# How to Optimize Concrete Deliveries Using Machine Learning and Concrete Truck Equipped with On-Board Sensors

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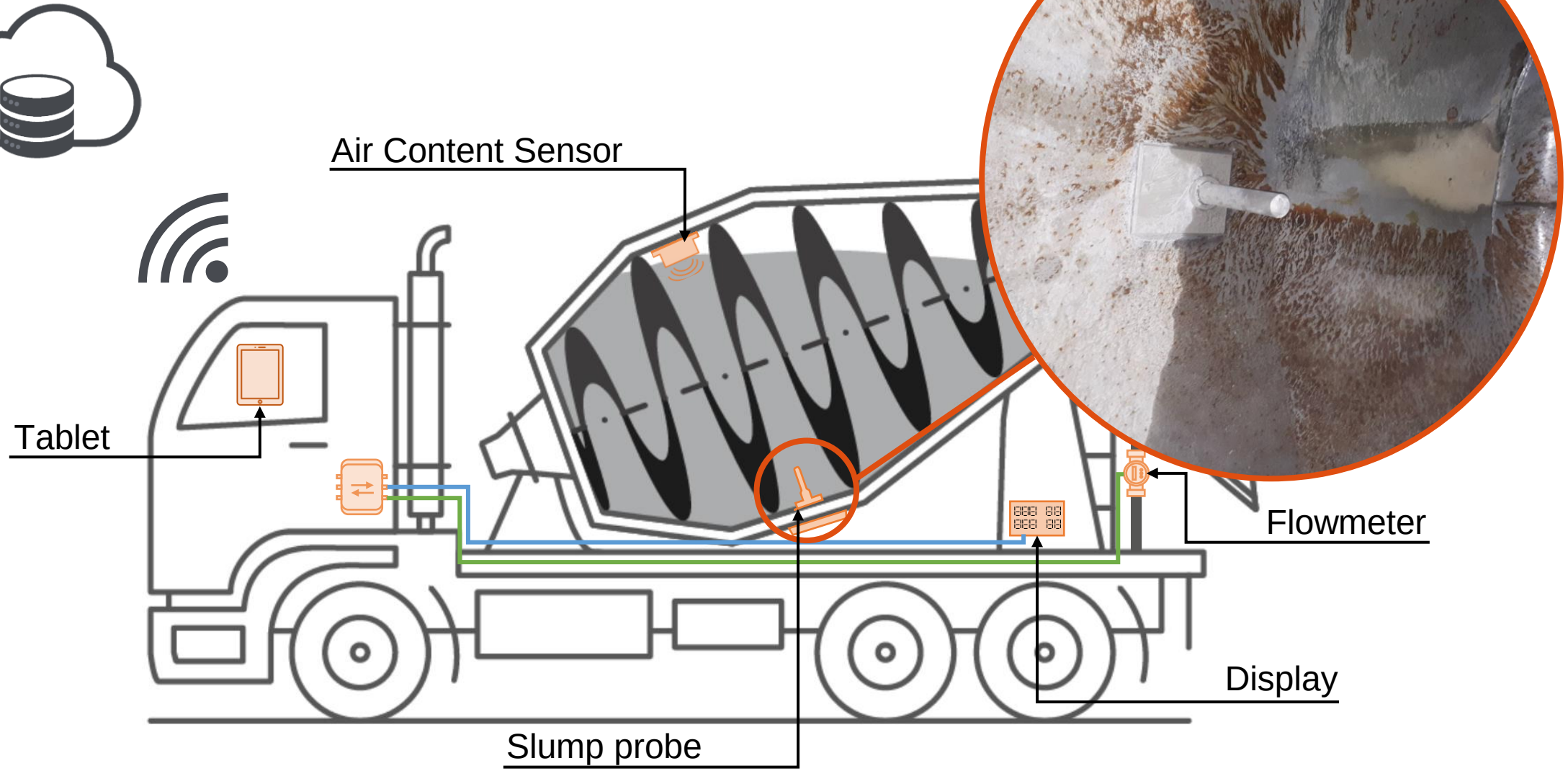
**Denis Beaupré, Ph.D.**

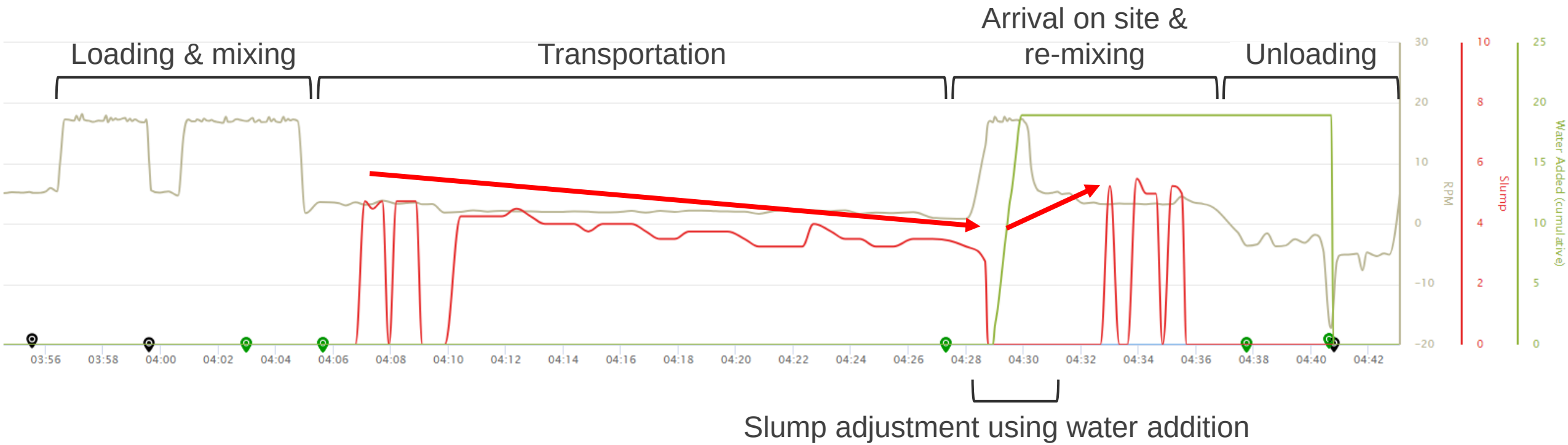
**ACI Concrete Convention – Boston, MA – October 29, 2023**

# In-transit monitoring system



# Real-time data measurement

- Drum direction and rotationnal speed
- Mixing turn count
- Volume of concrete
- Production status
- Temperature
- Air content
- **Slump**
- Water addition




Slump adjustment using water addition

# Real-time data measurement

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Around 2500 systems installed in North America

→ **Big Data!**

# Research project

## Five years project

Rheology, homogeneity and mixing completion, air content and density measurement,…

UNIVERSITÉ LAVAL

CRIB
Centre de recherche sur les infrastructures en béton

Command Alkon

béton provincial

NSERC CRSNG

Is there an **interest** in employing **machine learning** methods for the use of **data produced by the network of sensors**?

# The cost of retempering


**45%**

**Average concrete loads**

**10 min**

**Average time to test, retemper and retest**

**30$**

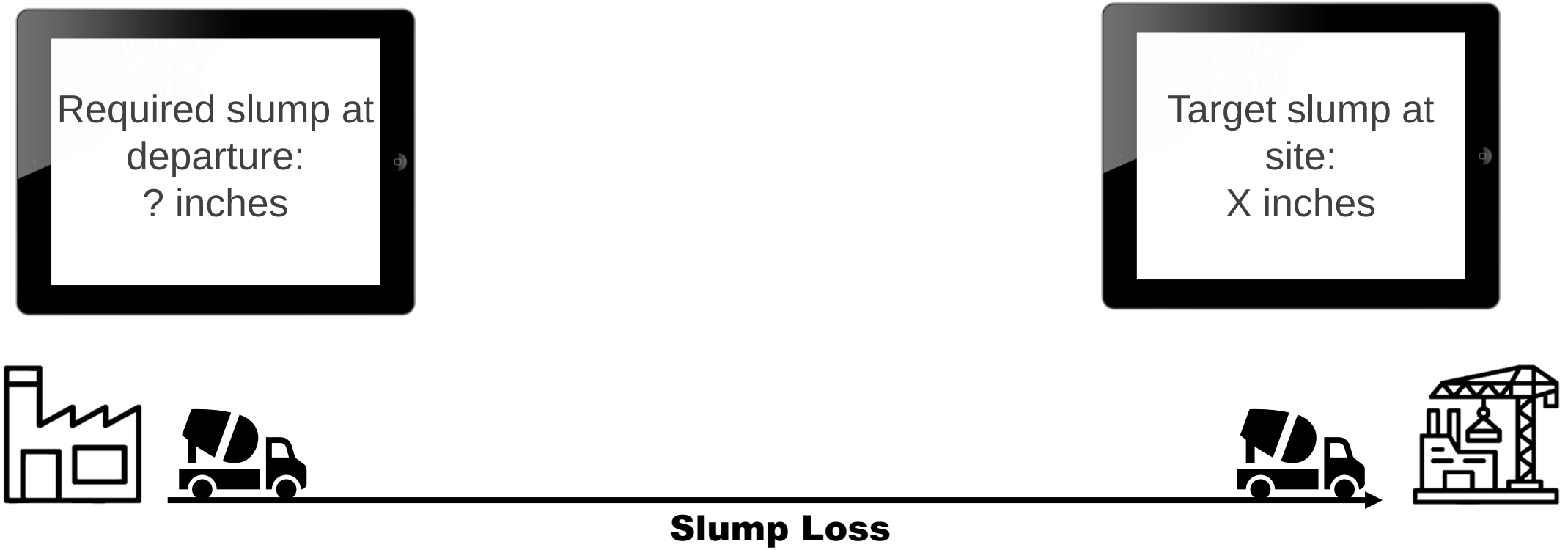
**Average material and operational costs to retemper**

Topic: Predict the **evolution of slump** during transportation

Reference: Master Builders

# The solution

Topic: Predict the **evolution of slump** during transportation




Perspectives:

- **Decision support** and alert **tool** for concrete plant operators
- **Improved** production automatisation

# The algorithm

Load volume

Concrete temperature

W/C

Age at departure

Slump at arrival

Travel time

Outside temperature

Outside humidity

Popular machine learning model:

*XGBoost*

Neural Network (NN)

…

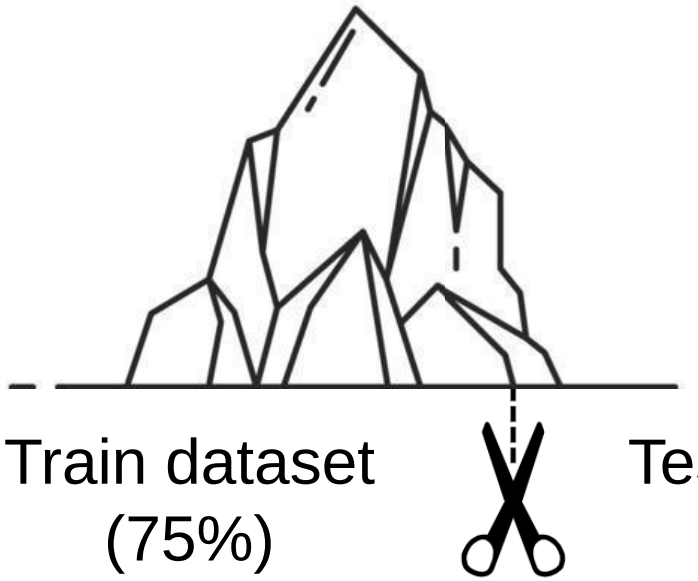

Target slump at departure

Other (not considered) parameters that might have an effect: mix design, aggregate moisture,…

# Database and performance

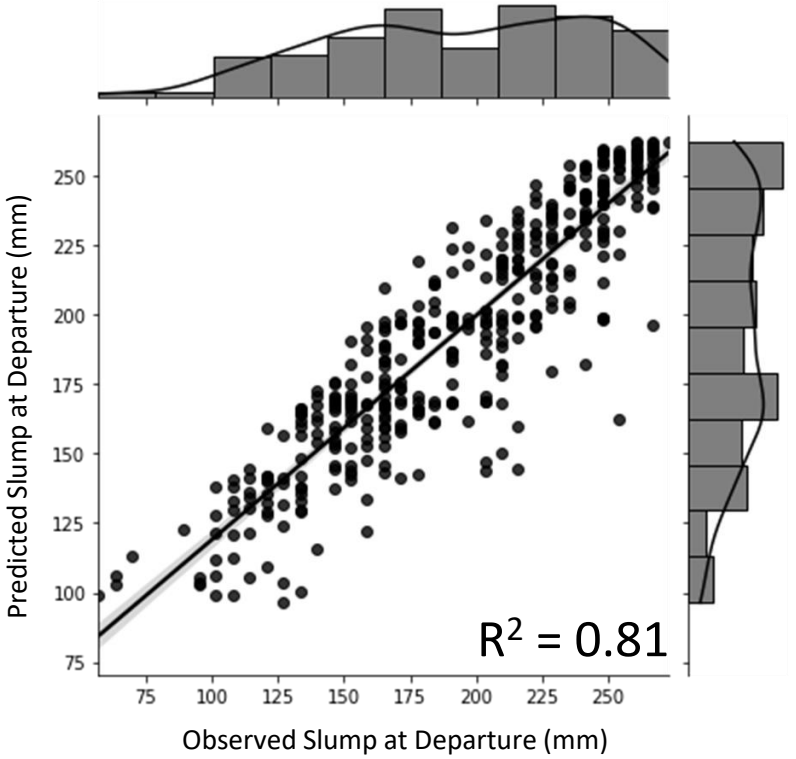
1607 loads of concrete

# Database and performance



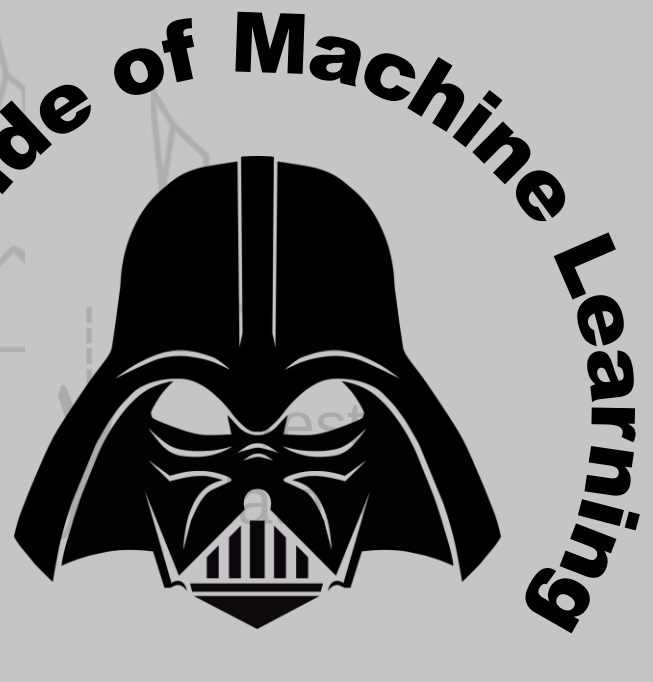
Train dataset
(75%)

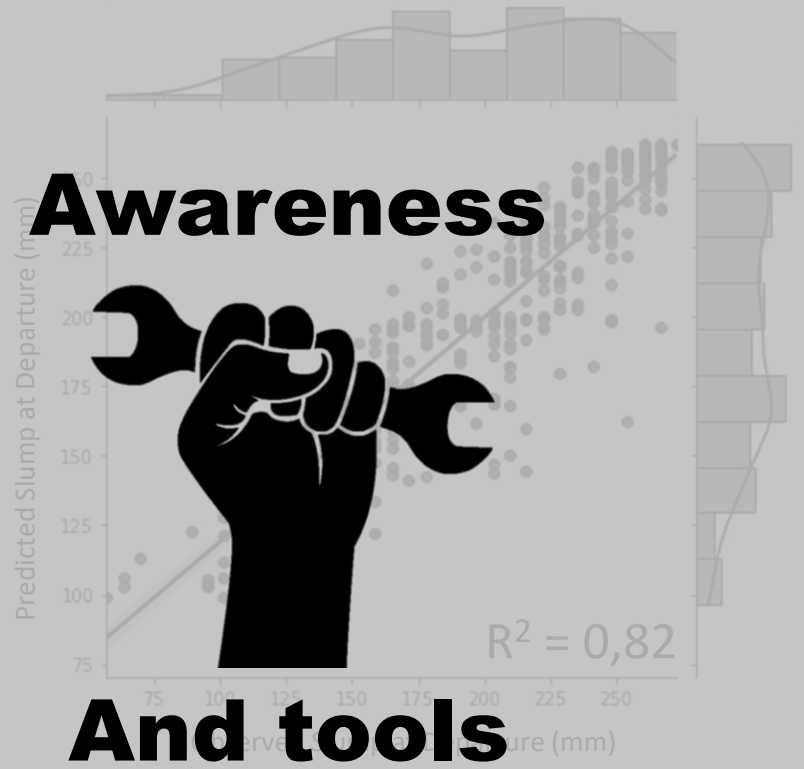
Test dataset
(25%)




It works!

# Database and performance

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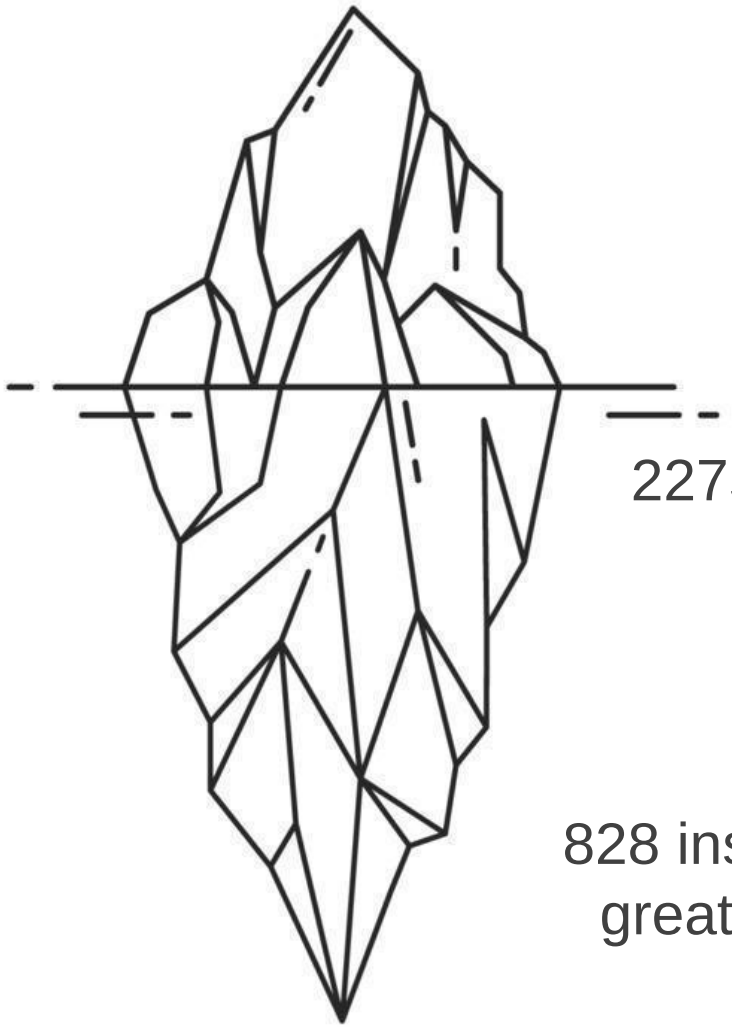


1607 loads of concrete (29%)

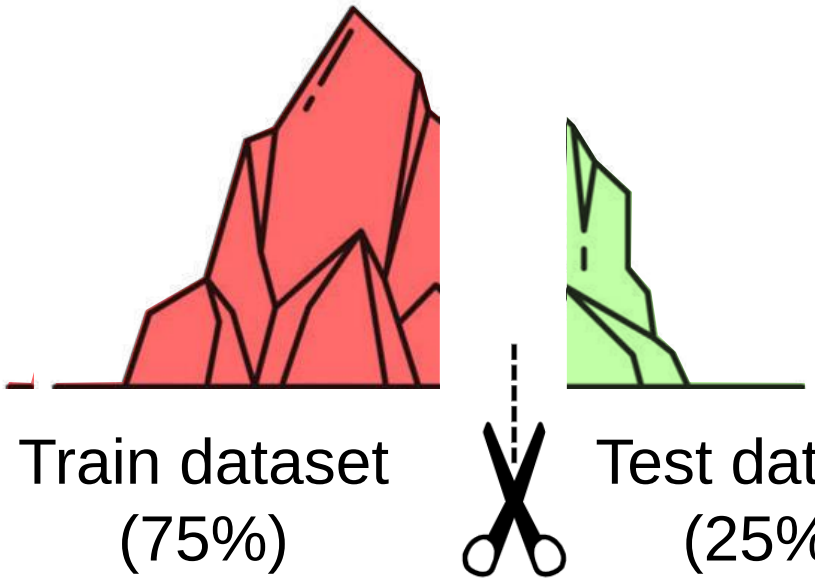
2275 incomplete instances (40%)

920 outliers (16%)

828 instances with arrival slump greater than departure slump (15%)

Note: That was a proof of concept

# Database and performance



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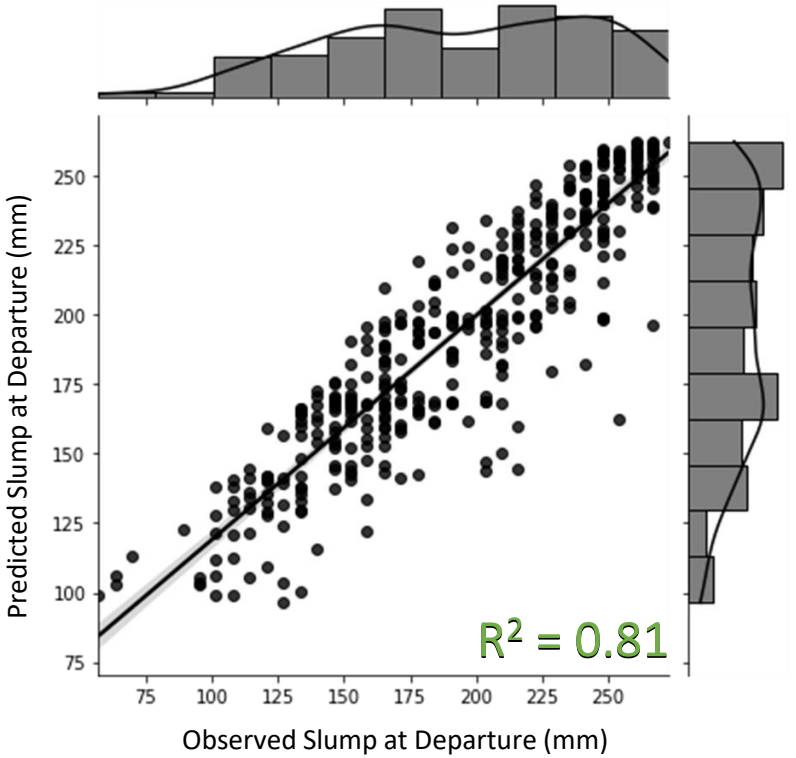


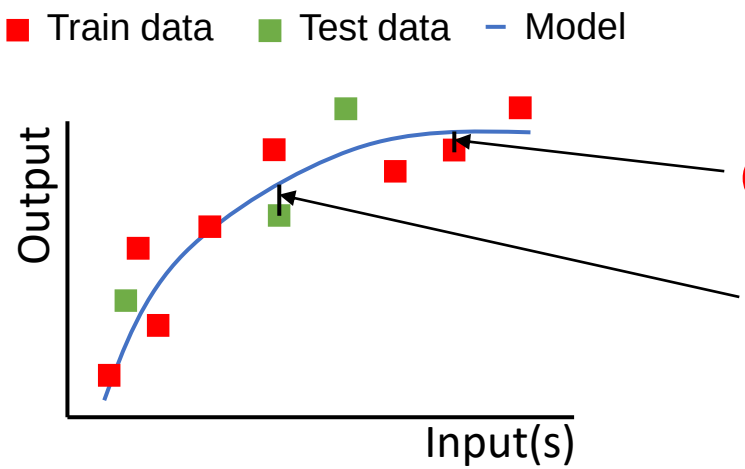

Using a popular machine learning model (*XGBoost)*:

Train set: $R^2$ = 0.82  Test set: $R^2$ = 0.81

Close and relatively high!

# Why is it a good situation?

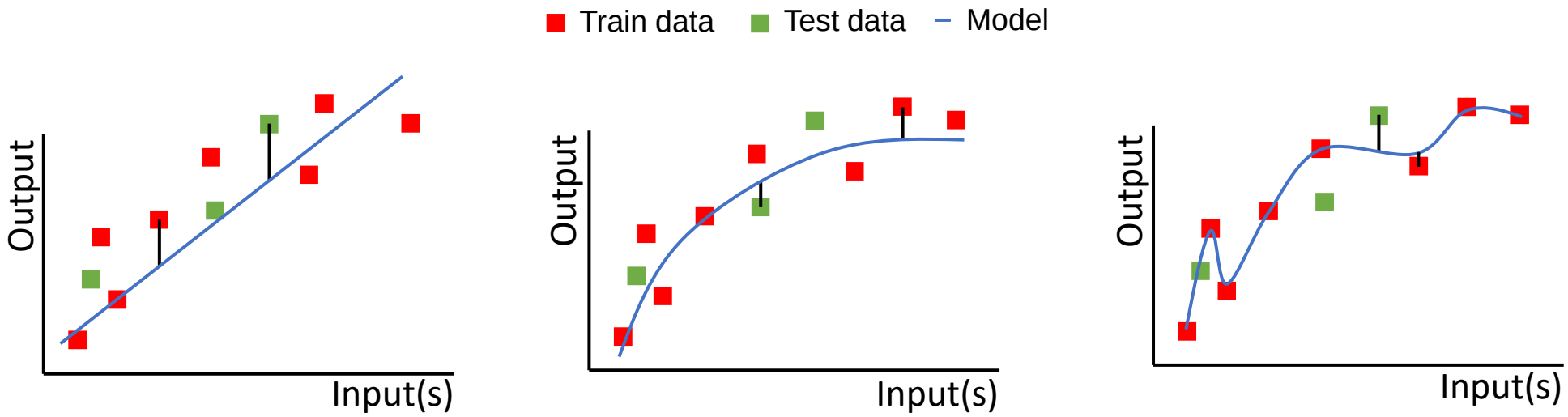
Two dimension representation of a multi dimension model




Correlation between model and Train dataset: $R^2 = 0.82$

Correlation between model and Test dataset: $R^2 = 0.81$

# Why is it a good situation?




Correlation with:

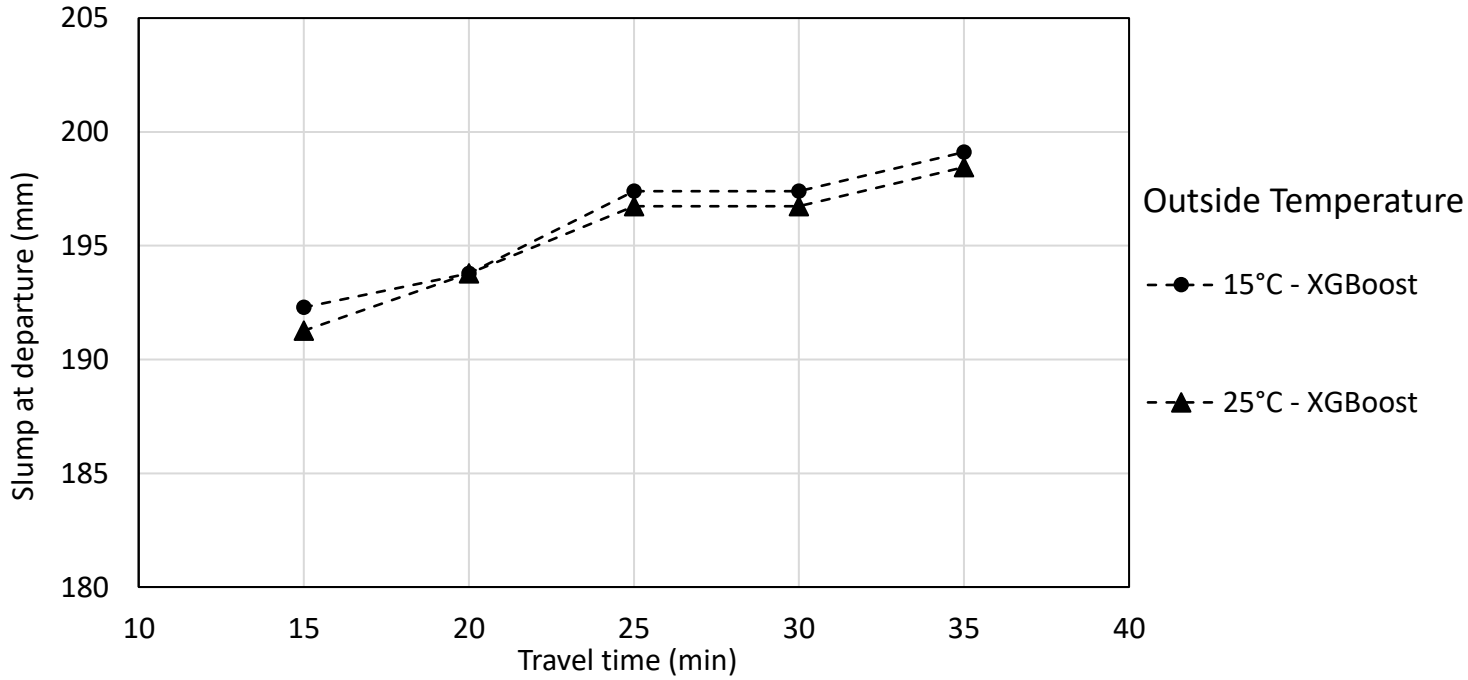
| | | | |
|---|---|---|---|
| Train dataset | 0.5 | 0.82 | 0.98 |
| Test dataset | 0.5 | 0.81 | 0.81 |
| | Underfitting | Balance | Overfitting |
| | 👎 | 👍 | 👎 |

# Reverse engineering

*'Machine learning is like a **black box'***

→ Parametric study with two different models

Volume: 8 $m^3$ – Concrete temperature at departure: 25ºC – Age at departure: 10 min – **Slump at arrival: 150 mm (6 in.)** – W/C: 0.45 – Outside humidity: 70%



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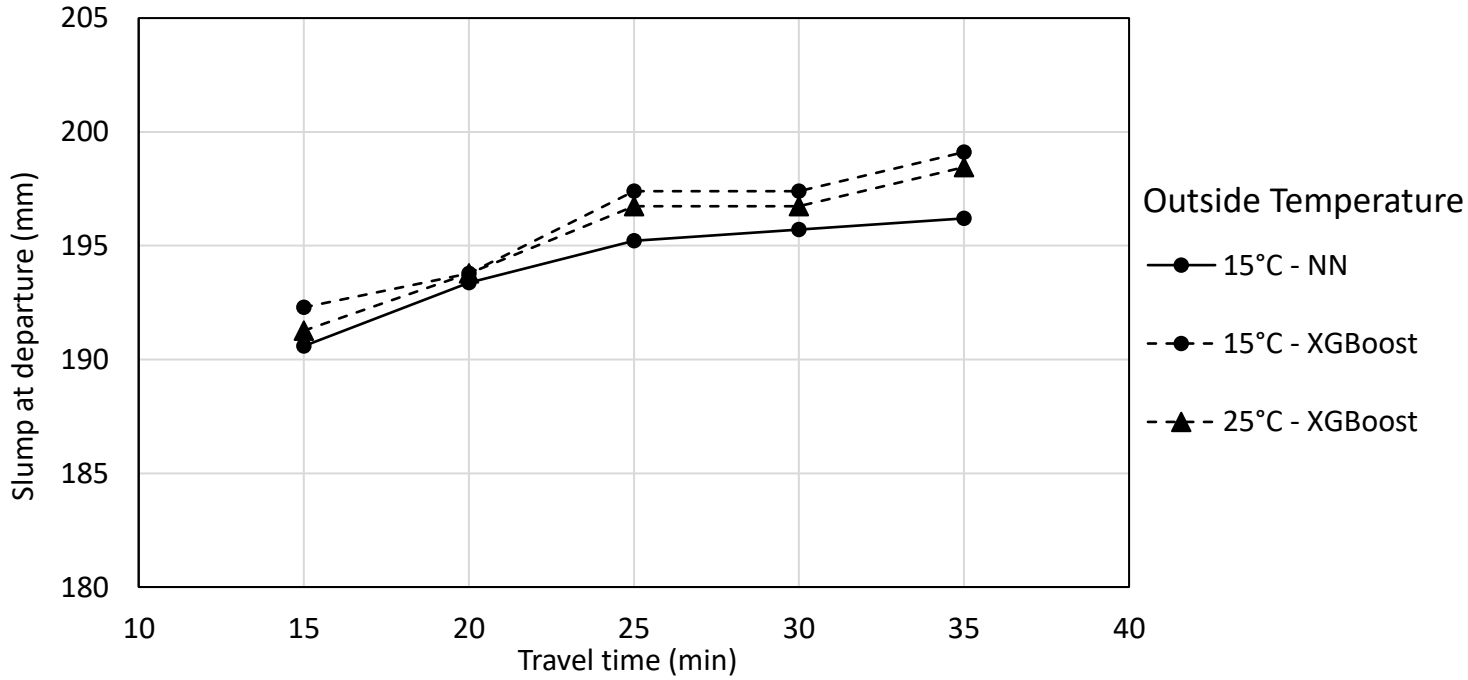

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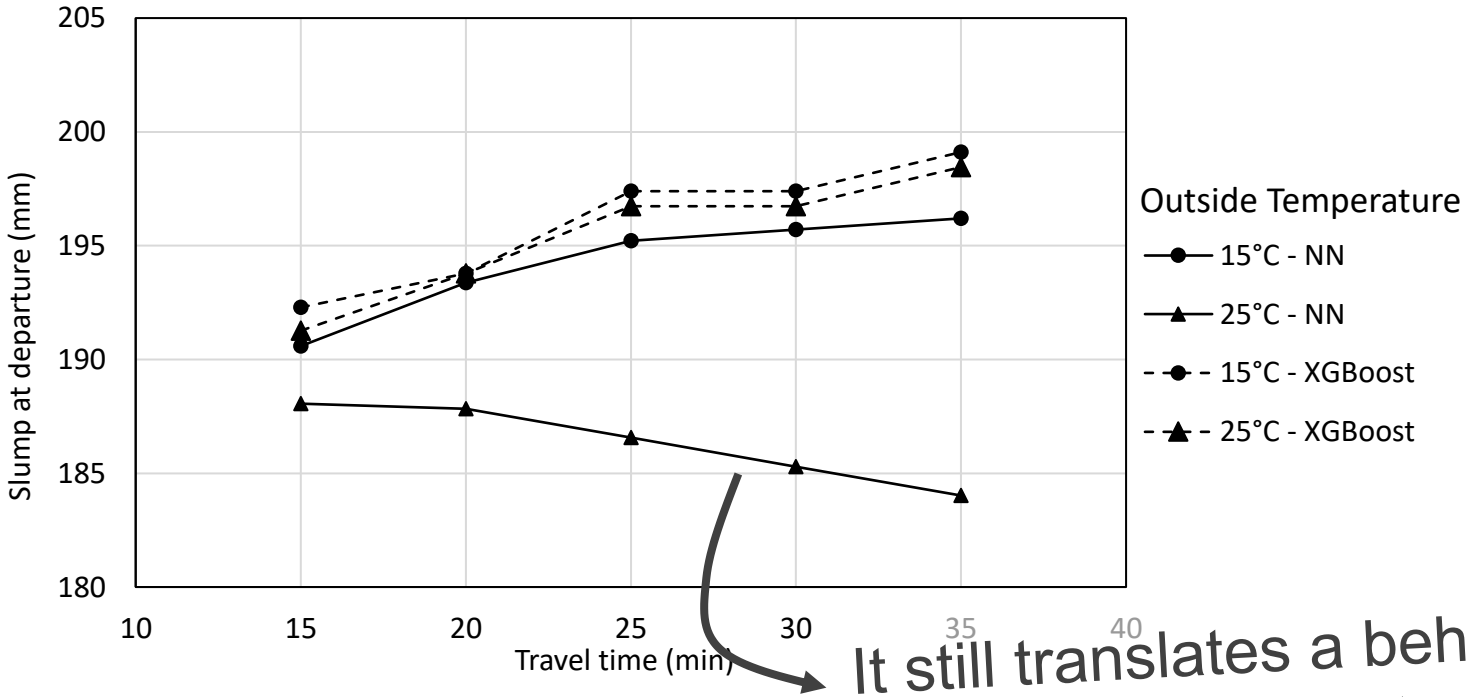


It still translates a behavior present in the dataset!

# Reverse engineering

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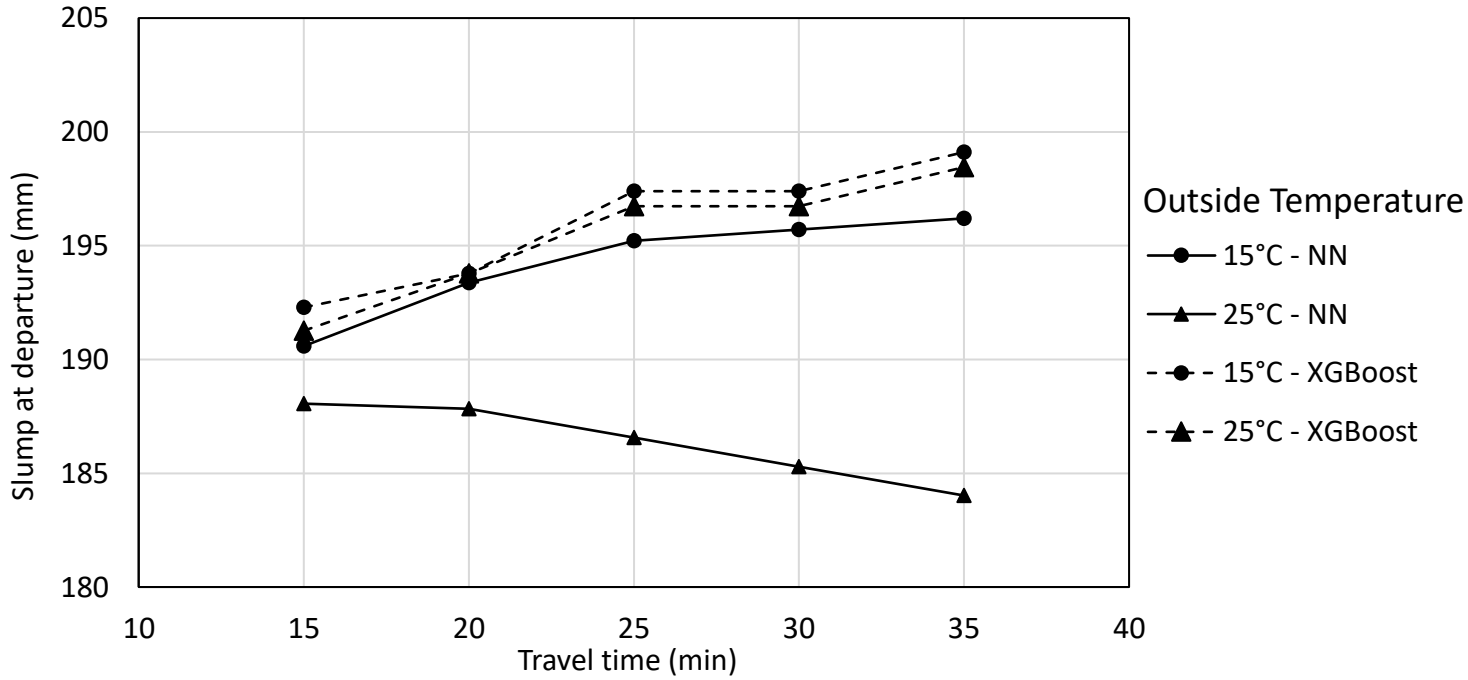
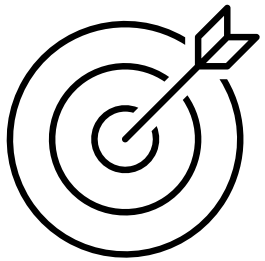



- **Different models** might yield **different results**
- We still need the understanding of **concrete science** to develop useful models

# Conclusion

Look for convincing results



And limited error

But…

Stay critical

And be alert

# Thank you!

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# Appendix

# Real-time data measurement

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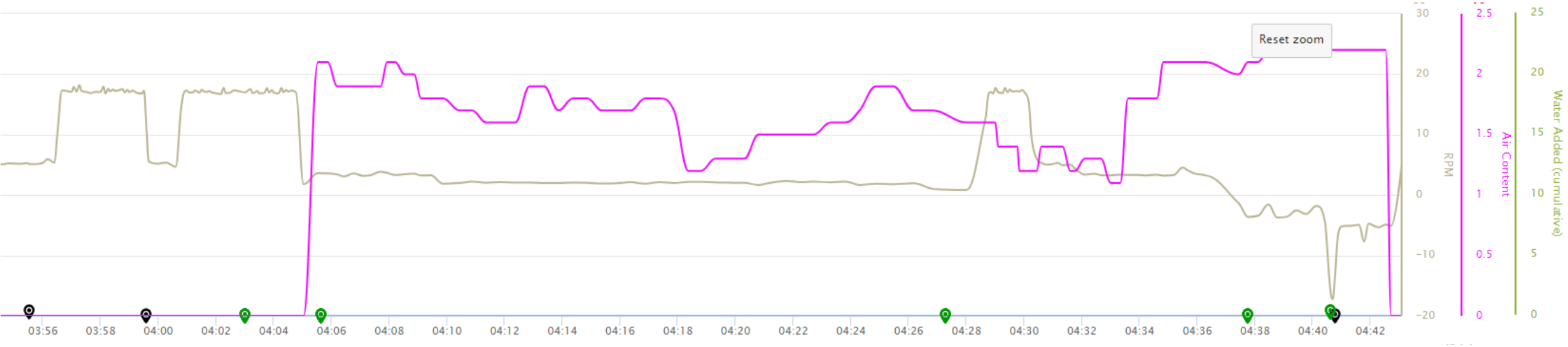
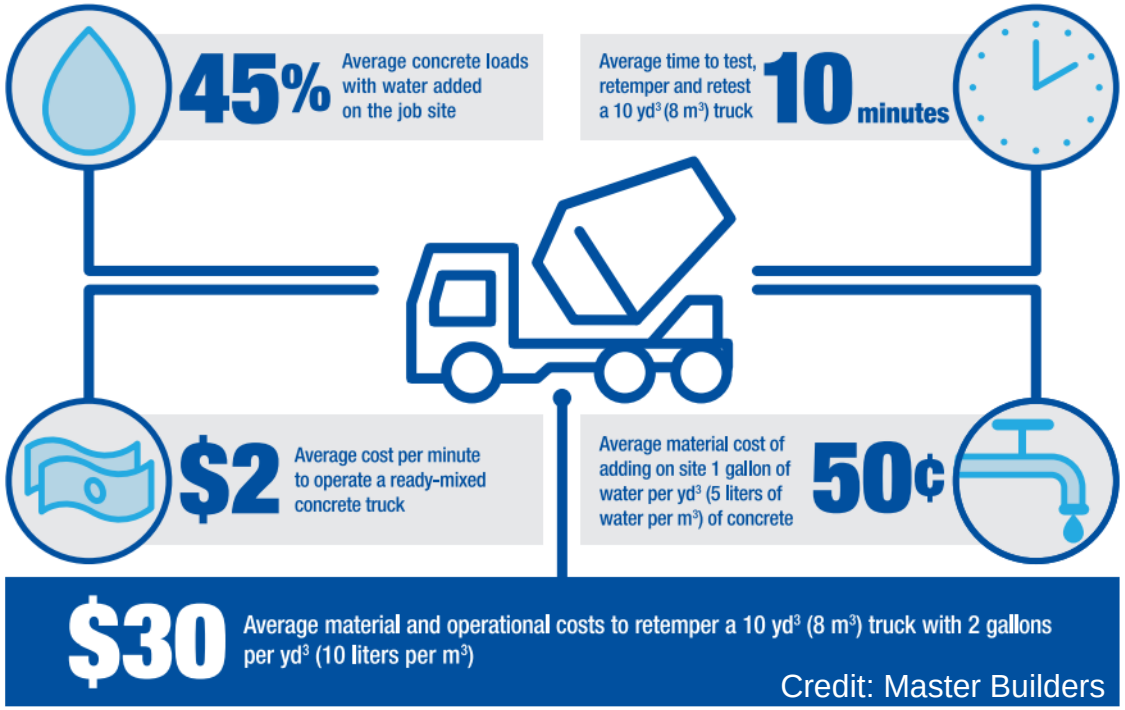


# The cost of retempering





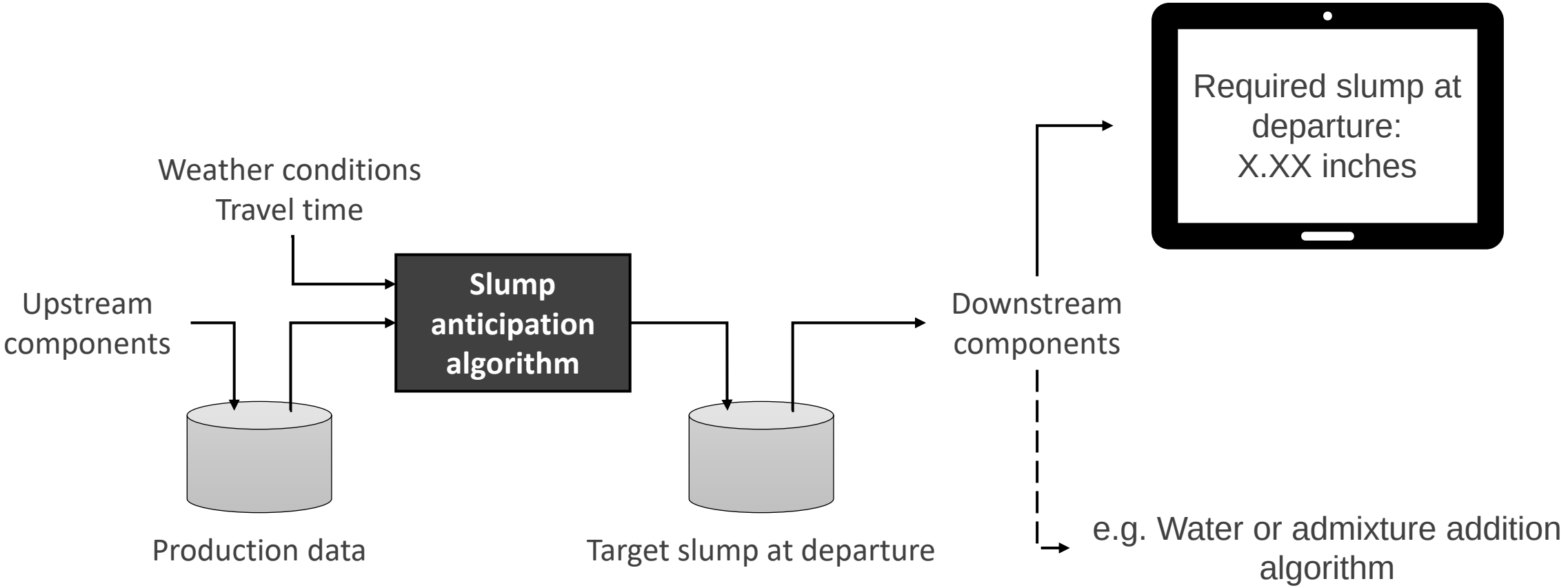
Topic: Predict the **evolution of slump** during transportation

Perspectives:

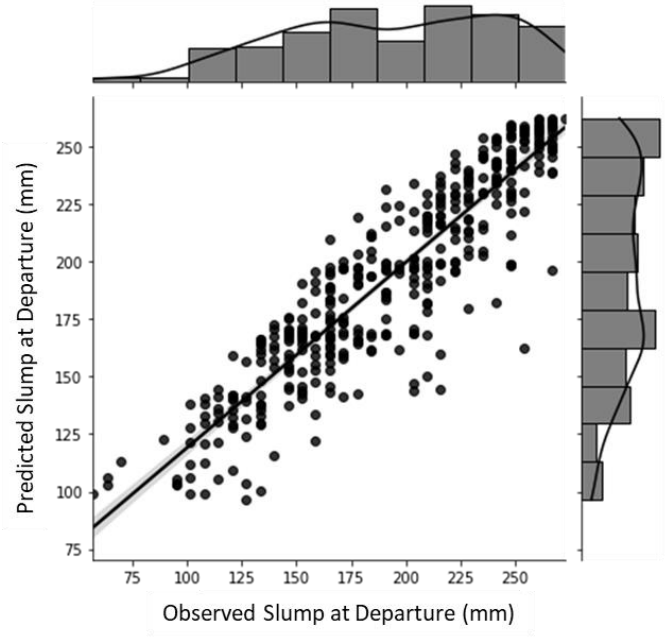
- **Decision support** and alert **tool** for concrete plant operators
- **Improved** production automatisation

# The data pipeline

Topic: Predict the **evolution of slump** during transportation



# Performance



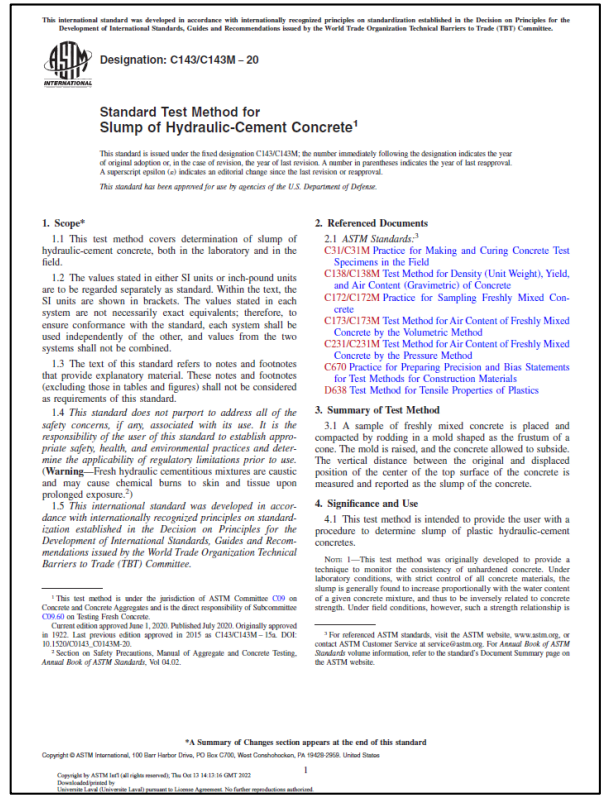

Using a popular machine learning model (*XGBoost*):

Train set: $R^2 = 0.82$ Test set: $R^2 = 0.81$

Root Mean Square Error (RMSE) = 21 mm

*'For a slump of 85 mm (3.4 in.), the acceptable range of two results (d2s) is 28 mm (1.1 in.)'*

Error is **acceptable**!



This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: C143/C143M – 20

**Standard Test Method for Slump of Hydraulic-Cement Concrete**[1]

This standard is issued under the fixed designation C143/C143M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

**1. Scope***

1.1 This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

1.2 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the SI units are shown in brackets. The values stated in each system are not necessarily exact equivalents; therefore, to ensure conformance with the standard, each system shall be used independently of the other, and values from the two systems shall not be combined.

1.3 The text of this standard refers to notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* (**Warning**—Fresh hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged exposure.[2])

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

**2. Referenced Documents**

2.1 *ASTM Standards:*[3]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field

C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete

C172/C172M Practice for Sampling Freshly Mixed Concrete

C173/C173M Test Method for Air Content of Freshly Mixed Concrete by the Volumetric Method

C231/C231M Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C670 Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials

D638 Test Method for Tensile Properties of Plastics

**3. Summary of Test Method**

3.1 A sample of freshly mixed concrete is placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold is raised, and the concrete allowed to subside. The vertical distance between the original and displaced position of the center of the top surface of the concrete is measured and reported as the slump of the concrete.

**4. Significance and Use**

4.1 This test method is intended to provide the user with a procedure to determine slump of plastic hydraulic-cement concretes.

NOTE 1—This test method was originally developed to provide a technique to monitor the consistency of unhardened concrete. Under laboratory conditions, with strict control of all concrete materials, the slump is generally found to increase proportionally with the water content of a given concrete mixture, and thus to be inversely related to concrete strength. Under field conditions, however, such a strength relationship is

[1] This test method is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.60 on Testing Fresh Concrete.

Current edition approved June 1, 2020. Published July 2020. Originally approved in 1922. Last previous edition approved in 2015 as C143/C143M – 15a. DOI: 10.1520/C0143_C0143M-20.

[2] Section on Safety Precautions, Manual of Aggregate and Concrete Testing, *Annual Book of ASTM Standards*, Vol 04.02.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard