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Controlling of the process based on resource efficiency indicators

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Outline

1. Aim of the project – A short introduction
2. Review on process control techniques
3. Role of operator
4. Indicators for assessment of processes
5. Missing inputs – The lack of instrumentation
6. Soft sensors - Process models as virtual sensors
7. Implementation of the system in a paper mill
8. Discussion of first results
9. Conclusion and outlook

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Introduction

- The recycling of paper for use in printing paper production relies on a set of high sophisticated processes.
- The quality of recycled fibres depends on furnish quality and the process parameters for the various steps of a deinking plant.
- More than a hundred closed loop controllers are necessary to stabilise the complex, interrelated sub-processes.
- The development of resource efficiency indicators for assessing the deinking processes is a target of the project.
- These resource efficiency indicators helps operators to adjust the parameters according to the dynamic variations of furnish quality and composition.

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Review on process control techniques

- **Standard closed loop control**: perfect for single processes without time lag
  - Setpoint (SP) as manual input from operator
  - Process variable (PV) as feedback from process
  - Error value (E) as offset between SP and PV
  - Actuating variable as reaction of a controller on error value
  - Actuator adjusts the process according to process demand (PD)
- **Control strategy**: Keep the process running at constant settings
  - PID controller as single loop or as cascade
    (typically more than 120 controllers installed in a single deinking line)
  - Model predictive control (MPC) as non-standard solution for special tasks
    e. g. dosage of chemicals for brightness control

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Supervision of the processes

- **Classical approach:**
  - Assessment of process state by tracing process data
  - Observation of processes by visual inspection
  - Adjust process parameters according to paper machine production rate and quality demands

  → Is production rate sufficient for feeding the paper machine? 

  → Is brightness high enough for the paper grade ? 
- **Sophisticated approach:**
  - Tune process parameters of every process stage separately based on resource efficiency indicators

  → Are the indicators of screening, flotation and dispersing in range?

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Indicators for assessment of processes

- Indicators are intended to give valuable information on regarded processes.
- Indicators should assist operators to find appropriate and advantageous adjustments and help to keep processes in good conditions
- There exist no appropriate indicators to control quality, yield, consumption of energy and water for the selected processes in stock preparation up to now. Thus, operators of deinking plants are not supported in decision making by meaningful indicators.

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Preselection of indicators for process assessment

AREA	INDICATOR
Energy	▪ Specific energy consumption of products in kWh/ton
Water	▪ Specific water consumption of products in m^3/ton
Emissions	▪ Carbon footprint in kg CO_2-equivalent per ton of products
Raw materials & waste	▪ Material efficiency (Yield) of products in %
Economic	▪ Profitability before fixed costs

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Key Performance Indicators (KPIs)

- Global warming potential (GWP) ≅ carbon footprint in kg $CO_{2\ eq.}$/t
- Fossil fuel depletion based on mills energy mix (→ gas and renewal sources)
- Fresh water eutrophication due to additives
- Water footprint within process steps and sub-processes
- Primary energy use ≅ specific energy consumption in kWh/t
- Change in energy and material consumption per product
- Variable cost indicator ≅ specific energy and water consumption etc. in €/t
- Revenue indicator ≅ increase in value of processed pulp in €/t
- Profitability indicator ≅ revenues / variable cost for individual processes
- Savings indicator ≅ current gross profit - gross profit of reference process

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Economic assessment of pulp quality

Approach:

Price of pulp = value of fibres, fines and fillers – a markdown for impurities like residual ink, specs and stickies

- Value of pure fibres based on Bauer-McNett fractions and pulp market price
- Value of fillers calculated from ash content
- Markdown for optical properties
  - Brightness R_{457} or whiteness Y, ERIC ppm and specs
- Markdown for detrimental substances
  - Stickies in mm^2/kg

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Evaluation of pulp price from current fibre composition

Haindl-McNett		Price	Feed	Accept	Reject
long fibres (sieve 30)	%	65,00	24,90	24,87	29,41
long fibres (sieve 30)	€/t	1000,00	249,01	248,66	294,12
short fibres (sieves 50+100)	%	30,00	45,10	45,14	42,29
short fibres (sieves 50+100)	€/t	500,00	225,49	225,68	211,45
organic fines (sieve 200+P200)	%	5,00	29,99	30,33	28,30
organic fines	€/t	50,00	14,99	15,16	14,15
fibre fraction total	€/t	802,50	489,49	489,50	519,72
Ash					
525°C	%	30,00	27,07	27,09	24,79
calcium carbonate	€/t	170,00	46,02	46,05	42,14
fibres and fillers	**€/t**	**612,75**	**403,00**	**402,95**	**433,03**

Price before markdowns due to pulp quality deficiencies

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Example: Coarse screening feed and accept

Price of pulp		Feed	Accept
pure fibres and ash	€/t	403,00	402,95
markdown due to sticky content	€/t	-101,23	-18,43
markdown due to ERIC	€/t	-193,03	-193,03
price of fibre suspension	**€/t**	**108,75**	**191,49**

- Coarse screening shows little effect on fibre fractions and ERIC value
- Sticky removal leads to a significant rise in value of 82 €/t (+76 %)

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Example: Computing coarse screening feed pump power

Energy	Type	Unit	MIX1	S1	S2
feed pump	flow	l/s	20,13	126,67	52,29
	pressure drop 1 (static)	bar	1,00	3,55	1,35
	pressure drop 2 (flow)	bar	0,50	0,50	0,50
	pressure drop total	kPa	150,00	405,00	185,00
	power (hydr.)	kW	3,02	51,30	9,67
	mechanical efficiency		0,80	0,80	0,80
	power (mech.)	kW	3,77	64,13	12,09
	electrical efficiency		0,95	0,95	0,95
	power (el.)	**kW**	**3,97**	**67,50**	**12,73**

- Total power consumption of coarse screening: 205 kW or 12,7 kWh/t
- Calculated carbon footprint is 3,4 kg CO_2/t

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Results on model-based estimation of indicators

Pros:

- Process models provide indispensable information and insights in sub-processes.
  - Balancing of mass and flows
  - Estimation of consistencies and changes in pulp quality
- Models can substitute complex filtering of online data and outlier detection.
- Calculations provide the whole set of Key Performance Indicators (KPIs)

Cons:

- Enormous effort for process modelling and validation

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Missing inputs – The lack of instrumentation

- Inconsistent online data due to
  - time lags,
  - measuring inaccuracies,
  - complex material flows,
  - uncertainties and outliers.
- Lack of sensors for measuring
  - flow rate and consistency for mass balancing,
  - energy consumption,
  - fibre morphology and ash content,
  - optical properties such as brightness, ERIC value and specs,
  - impurities like micro and macro stickies.

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Soft sensors - Process models as virtual sensors

Process modelling is the only way to gain information where process data are not available. They provide

- Mass flows by estimating consistencies and flow rates.
- Changes in the compositions of fibre suspensions due to fractionation, flotation or mixing, by calculating the flow of fibre fractions, ash, ink particles and stickies.
- Power consumption of pumps are estimated from hydraulic pressure and flow rate, where online measurements are not implemented.

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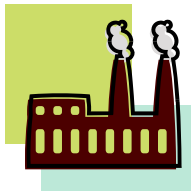
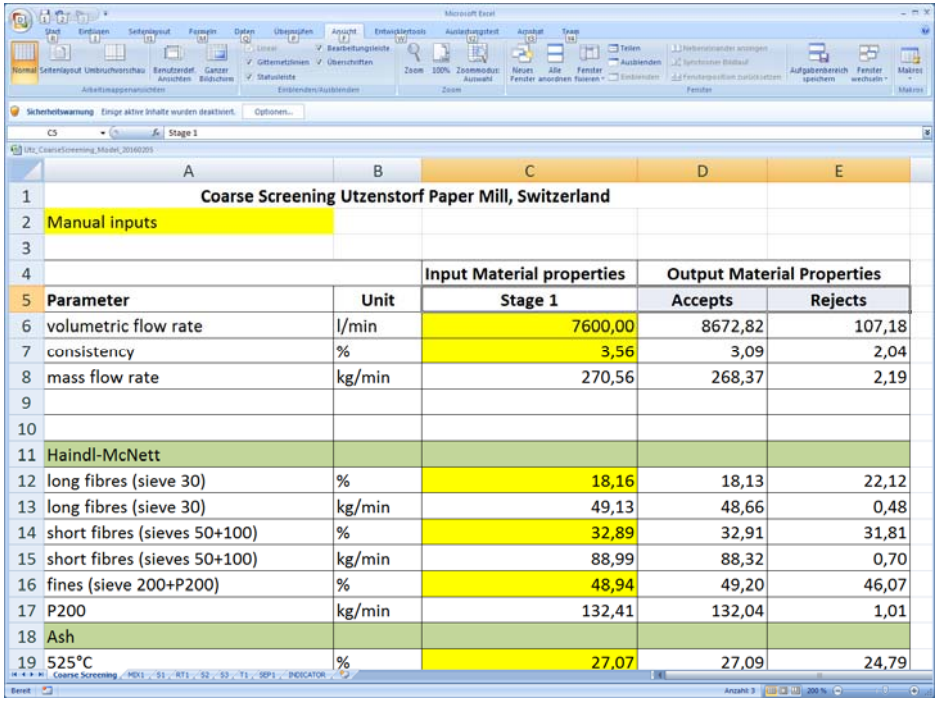
Model-based estimation of indicators



Process parameters

Lab measurements



	A	B	C	D	E
1	Coarse Screening Utzenstorf Paper Mill, Switzerland				
2	Manual inputs				
3					
4			Input Material properties	Output Material Properties	
5	Parameter	Unit	Stage 1	Accepts	Rejects
6	volumetric flow rate	l/min	7600,00	8672,82	107,18
7	consistency	%	3,56	3,09	2,04
8	mass flow rate	kg/min	270,56	268,37	2,19
9					
10					
11	Haindl-McNett				
12	long fibres (sieve 30)	%	18,16	18,13	22,12
13	long fibres (sieve 30)	kg/min	49,13	48,66	0,48
14	short fibres (sieves 50+100)	%	32,89	32,91	31,81
15	short fibres (sieves 50+100)	kg/min	88,99	88,32	0,70
16	fines (sieve 200+P200)	%	48,94	49,20	46,07
17	P200	kg/min	132,41	132,04	1,01
18	Ash				
19	525°C	%	27,07	27,09	24,79

Process model (WP 3.1)

Output

- Mass flow
- Consistency
- Pulp properties
- Consumption of energy and fresh water...

Computation of indicators for process monitoring (WP 3.5)

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Appropriate resolution for monitoring the processes

- The most relevant processes to be monitored are
  - Fractionation
  - Deinking flotation
  - Dispersing
- The relevant process steps have their own indicators based on process models and online data.
- Data from other process steps are collected for aggregated indicators.
- Default time scale for online indicators is one minute. Laboratory measurements and manual inputs contribute to indicators.

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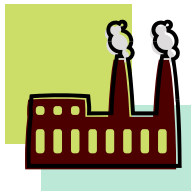
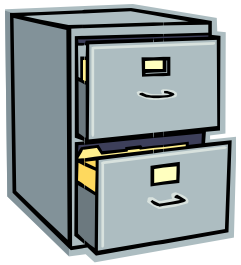
Implementation scheme of the system



Process parameters

Lab measurements



Database & archive

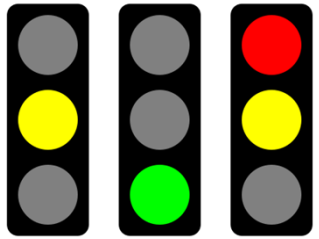
Data actually available

Query

Interface

Process models

Output



Reporting

List of indicators for process monitoring

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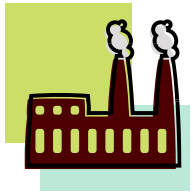
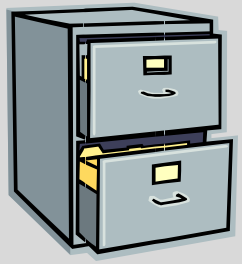
Implementation with Wedge system in a paper mill



Process parameters

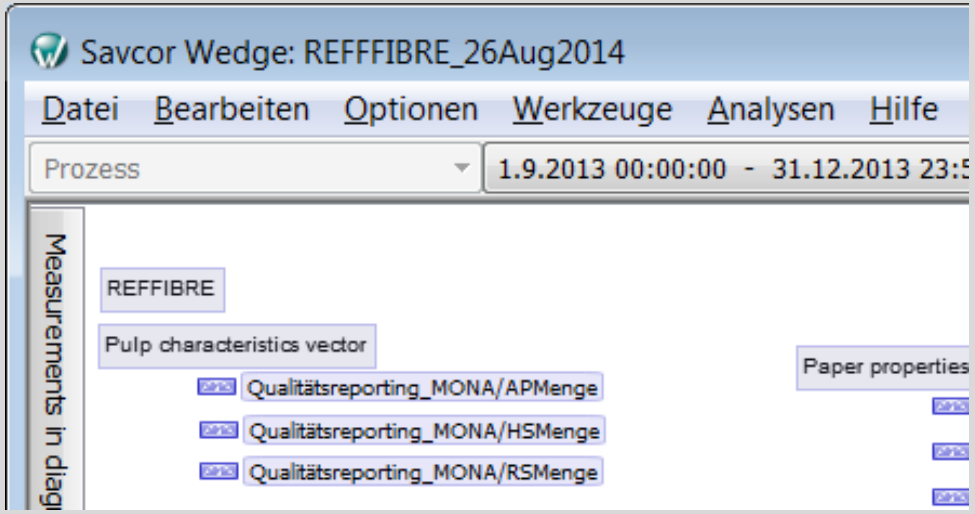
Lab measurements

Savcor Wedge



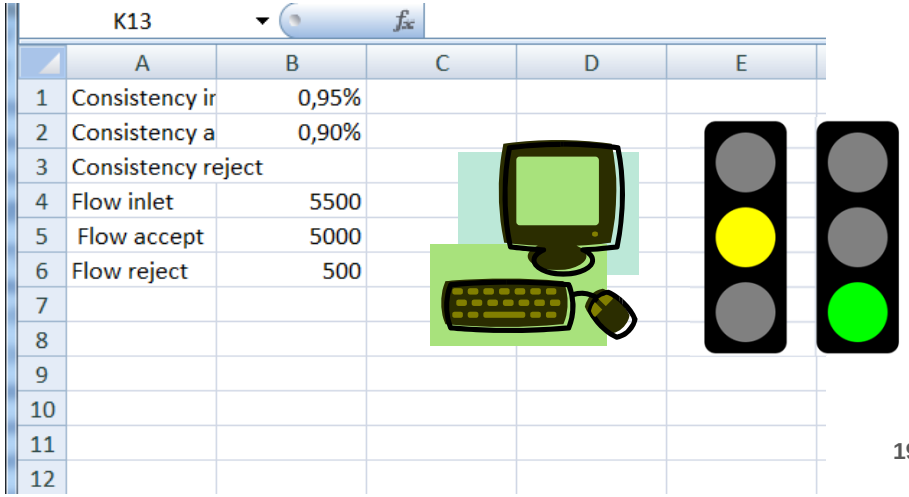
Database & archive

Query



Export MS Excel

Scripts perform data pre-processing, virtual sensing and data export



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Discussion of first results

Key Performance Indicators (KPIs)						
Indicators	**Unit**	**Coarse Screening**	**Pre Flotation**	**Fine Screening**	**Dispersion**	**Post Flotation**
Global warming potential (GWP)	%	0,00	0,00	0,00	0,00	0,00
Fossil fuel depletion	%	0,00	0,00	0,00	0,00	0,00
Fresh water eutrophication	%	0,00	0,00	0,00	0,00	0,00
Water footprint	%	0,00	0,00	0,00	0,00	0,00
Primary energy use	%	0,00	0,00	0,00	0,00	0,00
Change in energy and mat. cons.	%	0,00	0,00	-0,01	0,00	0,00
Variable cost indicator	%	0,00	0,00	0,00	0,00	0,00
Revenue indicator	%	0,00	0,00	-0,02	0,00	0,00
Profitability indicator	%	0,00	0,00	-0,02	0,00	0,00
Savings indicator	%	0,00	0,00	-0,02	0,00	0,00

Reset of indicators for a default process condition

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Modelling pulp prices for default conditions

		Coarse Screening	Pre Flotation	Fine Screening	Dispersion	Post Flotation
Price of pulp		Feed	Feed	Feed	Feed	Feed
Pur fibres and ash	€/t	316,24	316,14	328,63	308,67	306,21
Markdown due to sticky content	€/t	-101,23	-18,43	-2,53	-0,19	-0,19
Markdown due to specs	€/t	-10,52	-10,00	-7,91	-3,33	-2,57
Markdown due to ERIC	€/t	-110,30	-110,30	-53,43	-49,25	-49,25
Final price of pulp	**€/t**	**94,19**	**177,41**	**264,76**	**255,89**	**254,21**
Price of pulp		Accept	Accept	Accept	Accept	Accept
Pur fibres and ash	€/t	316,14	328,63	308,67	306,21	331,94
Markdown due to sticky content	€/t	-18,43	-2,53	-0,19	-0,19	-0,09
Markdown due to specs	€/t	-9,82	-7,91	-3,33	-2,44	-2,17
Markdown due to ERIC	€/t	-110,30	-53,43	-49,25	-49,25	-21,97
Final price of pulp	**€/t**	**177,59**	**264,76**	**255,89**	**254,33**	**307,72**
Revenues	€/t	83,40	87,34	-8,87	-1,56	53,51
Variable costs	€/t	1,20	1,88	0,12	0,21	1,84
Gross profit	**€/t**	**82,20**	**85,46**	**-8,98**	**-1,77**	**51,67**

Prices are notional and not based on mill data

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Indicators for less magazines in furnish

Key Performance Indicators (KPIs)						
Indicators	**Unit**	**Coarse Screening**	**Pre Flotation**	**Fine Screening**	**Dispersion**	**Post Flotation**
Global warming potential (GWP)	%	0,01	-0,94	-6,03	-0,95	-1,29
Fossil fuel depletion	%	0,01	-0,94	-6,03	-0,95	-1,29
Fresh water eutrophication	%	0,00	0,00	0,00	0,00	0,00
Water footprint	%	0,00	-0,96	-0,95	0,00	-1,29
Primary energy use	%	0,01	-0,94	-6,03	-0,95	-1,29
Change in energy and mat. cons.	%	32,68	24,50	24,56	22,83	9,25
Variable cost indicator	%	0,01	-0,94	-5,97	-0,95	-1,29
Revenue indicator	%	-0,07	-17,05	69,64	50,54	-1,82
Profitability indicator	%	-31,00	-33,61	37,28	17,67	-17,11
Savings indicator	%	-0,07	-17,40	68,65	44,35	-1,84

Ash content reduced from 27 % to 16 %

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Modelling pulp prices for less magazines in furnish

		Coarse Screening	Pre Flotation	Fine Screening	Dispersion	Post Flotation
Price of pulp		Feed	Feed	Feed	Feed	Feed
Pur fibres and ash	€/t	395,83	395,67	401,13	374,38	371,14
Markdown due to sticky content	€/t	-101,23	-18,43	-2,58	-0,19	-0,19
Markdown due to specs	€/t	-10,71	-10,00	-7,99	-3,36	-2,62
Markdown due to ERIC	€/t	-110,30	-110,30	-61,17	-56,48	-56,48
Final price of pulp	**€/t**	**173,58**	**256,94**	**329,39**	**314,35**	**311,85**
Price of pulp		Accept	Accept	Accept	Accept	Accept
Pur fibres and ash	€/t	395,67	401,13	374,38	371,14	395,35
Markdown due to sticky content	€/t	-18,43	-2,58	-0,19	-0,19	-0,09
Markdown due to specs	€/t	-10,00	-7,99	-3,36	-2,47	-2,24
Markdown due to ERIC	€/t	-110,30	-61,17	-56,48	-56,48	-28,63
Final price of pulp	**€/t**	**256,94**	**329,39**	**314,35**	**312,00**	**364,39**
Revenues	€/t	83,36	72,45	-15,04	-2,34	52,54
Variable costs	€/t	1,21	1,86	0,11	0,21	1,81
Gross profit	**€/t**	**82,14**	**70,59**	**-15,16**	**-2,55**	**50,73**
Gross profit of reference	€/t	82,20	85,46	-8,98	-1,77	51,67

Ash content reduced from 27 % to 16 %

Prices are notional and not based on mill data

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Indicators at 50 % production rate

Key Performance Indicators (KPIs)						
Indicators	**Unit**	**Coarse Screening**	**Pre Flotation**	**Fine Screening**	**Dispersion**	**Post Flotation**
Global warming potential (GWP)	%	47,31	52,74	74,52	84,09	0,27
Fossil fuel depletion	%	47,31	52,74	74,52	84,09	0,27
Fresh water eutrophication	%	0,00	0,00	0,00	0,00	0,00
Water footprint	%	100,00	86,63	84,09	0,00	0,27
Primary energy use	%	47,31	52,74	74,52	84,09	0,27
Change in energy and mat. cons.	%	26,74	-0,76	-47,32	-7,45	-4,60
Variable cost indicator	%	51,04	52,78	74,63	84,09	0,27
Revenue indicator	%	1,00	-12,93	-26,85	15,74	11,20
Profitability indicator	%	6,49	-6,75	-19,44	34,26	16,10
Savings indicator	%	0,27	-14,37	-25,51	23,96	11,59

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Modelling pulp prices at 50 % production rate

		Coarse Screening	Pre Flotation	Fine Screening	Dispersion	Post Flotation
Price of pulp		Feed	Feed	Feed	Feed	Feed
Pur fibres and ash	€/t	315,75	315,78	326,68	303,36	298,92
Markdown due to sticky content	€/t	-101,23	-18,43	-2,32	-0,17	-0,16
Markdown due to specs	€/t	-21,43	-20,00	-14,41	-5,99	-1,92
Markdown due to ERIC	€/t	-110,30	-110,30	-66,85	-60,58	-60,58
Final price of pulp	**€/t**	**82,80**	**167,05**	**243,11**	**236,62**	**236,26**
Price of pulp		Accept	Accept	Accept	Accept	Accept
Pur fibres and ash	€/t	315,78	326,68	303,36	298,92	323,69
Markdown due to sticky content	€/t	-18,43	-2,32	-0,17	-0,16	-0,08
Markdown due to specs	€/t	-20,00	-14,41	-5,99	-3,36	-1,62
Markdown due to ERIC	€/t	-110,30	-66,85	-60,58	-60,58	-26,22
Final price of pulp	**€/t**	**167,05**	**243,11**	**236,62**	**234,82**	**295,76**
Revenues	€/t	84,26	76,05	-6,49	-1,80	59,51
Variable costs	€/t	1,83	2,87	0,21	0,39	1,84
Gross profit	**€/t**	**82,43**	**73,18**	**-6,69**	**-2,19**	**57,67**
Gross profit of reference	€/t	82,20	85,46	-8,98	-1,77	51,67

Prices are notional and not based on mill data

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Conclusion and outlook

- Online mill data do not cover the relevant processes in detail.
- Models serve as soft sensors where sensors are missing or not available for the desired parameter (brightness, ERIC, stickies...).
- Process models are indispensible for computing the key performance indicators.
- The implementation based on Microsoft Excel and Visual Basic for Application (VBA) is easy to install.
- The concept is ready for evaluation as soon as process models are finalised.

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