International Association of Chinese Infrastructure Professionals

**THE 13th IACIP Annual Workshop:**
***Adaptive Infrastructure under Climate Change***

# Monitoring the Compaction Condition of Asphalt Pavement Based on Particle Kinematic Behaviors


**Shuai Yu**, Pennsylvania State University (University Park), sqy5325@psu.edu
**Shihui Shen**, Pennsylvania State University (Altoona), szs20@psu.edu


## Introduction

- **Compaction** is critical for pavement's performance and service life. Current compaction methods cause uniformity and over/under compaction issues.
- **Intelligent compaction (IC) technology** can improve compaction uniformity but still cannot well monitor pavement compactability.
- **Machine learning (ML) algorithm** and **sensing technology** will be combined for quality control of asphalt pavement compaction.

## Objective

- Explain the **compaction mechanisms** of asphalt pavement from **mesoscale**;
- Develop **an intelligent model** to predict the compaction of asphalt pavement to achieve an automated assessment of field compaction

## Methodology

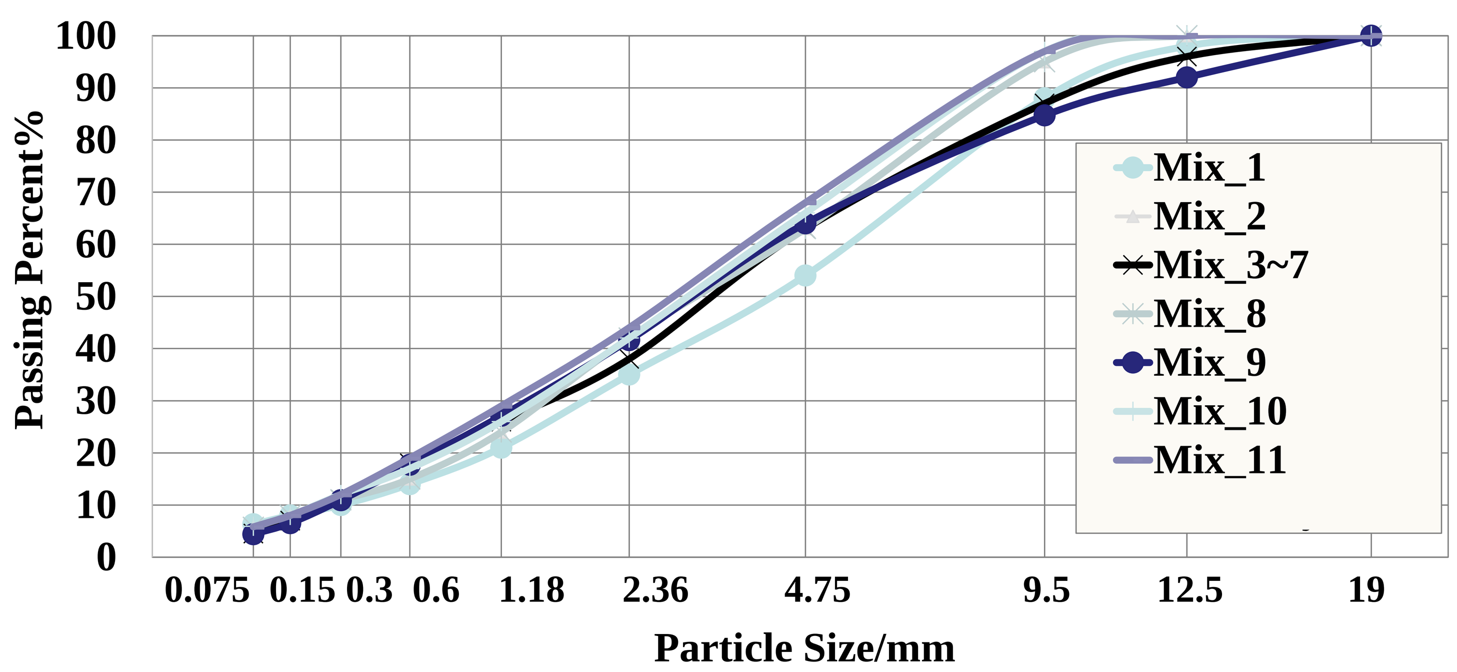

| | | |
|---|---|---|
| | Far under compaction | < 88%$G_{mm}$ |
| | Under compaction | 88%-91% |
| | Good compaction | 91%-93% |
| | High density compaction | 93%-96% |
| | Over compaction | > 96%$G_{mm}$ |

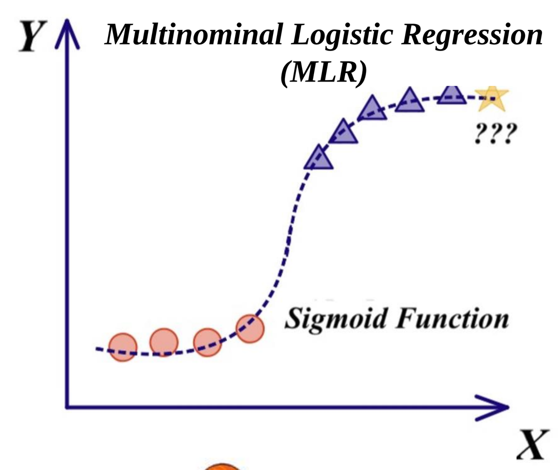
**Perception** (Data collection) — **Analysis** (Training the intelligent model by lab data) — **Decision-making** (compaction prediction)

- The **wireless sensor** and the **ML algorithm** are combined to predict the compaction condition of the asphalt mixture/pavement.
- **Multinominal Logistic Regression (MLR)** is selected for the compaction prediction **Artificial Neural Network (ANN)** is selected for the density prediction.

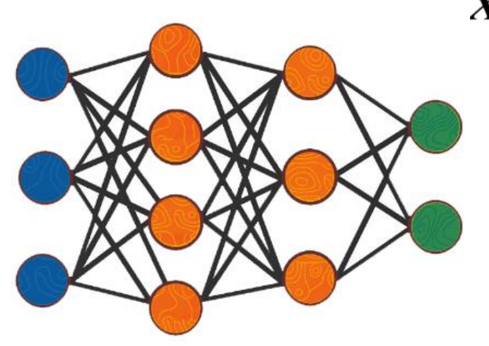
## Experiment and Model

- **11 asphalt mixtures, total 32 specimens** are compacted in the lab.
- **2 field compaction projects** (Altoona and Indiana project) are carried out.




| | | |
|---|---|---|
| 1 | Far under compaction | < 88%*Gmm* |
| 2 | Under compaction | 88%-91% |
| 3 | Good compaction | 91%-93% |
| 4 | High density compaction | 93%-96% |
| 5 | Over compaction | > 96%*Gmm* |



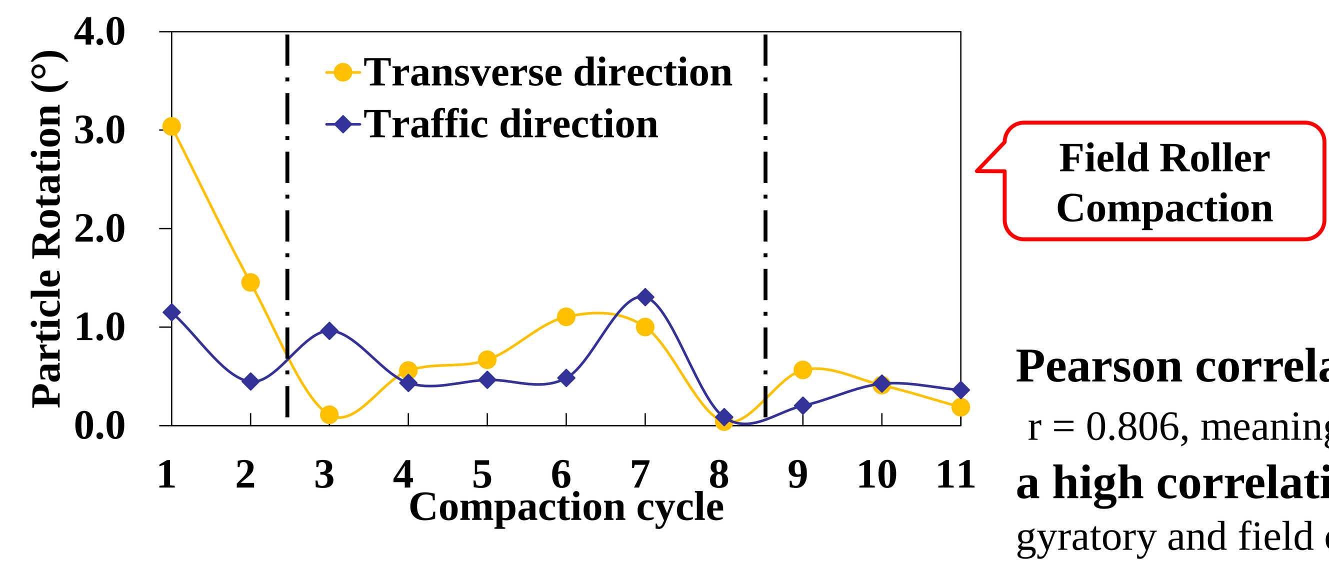
**Input for the ML model**
- Particle relative rotation;
- Mixture design information;
- Accumulated compaction energy.

**Output for the ML model**
- **MLR**: Compaction condition (5 category)
- **ANN**: Pavement density (*%Gmm*)

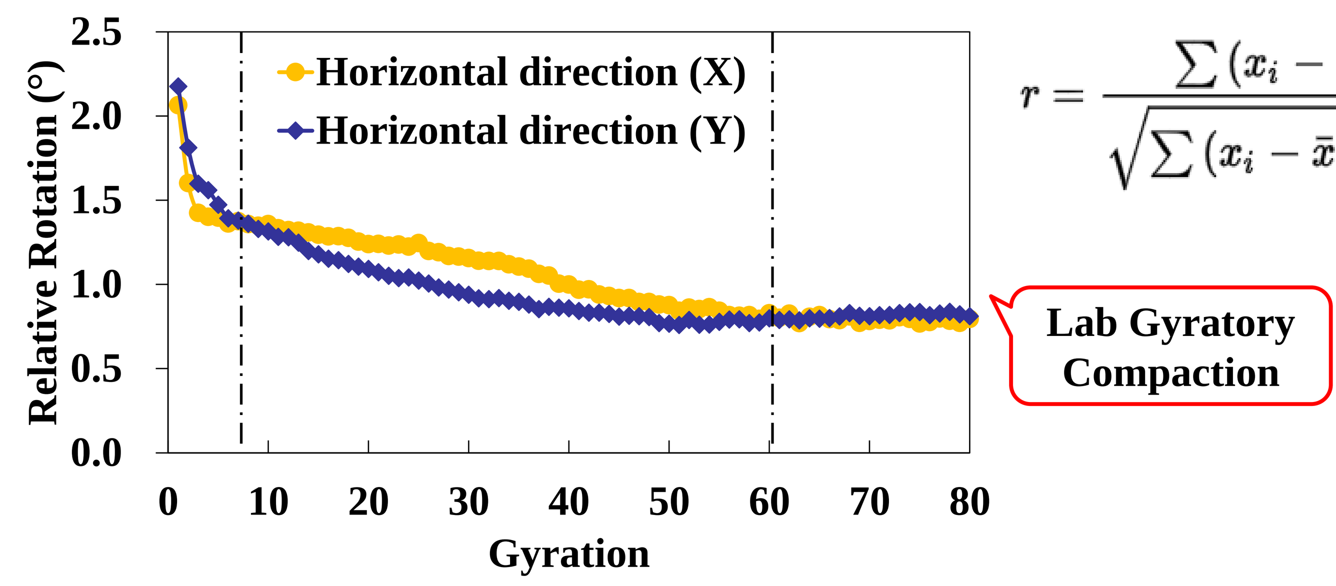
## Results and Analysis

### Correlation between the lab and field compaction

**Three-stage patterns are identified in both lab and field compaction:**
- **Breakdown stage:** Short, the most dramatic rotation and speedy decrease.
- **Main compaction stage:** Imbalance interaction between compaction loadings and particle shearing resistances.
- **Finishing stage:** Interactions are balanced and particle rotation is static.




**Pearson correlation coefficient:**
r = 0.806, meaning:
**a high correlation** between gyratory and field compaction.



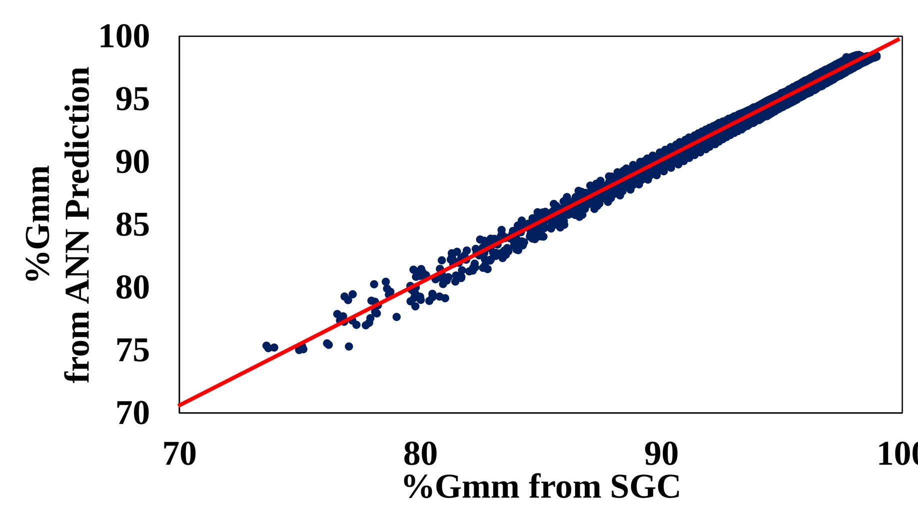

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}}$$

### Prediction Results

- Two **field projects** can be reasonably predicted based on the **Machine Learning (ML) model training by the laboratory compaction data**.

**Laboratory Compaction Prediction:**
**MLR model :**
- 90% Accuracy

**ANN model:**
- Mean Relative Error (MRE) < 0.5%




| Project | Altoona Project | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cycle | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| Roller | V | V | V | S | S | S | V | V | V | S | S |
| MLR | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | 3 | 3 |
| ANN | 78.2 | 83.7 | 88.3 | 88.8 | 89.8 | 90.3 | 91.4 | 92.2 | 92.4 | 92.8 | 93.1 |

Core density: 93.1; 93.6

| Project | Indiana | |
|---|---|---|
| Cycle | 1 | 2 |
| Roller | V | V |
| MLR | 2 | 3 |
| ANN | 91.7 | 93.1 |

Core density: 92.8; 92.5

**Note:**
- The Class 1,2,3 means the Far under compaction,
- Under compaction and Good compaction, respectively;
- Core density is the density of the core sample (%$G_{mm}$) as the true value for verification.

## Conclusions

- **Three-stage compaction patterns** are identified for both lab and field compaction based on **particle rotation**.
- **Multinominal logistic regression (MLR)** and **Artificial Neural Network (ANN)** are appropriate to predict the compaction conditions of the asphalt pavement.
- A reasonable density can be predicted by the ML model trained by the lab data using the **particle rotation, compaction energy, and mixture design** as inputs.