Valorisation and dissemination of EAF technology - VALEAF

Research Fund for Coal & Steel

Seminar: Steel scrap treatment and control

Mathematical tools for determination of scrap properties and optimisation of scrap mix

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Motivation for determination of the different scrap type properties

- Metallic yield and composition of the scrap types charged into the EAF can not be acquired exactly, but only with large uncertainties
- The properties of the scrap types vary with time
- A cost-optimal use of the scrap types is limited due to the uncertainties in acquisition of their properties.

➯ Application of a multi linear regression calculation to determine metallic yield and composition of the scrap types in use

  - Statistical analysis of metallic yield and composition of each scrap type
  - Continuous tracking of variations of the scrap properties
  - Cost-optimal determination of the scrap mix for the produced steel grades with consideration of various operational restrictions

Input data for regression calculation

For a statistical analysis of the scrap properties (yield as well as residual and alloy element concentration) the following process data are collected for a larger number of produced heats:

- Weights of the charged scrap types with a detailed diversification of different scrap categories
- Weight and analysis of charged DRI/HBI or pig iron material
- Tapping weight
- Lab analysis of a steel sample taken before EAF tapping

Possible additional process data to be taken into account:

- Hot heel amount
- Lab analysis of slag sample taken before EAF tapping
- Weights and types of charged slag formers

Statistical analysis of scrap type properties

Statistical analysis of scrap properties can be performed by multiple linear regression

Definition:

- **Dependent variables:** Weight and analysis of liquid steel
- **Explanatory variables:** Weights of charged scrap types
- **Regression coefficients:** Yield and element concentration of scrap types

Problem:

Metallurgical unreliable results might be possible for unfavourably constituted data sets:

- metallic yield higher than 100 %
- negative element concentrations

Modified multiple linear regression calculation

The multiple linear regression calculation is performed by a numerical minimizing algorithm with constraints

Definition:

- Minimum constraints to avoid negative results
- Maximum constraints to avoid unplausible large yields or concentrations
- The definition of fixed parameters is possible by setting Min = Max

Remarks:

Metallic losses by oxidation during melt down and refining

↳ Yield → Furnace yield

If significant changes in the hot heel amount cannot be assessed

↳ Grouping of consecutive heats for metallic yield calculation to compensate strong increases or decreases

Filter and plausibility check functions for data selections and settings

	metallic yield		effective element concentration: Cu	
	minimum / %	maximum / %	minimum / %	maximum / %
pig iron skulls	60	98	0	0.9
pig iron	60	98	0	0.9
cast iron	60	98	0	0.9
E1	60	98	0	0.9
E2	60	98	0	0.9
E3	60	98	0	0.9
E8	60	98	0	0.9
E1 / E3	60	98	0	0.9
cans	60	98	0	0.9
E6	60	98	0	0.9
E5M	60	98	0	0.9
E5H	60	98	0	0.9
briquetted turnings	60	98	0	0.9
steel skulls	60	98	0	0.9
casting residuals	60	98	0	0.9
return Cr	60	98	0	0.9
return CrMo	60	98	0	0.9
return CrNiMo	60	98	0	0.9
E40	60	98	0	0.9
remaining scrap types	60	98	0	0.9

language: english

tap weight / t: 140

min scrap type weight / t: 3

volume basket / cbm: 120

filling grade 1. basket: 90

filling grade 2. basket: 90

data filter

min scrap weight / t: 130

max scrap weight / t: 190

min tap weight / t: 100

max tap weight / t: 150

min max analysis / %: 0 1 Cu

min no. of usage: 1

heat groups

group size: 5

starting hot heel

hot heel / t: 30

constant hot heel

save

close

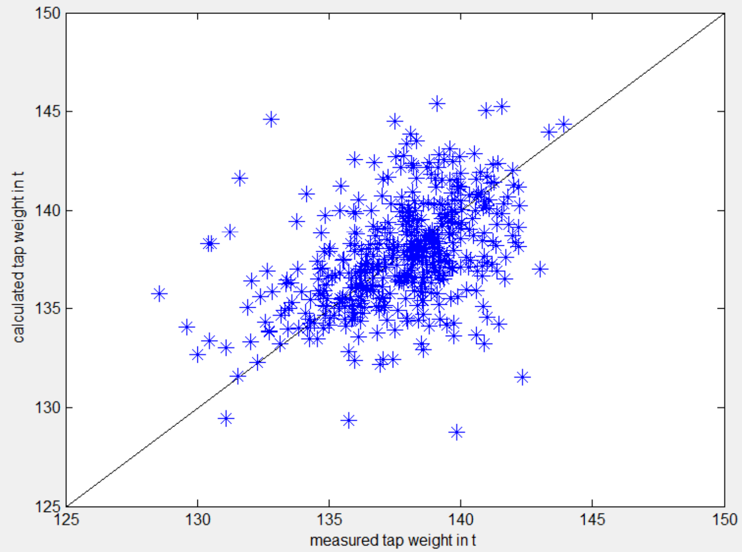
Determination of the metallic yield for each scrap type

	saved values	calc. values	No. of occurrence	
pig iron skulls	74.3	74.3	449	7.2
pig iron	74.5	74.5	103	2.3
cast iron	63.6	63.6	177	1.1
E1	85.6	85.6	386	6.0
E2	93.3	93.3	144	6.3
E3	89.3	89.3	448	26.4
E8	89.4	89.4	449	23.0
E1 / E3	86.3	86.3	250	5.9
cans	98.0	98.0	96	0.9
E6	94.2	94.2	331	8.2
E5M	90.1	90.1	439	9.8
E5H	79.6	79.6	42	4.1
briquetted turnings	86.7	86.7	198	3.2
steel skulls	84.7	84.7	195	2.9
casting residuals	95.5	95.5	295	5.2
return Cr	90.3	90.3	170	7.4
return CrMo	88.6	88.6	85	5.9
return CrNiMo	93.4	93.4	110	10.7
E40	96.0	96.0	227	4.3
remaining scrap	96.7	96.7	97	4.3

Ch.-No.: 680320, 682936

No. of heats: 449

estimated tap weight	saved values	calc. values
mean error / t	-1.36e-10	-1.36e-10
error STD / t	2.7	2.7
mean yield / %	88.7	



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Input data:

- Weights of different charge materials (scrap, DRI, pig iron ...)
- Tapped steel weight

Output data:

- Metallic (furnace) yield of each scrap type
- Overall metallic yield

Determination of the yield of residuals and alloy elements for the different scrap types: Example Cu

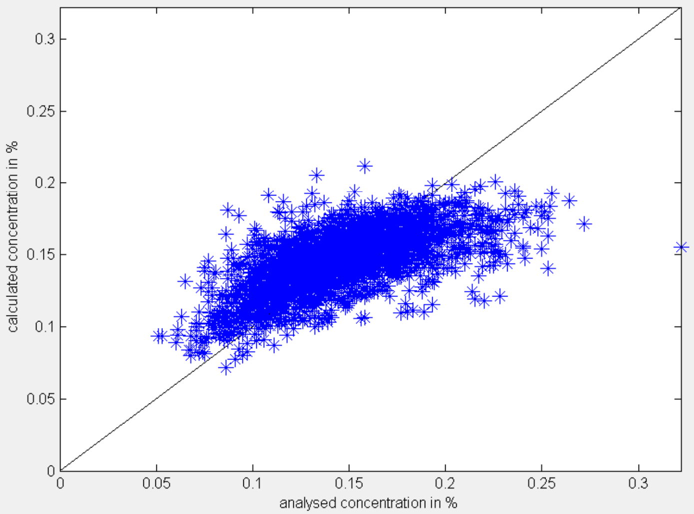
	saved values	calc. values	No. of occurrence	
pig iron skulls	0.051	0.051	2171	8.1
pig iron	0.000	0.000	237	5.5
cast iron	0.193	0.193	523	1.9
E1	0.223	0.223	1408	9.0
E2	0.102	0.102	347	15.0
E3	0.165	0.165	2307	27.5
E8	0.033	0.033	2426	23.1
E1 / E3	0.268	0.268	769	10.6
cans	0.000	0.000	259	1.8
E6	0.071	0.071	1003	15.0
E5M	0.251	0.251	1842	12.5
E5H	0.171	0.171	76	11.6
briquetted turnings	0.139	0.139	441	7.4
steel skulls	0.128	0.128	456	6.7
casting residuals	0.130	0.130	733	11.3
return Cr	0.114	0.114	380	17.2
return CrMo	0.118	0.118	159	16.6
return CrNiMo	0.138	0.138	227	28.9
E40	0.232	0.232	787	6.7
remaining scrap	0.137	0.137	200	11.7

Ch.-No.: 680316 – 682938

No. of heats: 2426

element: Cu

estimated concentration	saved values	calc. values
mean error / %	3.66e-07	3.66e-07
error STD / %	0.026	0.026
element efficiency hot heel	1.000	1.000



tracking | optimise | print | save | save to Excel sheet | close

Additional input data:

- Steel analysis from a sample taken before EAF tapping
- The influence of the hot heel is taken into account with the analysis of the previous heat
- After validation e.g. by a process engineer, the resulting data will be written into the database

Statistical analysis regarding oxidisable elements

For the determination of the scrap type composition regarding oxidisable elements (Si, Mn, Cr, ..), the following additional information is evaluated

- slag weight
- slag analysis

Estimation of the slag weight based on slag analyses

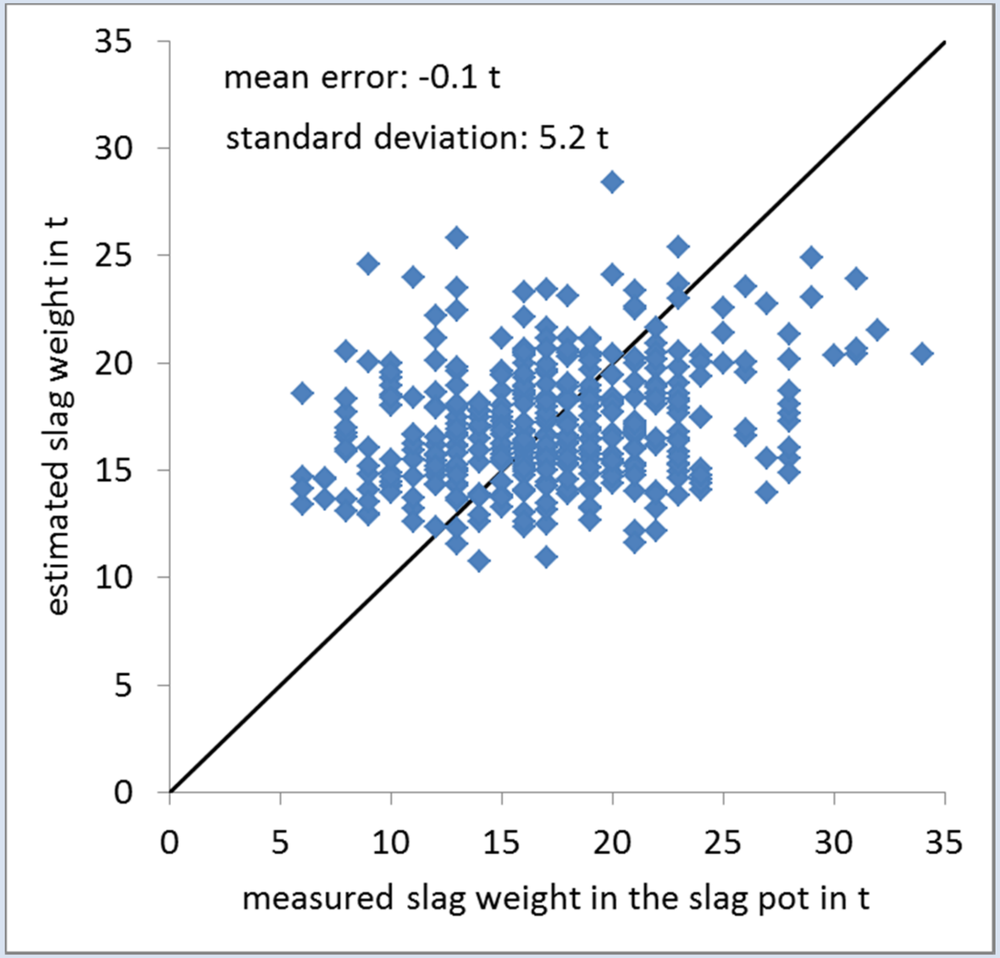
- With the help of a CaO balance, the slag weight can be estimated by its analysis, under the assumption that CaO is only introduced by the charged slag formers

Alternative:

- Determination of the slag weight with the help of a dynamic process model comprising an oxidation model

↳ Modification of the dependent variables for the regression calculation to the melt status derived from the taken steel and slag samples

Comparison between estimated and measured slag weight



The slag weight were estimated on the basis of a CaO balance

- CaO input by slag formers and pig iron
- a standard deviation of about 5 t indicates a large fluctuation of the remaining slag weight in the furnace

Determination of the scrap type composition regarding oxidisable elements: Example Cr

	saved values	calc. values	No. of occurrence	
pig iron skulls	0.026	0.026	133	4.5
pig iron	0.144	0.144	262	6.0
pig iron ma.	0.000	0.000	12	7.0
E1	0.190	0.190	92	8.6
E2	0.094	0.094	75	19.2
E3	0.198	0.198	251	26.2
E40	0.301	0.301	122	10.5
E8	0.230	0.230	270	23.0
E8 punch	0.164	0.164	48	13.1
E1 / E3	0.352	0.352	128	9.2
E6	0.122	0.122	144	14.9
E5M	0.857	0.857	192	12.4
briquetted turnings	0.419	0.419	32	10.0
steel skulls	0.259	0.259	63	6.4
unalloyed	0.198	0.198	89	12.4
return Cr	0.500	0.500	41	17.7
return CrMo	0.638	0.638	8	20.2
return CrNiMo	0.311	0.311	5	16.7
hot heel	1	1.00	30	weight / t

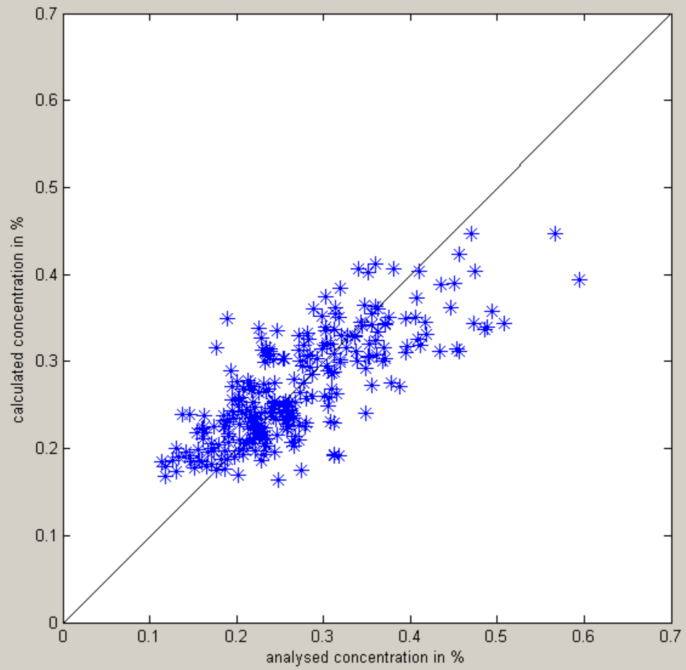
Ch.-No.: 696615, 697095

No. of heats: 277

element: Cr

estimated concentration	saved values	calc. values
mean error / %	3.07e-007	3.07e-007
error STD / %	0.055	0.055

all elements / single element



Additional input data:

- Charged slag formers
- Slag analysis from a taken sample

The comparison between furnace yield and estimated scrap composition shows the following element losses:

- Cr: 58 %
- Mn: 82 %
- Si: 99 %

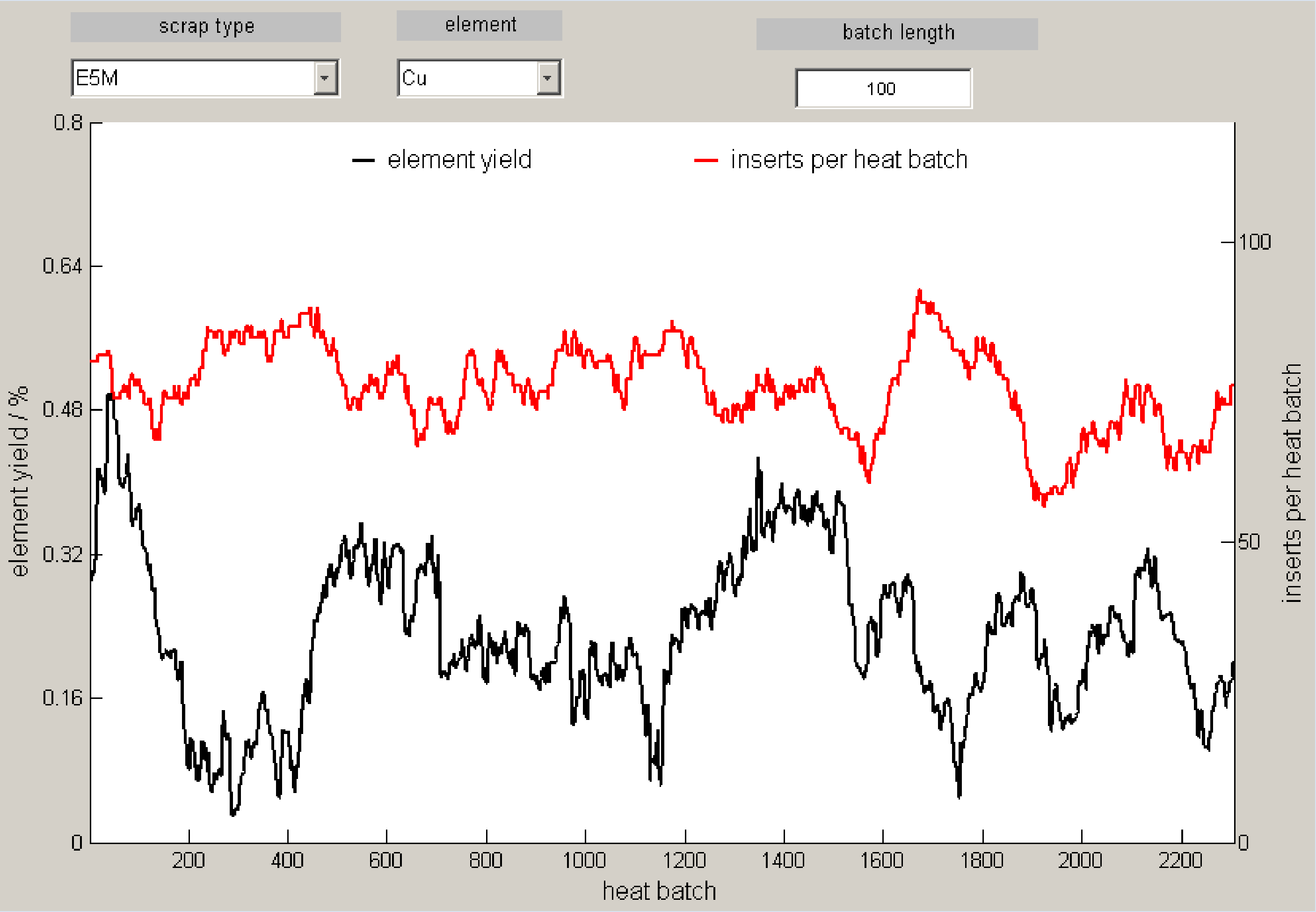
Tracking of scrap type properties over time

- Metallic yield and element composition of the different scrap types change over time (different suppliers and deliveries)
- The tracking bases on a data set of a longer time period (e.g. some months)
- Evaluation of scrap properties for short consecutive sections; the section window moves over the whole data set
- Chronological visualization of the evaluated scrap properties

  ⇨ Variations in the scrap properties can be tracked and used for quality control of the scrap deliveries

Continuous tracking of scrap properties
Example: Cu content of selected scrap types

Tracking of the Cu content for E5M (turnings) over a period of 9 months



Supervision of scrap type properties over time

- The regression analysis can be started automatically for a predefined number of recently produced heats
- The regression analysis can be started on operator demand for an individually selectable range of heats
- An automatic function checks the completeness and reliability of each data set, so that only heats with consistent data are included in the analysis

Input data for charge mix optimisation calculation

For calculation of the cost-optimal scrap mix the following information is required:

- Metallic and element-wise yield for each scrap type (from regression)
- Density, availability and costs of purchase of each scrap type
- Specific meltdown energy demand of each scrap type (optional, to be considered in addition to purchase costs)
- Special operating costs for lime, carbon etc.
- Load restrictions for the scrap baskets
- Load restrictions regarding different scrap types
- Maximal allowed element concentrations for the target steel quality

Predefined scrap properties and restrictions

	availability / t	density / t/cbm	part of scrap mix minimum / %	part of scrap mix maximum / %	purchase costs / t	process costs / t	part of process costs / t (natural gas)
pig iron skulls	50000	3	0	10	66.18	33	5
pig iron	50000	4.5	0	15	97.9	33	5
cast iron	50000	4.5	0	10	97.9	34	6
E1	50000	0.5	0	50	94.75	33	5
E2	50000	2.5	0	50	100	33	5
E3	50000	0.5	0	50	97.9	33	5
E8	50000	0.55	0	50	103.91	33	5
E1 / E3	50000	0.6	0	50	96.33	33	5
cans	50000	1.5	0	5	89.63	33	5
E6	50000	1.5	0	10	107.56	33	5
E5M	50000	1.1	0	30	83.6	33	5
E5H	50000	1.1	0	30	131.4	33	5
briquetted turnings	50000	1.5	0	15	131.4	33	5
steel skulls	50000	1.25	0	10	56.5	33	5
casting residuals	50000	5.5	0	5	100	33	5
return Cr	50000	4.5	0	40	100	33	5
return CrMo	50000	4.5	0	40	100	33	5
return CrNiMo	50000	4.5	0	40	100	33	5
E40	50000	1	0	30	94.56	33	5
remaining scrap types	0	1	0	5	100	33	5

save

close

Predefined steel grades to produce

	minimum / %	maximum / %	safety / %
Cr	0	1	0.03
Cu	0	0.25	0.025
Mo	0	0.05	0
Ni	0	0.15	0
P	0	0.025	0.003
Sn	0	0.025	0.002

quality

16MNCR5

part of scrap mix	minimum / %	maximum / %
pig iron skulls	0	100
pig iron	0	100
cast iron	0	100
E1	0	100
E2	0	100
E3	0	100
E8	0	100
E1 / E3	0	100
cans	0	100
E6	0	100
E5M	0	100
E5H	0	100
briquetted turnings	0	100
steel skulls	0	100
casting residuals	0	100
return Cr	0	100
return CrMo	0	100
return CrNiMo	0	100
E40	0	100
remaining scrap types	0	100

save

close

Charge mix optimisation calculation

- The cost-optimal scrap mix is calculated by the Simplex Algorithm
- All restrictions are considered by appropriate inequalities
- The optimisation calculation determines the cost-optimal scrap mix and the expected steel analysis at EAF tapping

Required information:

- Aim steel grade
- Aim tap weight
- (max basket volume)

Optimisation for one example steel quality

	weight / t	1. basket	2. basket
pig iron skulls	15.5	9.0	6.5
pig iron	-		
cast iron	-		
E1	-		
E2	-		
E3	12.4	7.2	5.2
E8	-		
E1 / E3	10.7	6.2	4.5
cans	7.7	4.5	3.2
E6	15.5	9.0	6.5
E5M	31	18.0	13.0
E5H	-		
briquetted	-		
steel skulls	15.5	9.0	6.5
casting residuals	-		
return Cr	-		
return CrMo	-		
return CrNiMo	-		
E40	46.5	27.0	19.5
remaining scrap	-		
scrap weight / t	154.8	90.0	64.8

tap weight / t: 140

defined qualities: 16MNCR5

filling grade 1. basket: 90.0 / 72.8

filling grade 2. basket: 90.0 / 52.4

scrap volume / cbm: 150

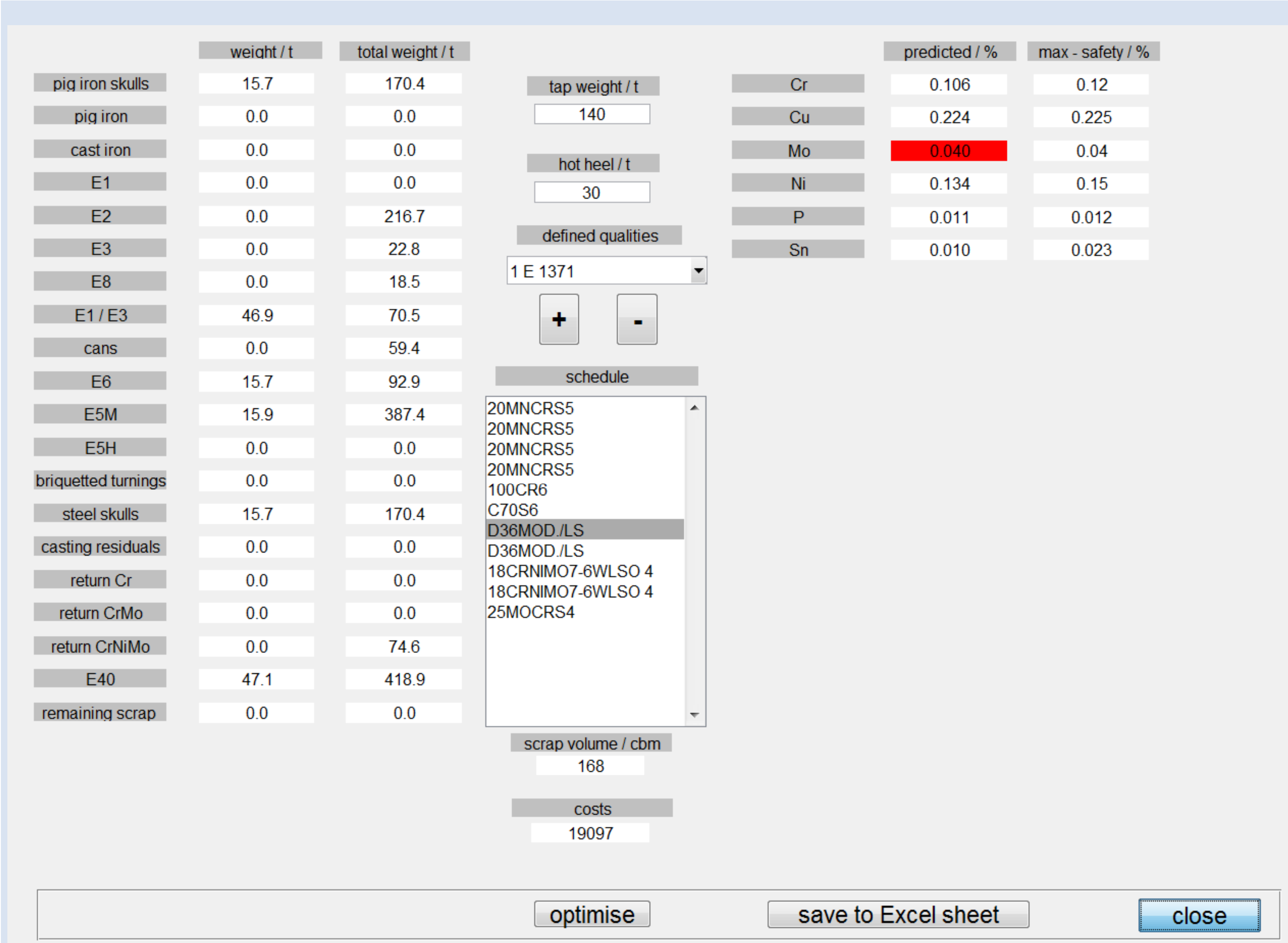
costs: 18601

	predicted / %	max - safety / %
Cr	0.115	0.97
Cu	0.196	0.225
Mo	0.050	0.05
Ni	0.150	0.15
P	0.009	0.022
Sn	0.017	0.023

Scrap types costs | Quality management | optimise | save to Excel sheet | close

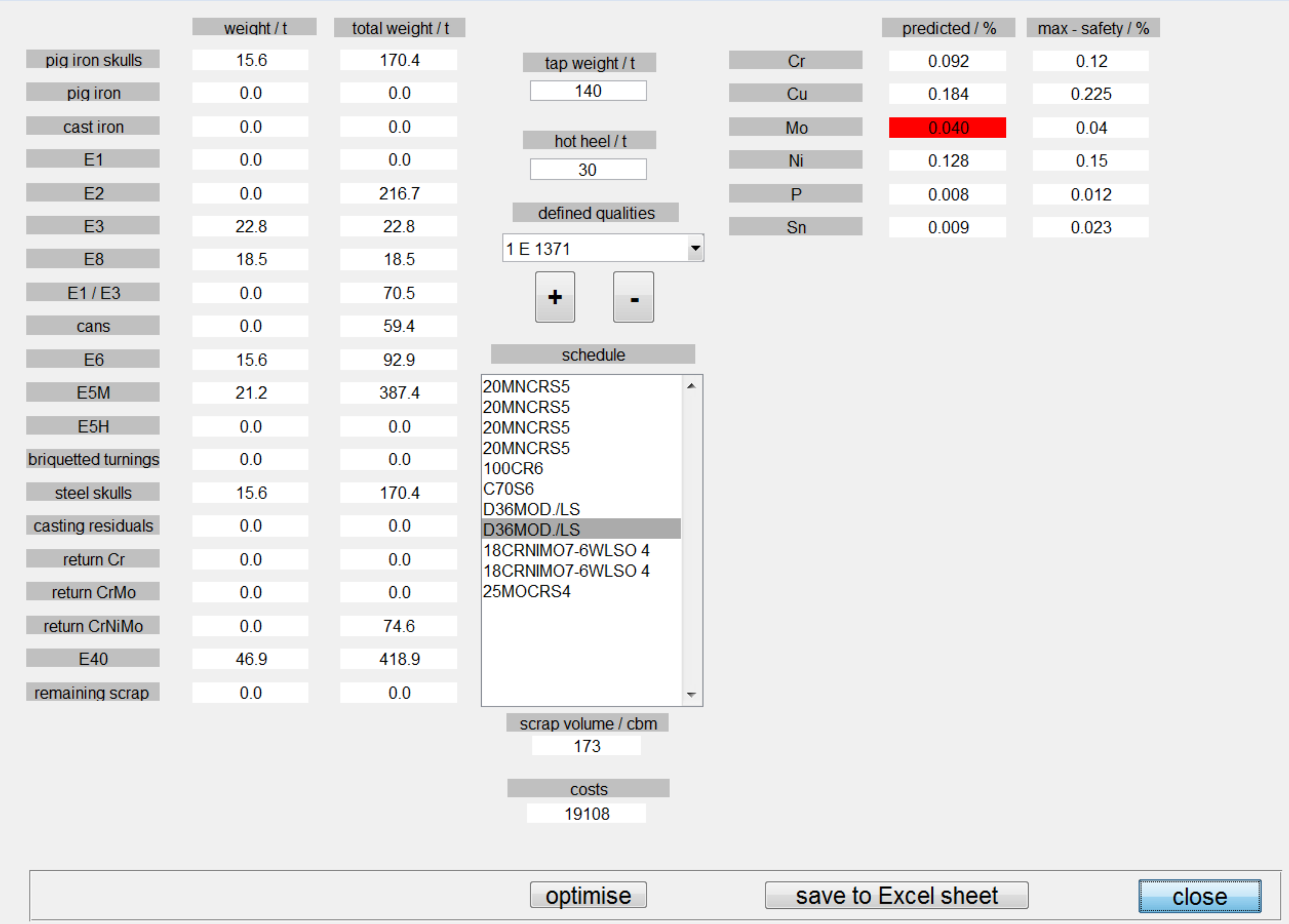
- Optimal Scrap mix and allocation into the two baskets is displayed
- Expected steel analysis at tapping is compared to target analysis
- Critical element concentrations are highlighted in red

Optimisation for a sequence of steel qualities



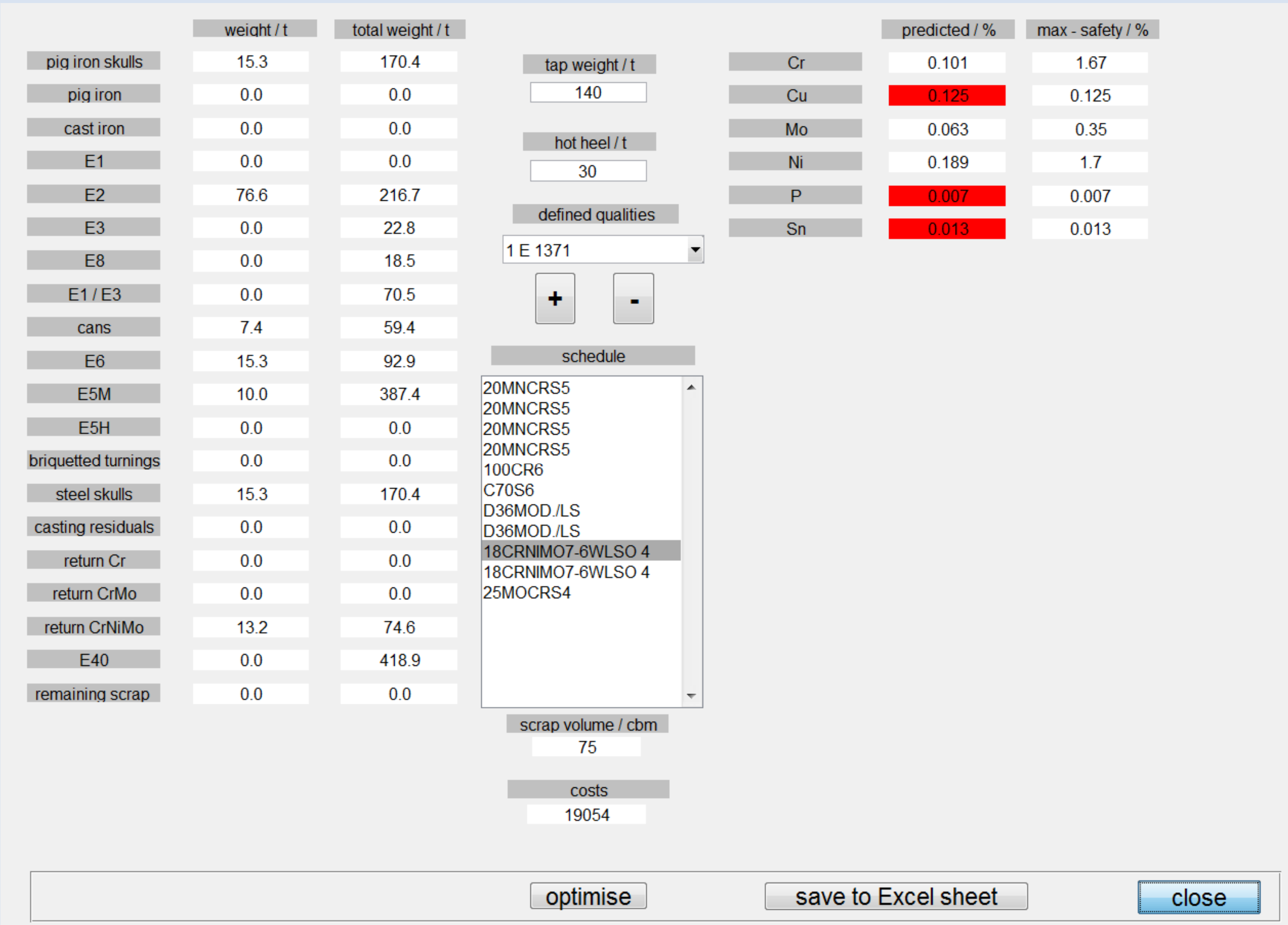
- The expected analysis is considered for the following heat via the hot heel
  - Important for significant changes in steel qualities

Example for a significant quality change I



- The predicted Cu content is significantly below the max allowed value

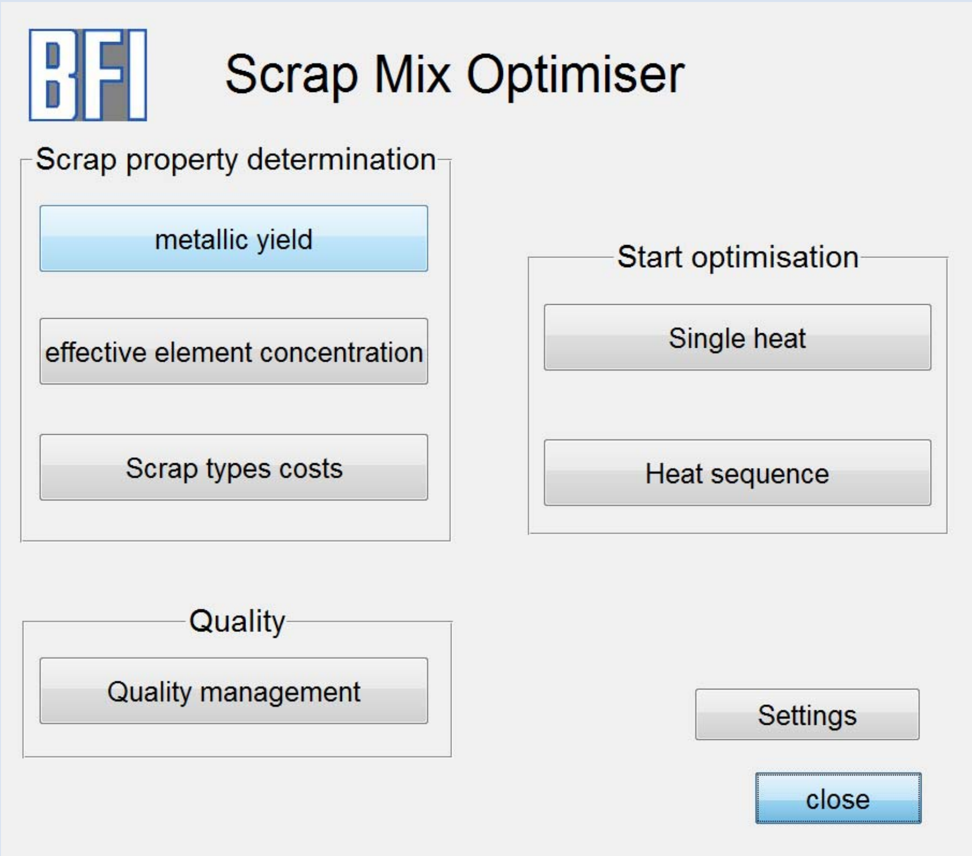
Example for a significant quality change II



- As the max allowed Cu content is very low, the Cu content of the hot heel has been reduced in a predictive manner for the heat before

Scrap mix optimisation tool

- All presented user interfaces are embedded in one user-friendly stand-alone application developed under MATLAB
- The data exchange is realised by Excel files



Conclusions

- Scrap quality determination regarding furnace yield and composition by statistical analysis of process data
- Tracking of scrap properties regarding changes over time
- Determination of cost-optimal scrap mix to achieve the target steel quality for single heats and heat sequences

Benefits regarding scrap mix calculation:

- Maximal use of cheap scrap types respecting the requested quality restrictions
- Aimed alloying via scrap types regarding elements like Cr, Ni, Mo, ..
- Cost benefits of about 10 % are possible depending on the steel grade

Prospects

Finalised projects dealing with scrap characterisation and optimisation

Contract Report	Title	Participants	Date Start / End	Topic regarding scrap characterisation and optimisation
RFSR-CT-2007-00008	Cost and energy effective management of EAF with flexible charge material mix (FLEXCHARGE)	BFI, CRM, CSM, FERALPI, GMH, MEFOS, OVAKO, SIDENOR	2007-07-01 to 2010-12-31	Development of appropriate tools for scrap characterisation and scrap mix optimisation

Actual projects dealing with scrap characterisation and optimisation

Contract Report	Title	Participants	Date Start / End	Topic regarding scrap characterisation and optimisation
RFSP-CT-2014-00004	Adaptive EAF online control based on innovative sensors and comprehensive models for improved yield and energy efficiency (AdaptEAF)	BFI, HSU, GMH	2014-07-01 to 2017-06-30	Determination of the hot heel amount
RFSR-CT-2014-00007	Optimization of scrap charge management and related process adaption for performances improvement and cost reduction (OptiScrapManage)	BFI, CRM, TECNALIA, FERALPI, GERDAU, TATA STEEL UK	2014-07-01 to 2017-06-30	Adaption of operating instructions according to the charged scrap mix

BFI

Stahl

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Thank you very much for your attention !

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