The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

1st BIOFMET Stakeholders' Workshop

Test and validation of a fully automated sampling system for solid biofuels

Work by DTI, CMI & PROMETEC

Henrik Kjeldsen, Danish Technological Institute (DTI)

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Outline

- The sampling issue
  - Sources of error
- Example of solution
  - Automated sampling system
- Comparison/test
  - *Truck driver* vs. *standard* vs. *automated sampling system*
- Outlook

- Presentation by PROMETEC (Timo Huotari) & DTI (Peter Friis Østergaard)

Do you know what you burn?

Realtime sampling solutions
for energy industry

Prometec

Energy
Efficiency
Solutions

Prometec, automated sampler

THE PROBLEM

The biggest problem in solid biofuel quality control process is SAMPLING* because the material is extremely heterogenous

80%

of error caused by sampling executed poorly

15% of error caused by sample handling
5% of error is caused by measurement

*Järvinen, 2012, VTT-R-01322-12
*Stömberg&Svärd, 2012, Bränslehandboken, p. 32

Prometec

RESEARCH

2 similar Q-Robots are operating on 2 different sites in Finland. The data collection has been made on both sites.

Comparison between manual samples collected by a professional, collected by Q-Robot and collected by a truck driver.

The main goal is to perform (an initial) validate the performance of the Q-Robots.

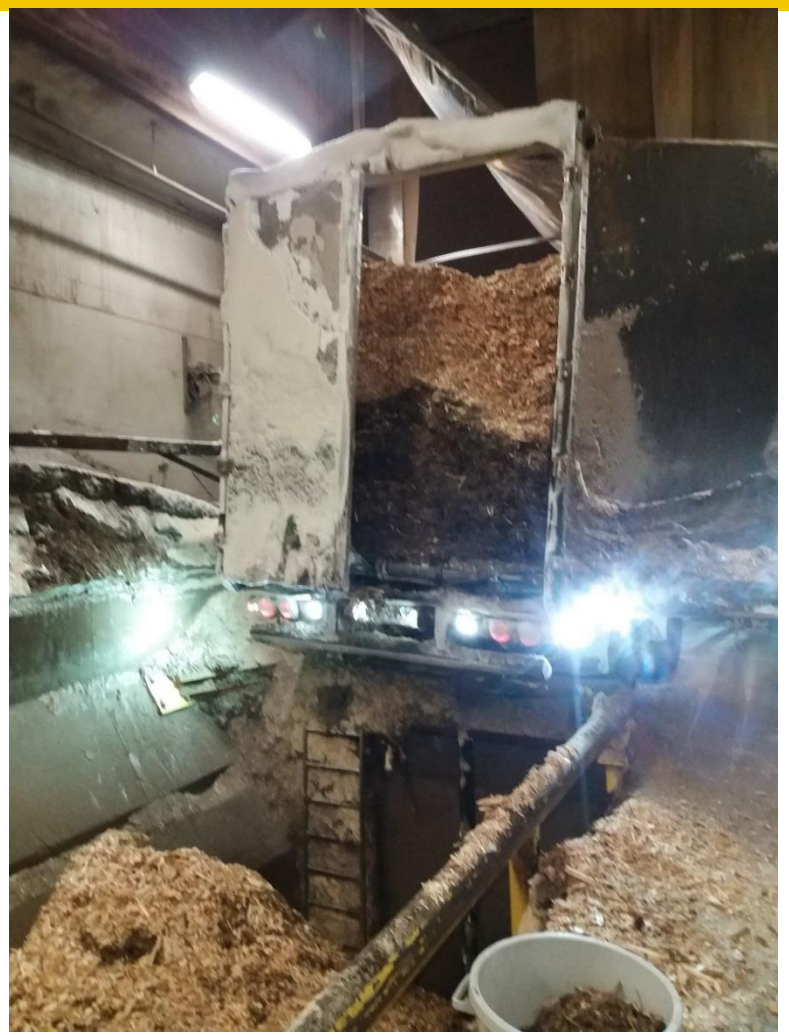
→ Test results are presented at the end of this presentation.

Prometec

Prometec

EXAMPLE OF HETEROGENOUS BIOMASS LOADS

Layered load

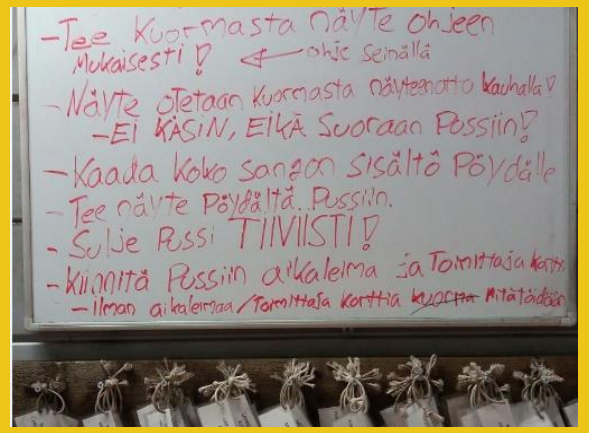


2 different materials in same load

MANUAL SAMPLING

Samples collected in different ways

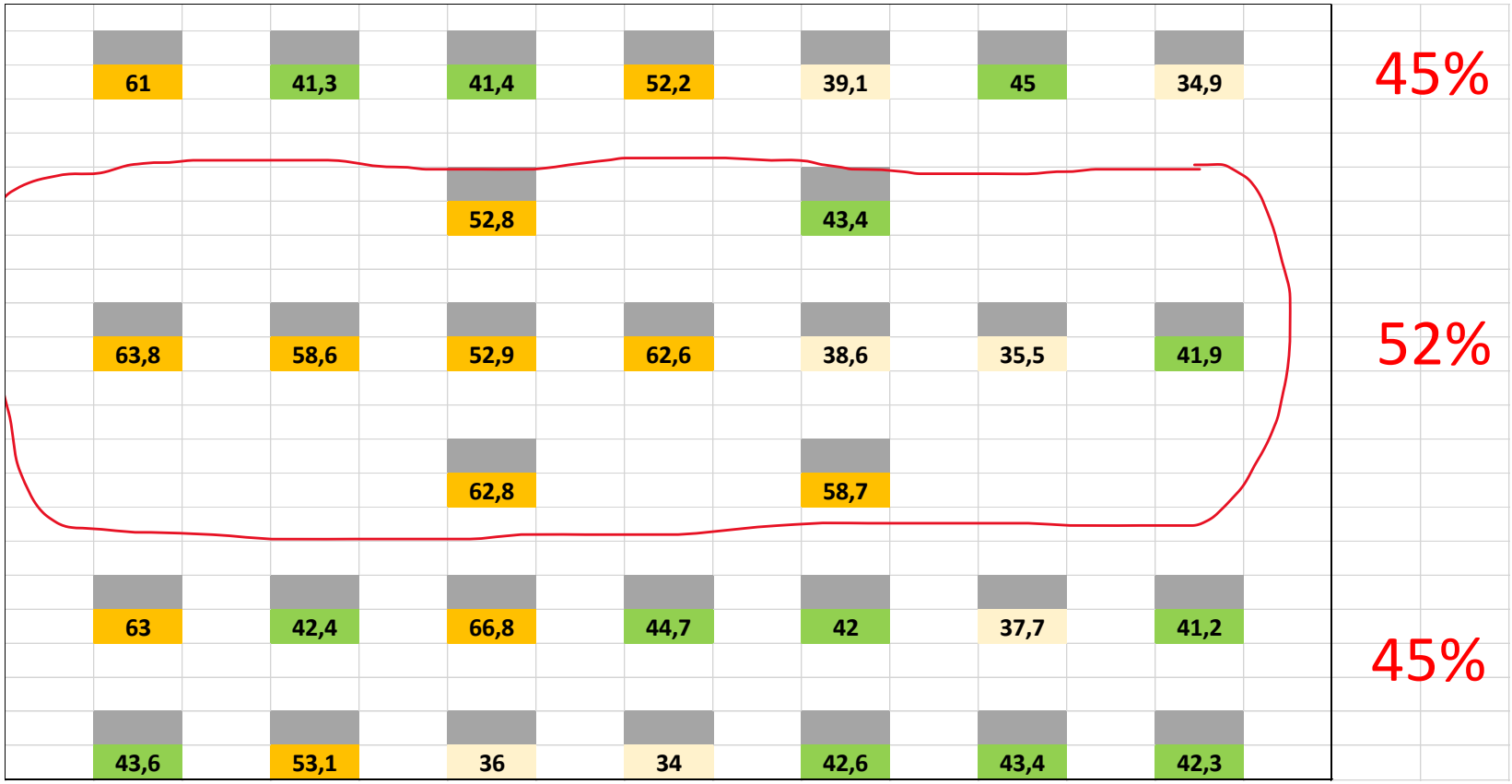
Hazardous working environment



Introductions can vary and they might not be followed

EXAMPLE OF MOISTURE VARIATION IN BIOMASS LOAD

Forest residue load 12.2.2021 – Moisture variation



Load average moisture from 32 increments is 47,5%

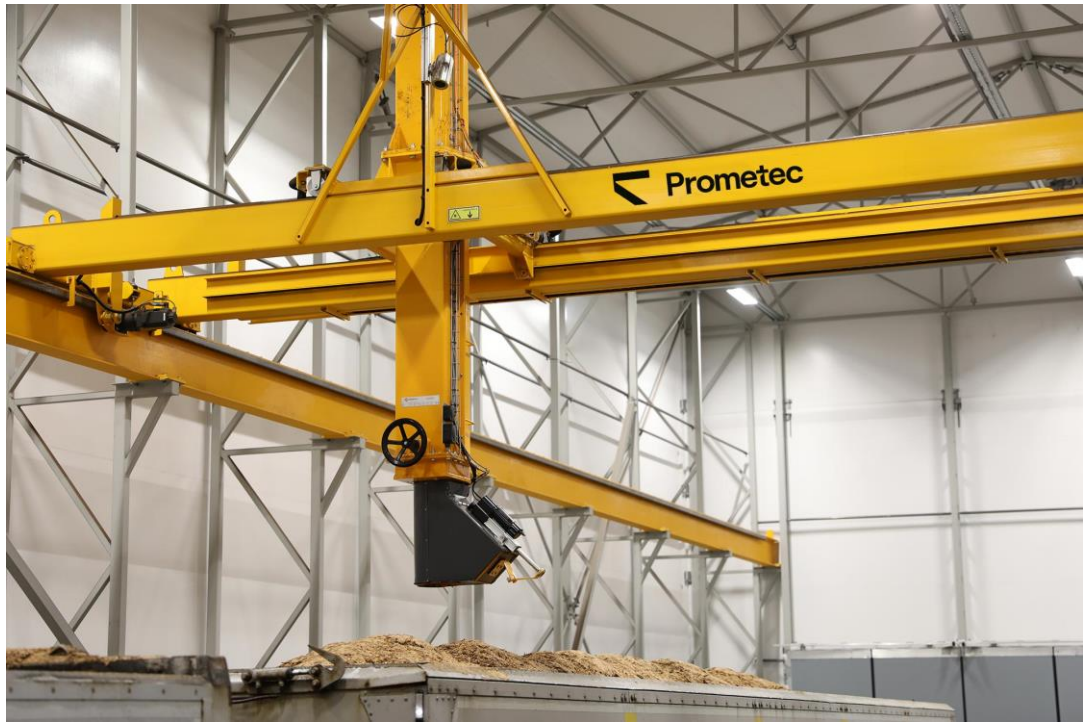
32 increments were taken by Q-Robot automated sampler from one semitrailer truck from different places and different depths. The moisture from each increment was measured separately and the results can be seen from the picture.

As one can clearly see the variation of the moisture is big depending on where the increment has been collected. Samples taken from the sides are about 7% units drier than samples collected from the middle.

Prometec

Robot

- Fully automatic sampling
- Samples quickly, reliably and safely from each load before unloading
- Installed to any site at the right logistical location
- Unique, patented and VTT verified solution
- Works according to ISO 18135 and ISO 14780 standards for all fuel types
- WEBSITE



Q Robot

Q Station Options

Outside on steel frame

Steel frame hall with container

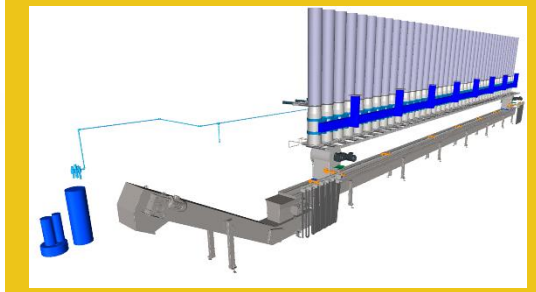
Conventional hall

Q Data For Q-Robot

Q Mixer Options

Cargo specific sample manual bagging

Bagging machine for cargo specific sample. Need at least container



Manual Q-Mixers for single or combined sample. Need at least container

Fully automated Q-Mixers for combined samples. Need at least container

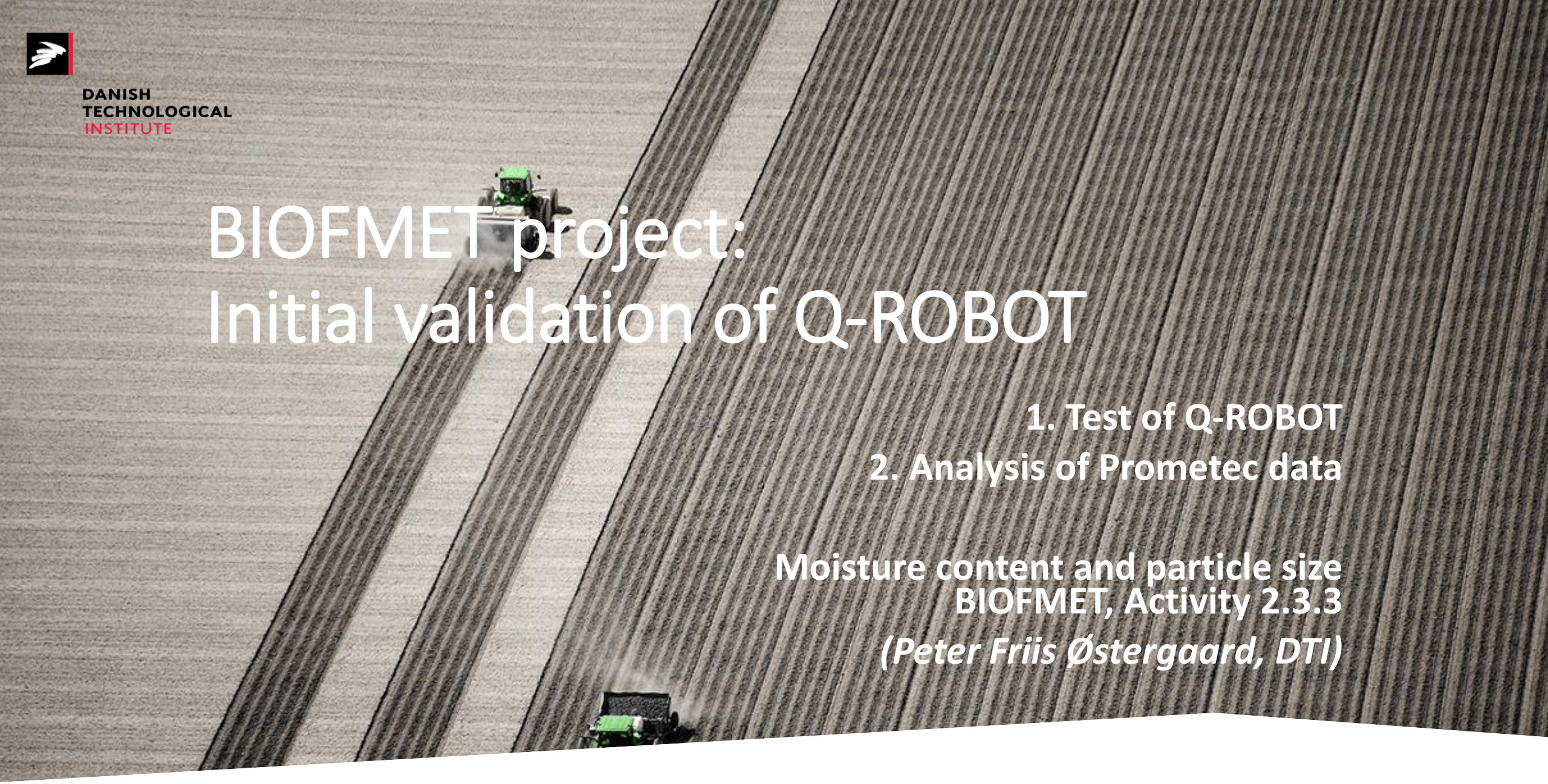
Q-Data for moisture content. Need Q-Robot

Prometec

Automated sampling
Sampler collects samples directly from the load before unloading. Sampler chooses places and depts randomly.

Representative samples
Proven accurate sampling solution for several types of wooden materials. No human bias happening during sampling.

Occupational safety
Automated sampling improves occupational safety because there is no need for human to collect samples



DANISH
TECHNOLOGICAL
INSTITUTE

BIOFMET project:
Initial validation of Q-ROBOT

1. Test of Q-ROBOT

2. Analysis of Prometec data

Moisture content and particle size
BIOFMET, Activity 2.3.3

(Peter Friis Østergaard, DTI)

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Initial validation of Q-ROBOT

- About 113 truck loads use for the test
- Use different sampling methods
  - Truck driver
  - Sampling according to ISO standard by VTT
  - Sampling using Q-ROBOT
- Compare moisture and particle size distribution

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Purpose of analysis

- Compare moisture content of samples collected using Q-robot with samples collected using other, common methods
- Compare particle size distribution of samples collected using Q-robot with samples collected using other, common methods

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Sample gathering and analysis

- For both factors, samples are prepared from the same truckload of material, using both the Q-robot, an ISO-standard procedure, and by the truck driver
- Moisture content is analysed using two statistical methods. A Student's t-test, where the difference between two sampling methods is compared to the standard deviation, as well as a binomial analysis, analysing the ratio of times, one sampling method produces a higher result than the other.
- Particle size is analysed using a Student's t-test

- Student's t-test resembles a regular z-score test for normal distributions, but takes into account the limited number of samples.

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Moisture content binomial analysis results

- Results for the binomial analysis is shown in the table on the next slide.
- Differences are seen between samples obtained by the Q-robot and truck drivers
- This difference is particularly large on peat material
- Further analysis shows, that excluding peat from the combined group will result in no statistically significant difference between sampling by Q-robot and sampling by the truck driver

- There is no significant difference on any material when comparing the Q-robot with the standard method

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Binomial analysis / Student's t-test

- X = difference between mean values
- Test value = dif./uncertainty

$$t_{value} = \frac{X}{u_X}$$

- $|t| \leq approx\ 1$; prop = 66 %
- $|t| \leq approx\ 2$; prop = 95 %

Moisture content binomial analysis results

Q-robot vs. Truck Driver			Q-robot vs. Standard	
OVERALL				
number of samples	113		number of samples	24
number of samples, where water content is higher with Q-robot	78		number of samples, where water content is higher with Q-robot	12
probability of this happening by chance	0%		probability of this happening by chance	58%
PEAT				
number of samples	59		number of samples	0
number of samples, where water content is higher with Q-robot	45		number of samples, where water content is higher with Q-robot	0
probability of this happening by chance	0%		probability of this happening by chance	
STEMWOOD				
number of samples	32		number of samples	11
number of samples, where water content is higher with Q-robot	21		number of samples, where water content is higher with Q-robot	6
probability of this happening by chance	6%		probability of this happening by chance	50%

Q-robot vs. Truck Driver			Q-robot vs. Standard	
SAWDUST				
number of samples	9		number of samples	0
number of samples, where water content is higher with Q-robot	4		number of samples, where water content is higher with Q-robot	0
probability of this happening by chance	75%		probability of this happening by chance	
FOREST RESIDUE				
number of samples	2		number of samples	2
number of samples, where water content is higher with Q-robot	1		number of samples, where water content is higher with Q-robot	1
probability of this happening by chance			probability of this happening by chance	
STUMPS				
number of samples	11		number of samples	11
number of samples, where water content is higher with Q-robot	7		number of samples, where water content is higher with Q-robot	5
probability of this happening by chance	27%		probability of this happening by chance	73%

Moisture content Student's t-test analysis results

- Results for the Student's t-test analysis is shown in the table on the next slide.
- Differences are seen in the same blocks as for the binomial analysis, strengthening the result
- As for the binomial analysis, there is only an overall difference between Q-robot and truck driver, when the peat is included in the analysis. Excluding peat from the analysis removes this difference

Moisture content binomial analysis results

Q-robot vs. Truck Driver		Q-robot vs. Standard	
OVERALL			
mean difference	1,6	mean difference	0,1
std	3,3	std	3,3
std(mean)	0,3	std(mean)	0,7
critical t-	2,0	critical t-	2,1
t-value	5,2	t-value	0,2
PEAT			
mean difference	2,5	mean difference	
std	3,6	std	
std(mean)	0,5	std(mean)	
critical t-	2,0	critical t-	#NUM!
t-value	5,3	t-value	#VALUE!
STEMWOOD			
mean difference	0,8	mean difference	0,6
std	2,9	std	4,6
std(mean)	0,5	std(mean)	1,4
critical t-	2,0	critical t-	2,2
t-value	1,6	t-value	0,4

Q-robot vs. Truck Driver		Q-robot vs. Standard	
SAWDUST			
mean difference	0,2	mean difference	
std	1,6	std	
std(mean)	0,5	std(mean)	
critical t-	2,3	critical t-	#NUM!
t-value	0,5	t-value	#VALUE!
FOREST RESIDUE			
mean difference	0,1	mean difference	0,1
std		std	
std(mean)		std(mean)	
critical t-	12,7	critical t-	12,7
t-value	#VALUE!	t-value	#VALUE!
STUMPS			
mean difference	0,8	mean difference	-0,3
std	2,2	std	1,6
std(mean)	0,7	std(mean)	0,5
critical t-	2,2	critical t-	2,2
t-value	1,1	t-value	-0,6

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Particle size Student's t-test analysis results

- Results for the Student's t-test analysis is shown in the table on the next slide.
- No overall significant difference could be found between particle sizes in samples obtained using the Q-robot and samples obtained using the standard method
- A "significant difference" (see explanation below) was observed in the particle-size distribution on the stemwood from Kajaani. The nature of this difference was that the Q-robot had a tendency of sampling more small particles – and thus less large – than the standard method.
  - In this context, the term "significant difference" means a measurable difference. In order words, the observed difference is larger that the statistical variation of the dataset.
- Comparing the Q-robot to the samples obtained by the truck driver shows significant differences in particle sizes for small particles, as well as particles in the range 16 mm-45 mm. The truck driver collected samples after unloading from the pile. Unloading is causing sorting and usually bigger particles will be on the top of the pile from where it's easier to collect samples manually.

Particle size Student's t-test analysis results

The critical t-value is the maximum value, the comparison can give, without identifying a significant/measurable difference between the two methods.

Kajaani forest residue	particle size	Student's t-value	Q-robot - Standard	Q-robot - manual	Critical t-value
	<3,15mm		Not enough data	Not enough data	
	3,15-16mm		Not enough data	Not enough data	
	16-45mm		Not enough data	Not enough data	
	45-63mm		Not enough data	Not enough data	
	63-100mm		Not enough data	Not enough data	
	>100mm		Not enough data	Not enough data	
Kajaani Stemwood					
	<3,15mm		4,5	5,0	3,2
	3,15-16mm		2,5	0,4	3,2
	16-45mm		1,2	1,3	3,2
	45-63mm		1,1	0,5	3,2
	63-100mm		2,0	1,0	3,2
	>100mm		1,0	1,0	3,2
Kajaani Stump					
	<3,15mm		0,6	11,7	2,8
	3,15mm-16mm		0,4	2,1	2,8
	16mm-45mm		0,2	3,2	2,8
	45mm-63mm		1,3	1,0	2,8
	63mm-100mm		1,3	1,0	2,8
	>100mm		0,0	2,0	2,8

Please add Forest residue to the Kuopio VTT table

Kuopio VTT	particle size	Student's t-value	Q-robot - Standard	Q-robot - manual	Critical t-value
	< 3.150		1,7		2,8
	3.150 - 16.000		0,4		2,8
	16.000 -45.000		0,5		2,8
	45.000 - 63.000		0,5		2,8
	63.000 - 100.000		1,4		2,8
	> 100.000		2,2		2,8
Overall					
	< 3.150		2,0	4,3	2,1
	3.150 - 16.000		0,4	2,0	2,1
	16.000 -45.000		0,4	2,9	2,1
	45.000 - 63.000		0,4	1,1	2,1
	63.000 - 100.000		0,4	1,7	2,1
	> 100.000		2,0	0,9	2,1

Conclusion of comparison

- In the moisture analysis, there was a significant difference in the moisture content of samples obtained by the Q-robot and samples obtained by the truck driver on the peat sample
- All other sample types showed similar levels of moisture content, regardless of sampling method.

- In the particle size analysis, the is significantly more small particles in samples obtained by the Q-robot from Kajaani Stemwood.
- There are no overall significant difference between the particle sizes in samples obtained using the standard and samples obtained using the Q-robot
- There are significant differences between particle sizes, especially small particles, when comparing the Q-robot to samples obtained by the truck driver

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Status / Outlook

- Automatic sampler (Q-robot) vs standard
- Done:
  - No significant difference in moisture
  - Small difference in particle size
  - *Better work environment*
- To do:
  - Formal validation
- Truck driver may be biased …

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Thank you for your attention!