How On-Board Sensor Can Help Improve Productivity

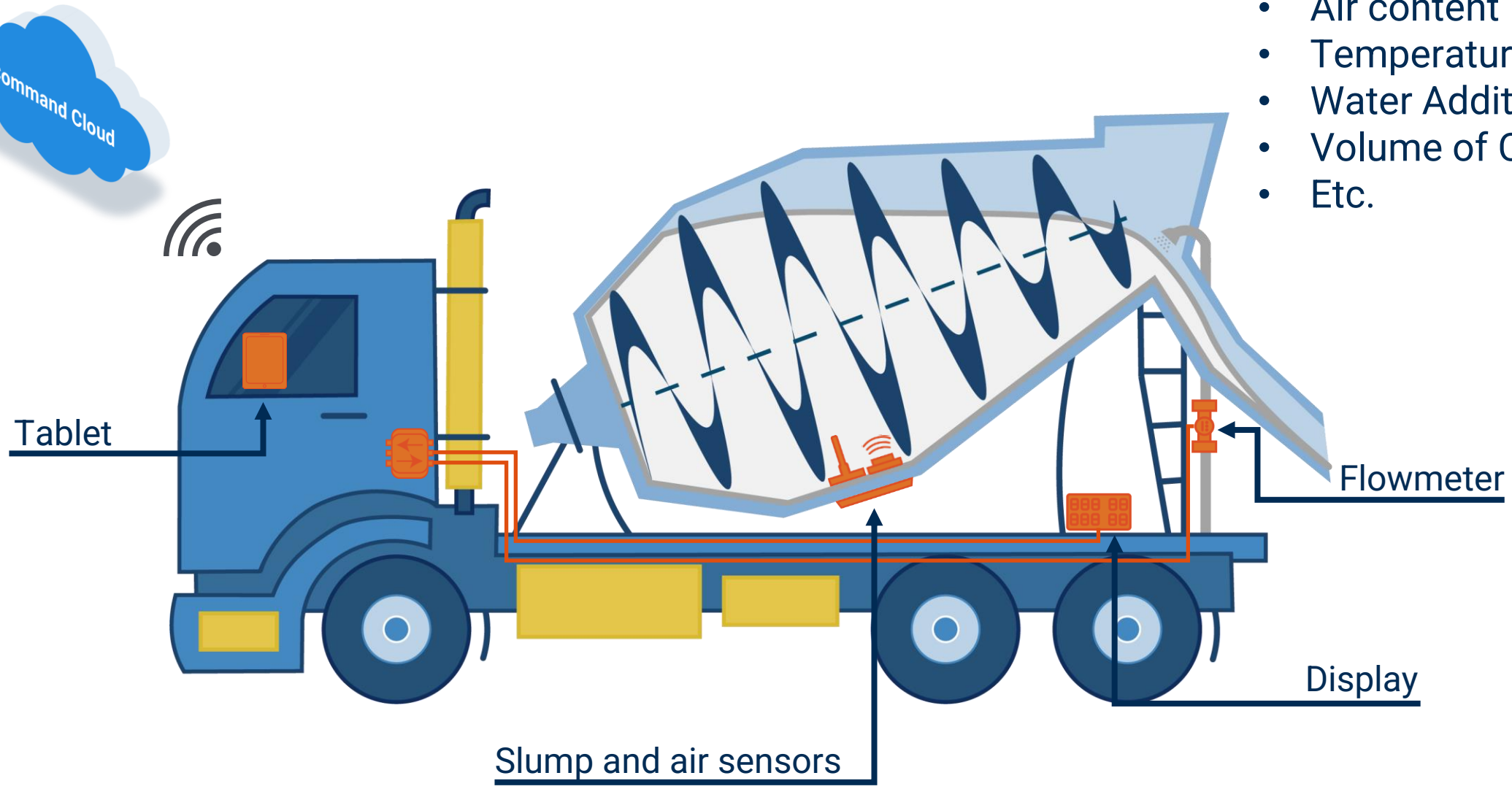
Pierre Siccardi, Ph.D.

ACI Concrete Convention – Philadelphia – October 6, 2024

On-board Monitoring System

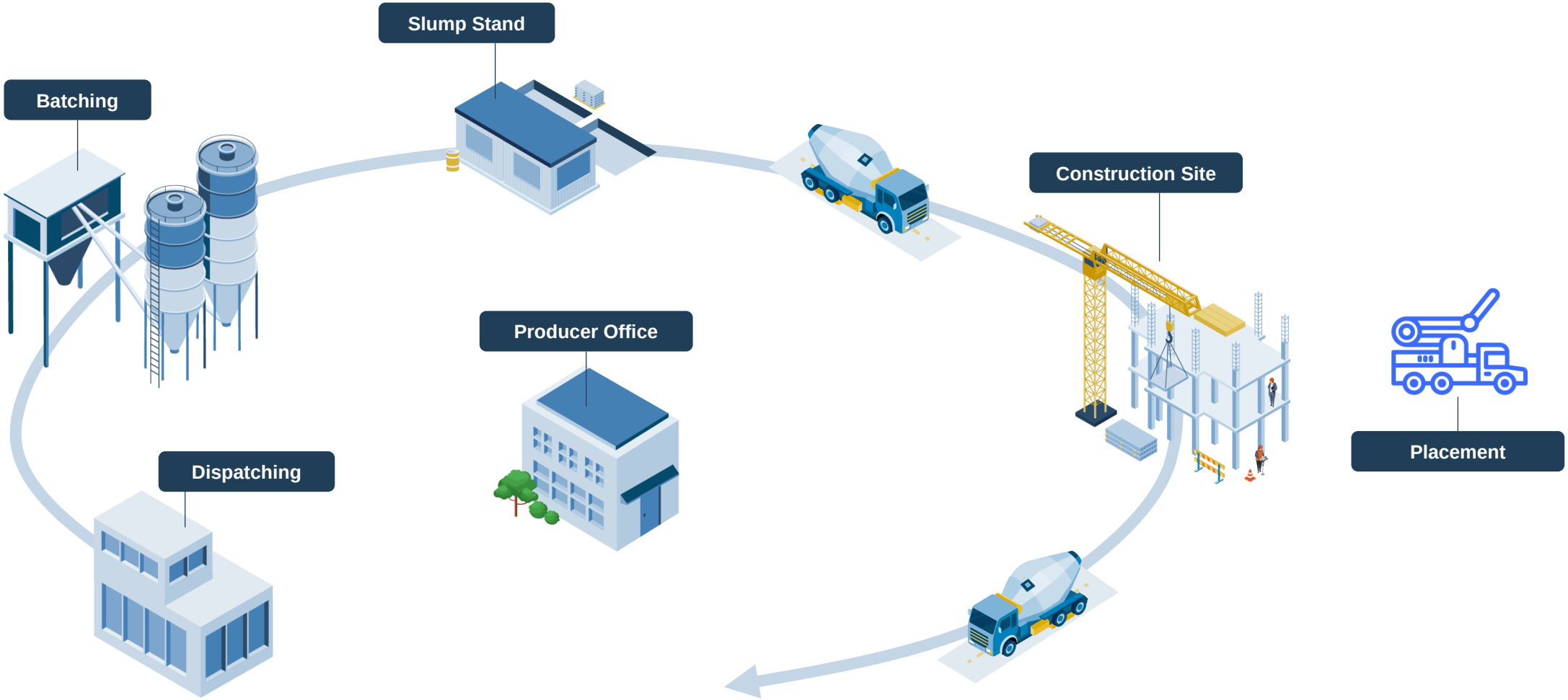
On-board Monitoring System

- Slump
- Air content
- Temperature
- Water Addition
- Volume of Concrete
- Etc.



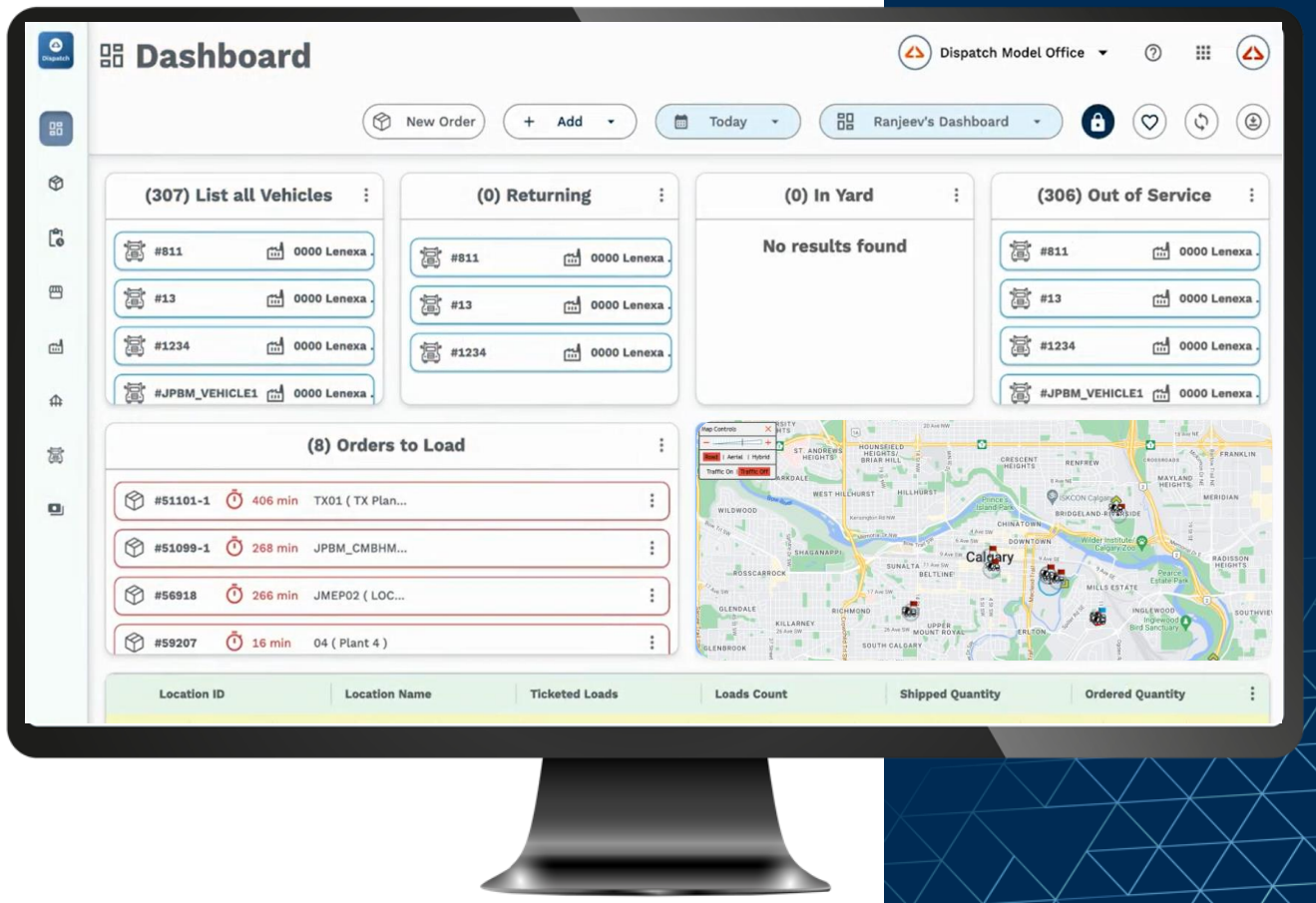
How on-board monitoring systems can help improve productivity?

The concrete delivery cycle



Dispatching

- Production schedule
- Ticketing
- Truck GPS positioning
- Truck production status



Command Alkon®

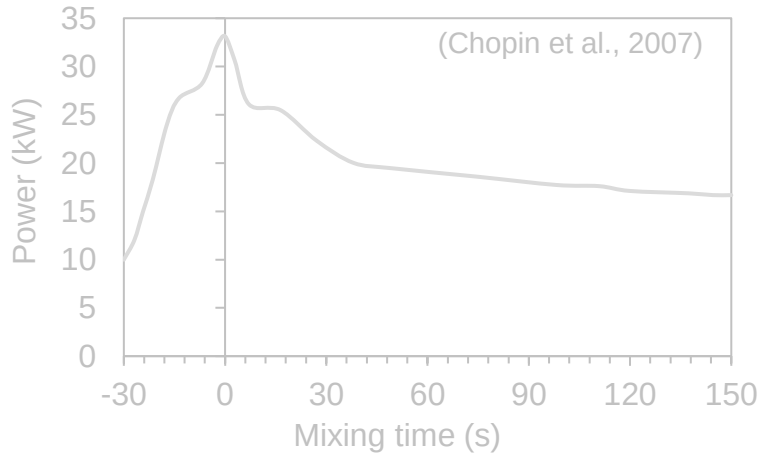
The cost of mixing – For the truck alone:

	Time (Loading + Mixing + Adjustment)	Fuel	Cost (Salary + Truck cost + Fuel)	CO_2
	14.5 min	4.26 L	29$	11.5 kg
	11 min	3.31 L	22$	9 kg

Crédit : Rapid

+ 30%

How on-board sensors can help detect concrete **homogeneity** and the end of mixing for dry-batch to save **time, emissions and money** while ensuring **quality**?



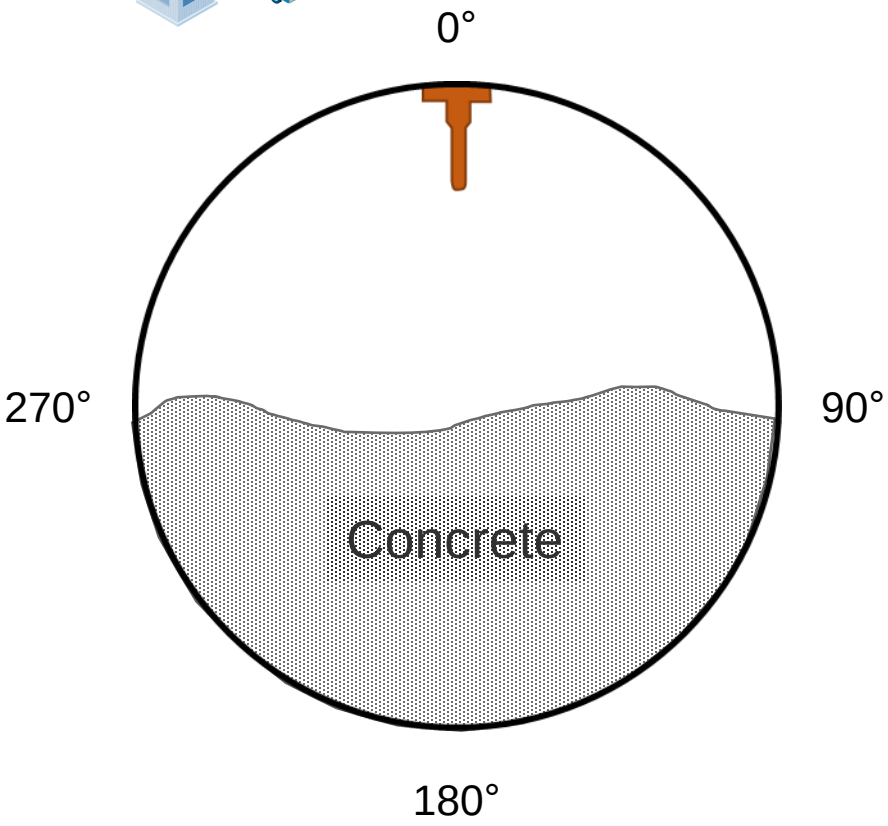
↘ 17% energy consumption

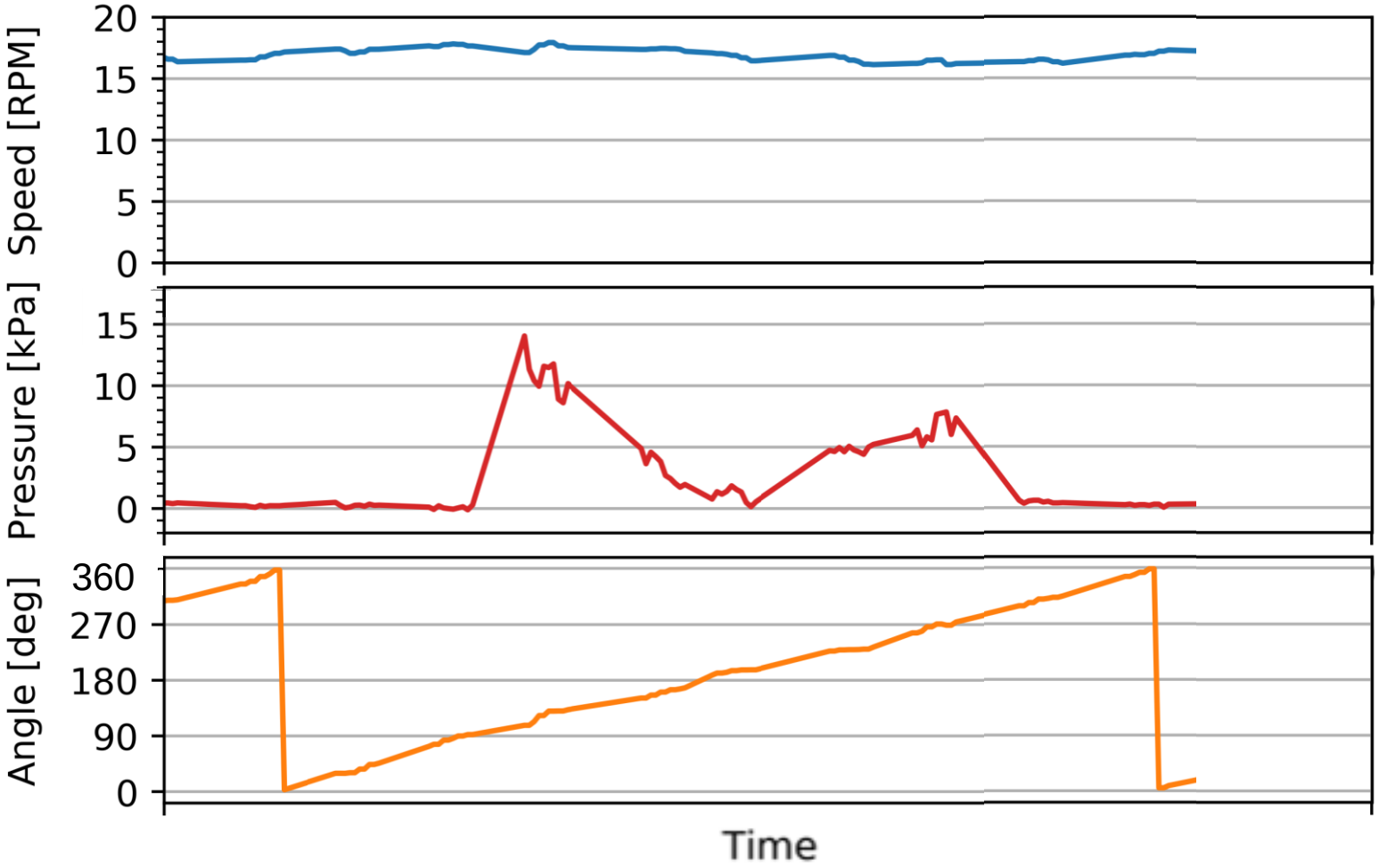
and

↘ 32% mixing duration

(Ngo et al., 2017)

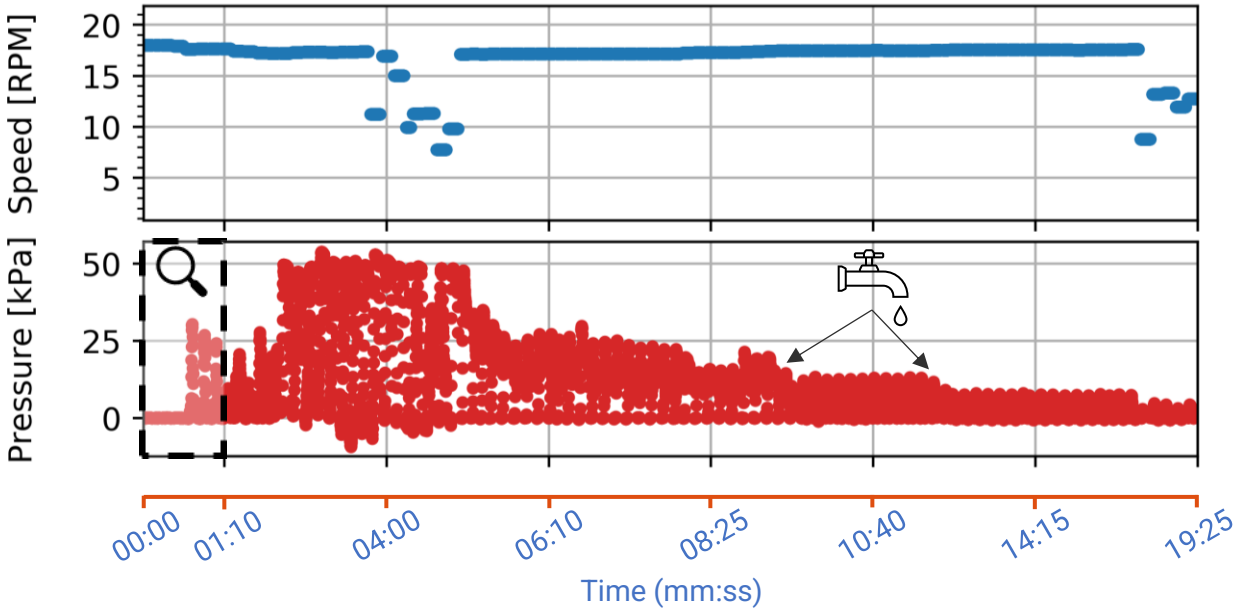
Measurements from the slump probe

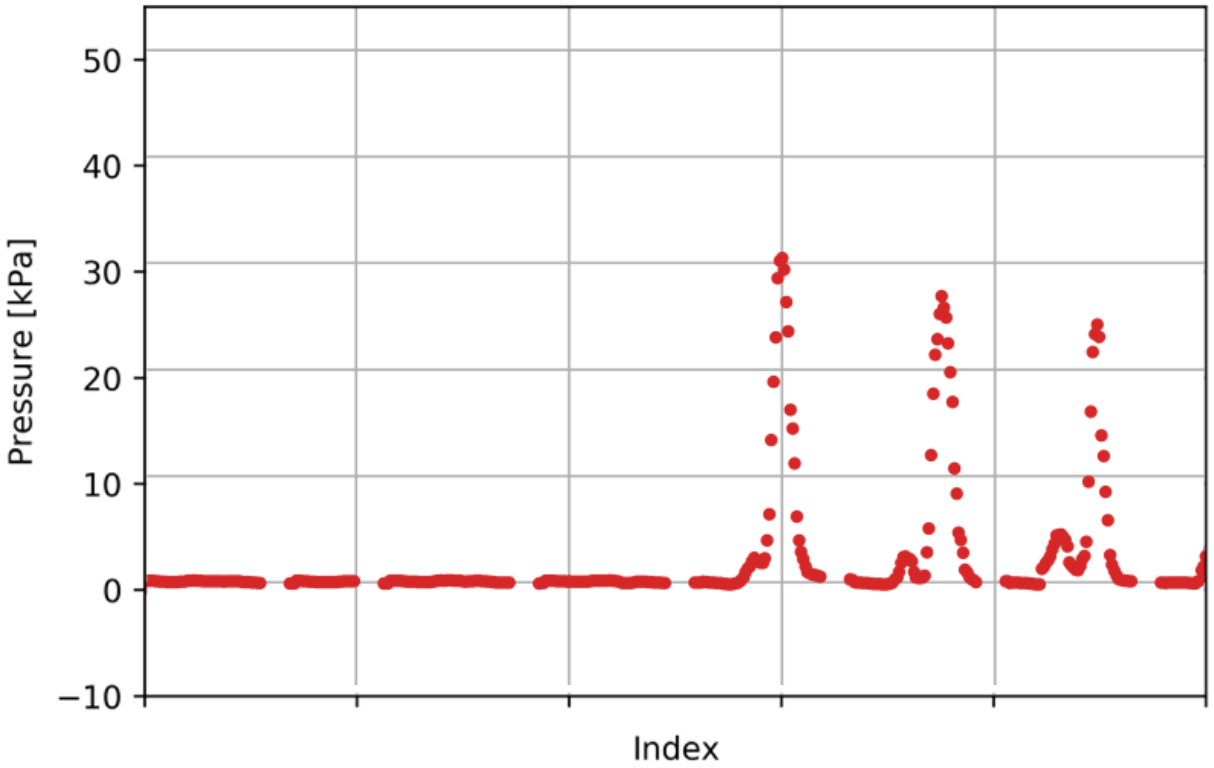




Pressure evolution

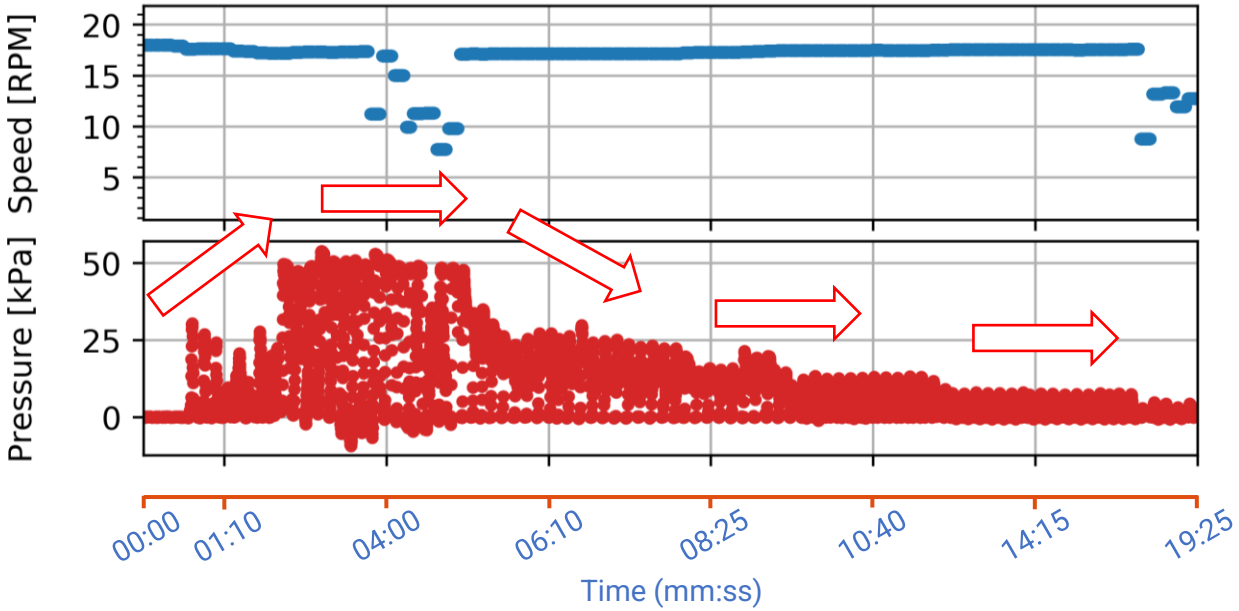
Example of a typical load





Step: Mixing + Slump adjustment with water

Pressure evolution



Challenge:

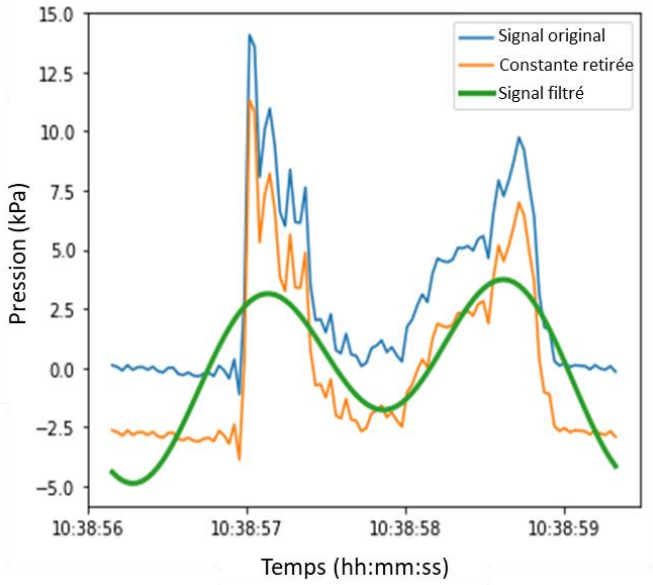
How to analyse *pressure data* to detect homogeneity?

→ *Development of the End of Mixing Detection Algorithm (ADFMI)*

Batching

Outcomes

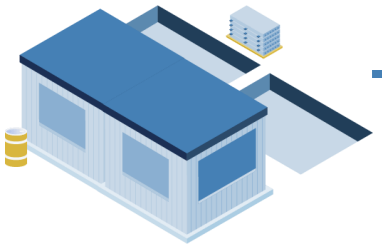
After the monitoring and post-processing of several hundred loads, the developped **algorithm** has been validated on **test batches.**



The main observations were:

- **Homogenization** occurs during mixing and is **quantifiable** through slump probe data
- Material loading sequence and many other **parameters** (load volume, drum speed, quantity of water, etc.) influence **mixing kinetic**
- Homogenization occurs after retempering and is detectable by the slump probe
- Revolution **amount needed** to achieve homogeneity vs. **recommandation** in standards

Slump Stand



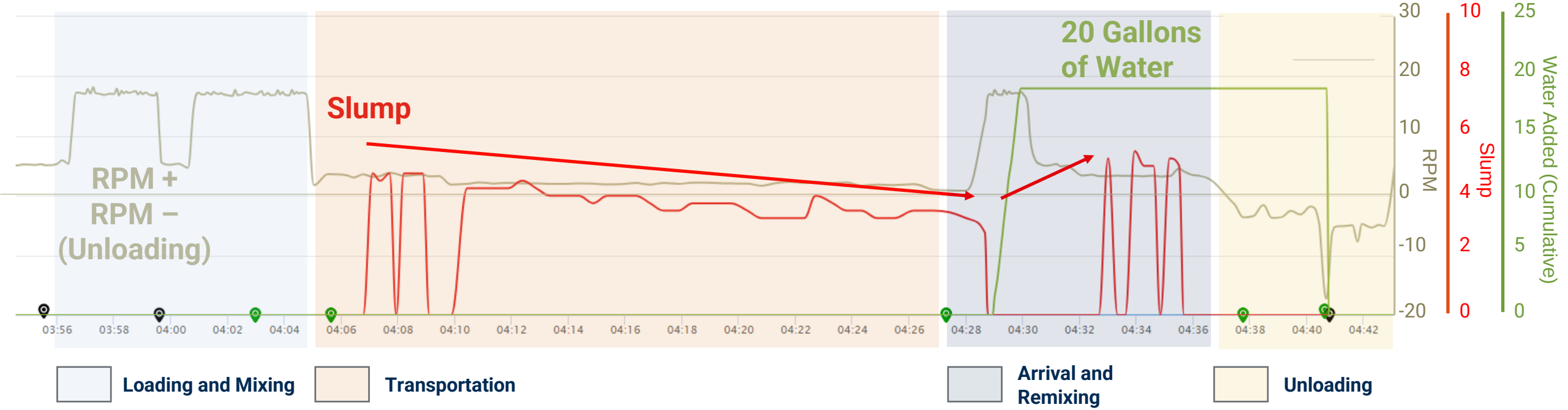
Construction Site

Command Alkon®

Workability adjustment

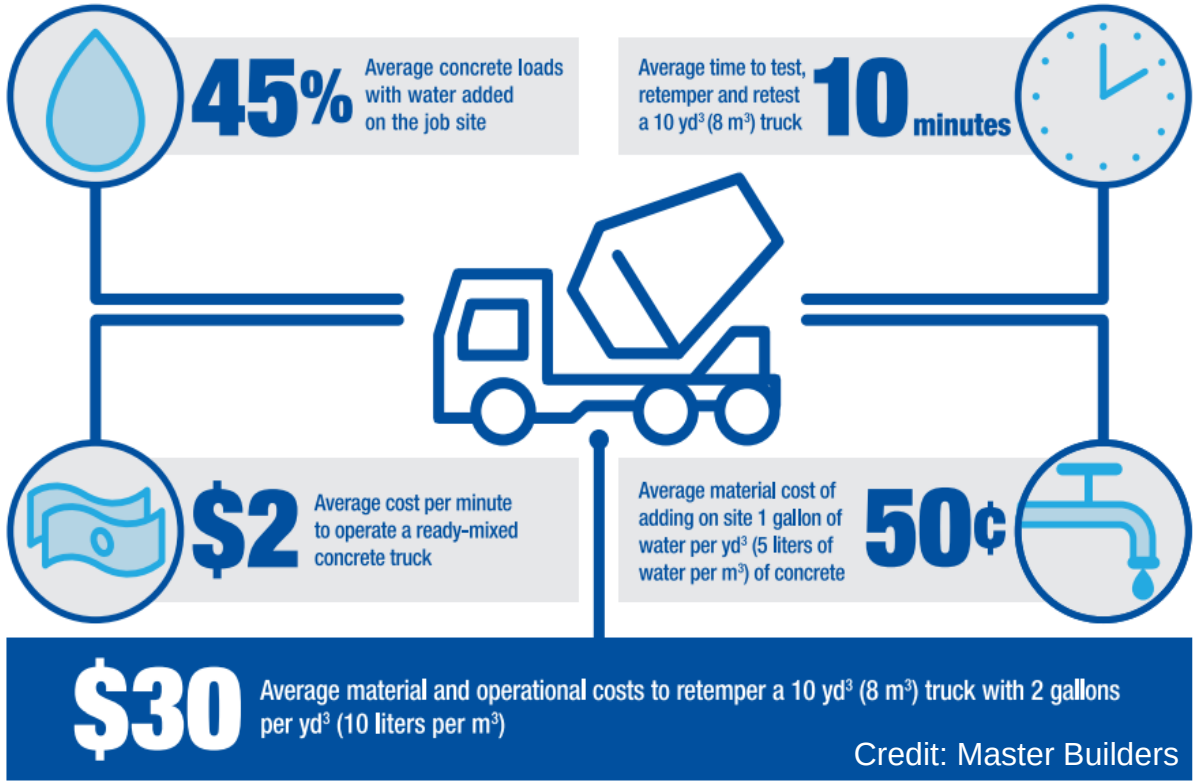
No more blind spot during transportation

Out of target detection



+faster / +control / +robustness

The cost of retempering

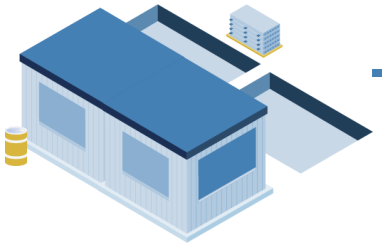


Existing solution: Close-Loop with batching system
Load advice to trim water based on slump loss

Is it possible to go further?
Topic: Predict the **evolution of slump** during transportation

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

Slump Stand



Construction Site

Required slump at departure:
? inches

Slump anticipation algorithm

Target slump at site:
X inches

The algorithm

Load volume

Concrete temperature

W/C

Age at departure

Slump at arrival

Travel time

Outside temperature

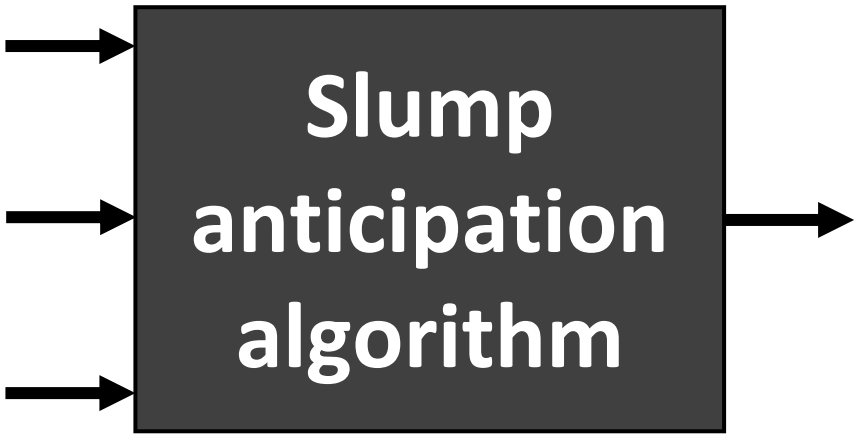
Outside humidity

Popular machine learning model:

XGBoost

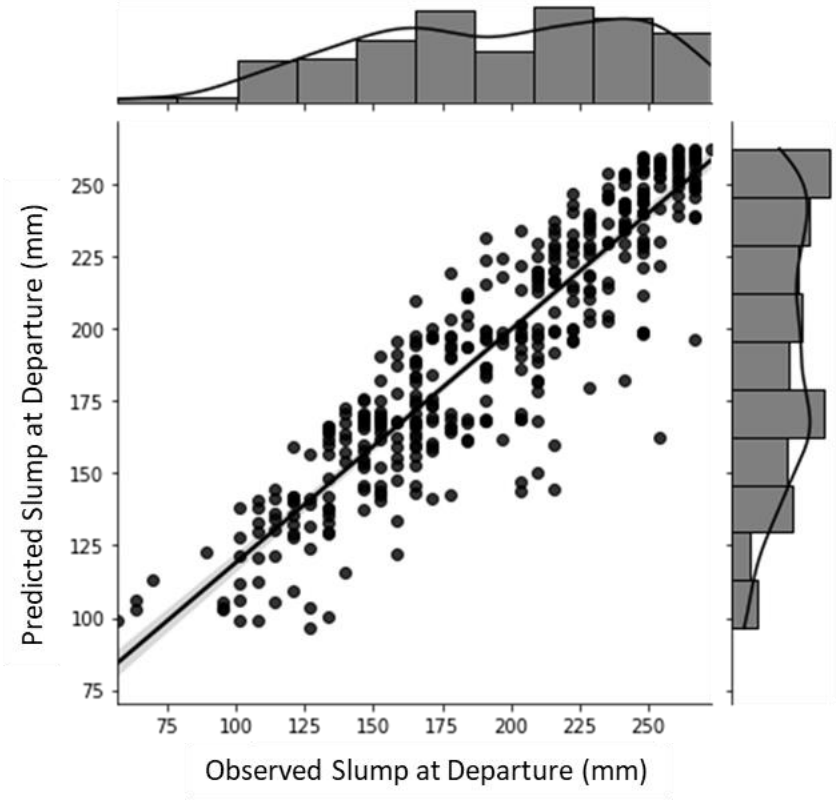
Neural Network (NN)

…



Target slump at departure

Performance

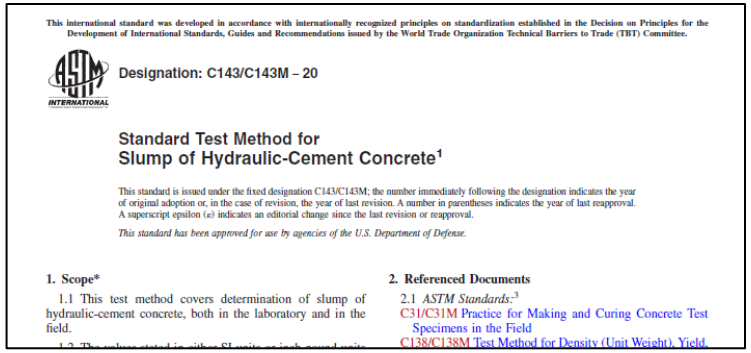


Train set: $R^2 = 0.82$ Test set: $R^2 = 0.81$

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*

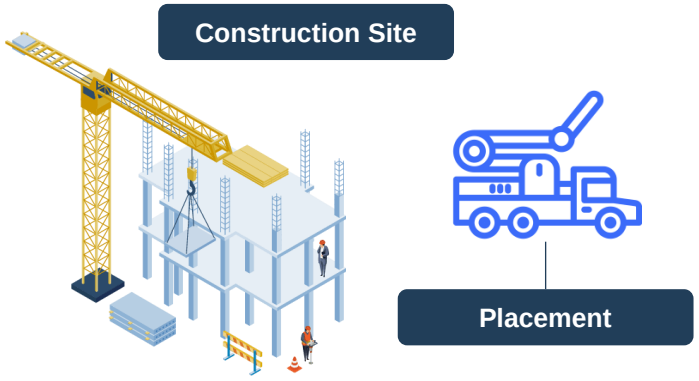
1.1 This test method covers determination of slump of hydraulic-cement concrete, both in the laboratory and in the field.

2. Referenced Documents

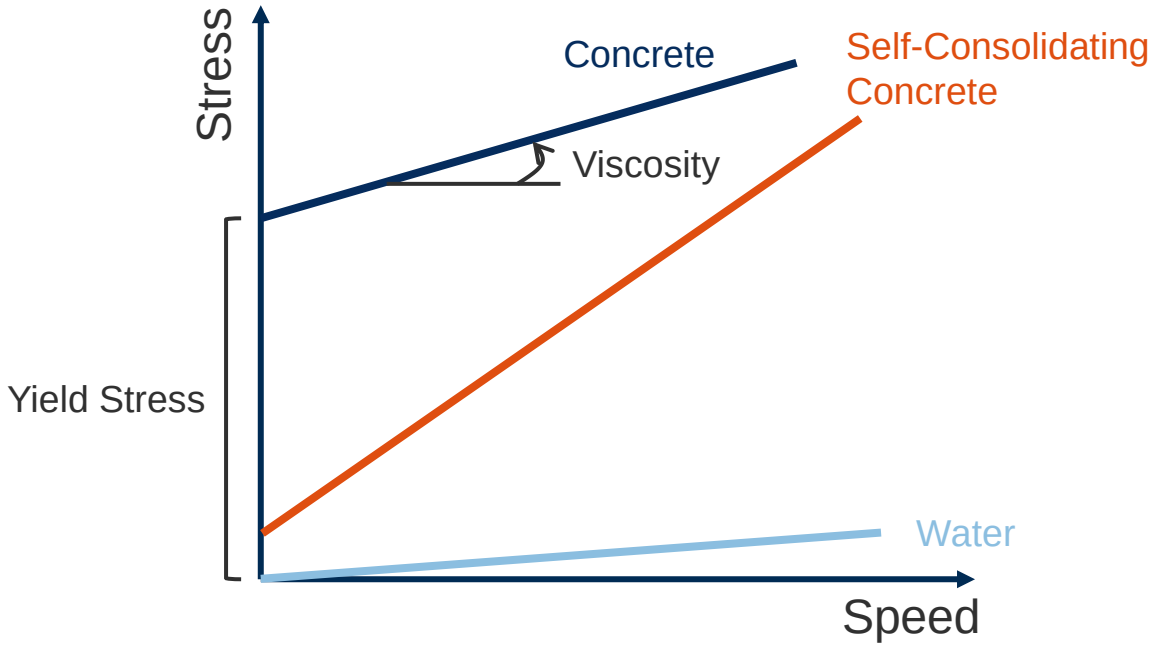
2.1 *ASTM Standards:*[3]

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

C138/C138M Test Method for Density (Unit Weight), Yield,



Rheology: Study of flow behavior



When? SCC, pumping, shotcrete…

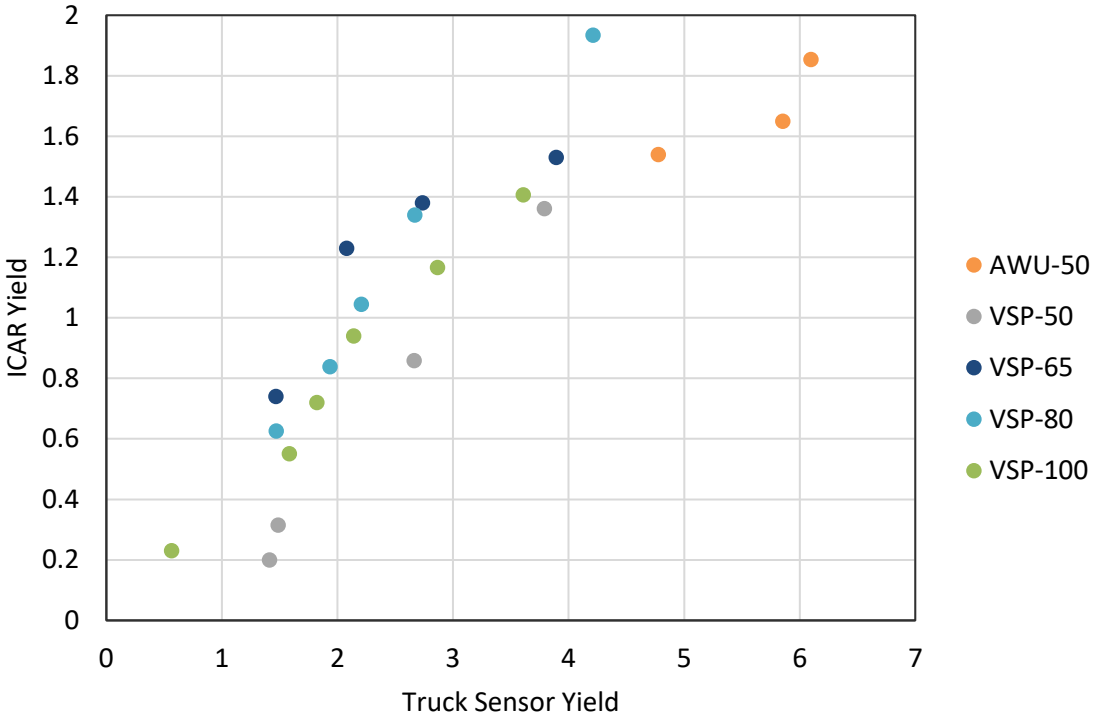
Why? Workability, segregation, pump blocage, rebar encapsulation…

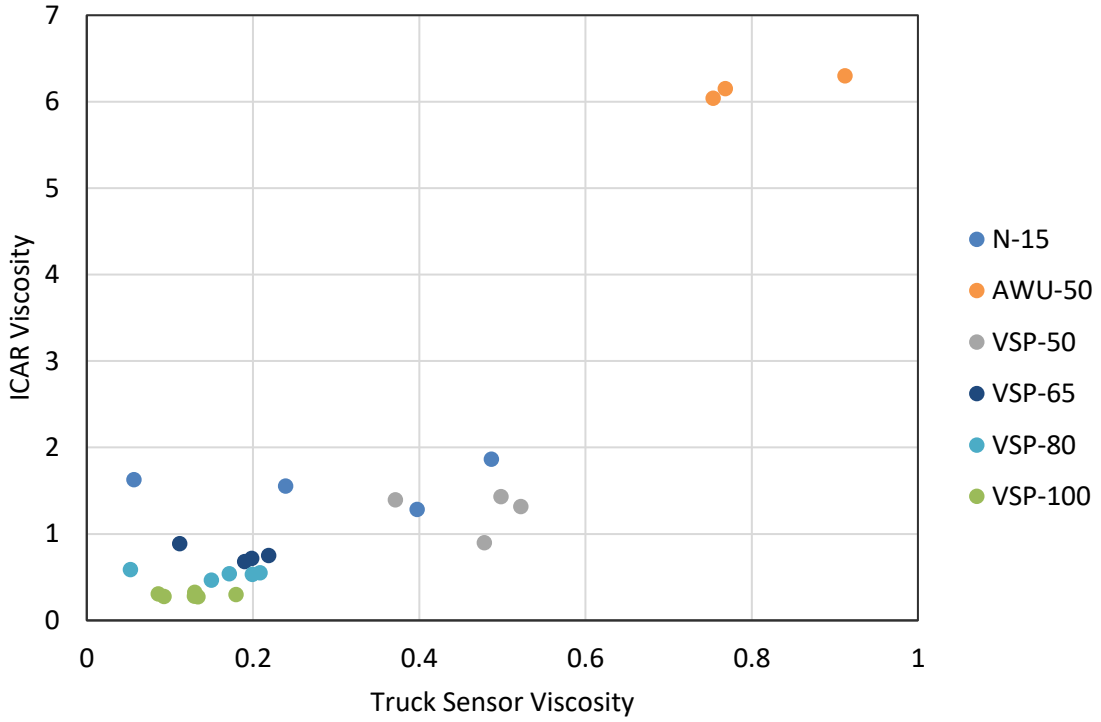
Rheology in a truck

Command Alkon®

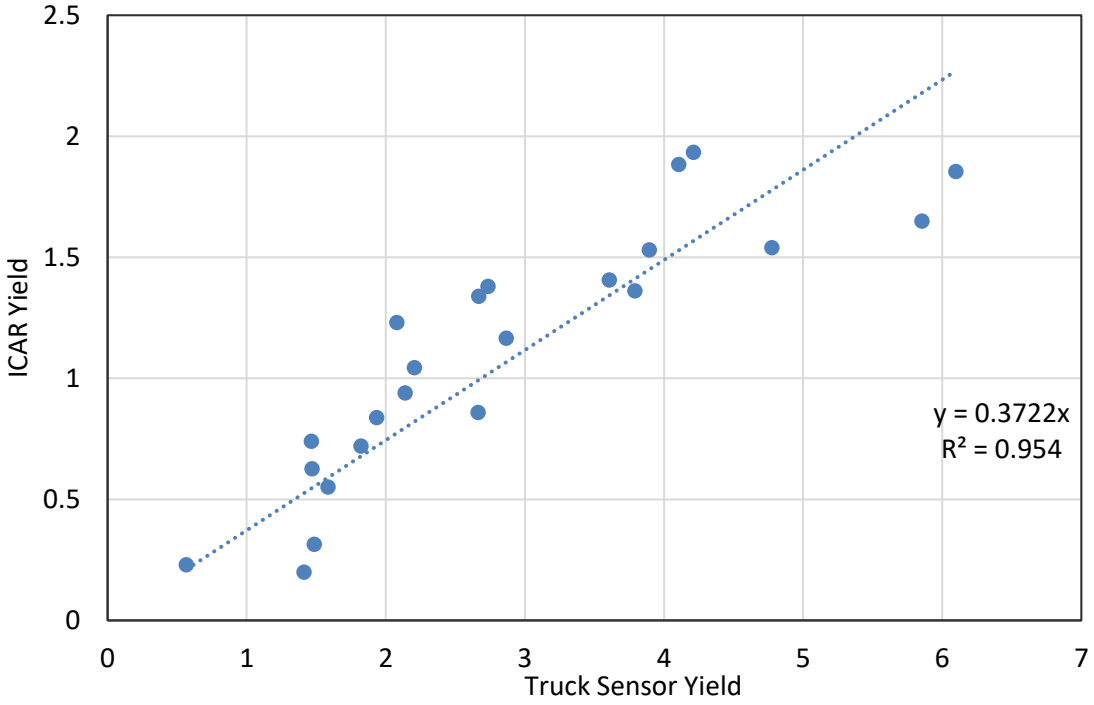
Truck equipped with on-board sensors vs ICAR Rheometer

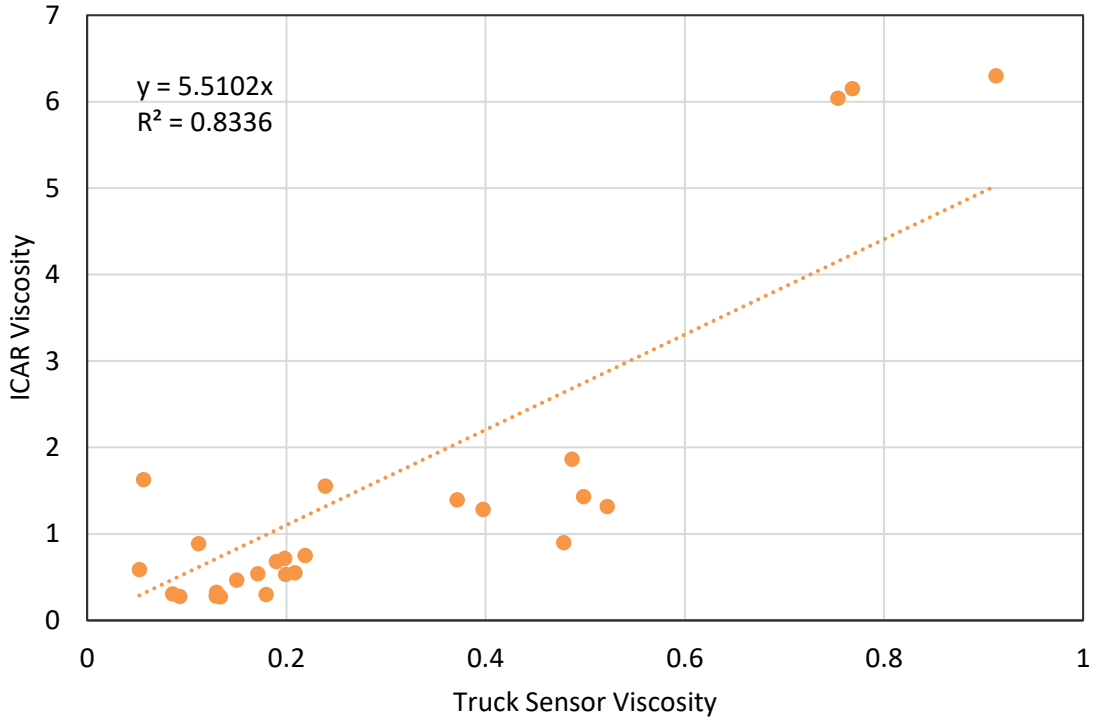
Rheology in a truck

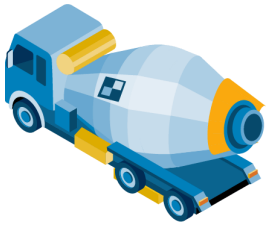




Rheology in a truck







Return

3-5% of the total produced concrete is **leftover** (NRMCA)
→ **20 million cubic yards** per year in the US

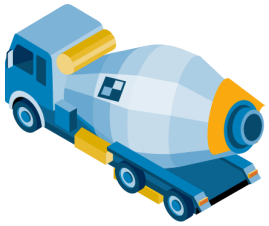
+ Environmental benefit

+ Economical benefit

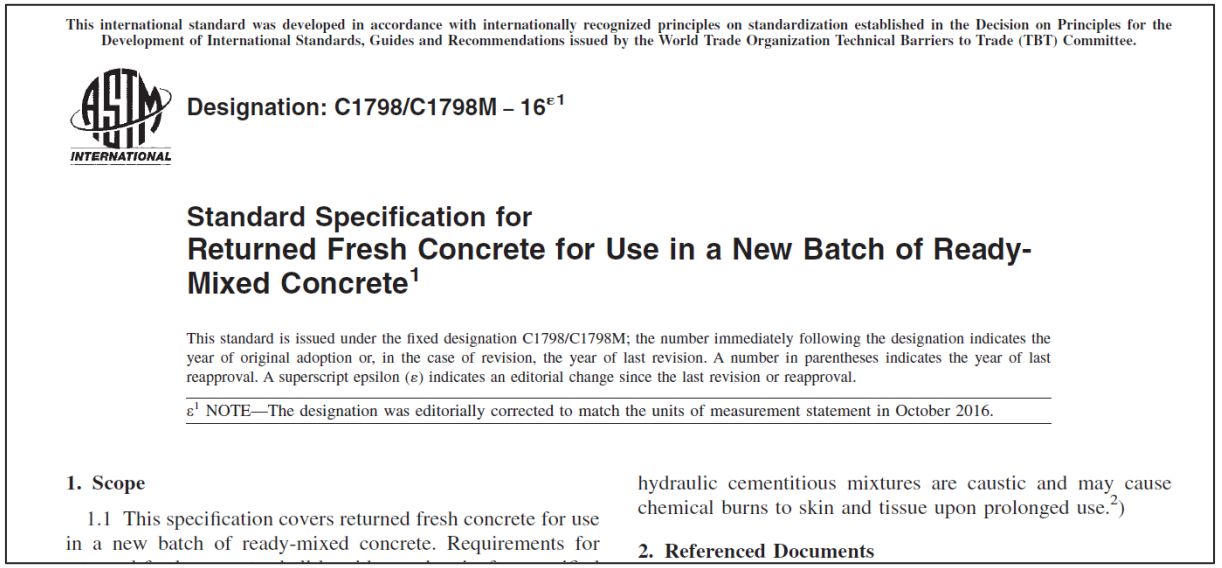
+ Complexity

Various strategies:

- Let concrete set on the ground and **crush it**
- Fill **precast block** forms
- Use admixture to induce instant dry-up to reuse as **backfill or aggregate** in new concrete
- **Redirect leftover** concrete to another construction site
- **Re-use leftover** concrete in a new batch (ASTM C1798)



Re-use leftover concrete



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: C1798/C1798M – 16$^{\varepsilon 1}$

Standard Specification for Returned Fresh Concrete for Use in a New Batch of Ready-Mixed Concrete[1]

This standard is issued under the fixed designation C1798/C1798M; 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.

ε^1 NOTE—The designation was editorially corrected to match the units of measurement statement in October 2016.

1. Scope

1.1 This specification covers returned fresh concrete for use in a new batch of ready-mixed concrete. Requirements for

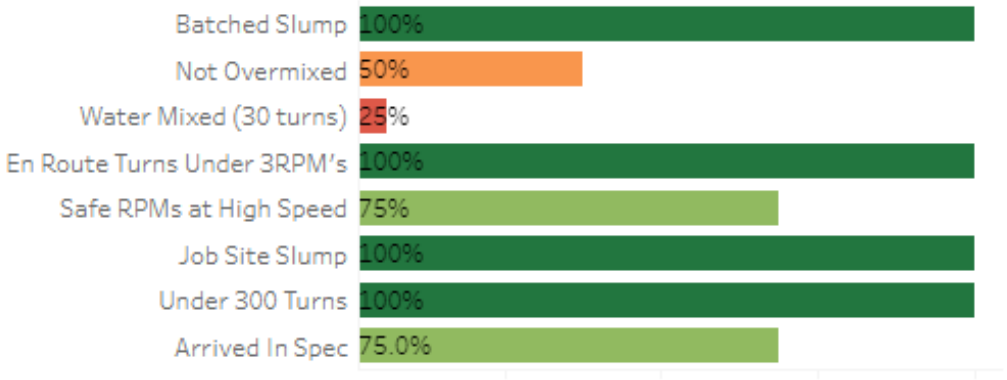
hydraulic cementitious mixtures are caustic and may cause chemical burns to skin and tissue upon prolonged use.[2])

2. Referenced Documents

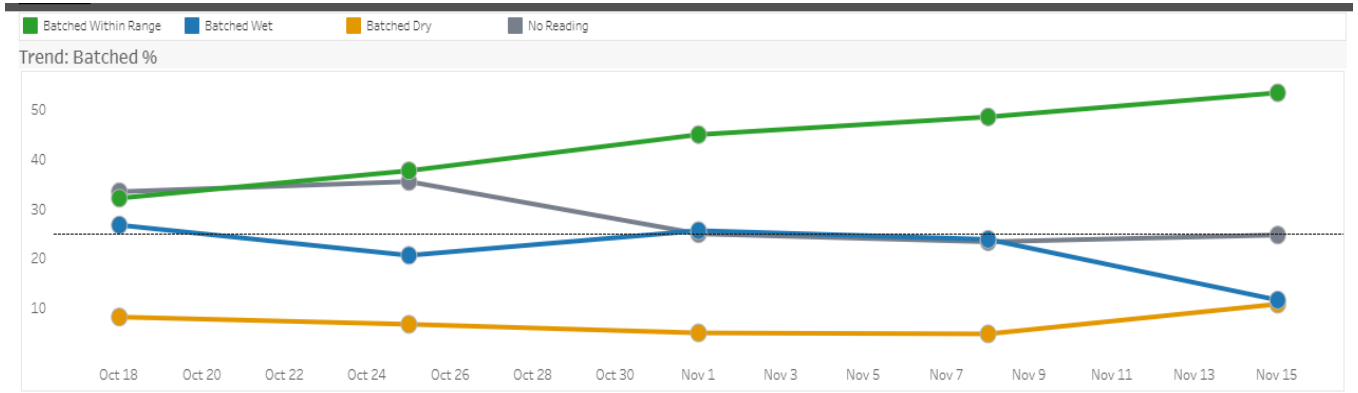
- Leftover volume **measurement accuracy**: 0.25 yd^3
- 90 minutes – Use a **hydration stabilizing admixture** after 90 minutes
- Leftover concrete has to have a **specified strength equal or greater** of the new batch
- Volume of leftover incorporated shall not exceed **50%** of the total volume of the new batch

Training and continuous improvement

Driver training and evaluation



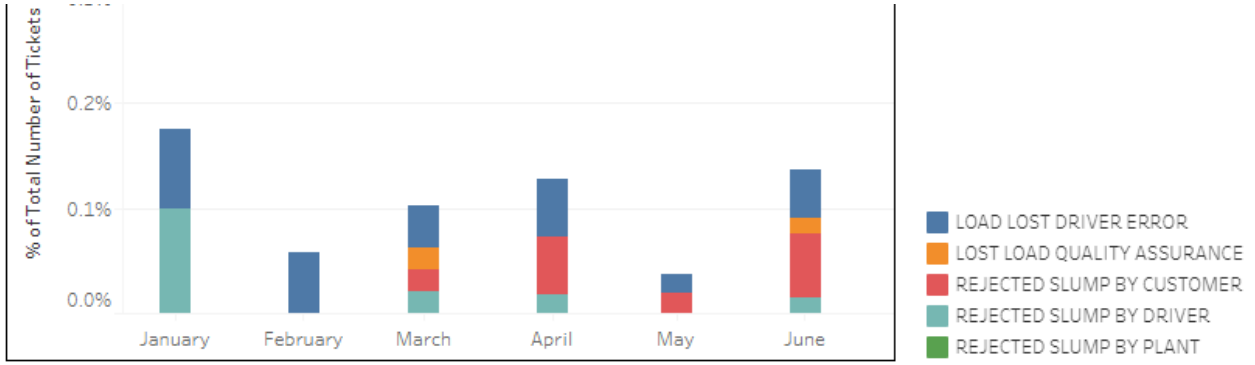
Batcher performance



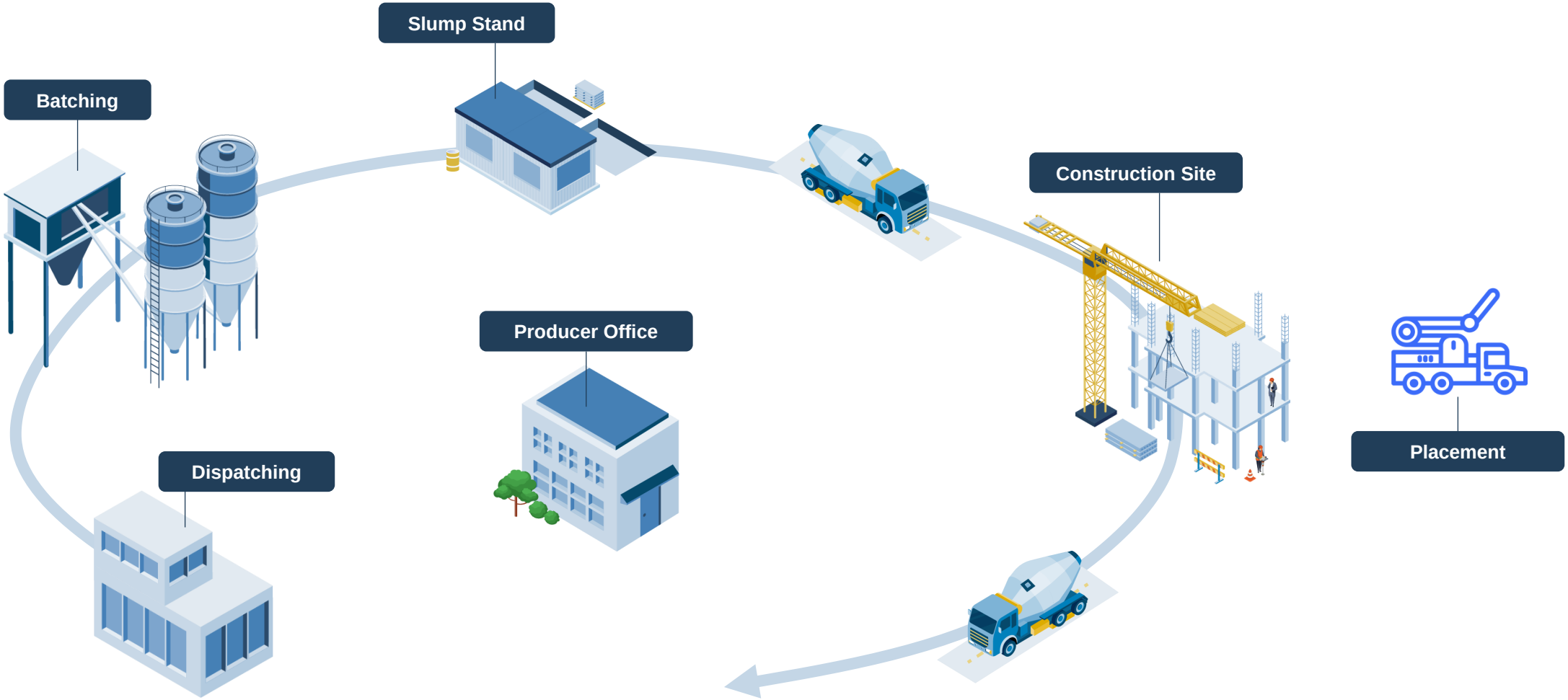
Compliance with onsite specifications

	At Job W/C %	At Begin Pour W/C %	At Job W/C %	At Begin Pour W/C %
Plant	93.14%	87.18%		
Plant	92.61%	88.04%		
Plant	91.21%	78.02%		

Rejected loads tracking



The concrete delivery cycle



Where can I get information?

- ACI Subcommittee 304G - In-Transit Ready-Mix Concrete Monitoring
- Ongoing work on an Emerging Technology Report
- Soon to be completed!

Thank you!

Pierre Siccardi, Ph.D.
psiccardi@commandalkon.com

What's next?

Why sampling is needed on site?

- Slump ✓
- Air content ✓
- Cylinders for compressive strength ...

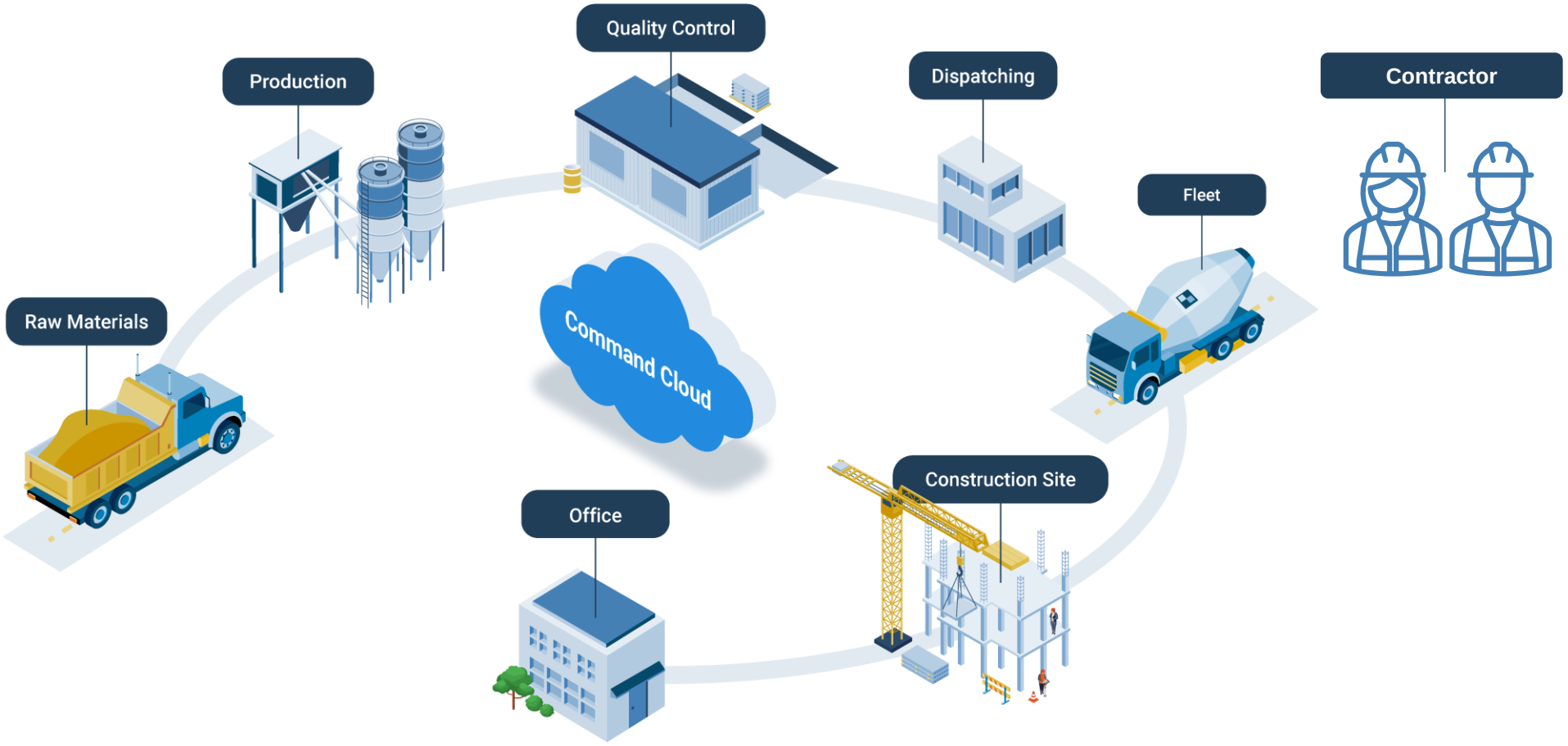
Appendix

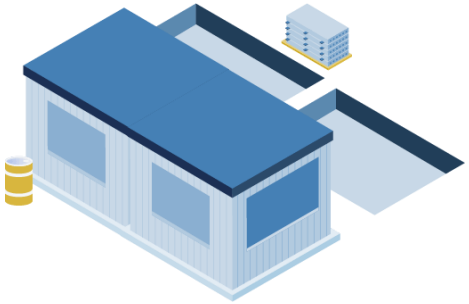
Command Alkon

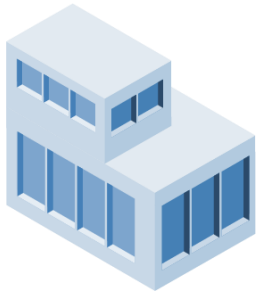
Command Alkon

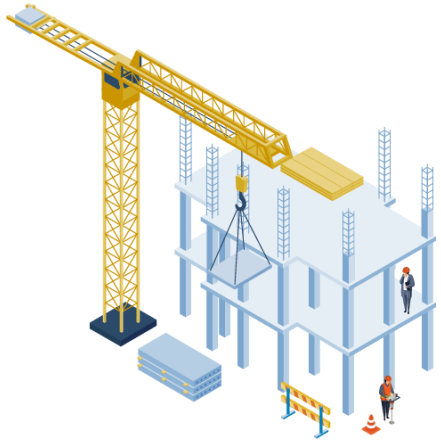
Ready Mix Industry Software Solutions

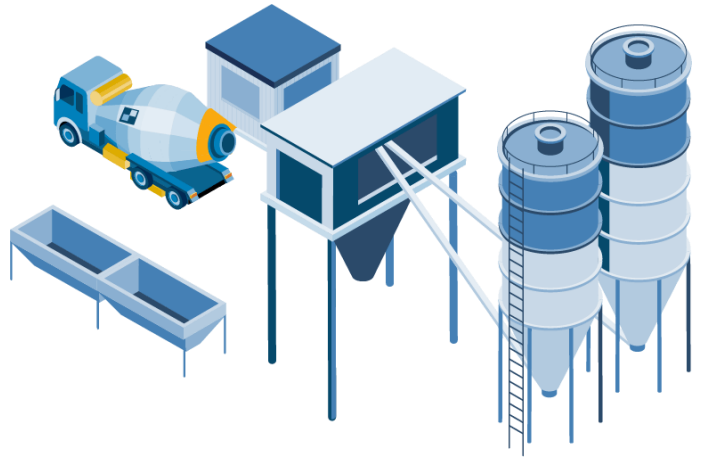
Raw Materials > Production > Quality Control > Dispatching > Fleet > Construction Site > Office

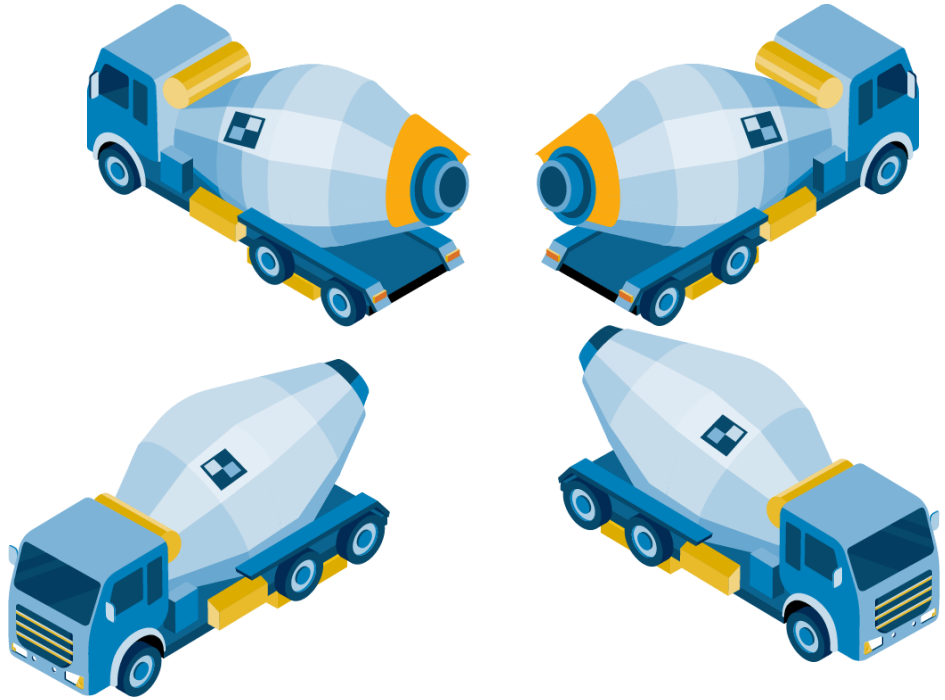








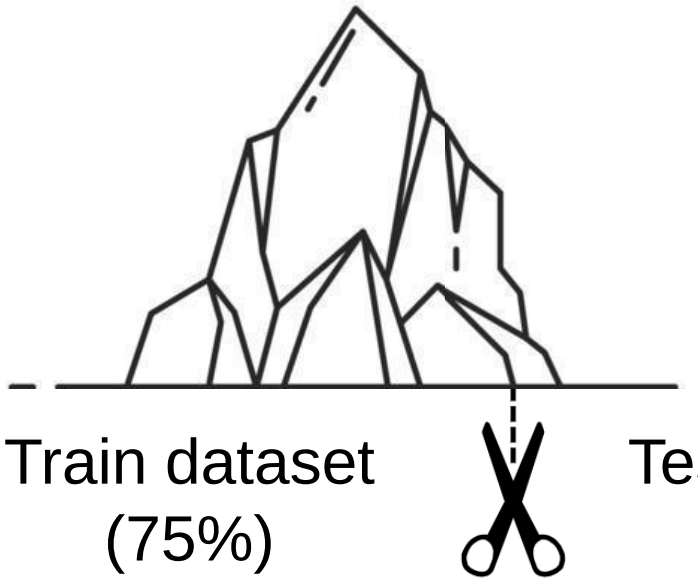




Database and performance

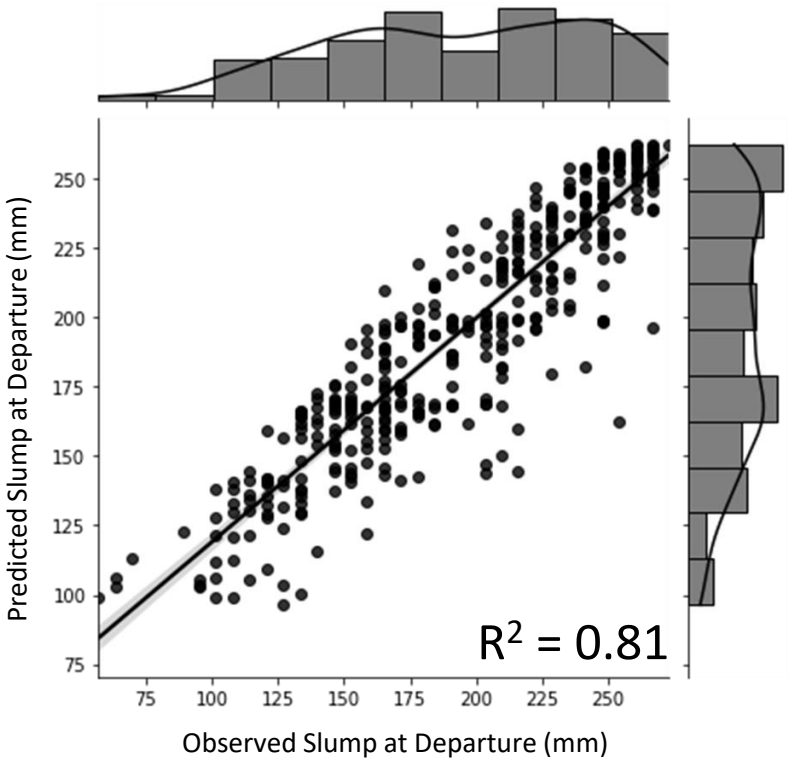
1607 loads of concrete

Database and performance



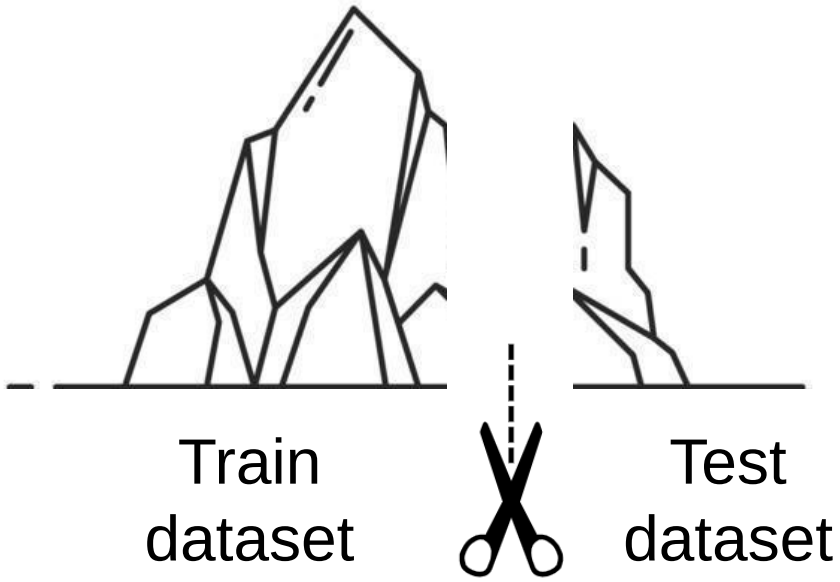
Train dataset (75%)

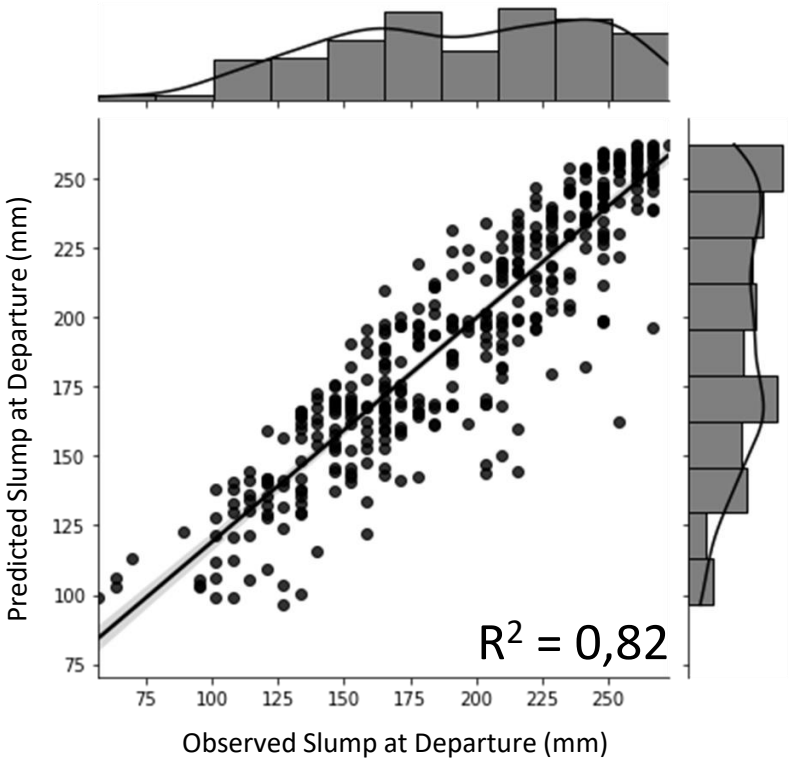
Test dataset (25%)



It works!

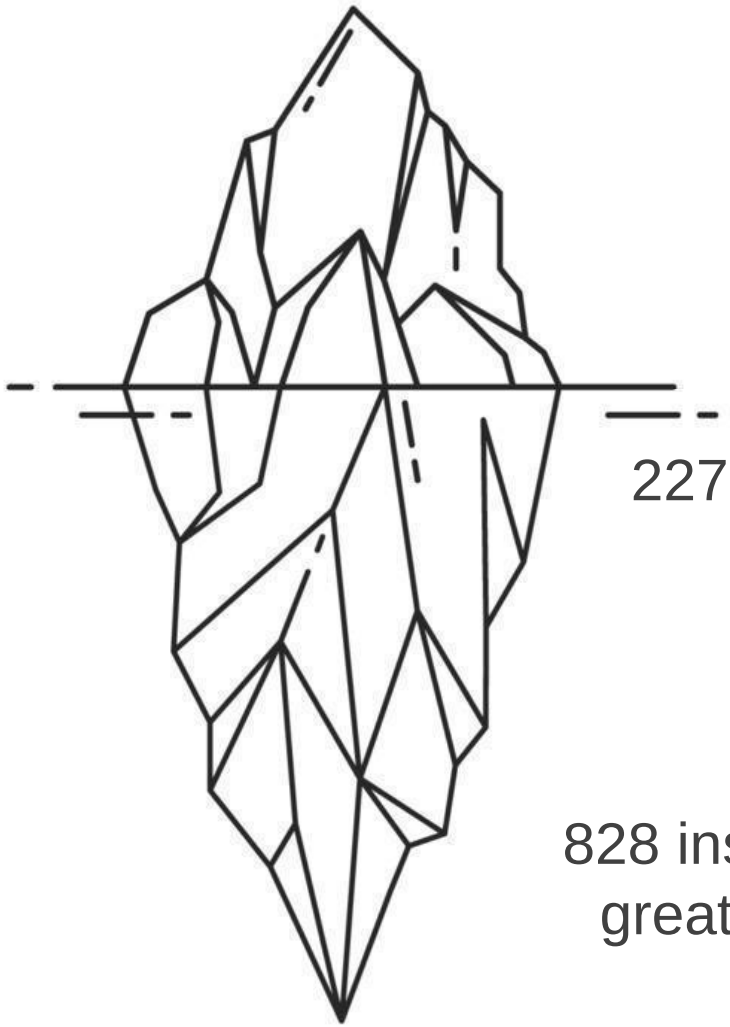
Database and performance





It works!

Database and performance



1607 loads of concrete (29%)

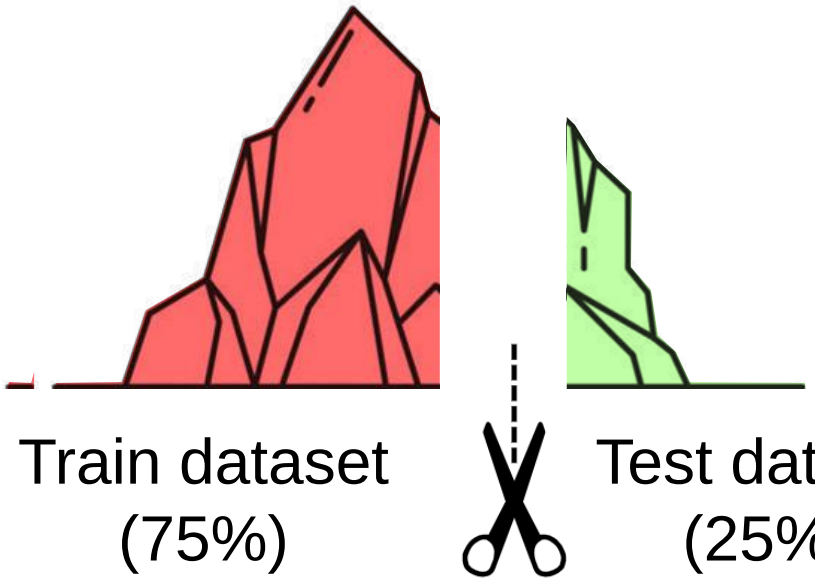
2275 incomplete instances (40%)

920 outliers (16%)

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

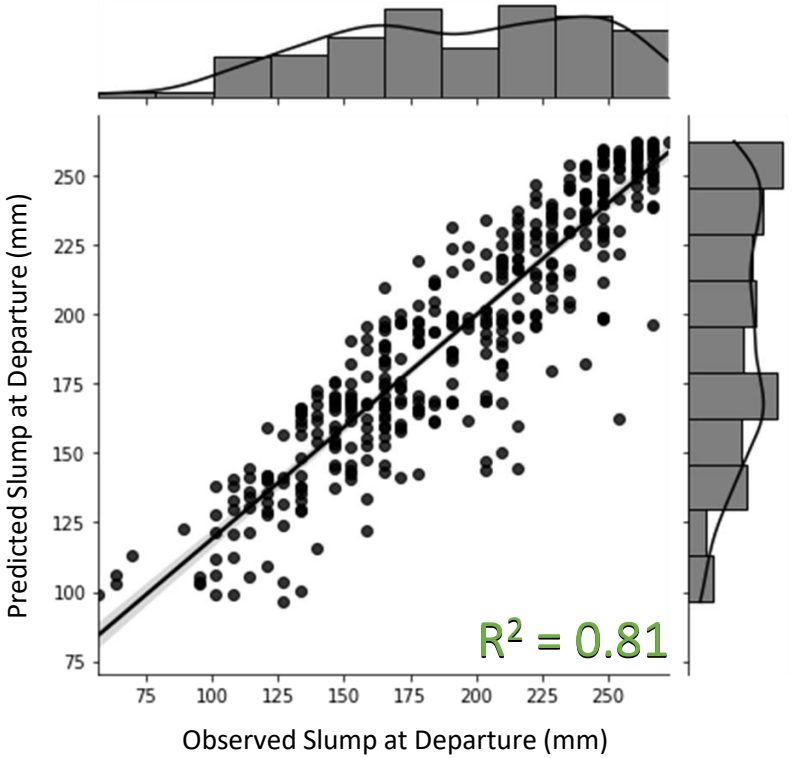
Note: That was a proof of concept

Database and performance



Train dataset (75%)

Test dataset (25%)

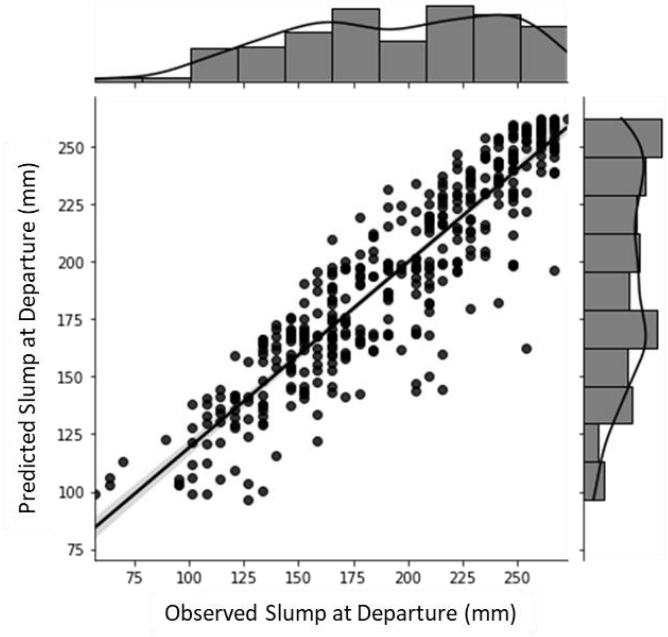


Using a popular machine learning model (*XGBoost)*:

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

Close and relatively high!

Performance



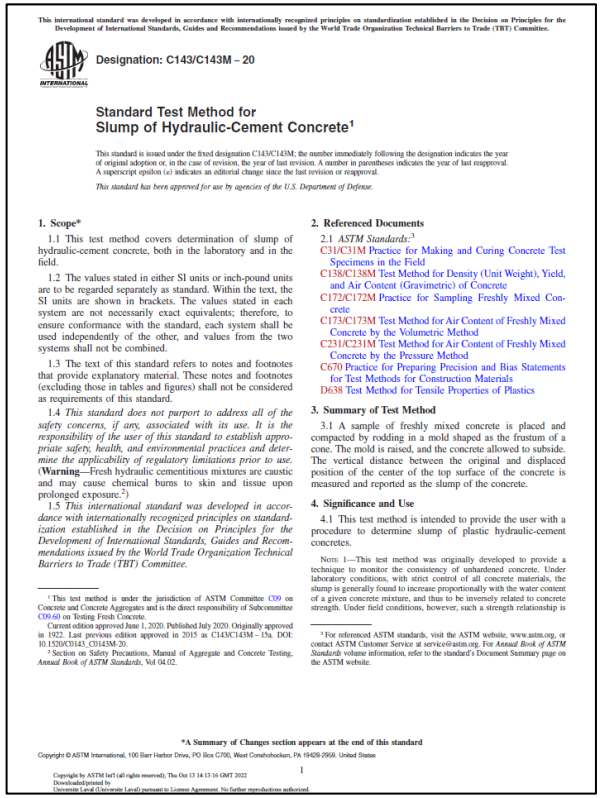
Using a popular machine learning model (*XGBoost*):

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

Productivity & profitability

- What is productivity and profitability?
  - The easy ones – mainly related to production operations – can easily be monitored through KPIs:
    - Time saving: delivery, training…
    - Material saving
  - The not so easy ones:
    - Safety
    - Worker retention
    - Dispute solving
    - …

- Who are the stakeholders who benefit from it?
  - Producers will learn what data can be obtained, how this data can inform both their quality control and operations, and how to evaluate the effectiveness of these systems in comparison to currently accepted standard test methods.
  - Contractors will understand how real-time data can inform the planning and execution of concrete placing and finishing operations.
  - Owners, building officials, designers, specifiers, and inspectors will see opportunities for increased confidence in the quality of the constructed facility.

Training and continuous improvement