.1 Data Collection

We associated some factors with a part of secondary data as in land use and slope since the primary data is incomplete or unavailable. By far, the secondary data that we use is the land use data that determine and label by photogrammetry method and usage of satellite imagery, and slope that determined by the 1-meter interval contour of the area which slope can be calculated by differences of elevation. The collection of data involved 5 major area-based risk factors including average total rainfall in rainy season, waterway density, land use, slope, and elevation, in railway tracks flooding, from various sources in Table 1.

Table 1. Data sources

Data	Sources	Type of data	Boundary of data
Digital Surface Model	GTOPO30/ NASA SRTM DEM30	numeric	-15 – 1506 m.
Land Use	Google Earth Imagery	nominal	field, residential
Average Total Rainfall in rainy season	Thai Meteorological Department	numeric	0 – 13.6 cm.
Elevation/ Slope	Contour maps from Department of Geology, Chulalongkorn University NASA SRTM DEM30	numeric	-15 – 1506 m.
Railway Tracks	Department of Geography, Chulalongkorn University	Line	-
Flood history	Geo-Informatics and Space Technology Development Agency	area and ordinal	0 – 9
Waterway density	Department of Geology, Chulalongkorn University	line	-
Catchment Area	Department of Geology, Chulalongkorn University	area	0 – 2,210 km^2
Administrative District	Department of Geography, Chulalongkorn University	nominal	-
Extreme Weather Condition	Thai Meteorological Department	numeric	0 – 20

2.2 Flood Risk Index Calculation

To estimate the risk of the railway tracks in floodplain area, we use the Flood Risk Index (MarshMcLennan, 2021), which describe the flood risk in 3 components which we modified to better suited for local area in Thailand and railway industry which will be described in the table 2 below.

Table 2. Index Components, indicators and data sources

Index components	Indicators	Data Sources
Hazard	Riverine Flood	Digital Surface Model Average Total Rainfall and thunderstorm in rainy season Elevation/ Slope Waterway density
Exposure	Railway Track Exposure	Flood Area Maps: GISTDA Railway Tracks Elevation: SRT
Vulnerability	Railway vulnerability	Flood History: GISTDA

To calculate the Flood Risk Index or FRI, the methodology that we used is to combine 3 components of risk as hazard in form of Flood Hazard Score (FHS), exposure as Flood Exposure Score (FES) and vulnerability as in Flood Vulnerability Score (FVS) into index in the form of Equation (1) which gives us the index to interpret and into risk map

$$FRI = 0.5(FHS) + 0.3(FES) + 0.2(FVS) \tag{1}$$

All of the data in Table 2 is interpreted into one score as in FHS, FES and FVS which can be obtained by Equation (2), (3), (4).

$$FHS = f(Elevation, Slope, Precipitation, Thunderstorm) \tag{2}$$

$$FES = f(ArialExtent, RailTrackElevation) \tag{3}$$

$$FVS = f(FloodHistory) \tag{4}$$

Which f(x) is functions of variable that model automatically tunes

FRI will be classified into 4 categories ranging from 0 – 1 which expressed in Table 3

Table 3. Flood Risk Index

Flood Index Range	Risk Class	Interpretation	Potential Damages
0 – 0.25	Low Risk Area	The area potentially have some flood over the years that can be prevented or mitigated (Low FHS, FES, FVS)	- Embankment seepage - Mud pumping
0.25 – 0.5	Medium Risk Area	The area potentially have some flood over the years that poses risk to railway embankment and needed to be repaired (Medium FHS, FES, FVS)	- Embankment seepage - Mud pumping and track settlement
0.5 – 0.75	High Risk Area	The area mostly flooded over the years and poses threats to railway embankment which damages may extend through ballast and rail track, which needed to be close for operation and repair (High FHS, FES, FVS)	- Embankment seepage - Ballast washaway - Mud pumping and track settlement - Track settlement due to ballast
0.75 – 1	Repeated Flood Area	The area potentially have repeated flood every other year. It poses significant threats to the railway tracks and embankment, which needed to be repaired and closed for unspecified period of time (Highest FVS)	- Ballast washaway - Embankment scour - Mud pumping and track settlement - Track settlement due to ballast

2.3 Risk Index Interpretation

(1) Idealize Track Condition.

To reference the ideal condition of track. We use State Railway of Thailand's standard for double track construction project. Which include engineering parameters, material properties and geometry of the track. Those data are presented in Table 4.

Table 4. Engineering parameters, material properties and geometry of the track.

Engineering Parameters	Data
Track Gauge	1 Meter
Rail Section	Bs100a
Sleeper Type	Prestress Concrete
Sleeper Dimension	200 X 50 X 25 cm
Ballast Material	Andesite, Rhyolite
Ballast Depth	70 cm
Embankment Height	2-6 m

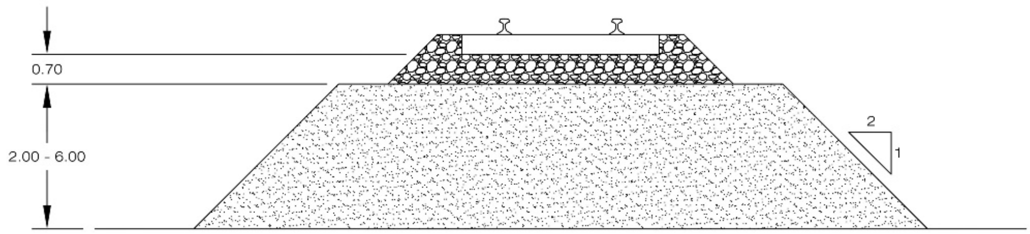


Figure 2. Railway Embankment

(2) Track Damage Interpretation from Flood Risk Index.

Track damage can be interpreted from flood risk index by categorizing character of flood area. Which can be categorized into 2 characters. One-sided flood and Two-sided flood. Those 2 categories are different in behavior of failure.

1.) One-sided flood

One-sided flood can be determined as a section of track which has high flood risk index area on one side but low or insignificant flood risk index on the other side. Or both of them are very different in value. This type of flood tends to have high movement and force. which causes damage to the track structure via 3 different processes.

Categorized by height and speed of the flood, 3 processes are described as in and in Figure 3 denoting by the letter (a), (b), and (c)

(a.) Embankment seepage

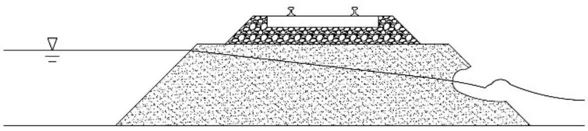
Embankment seepage caused by one-sided flood with water level is lower than ballast level. Or described as water level are within the area of embankment. According to State Railway of Thailand's standard for double track construction project. Track embankment is constructed by compacting earth materials. This type of material can have a phenomenon that existing water on one side of the material tends to move to the other side. Called water seepage. This phenomenon creates seepage force which can damage the track embankment. Causing embankment material to wash away on the other side of the flood.

(b.) Ballast washaway

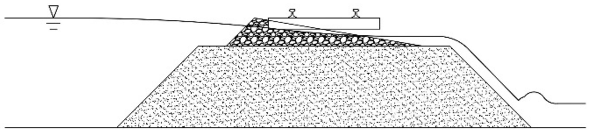
Ballast washaway caused by one-sided flood with water level is higher than ballast level. Creating overtopping flow of flood. Which can wash away ballast with it. Track with missing ballast can affect strength and stiffness of the track.

(c.) Embankment scour

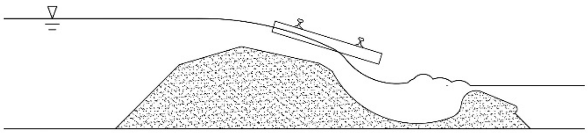
Embankment scour caused by one-sided flood with water level is higher than ballast level and have extreme velocity. A great amount of force created by water streams can damage whole structure. making the whole embankment fail and collapse.



(a.) Embankment seepage



(b.) Ballast washaway



(c.) Embankment scour

Figure 3. Type of Railway tracks failure in one-sided flood condition

2.) Two-sided flood

Two-sided flood can be determined as a section of track which area in both sides have high flood risk index, and no significant differences in term of value. This type of flood tends to remain stationary with no or negligible stream flow. With that, this type of flood causes damage to the track structure via 2 different processes,

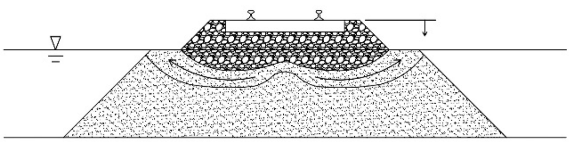
Categorized by level of the flood. 2 processes are described as in and in Figure 4 denoting by the letter (a), and (b)

(a.) Mud pumping and track settlement due to embankment material movement

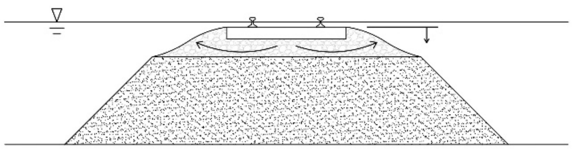
This type of damage is caused by flood on both sides of the track with water level lying within the area of embankment. When embankment material is soaked. Material swells and loses its compactness and becomes slurry substances. This mud-like substance is poor in performance of withstanding train load due to its high fluidity. This substance can seep through ballast layer and eject out caused by high pressure from train load when train is passing by. This phenomenon is mud pumping. Which can reduce stiffness of the track and increase track settlement.

(b.) Track settlement due to reduction of ballast interlocking

This type of damage is caused by flood on both sides of the track with water levels higher than the ballast level. The presence of water in the ballast layer acts like a lubricant causing the ballast aggregate to lose its skin friction and interlocking. Which can reduce stiffness of the track and increase track settlement.



(a.) Mud pumping and track settlement due to embankment material movement



(b.) Track settlement due to reduction of ballast interlocking

Figure 4. Type of Railway tracks failure in two-sided flood condition

2.4 Risk of Hazard in Floodplain Area Around Railway Tracks

To estimate the risk of floodplain area around railway tracks, making computers understand the physical parameters surrounding railway tracks from geological data is needed. This involves collecting data such as the elevation of the tracks, the distance from the nearest water source, and the surrounding rail track characteristics such as embankment, ballast. Also, we need flood history to be able to correctly predict and calculate the flood risk index (FRI).

Once we have this data, we can select candidate estimators that might be able to accurately estimate the area of the floodplain. The model which we select will be called estimators which calculate and predict the flood risk index that will be able to represent the flood history. These estimators include machine learning algorithms, statistical models, and other computational methods via transferring data from numerical data into raster and then transform into dataframe which can be used in the model.

Table 5. Floodplain estimators

Model	Type of processing
Multinomial Logistic Regressor*	Classifier
Multinomial Naïve Bayes*	Classifier
Multi-Layer Perceptron (MLP)*	Fully connected ANN
Convolutional Neural Network based	Backpropagation
Transformers based model	Attention-based

*Model use for classified flood on rail

(1) Model Inputs

The input of the model is digitalised into raster data and put into the python which then integrated with DEM data, all of the input can be found in Table 2. Then, transformation of independent variables and integrated into the dataframe and put into the model as explained in Figure 5.

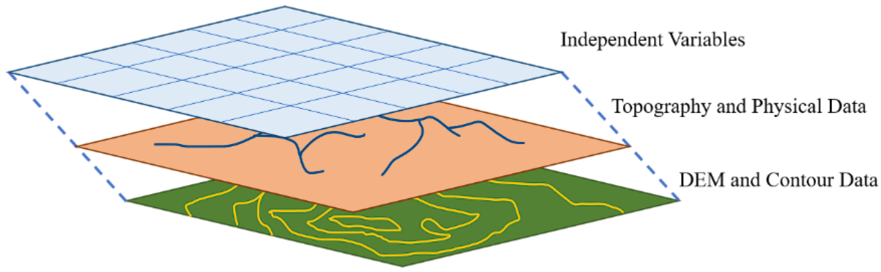


Figure 5. Process of creating model inputs

After the data overlayed, integrated and expressed in the form of raster data, the data can be converted into dataframe as explained in Figure 6.

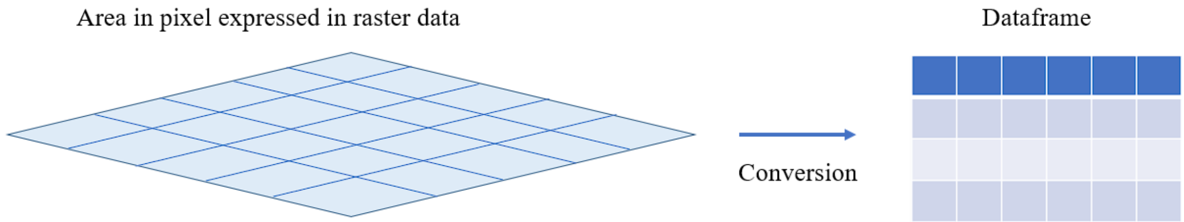


Figure 6. Process of conversion into model inputs

(2) Train-Validation-Test Split

After the data in the form of dataframe, the process of splitting data and validation take place, which is crucial in training the machine learning model, the process is done by splitting the raster data between 16 years into test set, validation set, and training set using KFold cross-validation method, 6 folds.

Prediction of the model is done by parameters of splitting in Table 6.

Table 6. Floodplain estimators

Splitting Type	Number of years
Training	10
Validation	2
Tests	4

(3) Metrics

After selecting the candidate estimators, we evaluate the results based on the accuracy of measuring the basic criteria of the floodplain. This can include measuring the amount of correctly estimated area and other metrics such as precision and recall. To quantify the area, we use Intersect over Union (IoU) (Hamid Rezatofighi, Nathan Tsoi, JunYoung Gwak, Amir Sadeghian, Ian Reid, Silvio Savarese, 2019), which provides the intersect segment area of the real floodplain compared to the estimated floodplain. This allows us to compare the estimated floodplain to the actual floodplain and determine how accurate our estimator is.

$$\text{IoU} = \frac{\text{Area of Overlap}}{\text{Area of Union}} =$$

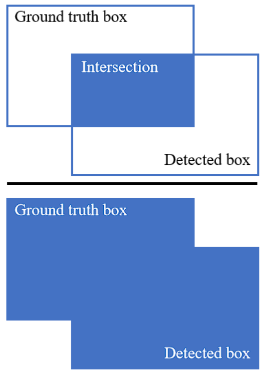


Figure 7 Explain how Intersect over Union (IoU) metrics works.

Overall, accurately estimating the floodplain area around railway tracks is crucial for assessing the risk of flooding and ensuring the safety of the railway system. By using computational methods and statistical models, we can make these estimations with a high degree of accuracy, allowing us to take the necessary steps to prevent flooding and minimize the risk to both the railway system and the surrounding area.

The performance metrics interpretation is described in Table 7.

Table 7. Metrics interpretation

Metrics	Range	Interpretation
IoU	0 - 1	IoU > 0.8 as excellent score, IoU > 0.5 as good, and any other score as poor
Dice Index	0 - 1	0, indicating no spatial overlap to 1, indicating complete overlap, meaning if the score is closer to 1, the better
F1 Score	0 - 1	The closer it is to 1, the better the model.
Precision	0 - 1	A measure of quality if the score is closer to 1 more ground truth to all data (True Positive)
Recall	0 - 1	A measure of quantity if the score is closer to 1 the more ground truth to the relevant data.

3. RESULTS

Using Computer vision technology to explore the impact of flooding on railway tracks and surrounding areas, examining track damage and structure. We divided flood risk into 4 categorical types as shown in Table 8 with the result of specific metrics.

Table 8. Performance results on the snapshot image dataset.

	Validation set					Testing set				
	Precision	Recall	F1 score	IoU	Dice Index	Precision	Recall	F1 score	IoU	Dice Index
Logistic Regression (Macro-average)	0.68	0.69	0.68	-	-	0.50	0.50	0.50	-	-
Naïve Bayes (Macro-average)	0.54	0.53	0.52	-	-	0.27	0.35	0.40	-	-
MLP (Macro-average)	0.95	0.93	0.94	-	-	0.83	0.75	0.73	-	-
CNN (Macro-average)	0.54	0.51	0.52	0.62	0.66	0.42	0.43	0.47	0.55	0.61
Transformer (Macro-average)	0.62	0.63	0.66	0.68	0.73	0.59	0.57	0.61	0.67	0.72

Table 9. Prediction results on FRI

FRI Range	Arial Extent
Low Risk area	0.12
Medium Risk area	0.35
High Risk area	0.25
Repeated Flood area	0.28

4. DISCUSSION

According to Tables 8 and 9, the results show the performance on the snapshot image dataset for each condition. Table 8 displays the precision, recall, and F1 score for each model, including categorical and area digitized in macro-averages due to limited samples. Due to the small testing set, the performance of the model can be explored further if we expand the study area to include more samples.

The results show that the Multi-Layer Perceptron (MLP) area has the highest precision, recall, and F1 score, indicating that the model is most effective when applied with this category of area. For others, overall results are not good because the small area and number of years, but the results would suggest that this model can be used as a tool for identifying flood risk areas more efficiently if provided more data.

5. CONCLUSIONS

The study considers five main major factors, including average total rainfall in the rainy season, waterway density, land use, slope, and elevation, to analyze the area-based risk factors that cause railway track flooding. Using computer vision technology, we had generated a comprehensive map showing the flood risk index of railway track flooding in the area. The digital surface model used in this study help in identifying the damages to railway tracks, track structures, and surrounding areas due to the influences of different flooding conditions.

This study is expected to provide us with an understanding of the relationship between flooding conditions and railway embankment and track damages, which can be used to develop more effective flood risk management strategies. With a remarkable potential, the findings of this study will contribute to the development of a more resilient railway infrastructure that can withstand the impacts of natural disasters.

Utilizing this process, railway operators will be able to mitigate the risks of flooding and prevent future damages to the railway embankment efficiently. The study is expected to provide a more comprehensive understanding of the relationship between flooding conditions and railway track damages and provides a useful framework for analyzing and preventing railway track flooding using computer vision technology and risk factor analysis. The findings can be applied to other regions with similar flooding problems to develop a more resilient railway infrastructure that can withstand natural disasters.

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