Concrete Sustainability in Motion: Environmental Benefits of On-Board Monitoring Systems for Ready-Mix Trucks

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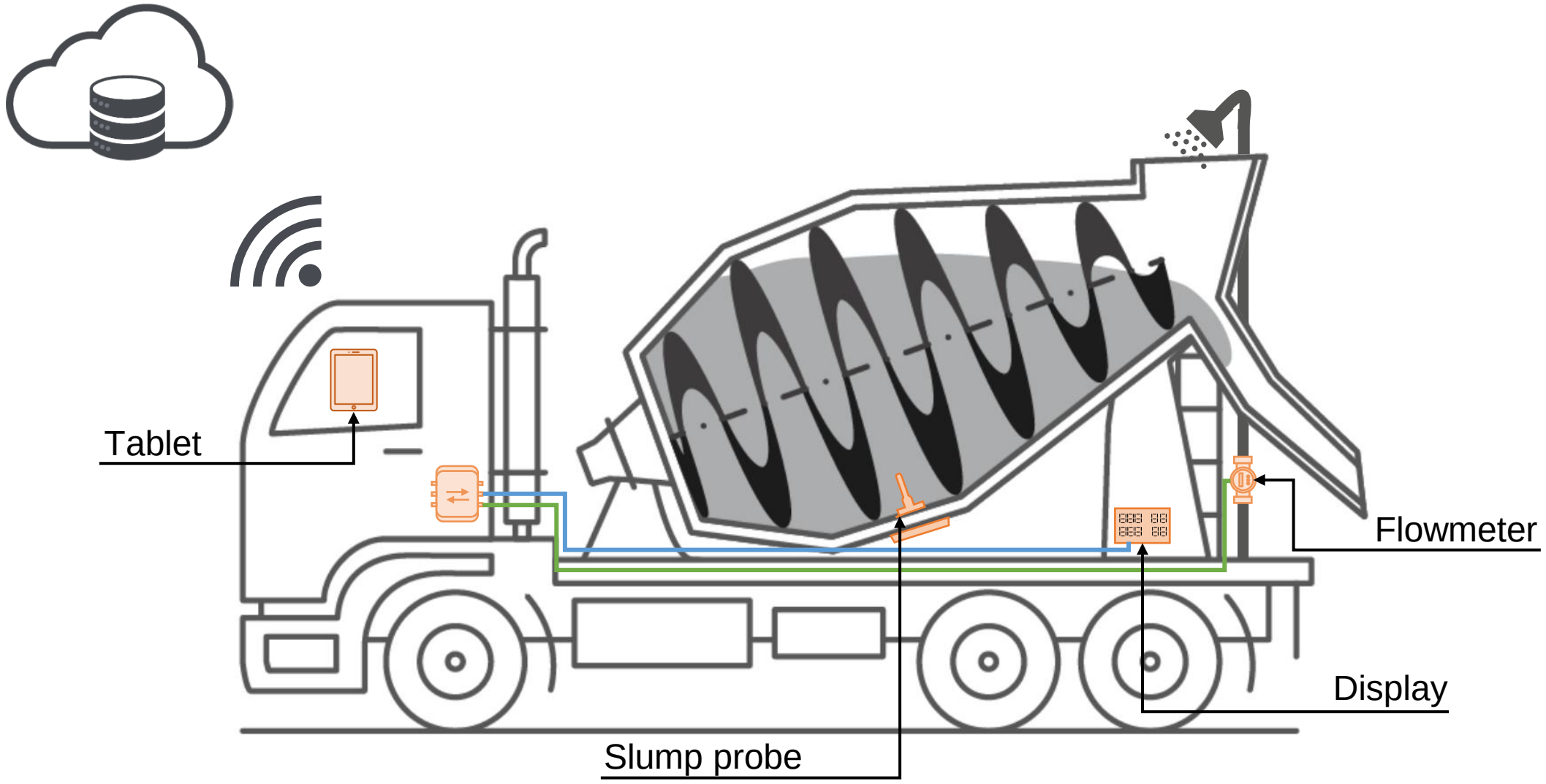
‘Measure what is measurable and make measurable what is not so.’
Galileo (1564-1642)

‘If you can’t measure it, you can’t improve it.’
Lord Kelvin (1824-1907)

‘If you torture the data long enough, it will confess to anything.’
Ronald Coase (1910-2013)

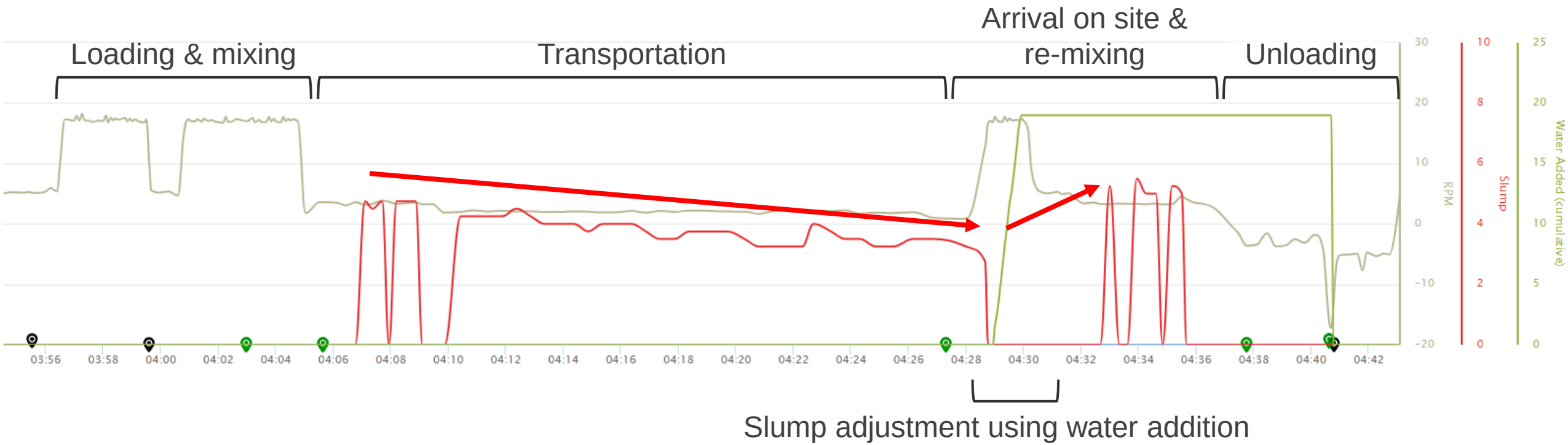
‘More development is needed, but let's remain cautious…!’
Pierre Siccardi (1993-)

On-board monitoring system



Real-time data measurement

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



Slump adjustment using water addition

Research project

Five years project on on-board monitoring sensors and systems

Different topics: rheology, air content and density measurement, machine learning, **concrete mixing and homogeneity**…

The cost of mixing

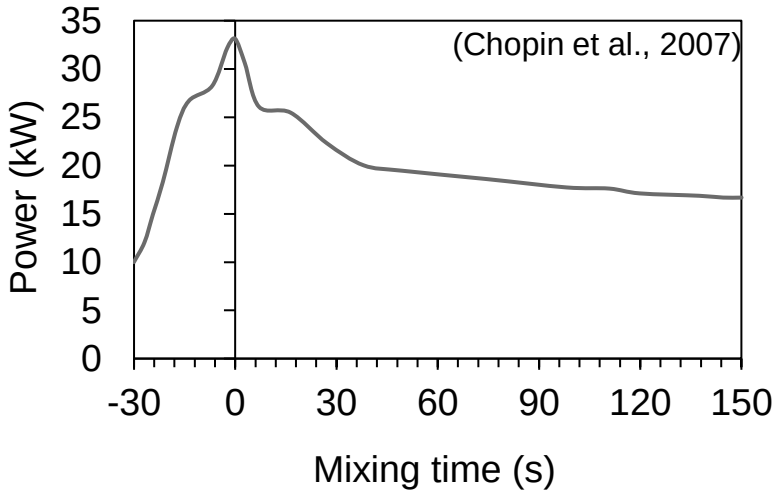
For the truck alone:

	Time (Loading + Mixing + Adjustment)	Fuel	Cost (Salary + Truck cost + Fuel)	CO_2
Dry-Batch 	14.5 min	4.26 L	29$	11.5 kg
Wet-Batch  Crédit : Rapid	11 min	3.31 L	22$	9 kg

+ 30%

Current situation for wet-batch

- Using a wattmeter for stationnary mixer



↘ 17% energy consumption

and

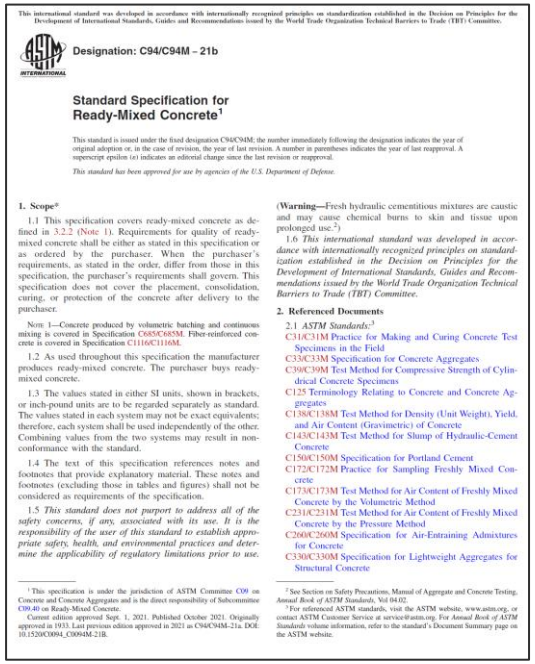
↘ 32% mixing duration

(Ngo et al., 2017)

- ASTM C94 requires **no minimum mixing duration** if mixer performance tests have been conducted

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**?

What's in ASTM C94?



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: C94/C94M – 21b

Standard Specification for Ready-Mixed Concrete[1]

This standard is issued under the fixed designation C94/C94M; 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 specification covers ready-mixed concrete as defined in 3.2.2 (Note 1). Requirements for quality of ready-mixed concrete shall be either as stated in this specification or as ordered by the purchaser. When the purchaser's requirements, as stated in the order, differ from those in this specification, the purchaser's requirements shall govern. This specification does not cover the placement, consolidation, curing, or protection of the concrete after delivery to the purchaser.

NOTE 1—Concrete produced by volumetric batching and continuous mixing is covered in Specification C685/C685M. Fiber-reinforced concrete is covered in Specification C1116/C1116M.

1.2 As used throughout this specification the manufacturer produces ready-mixed concrete. The purchaser buys ready-mixed concrete.

1.3 The values stated in either SI units, shown in brackets, or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 The text of this specification references notes and footnotes that provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the specification.

1.5 *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 use.[2])

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2. Referenced Documents

2.1 *ASTM Standards:*[3]

C31/C31M Practice for Making and Curing Concrete Test Specimens in the Field
C33/C33M Specification for Concrete Aggregates
C39/C39M Test Method for Compressive Strength of Cylindrical Concrete Specimens
C125 Terminology Relating to Concrete and Concrete Aggregates
C138/C138M Test Method for Density (Unit Weight), Yield, and Air Content (Gravimetric) of Concrete
C143/C143M Test Method for Slump of Hydraulic-Cement Concrete
C150/C150M Specification for Portland Cement
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
C260/C260M Specification for Air-Entraining Admixtures for Concrete
C330/C330M Specification for Lightweight Aggregates for Structural Concrete

[1] This specification is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.40 on Ready-Mixed Concrete.

Current edition approved Sept. 1, 2021. Published October 2021. Originally approved in 1933. Last previous edition approved in 2021 as C94/C94M-21a. DOI: 10.1520/C0094_C0094M-21B.

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

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In 1955, limits have been introduced for concrete delivery:

- 300 revolutions maximum – Removed in 2013 but still required in many states
- 90 minutes maximum – Removed in 2021

In 1935, limits have been introduced for **dry-batch initial in-drum mixing**:

- 70 to 100 revolutions – Still required

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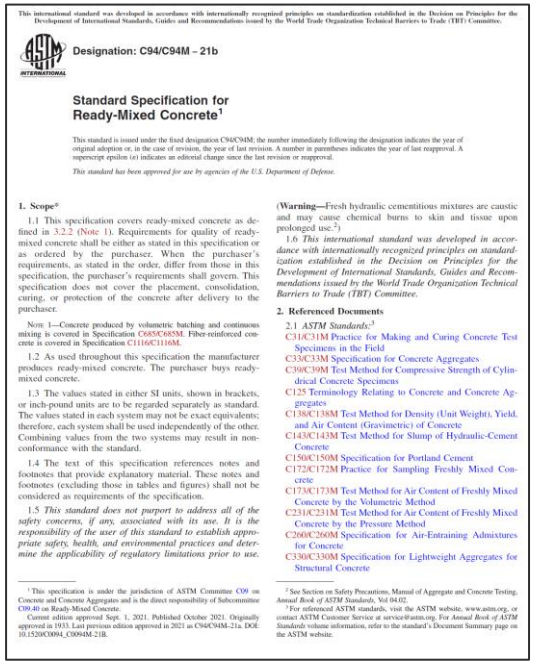

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Can sensors challenge this?

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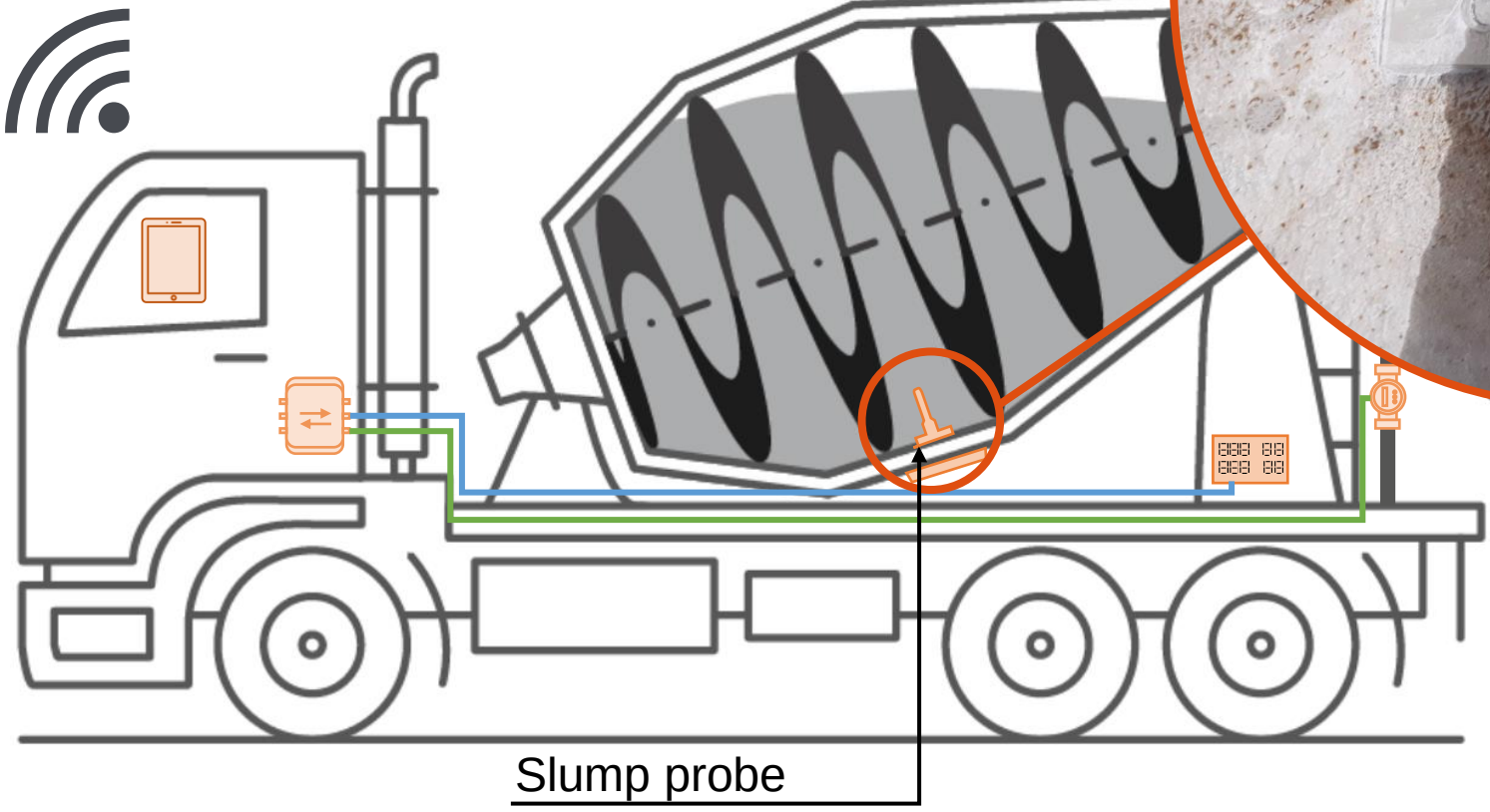
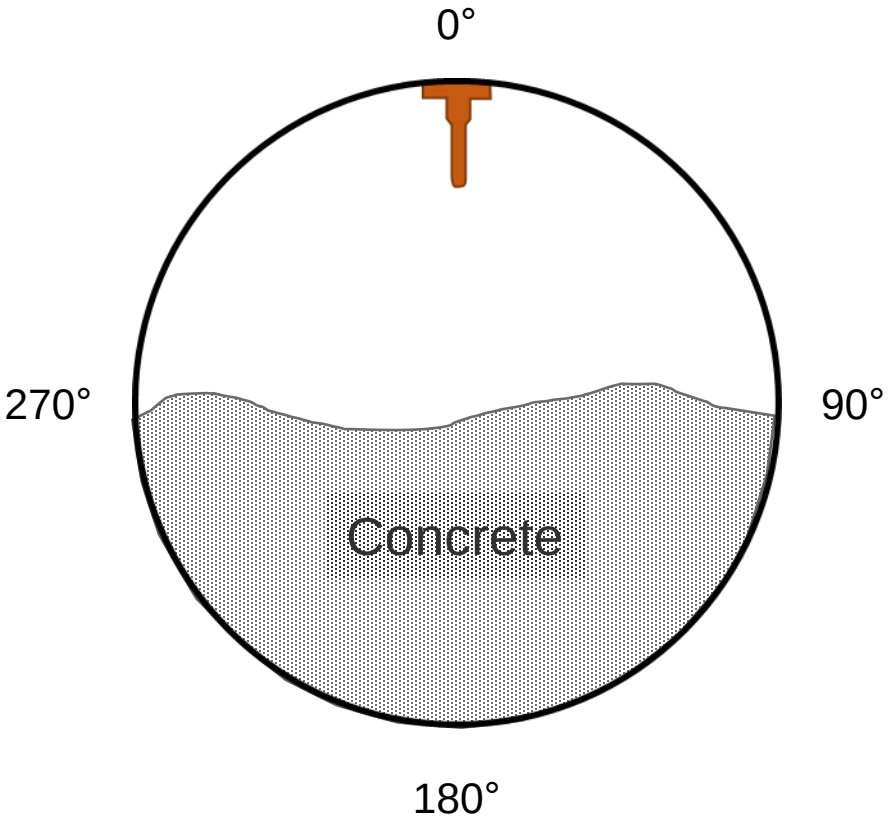
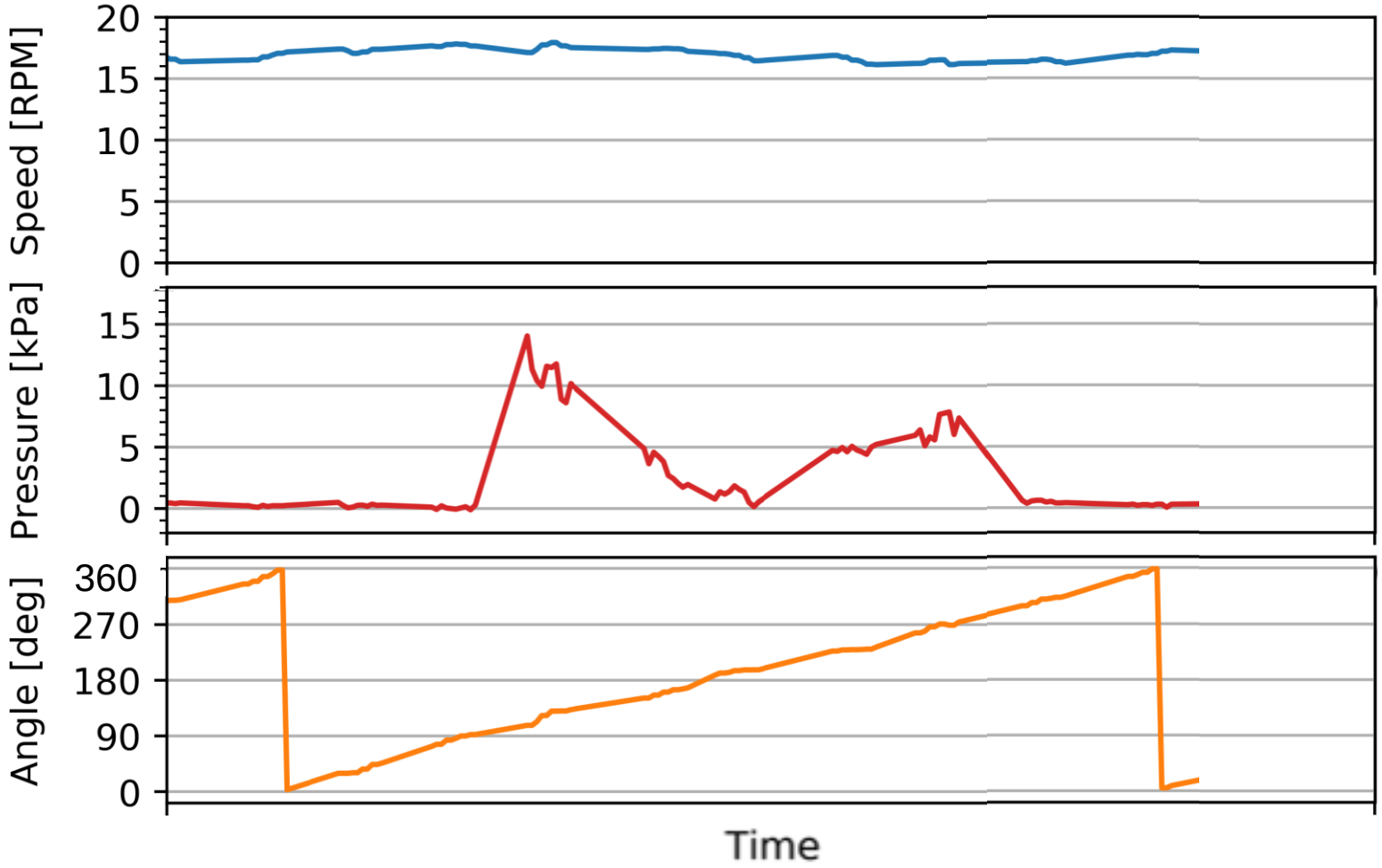
- 70 to 100 revolutions – Still required

On-board monitoring system



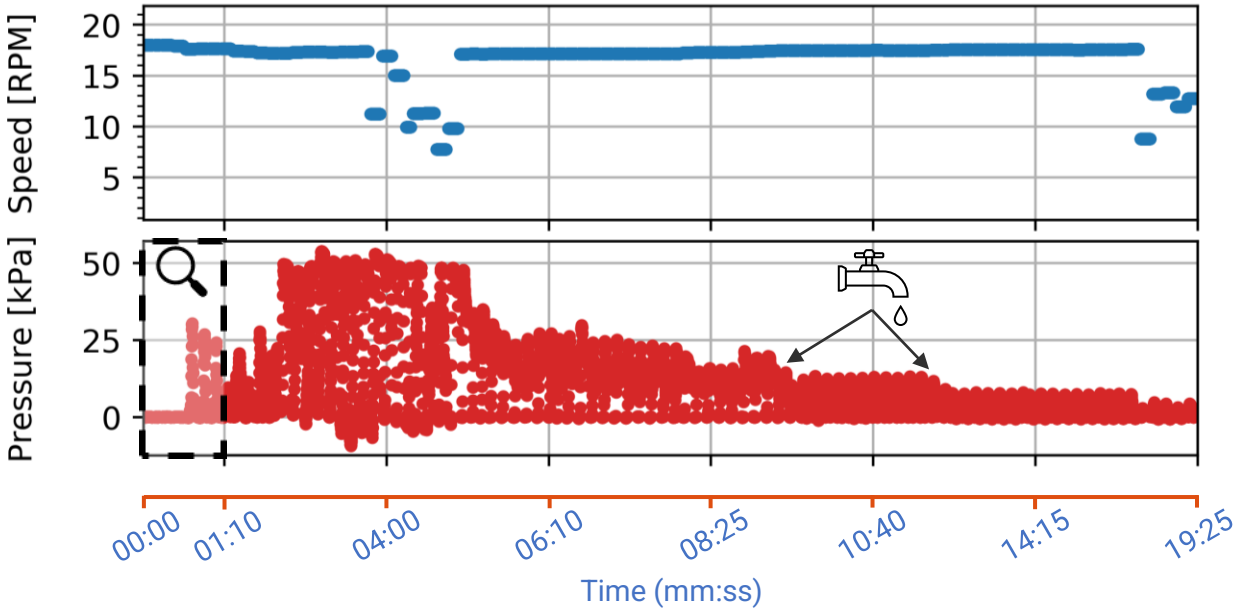
Measurements from the slump probe

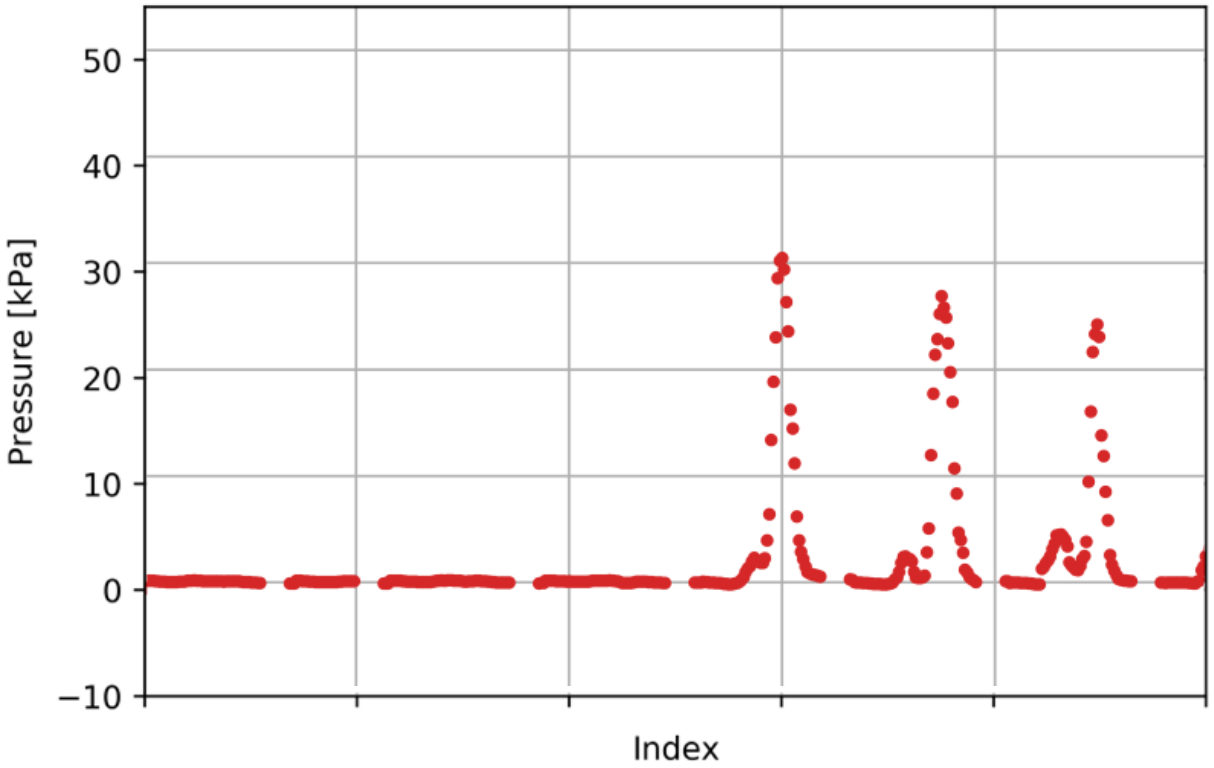




Pressure evolution

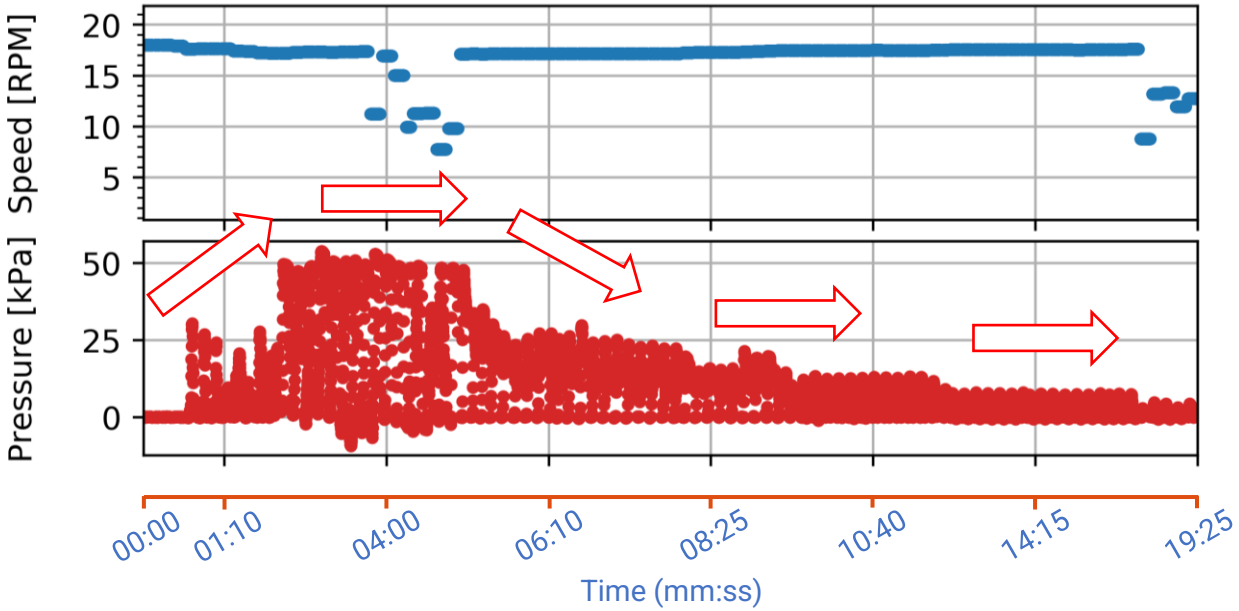
Example of a typical load





Step: Mixing + Slump adjustment with water

Signal processing



Challenge:

How to analyse *pressure data* to detect homogeneity?

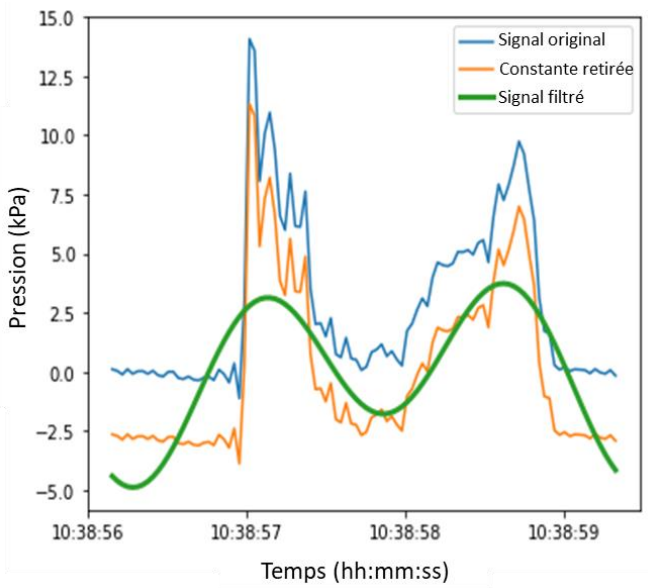
→ *Development of the End of Mixing Detection Algorithm (ADFMI)*
(The torture phase…)

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. **prescription** in standards



Environmental Benefits

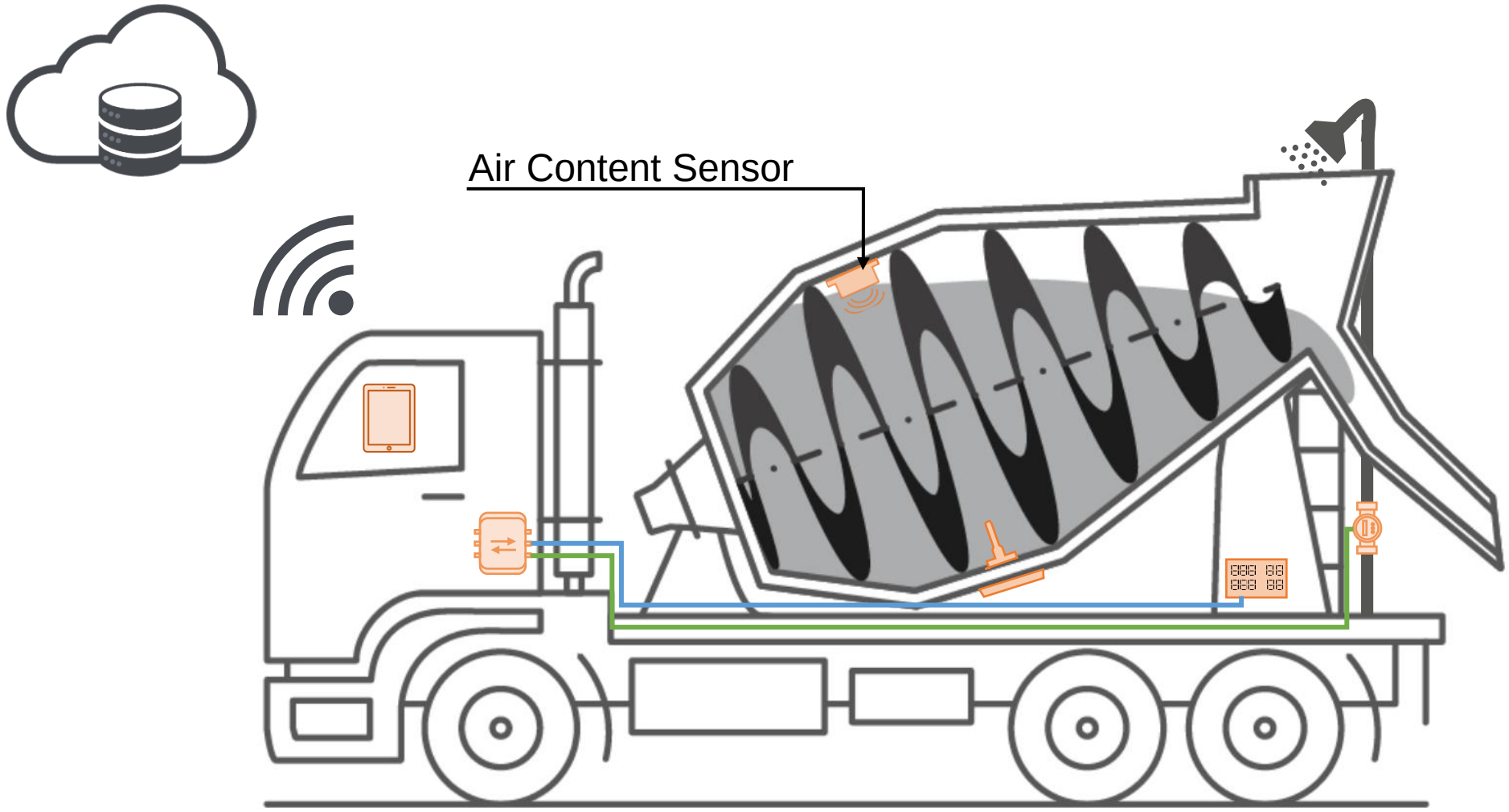
To conclude:

- **On-board sensors** enable end of mixing detection thereby enhancing production and delivery cycles and consequently **reducing CO_2 emissions**
- This questions the existence of prescribed mixing revolution limits

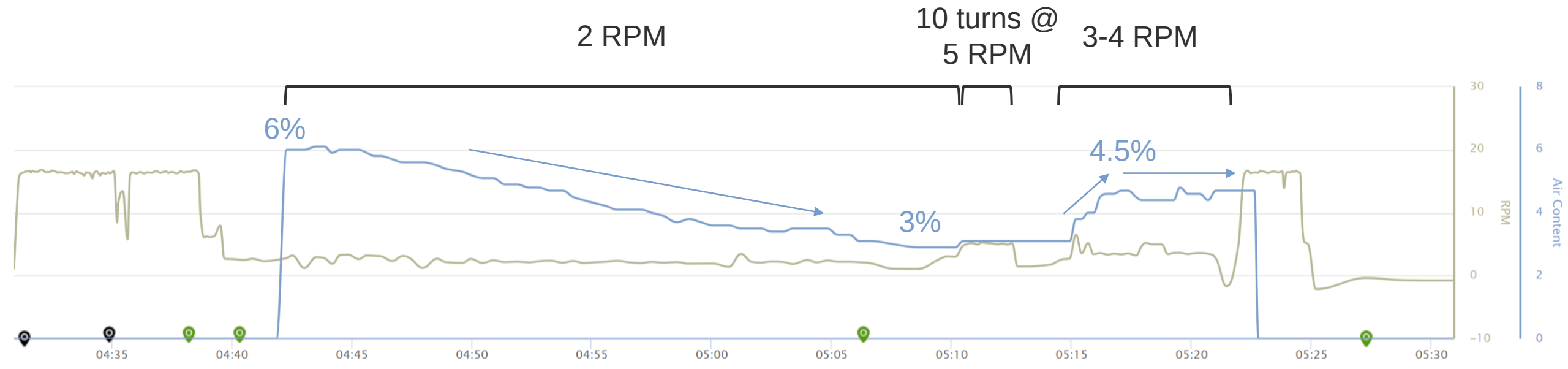
Additionally, on-board workability sensors have also helped in **minimizing load rejection** on-site by detecting out-of-specification slump.

Is it possible to go further?

Improved on-board monitoring system



Air content evolution in a truck



Air content is somewhat like slump; it **evolves during delivery**.

This evolution is influence by many parameters as mix design, air entraining admixture composition, mixing history, etc.

Real-time air content monitoring **helps the operator** in making **inform decisions** thereby allowing to **reduce rejection at site**.

Thank you!

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