



SMART STEEL
TECHNOLOGIES

TACKLING THE LAST EFFICIENCY FRONTIER IN
STEEL MANUFACTURING THROUGH AI

Dr. Jan Daldrop
Team Lead
Machine Learning

Smart Steel Technologies GmbH
Am Treptower Park 75
12435 Berlin, Germany

Phone: +49 30 403 673 720
E-Mail: request@smart-steel-technologies.com
Web: www.smart-steel-technologies.com

Smart Steel Technologies Company Profile



BUSINESS

- Improving the performance of steel manufacturing operations through the deployment of ready-to-use AI software
- Enabling steelmakers to achieve superior quality levels
- Achieving superior energy consumption, CO2 production standards



TEAM

- Interdisciplinary integrated team of 20 associates with ...
- ... world-class AI and steel know-how ...
- ... PhDs in metallurgy, math, physics.
- Languages: English, German, Russian



EXPERIENCE

- Commissioning and optimizing steel production lines: 20 years
- Data transformation, industrial AI applications: 10 years
- Building up steel focus: 4 years



REFERENCES

- ArcelorMittal (3 production sites)
- Buderus Edelstahl
- Ternium, British Steel

Blending AI and metallurgical expertise in one team

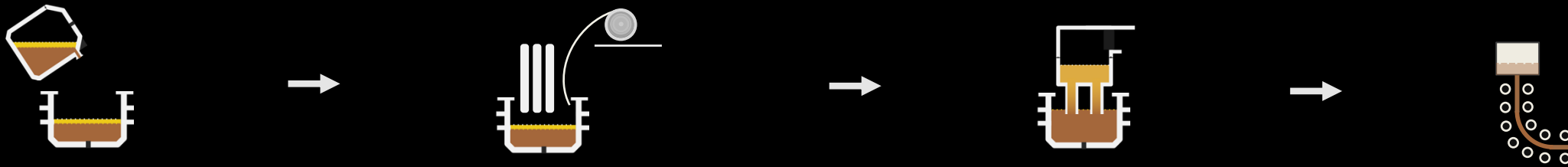
Steel Manufacturing: More Than 10 Shops / Site



- 3500 steel grades, from low carbon up to grain oriented electrical steel
- 4 major processing steps up to casting
- 4 to 6 thermo-mechanic processing steps after casting

E.g., 920 continuous casting lines (1.9 Mt each) worldwide

Secondary Metallurgy and Casting



Basic Oxygen Furnace

- hot metal to steel
- decarburization
- de-Si, de-P

Ladle Furnace

- temperature
- chemical composition

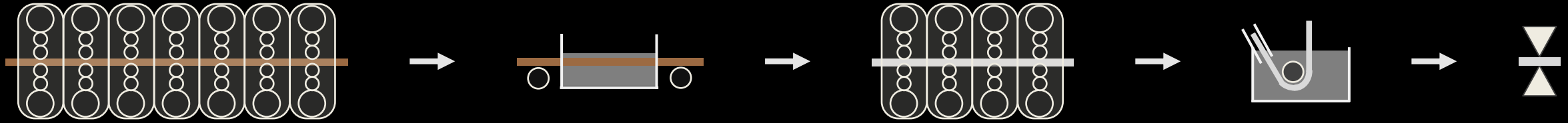
Ruhrstahl Heraeus

- vacuum degassing
- H, O

Continuous Casting

- solidification
- shaping

Rolling and Galvanizing



Hot Rolling

- thickness reduction
- above recrystallization temperature
- mechanical properties

Pickling

- acid bath
- remove oxides, scale

Cold Rolling

- thickness reduction
- mechanical properties
- surface finishing

Galvanizing

- zinc coating to prevent corrosion
- liquid zinc bath

Surface Inspection

- automated visual inspection

A SOPHISTICATED PROCESS CHAIN FOR HIGH QUALITY PRODUCTS

Steel Plant Impressions



Basic Oxygen Furnace



Hot Strip Mill



Galvanized Coils

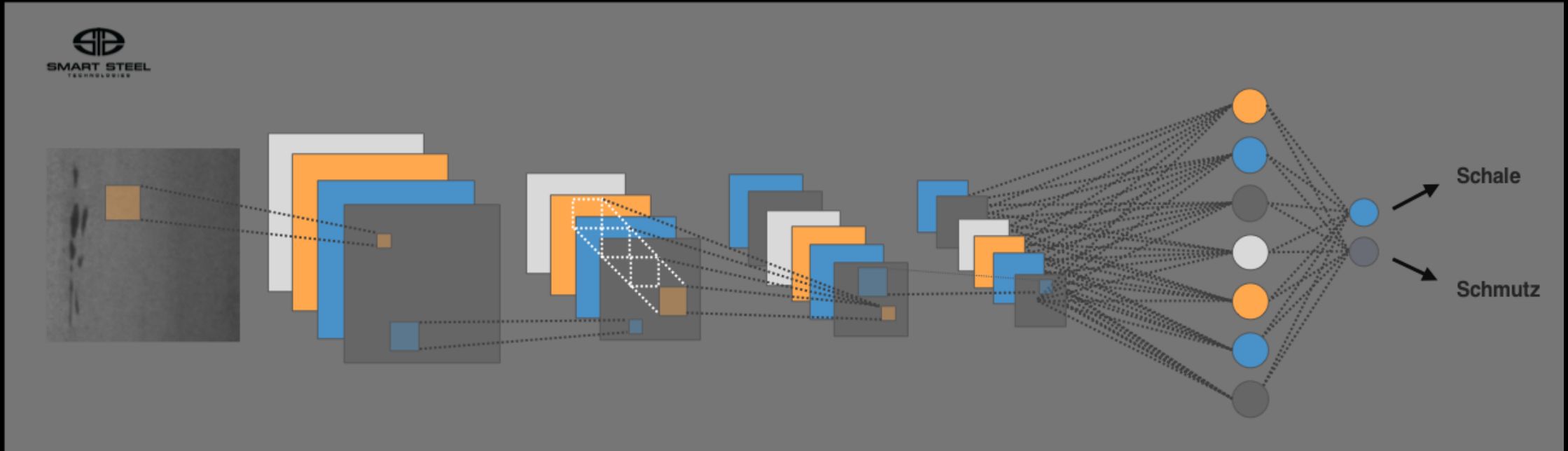
SST Surface Inspection AI Project

Building Blocks

- 1 CNN Surface Defect Classification
 - 2 Training Data Optimization
 - 3 SST Image Search
-
- 4 Online Integration



CNN Surface Defect classification

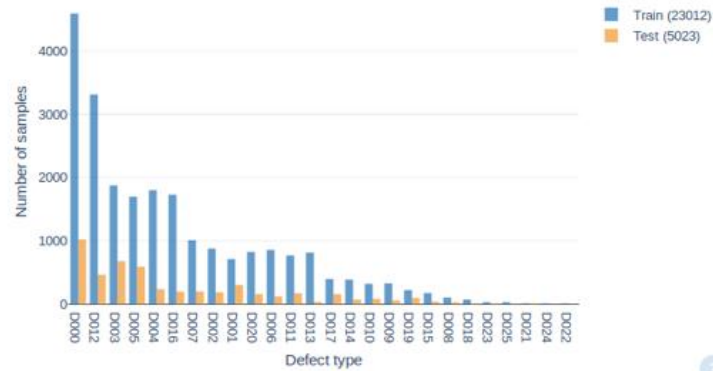


- Existing ASIS systems typically based on classical image features
- SST uses advanced CNN ensembles optimized for steel surface defect classification
- Steel-specific image augmentation, problem-specific class weights + losses
- Transfer learning + Semi-supervised learning

SST Training Set Optimizer



Defect type distribution



Train / test split



Total number of images

28035

Train / test correlation

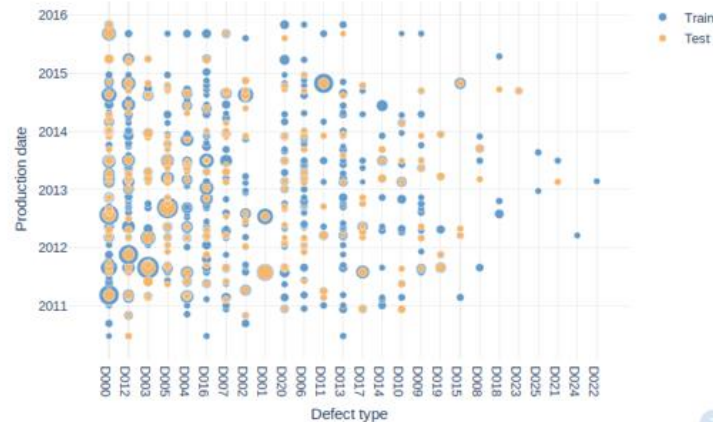
74%

Total number of samples	28035
Number of training samples	23012
Number of test samples	5023

Number of coils	774
Number of coils in training set	701
Number of coils in test set	276
Number of coil ids found in train and test	203
Average number of different defect types per coil	1.32

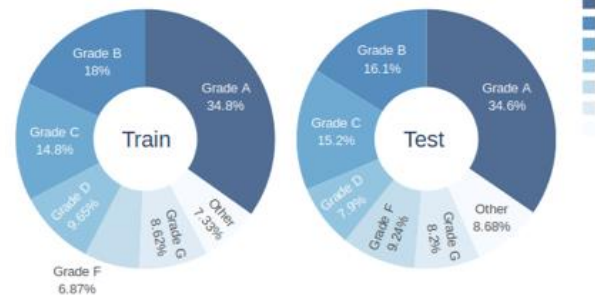
Train / test

Train / test distribution



Train / test

Recipe distribution



Other: Grade H: 3.5%, Grade K: 1.3%, Grade E: 0.6%, Grade L: 0.6%, Grade J: 0.6%, Grade I: 0.5%, Grade N: 0.1%, Grade Q: 0.1%, Unknown: 0.1%, Grade O: 0.0%, Grade R: 0.0%, Grade P: 0.0%

QUICKLY SCAN THROUGH 500,000,000 DEFECT IMAGES

SST Defect Image Search for QUICK Classifier Tuning

Image

Upload image

Filters

Production period
From: 2016-09-30 00:00 To: 2019-09-01 23:59

Heat ID / Slab ID / Coil ID: Number of images to return: 10

Advanced filters

Defect width (mm): Enable

Defect length (mm): Enable

Cross position from operator side (BS) (mm): Enable

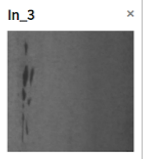
Cross position from drive side (AS) (mm): Enable

Longitudinal position from head (m): Enable

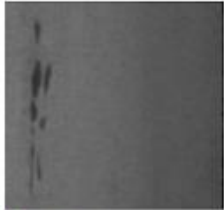
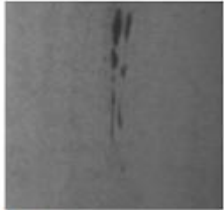
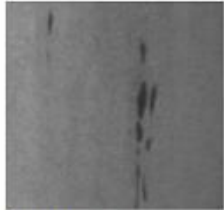
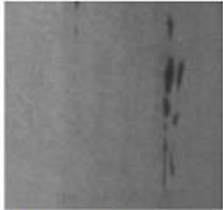
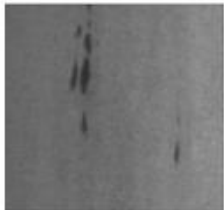
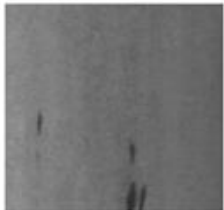
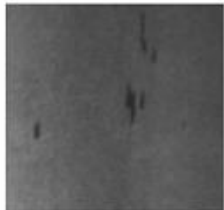
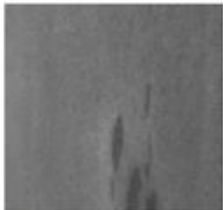
Longitudinal position from tail (m): Enable

Recipe: Enable

Query images



Result images Found 10 images matching query.

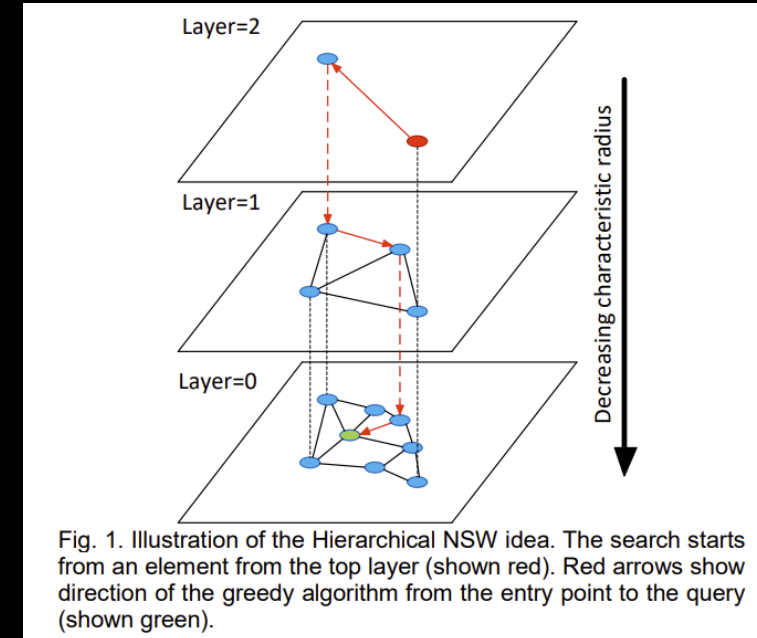
In_3  Distance: 0.00 ASIS: inclusion Date: 2019-06-02 00:00 Add to query	In_4  Distance: 0.06 ASIS: inclusion Date: 2019-06-01 00:00 Add to query	In_1  Distance: 0.06 ASIS: inclusion Date: 2019-06-02 00:00 Add to query	In_5  Distance: 0.07 ASIS: inclusion Date: 2019-06-01 00:00 Add to query
In_10  Distance: 0.08 ASIS: inclusion Date: 2019-06-04 00:00 Add to query	In_2  Distance: 0.09 ASIS: inclusion Date: 2019-06-01 00:00 Add to query	In_140  Distance: 0.10 ASIS: inclusion Date: 2019-06-03 00:00 Add to query	In_175  Distance: 0.11 ASIS: inclusion Date: 2019-05-31 00:00 Add to query

Search through 100,000,000 defect images within 100 ms

SST Image Search Technology

Image features / embedding

- Images are indexed by CNN features (cosine distance in Euclidean space)
- Imagenet pre-training
- Select CNN architecture by class-based image retrieval on a test set (MAP, truncated VGG16)
- Dimensionality reduction: Transfer learning (of cosine distance) to a smaller CNN with less outputs + PCA
- Image augmentation during transfer learning improves MAP

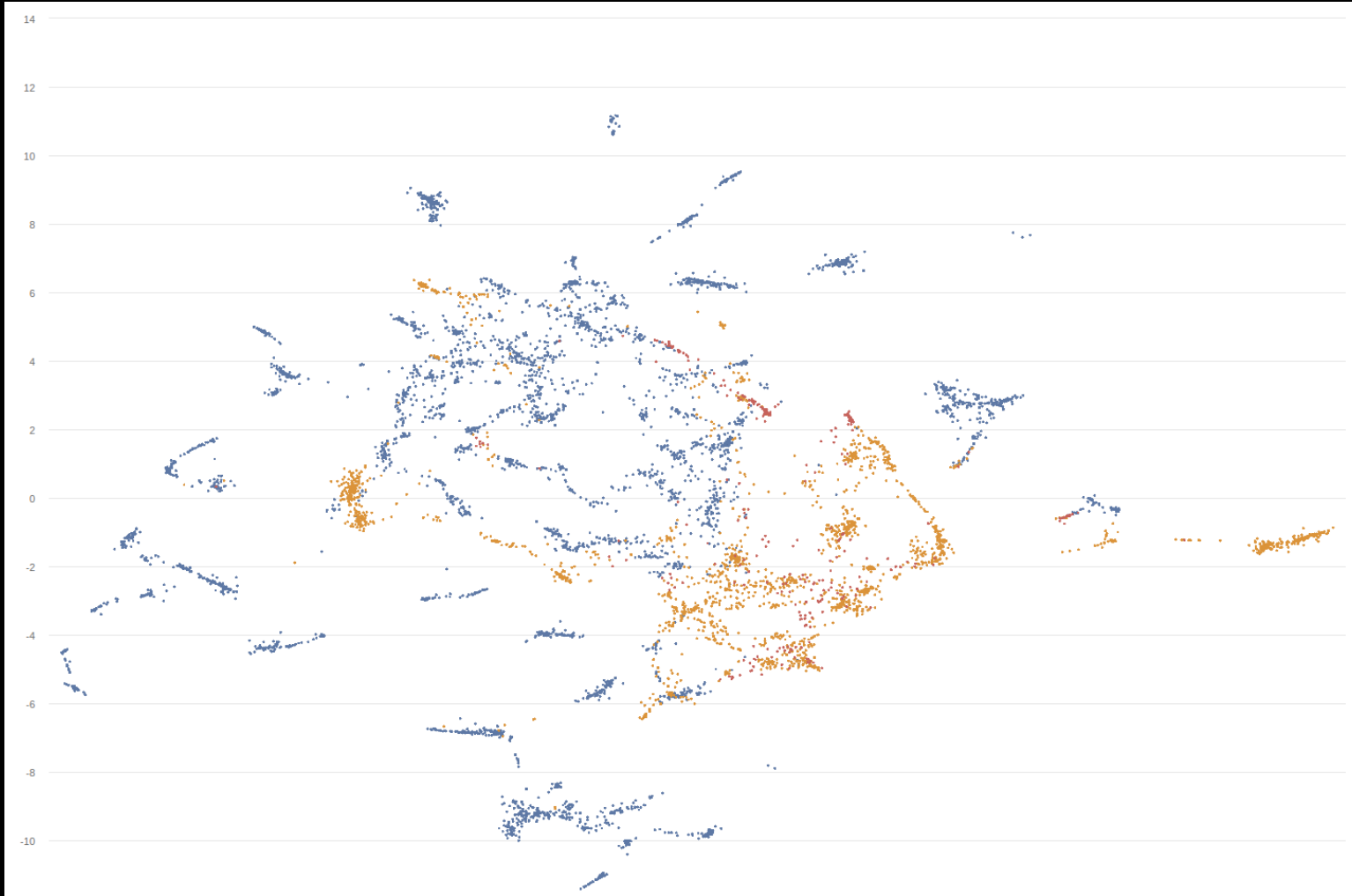


Fast approximate nearest neighbor search

- Fast image retrieval with Hierarchical Navigable Small World graphs

CNN FEATURES SEPARATE DEFECT CLASSES WELL

UMAP Projection of Feature Vectors



Colors: different defect types

SST Casting Optimization AI Project

Building Blocks

- 1 Centralized Coil Map
- 2 Defect Classification
- 3 Caster Data, Model Tuning
- 4 Automatic Casting Parameter Optimization
- 5 Testing in Production

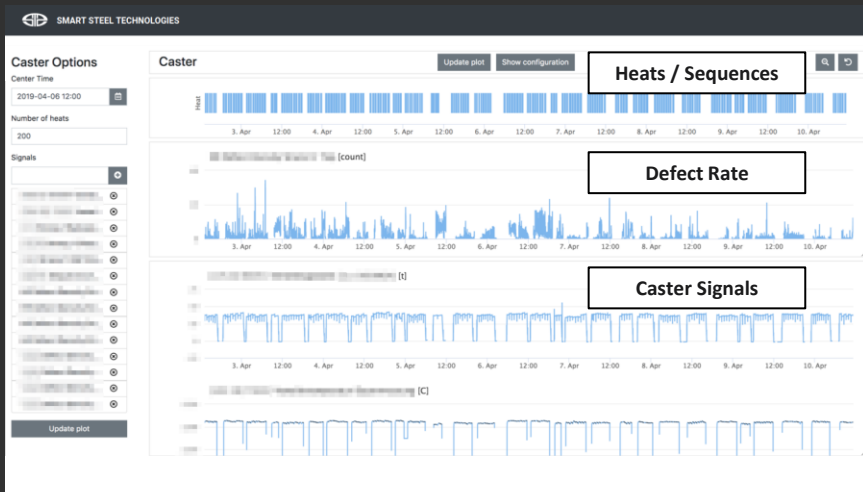


Installing Deep CNN Classifiers and Centralized Coil Map



Matching of defect positions across all routes: HSM, PL, TCM, CGL, inspection lines

Merging Quality, Caster, Melt Shop Data, Model Tuning

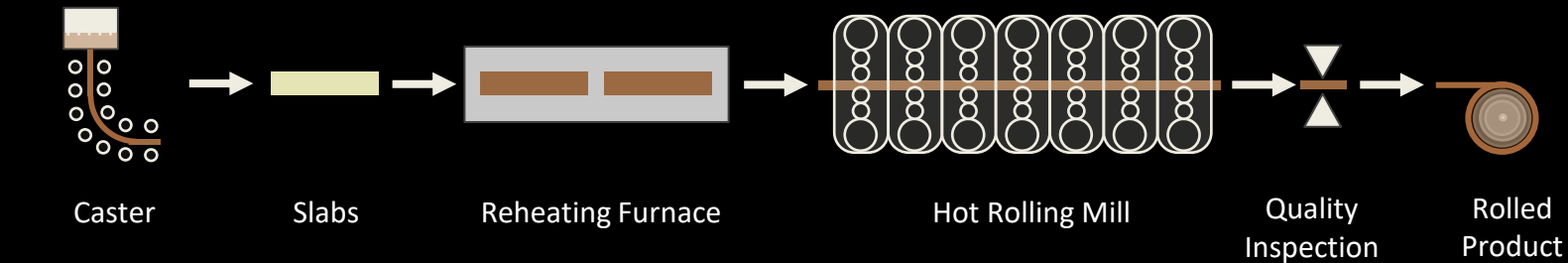


Mapping defect rates onto strand position
Merging caster and melt shop data



Explainable AI:
Inspecting arbitrary subspaces of caster settings

SST Casting Optimization AI: Significantly Reduce Defects



PROCESS DATA

- Steel analysis
- Speed, mould level
- Heat flux, water flow
- More casting parameters

QUALITY INSPECTION DATA

- Defect images
- Defect positions on strip
- Defect types
- Normalized defect rates

AUTOMATED IDENTIFICATION OF OPTIMAL SETTINGS IN HIGH DIMENSIONAL CONFIGURATION SPACE

- Changes: speed / width / taper, more
- Ranges: heat flux, more
- Wear: copper plates, more

SMART STEEL TECHNOLOGIES IMPLEMENTS OPTIMIZATION ACTIONS

Example 1:
Optimized mould settings for best primary solidification

Example 2:
Adapted strand cooling for best surface and internal quality

Example 3:
Process chain optimized speed management

Applicable to manufacturing of both, flat and long products
Permanently reduced rate of casting defects without installation of new equipment

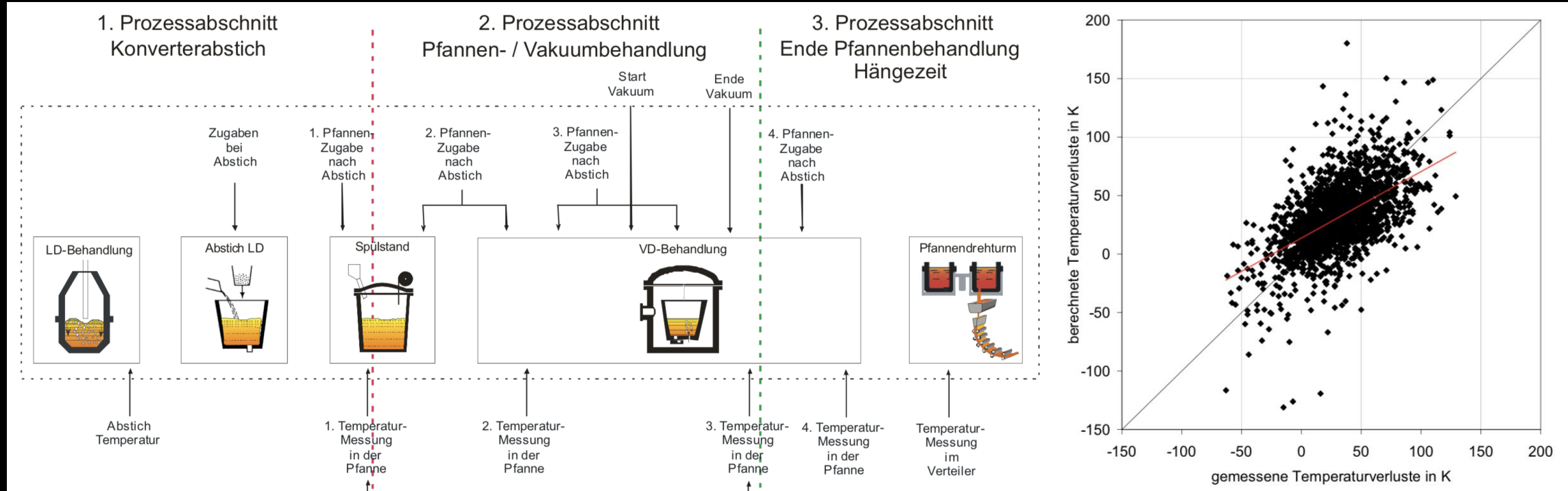
SST Temperature Optimization AI Project

Building Blocks

- 1 Live Data Transformation
- 2 Live Integration in Melt Shop OT
- 3 Model Tuning
- 4 Testing in Production



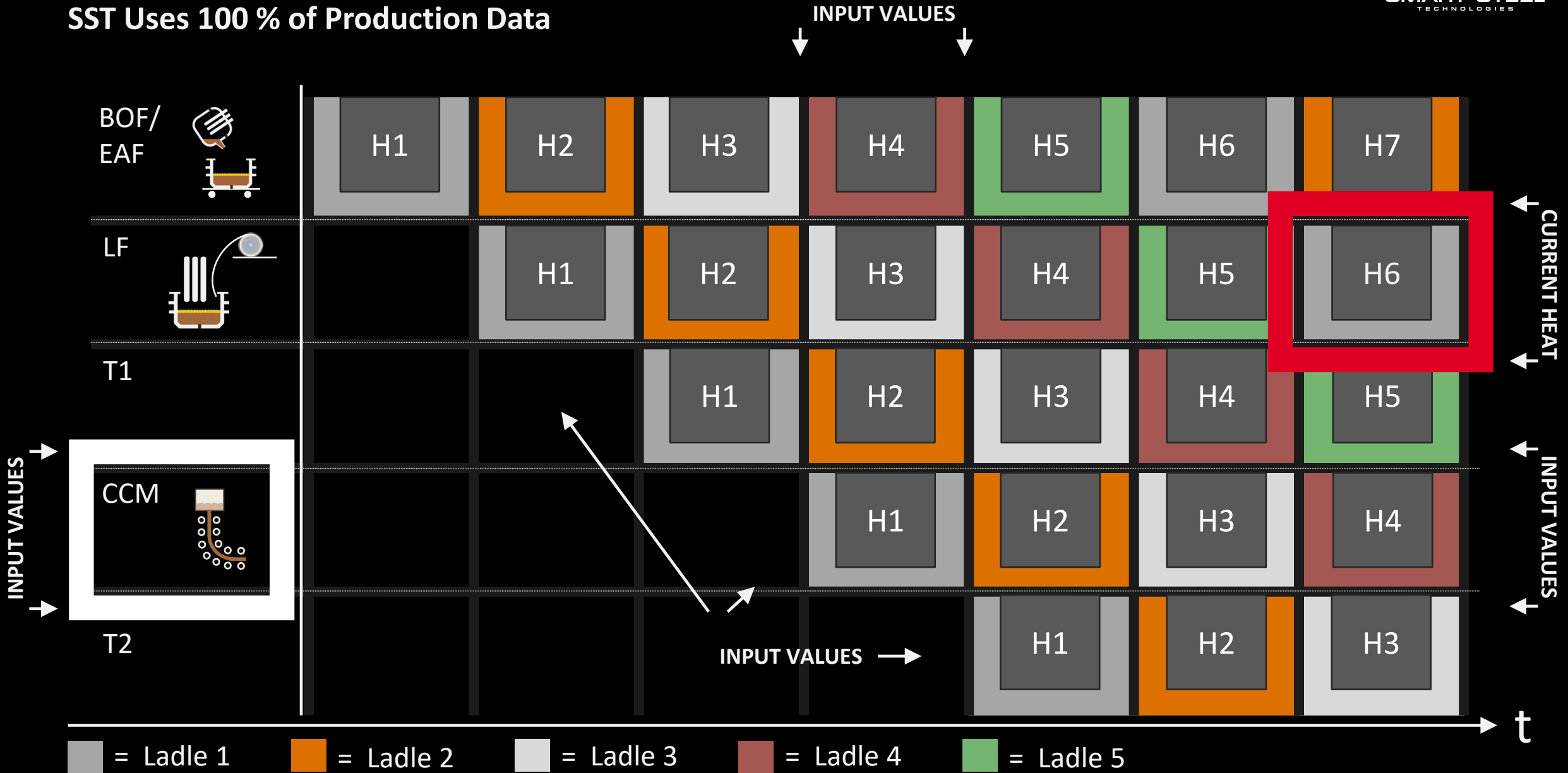
Conventional Temperature Optimization (This is *****NOT***** the SST Approach)



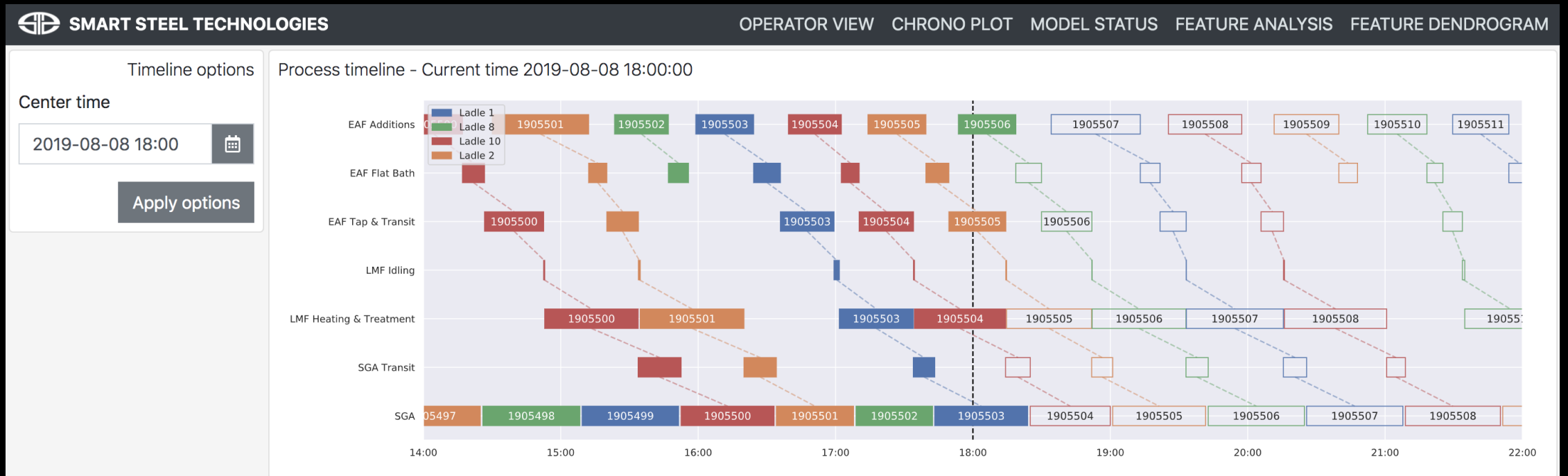
$$\Delta T = (FRT_1 \cdot T_{\text{Abstich}}^4) \cdot t_1 + (FRT_2 \cdot T_{\text{Abstich}}^4) \cdot t_2 + (RT_3 + \sqrt{t_{\text{PflLeer}}} \cdot FRT_3) \cdot t_3 + (RT_4 + \sqrt{t_{\text{PflLeer}}} \cdot FRT_4) \cdot t_4 + \sum_Z RT_Z \cdot m_Z + \sum_A RT_A \cdot m_A - \sum_Y RT_Y \cdot M_Y$$

MORE DATA LEADS TO HIGHER PRECISION AND ROBUSTNESS

SST Uses 100 % of Production Data

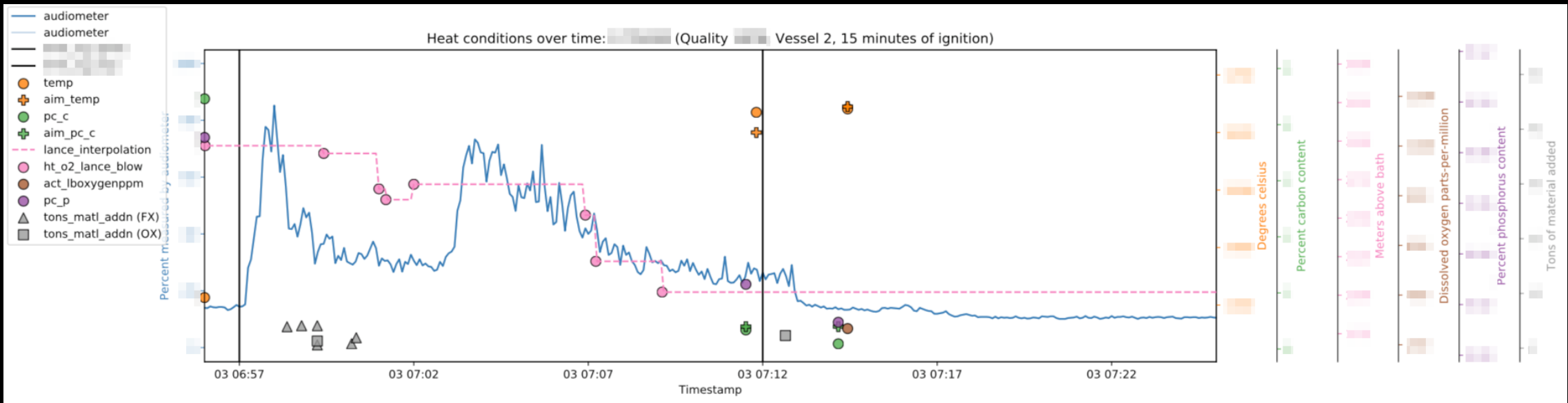


SST Process Timeline View



SST covers all melt shop configurations from BOF / EAF to caster

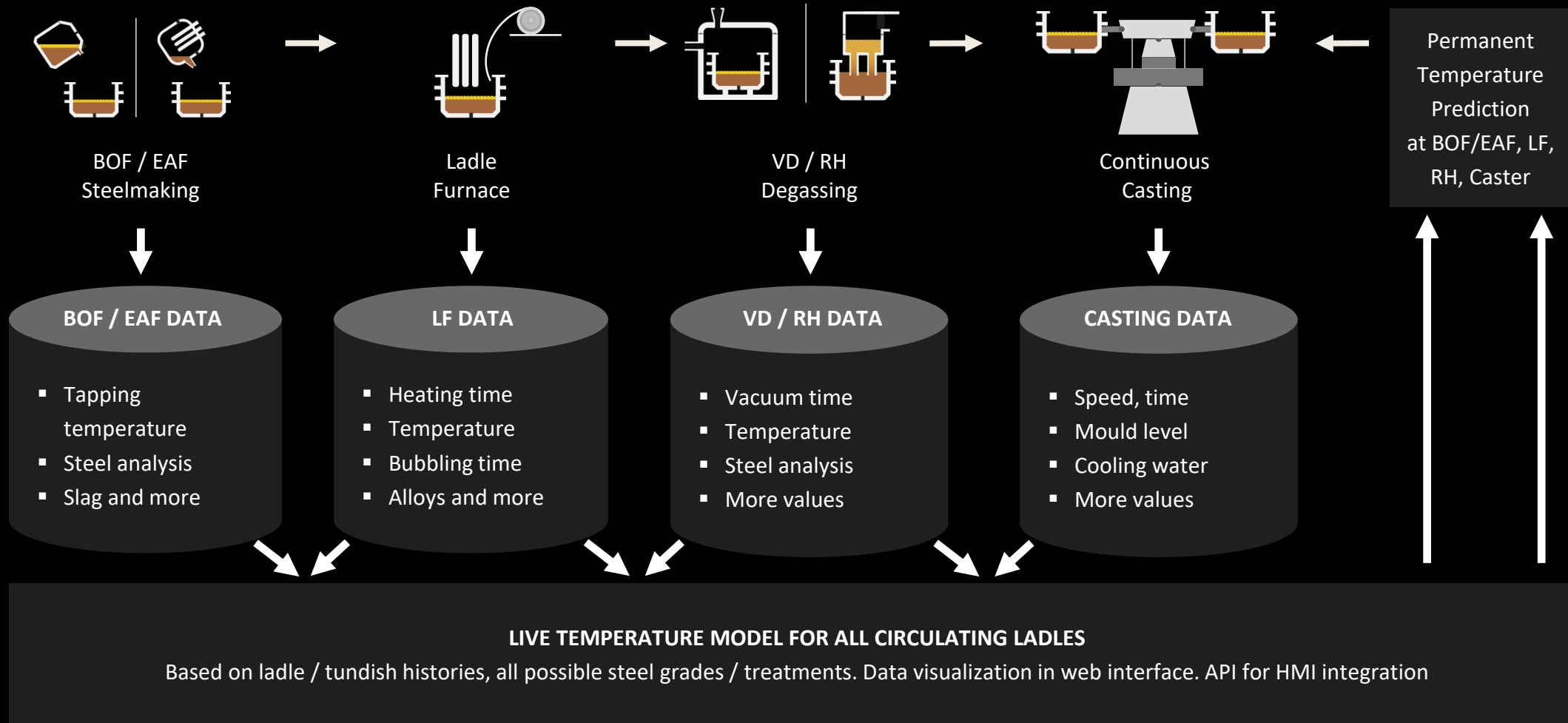
SST Temperature Guidance For BOF Steelmaking



Live Predictions:

- Expected tapping temperature of current heat based on local BOF model
- Optimal target tapping temperature of current heat based on global temperature model
- Recommendation to operator (e.g., set-point for blow-end)
- Chemical composition

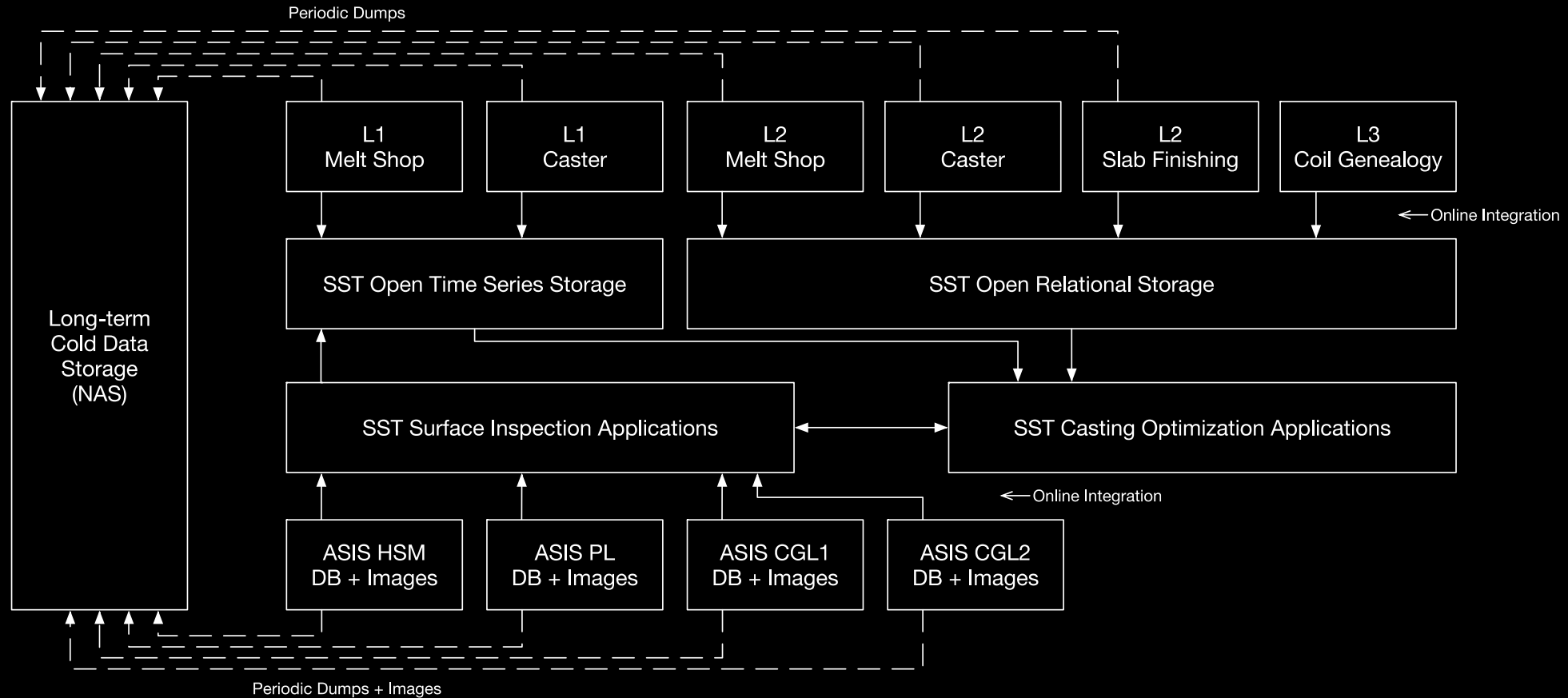
SST Temperature Optimization AI – Reduce Temperature Levels By 10 Kelvin



SST covers all melt shop configurations and processes

No cloud and no supercomputing needed

SST Builds On Future Proof IT Architecture



Live integration of machine learning applications is a lot of work!

Thank you for your attention.