A Network-based Analysis of Technology-driven and Load-driven Constraints in Production Data

Serhat Kosif

Jacobs University

Spring Semester 2021

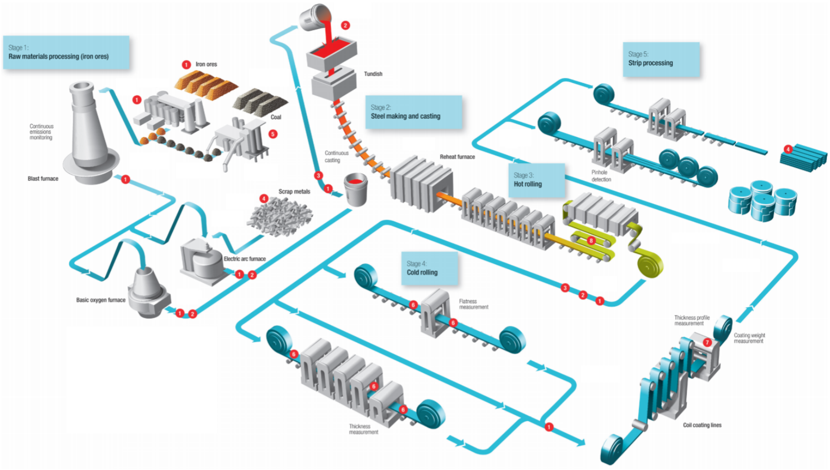
Introduction
- Production Lines and Handling Types

Operations Research Model
- Steel Production Data Analysis
- Abstract Theoretical Framework
- Concepts Integration

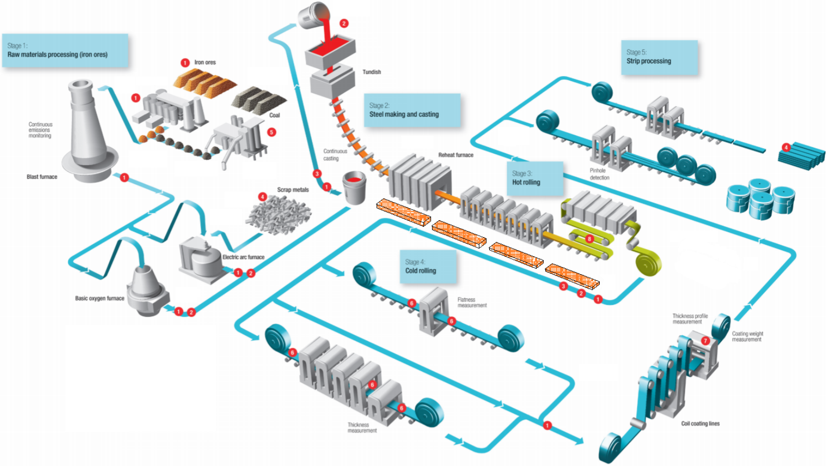
Implementation, Analysis and Results
- Steel Production Events Analysis
- Simulation Events Analysis

Conclusion and Outlook

Production Lines and Handling Types



Production Lines and Handling Types



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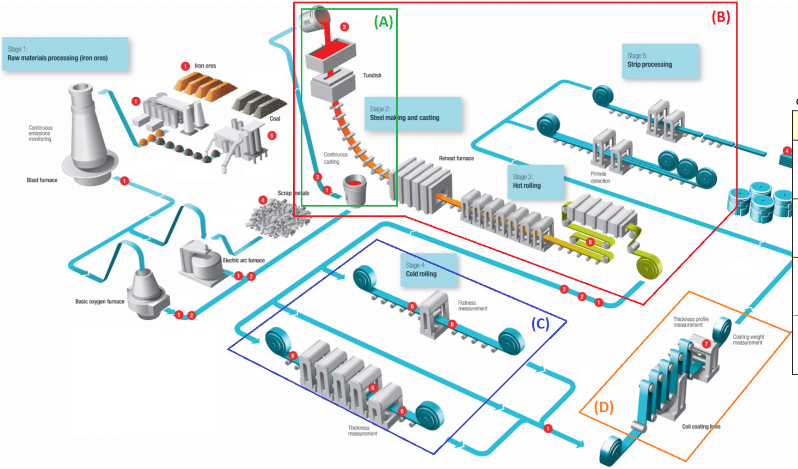
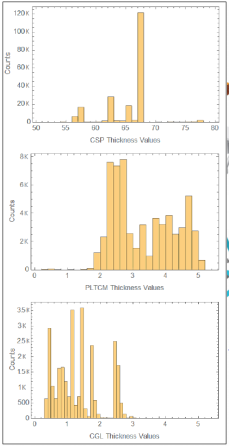
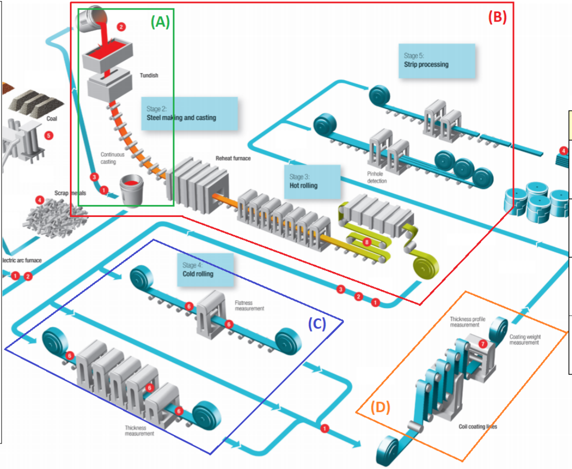


Compact Production Lines with Various Machine Modules.

No	Production Unit / Line	Description	Events Number
A	Continuous Casting Machine (**CCM**)	Steel cools, passing through the mould cavity and solidifies after water spraying.	347, 418
B	Compact Strip Production (**CSP**)	Compact plant including CCM, reheating furnace, hot rolling unit and strip processing unit.	205, 496
C	Pickling Line & Tandem Cold Mill (**PLTCM**)	Compact plant including a turbulence pickling section and a tandem mill.	59, 604
D	Continuous Galvanizing Line (**CGL**)	Application of protective zinc coating on the steel surface to improve corrosion resistance.	27, 147

Production Lines and Handling Types





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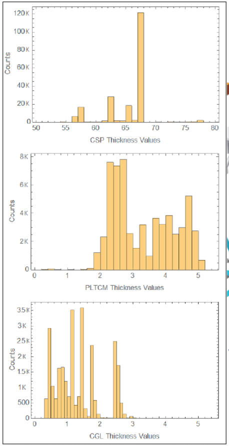

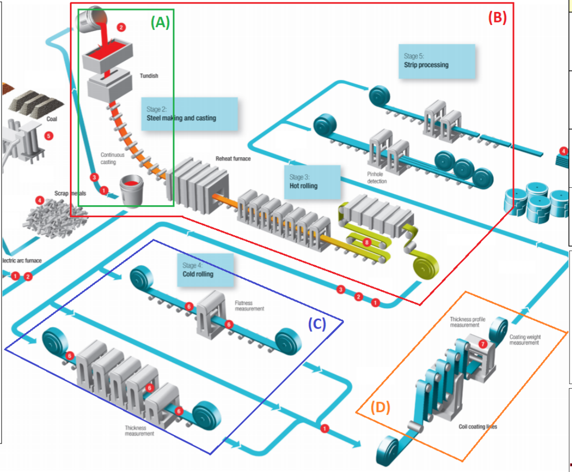

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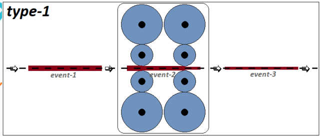

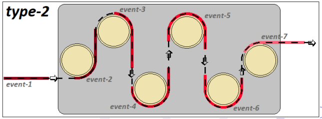

Association Networks

Events	Feature-A	Sequence ID
1	280	1
2	250	1
3	890	2
4	850	2
5	650	2
6	745	2
7	795	2
8	150	3
⋮	⋮	⋮
n-4	940	k-1
n-3	540	k
n-2	520	k
n-1	630	k
n	610	k

$$Lift(A \leftrightarrow B) = \frac{P(A,B)}{P(A) * P(B)}$$

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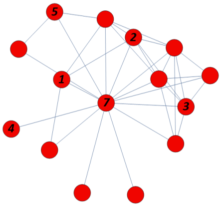
n-2	520	k
n-1	630	k
n	610	k

Lift > 1, B occurs likely if A occurs
Lift < 1, B unlikely occurs if A happens

Events	1	2	3	...	n-1	n
1	0	1	0	...	0	0
2	1	0	0	...	0	0
3	0	0	0	...	0	0
⋮	⋮	⋮	⋮	⋱	⋮	⋮
n-1	0	0	0	...	0	1
n	0	0	0	...	1	0



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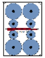
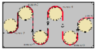
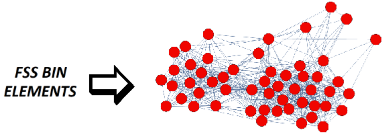
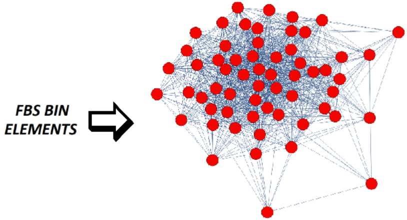
Binning Schemes





Event ID	Feature-A	FSS Bins	FBS Bins	Sequence ID
1	280	200-299	200-599	1
2	250	200-299	200-599	1
3	890	800-899	630-899	2
4	850	800-899	630-899	2
⋮	⋮	⋮	⋮	⋮
n-2	520	500-599	200-599	k
n-1	630	600-699	630-899	k
n	610	600-699	600-629	k





Network Metrics Analysis

Modularity calculation was performed for the real network based on Newman (2006) formulated in his article.

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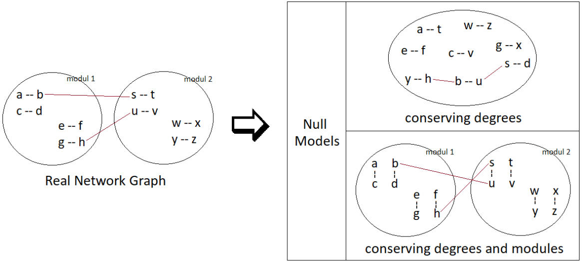


Network Metrics Analysis

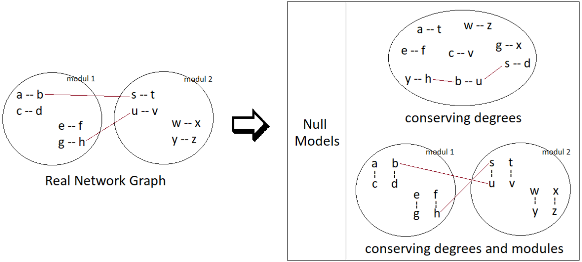
Modularity calculation was performed for the real network based on Newman (2006) formulated in his article.

$$z = \frac{Q - \mu}{\sigma}$$

Q: modularity value

μ: expectation value (mean) of Q for 1000 randomised graphs.

σ: standard deviation of Q in randomised graphs



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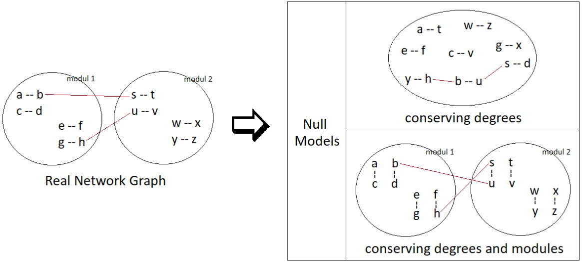


Network Structures Concerning Different Null Models.

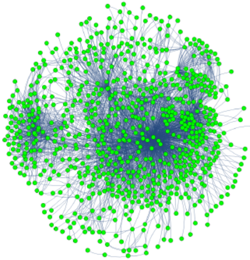
Real Network Z-score	Conserving Degrees Sequence (NM-d)	Conserving Degrees Sequence and Modules (NM-m)
$z \leq -2$	nonrandom, non-modular	hierarchical
$-2 < z < 2$	random, non-modular	simple
$z \geq 2$	nonrandom, modular	hierarchical

$$f(x) = \begin{cases} 0, & \text{if } x = 0 \\ 1, & \text{if } x \neq 0 \end{cases}$$

normalisation

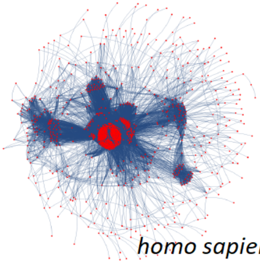
$$S = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1r} \\ s_{21} & s_{22} & \dots & s_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \dots & s_{mr} \end{bmatrix} \Rightarrow$$

$$S.S^T = \begin{bmatrix} s'_{11} & s'_{12} & \dots & s'_{1m} \\ s'_{21} & s'_{22} & \dots & s'_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ s'_{m1} & s'_{m2} & \dots & s'_{mm} \end{bmatrix} \Rightarrow$$



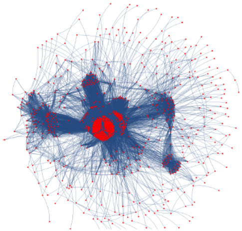
Metabolic-centric Network

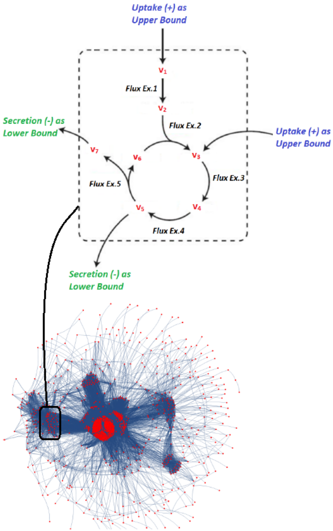
$$S^T.S = \begin{bmatrix} s''_{11} & s''_{12} & \dots & s''_{1r} \\ s''_{21} & s''_{22} & \dots & s''_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ s''_{r1} & s''_{r2} & \dots & s''_{rr} \end{bmatrix} \Rightarrow$$

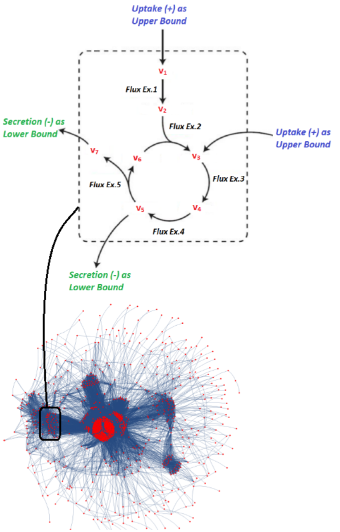


Reaction-centric Network

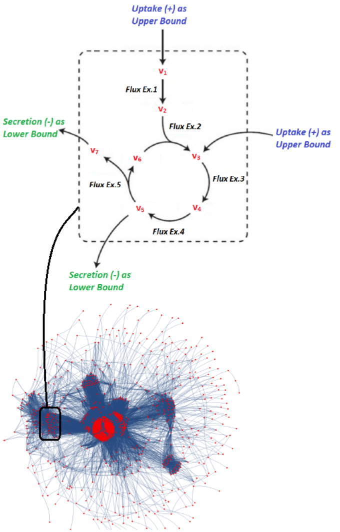
homo sapiens metabolism




Uptake (+) as
Upper Bound
v_1
Flux Ex.1
v_2
Flux Ex.2
Uptake (+) as
Upper Bound
Secretion (-) as
Lower Bound
v_7
v_6
v_3
Flux Ex.3
Flux Ex.5
v_5
v_4
Flux Ex.4
Secretion (-) as
Lower Bound



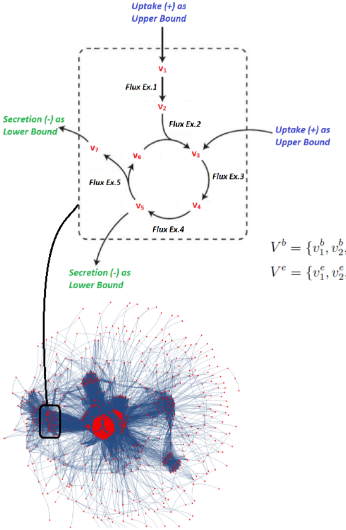
$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_r \end{bmatrix} = (v_i) \in \mathbb{R}$$



Optimisation Scheme (FBA)

$$V = \begin{bmatrix} v_1 \\ v_2 \\ \vdots \\ v_r \end{bmatrix} = (v_i) \in \mathbb{R} \quad \Rightarrow \quad S.V = \begin{bmatrix} s_{11}v_1 + s_{12}v_2 + \cdots + s_{1r}v_r \\ s_{21}v_1 + s_{22}v_2 + \cdots + s_{2r}v_r \\ \vdots \\ s_{m1}v_1 + s_{m2}v_2 + \cdots + s_{mr}v_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

steady-state solution space



Optimisation Scheme (FBA)

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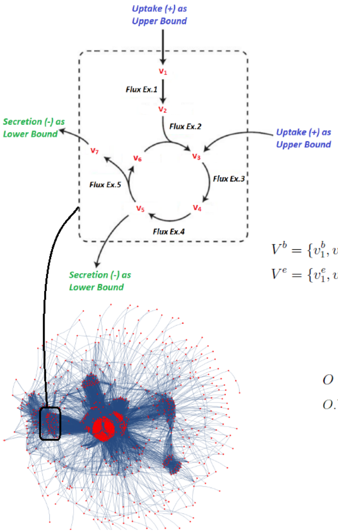
steady-state solution space

$$V^b = \{v_1^b, v_2^b, \ldots, v_x^b\} = (-a \leq v_i^b \leq a) \in V$$
$$V^e = \{v_1^e, v_2^e, \ldots, v_y^e\} = (0 \leq v_i^e \leq 0) \in V \quad \Rightarrow \quad S.V = \begin{bmatrix} s_{11}v_1 + s_{12}v_2 + \cdots + s_{1r}v_r \\ s_{21}v_1 + s_{22}v_2 + \cdots + s_{2r}v_r \\ \vdots \\ s_{m1}v_1 + s_{m2}v_2 + \cdots + s_{mr}v_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

resource utilisation



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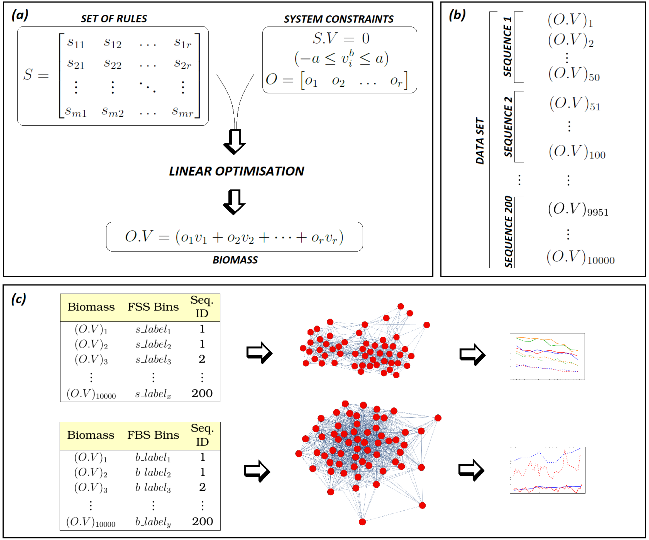
$$\Rightarrow \quad S.V = \begin{bmatrix} s_{11}v_1 + s_{12}v_2 + \cdots + s_{1r}v_r \\ s_{21}v_1 + s_{22}v_2 + \cdots + s_{2r}v_r \\ \vdots \\ s_{m1}v_1 + s_{m2}v_2 + \cdots + s_{mr}v_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

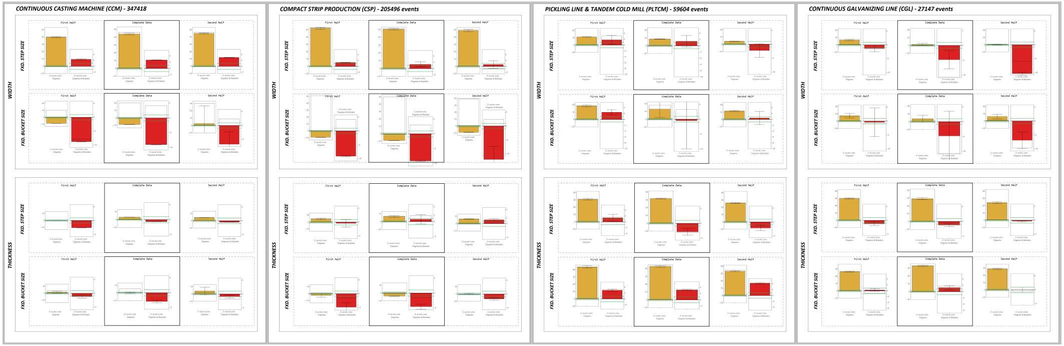
resource utilisation

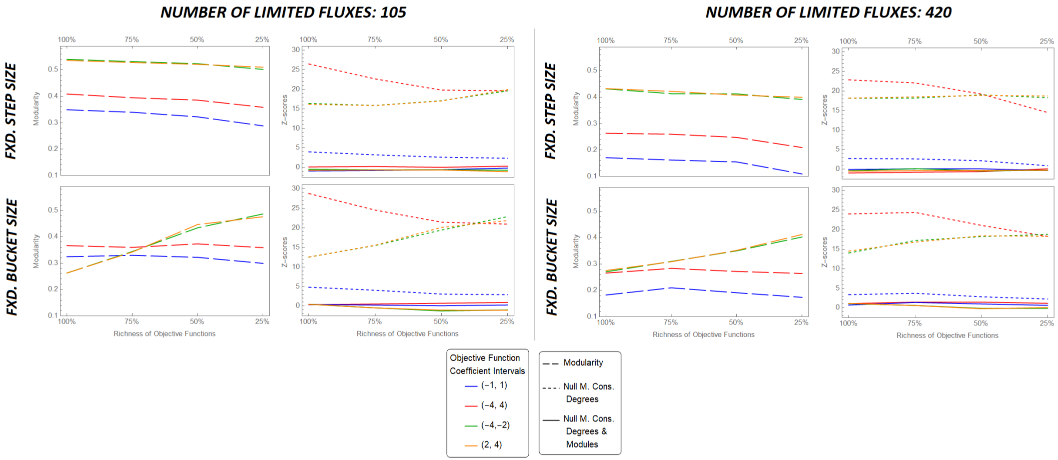
$$O = \begin{bmatrix} o_1 & o_2 & \ldots & o_r \end{bmatrix} = (o_i) \in \mathbb{R}$$
$$O.V = (o_1v_1 + o_2v_2 + \cdots + o_rv_r)$$
$$(O.V)_1$$
$$(O.V)_2$$
$$\vdots$$

$$\Rightarrow \quad S.V = \begin{bmatrix} s_{11}v_1 + s_{12}v_2 + \cdots + s_{1r}v_r \\ s_{21}v_1 + s_{22}v_2 + \cdots + s_{2r}v_r \\ \vdots \\ s_{m1}v_1 + s_{m2}v_2 + \cdots + s_{mr}v_r \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 0 \end{bmatrix}$$

product portfolio diversification


(a)
SET OF RULES
$S = \begin{bmatrix} s_{11} & s_{12} & \dots & s_{1r} \\ s_{21} & s_{22} & \dots & s_{2r} \\ \vdots & \vdots & \ddots & \vdots \\ s_{m1} & s_{m2} & \dots & s_{mr} \end{bmatrix}$
SYSTEM CONSTRAINTS
$S.V = 0$
$(-a \leq v_i^b \leq a)$
$O = [o_1 \quad o_2 \quad \dots \quad o_r]$
LINEAR OPTIMISATION
$O.V = (o_1 v_1 + o_2 v_2 + \dots + o_r v_r)$
BIOMASS
(b)
DATA SET
SEQUENCE 1
$(O.V)_1$
$(O.V)_2$
$(O.V)_{50}$
SEQUENCE 2
$(O.V)_{51}$
$(O.V)_{100}$
SEQUENCE 200
$(O.V)_{9951}$
$(O.V)_{10000}$
(c)
Biomass | FSS Bins | Seq. ID
$(O.V)_1$ | s_label_1 | 1
$(O.V)_2$ | s_label_2 | 1
$(O.V)_3$ | s_label_3 | 2
$(O.V)_{10000}$ | s_label_x | 200
Biomass | FBS Bins | Seq. ID
$(O.V)_1$ | b_label_1 | 1
$(O.V)_2$ | b_label_2 | 1
$(O.V)_3$ | b_label_3 | 2
$(O.V)_{10000}$ | b_label_y | 200


CONTINUOUS CASTING MACHINE (CCM) - 347418
COMPACT STRIP PRODUCTION (CSP) - 205496 events
PICKLING LINE & TANDEM COLD MILL (PLTCM) - 59604 events
CONTINUOUS GALVANIZING LINE (CGL) - 27147 events
WIDTH
THICKNESS
FXD. STEP SIZE
FXD. BUCKET SIZE
First Half
Complete Data
Second Half


NUMBER OF LIMITED FLUXES: 105
NUMBER OF LIMITED FLUXES: 420
FXD. STEP SIZE
FXD. BUCKET SIZE
Modularity
Z-scores
Richness of Objective Functions
100%
75%
50%
25%
Objective Function Coefficient Intervals
(−1, 1)
(−4, 4)
(−4,−2)
(2, 4)
Modularity
Null M. Cons. Degrees
Null M. Cons. Degrees & Modules

- We linked these two data processing schemes: Fixed Step Sized binning and Fixed Bucket Sized binning, to different constraint categories and obtained different results in the steel production events analysis.
- With Flux Balance Analysis, we constrained the system at different levels and allowed for fluctuations in the input and controlled the products via objective functions.
- Further perturbation experiments can be performed with a randomly structured graph (set of production rules) instead of a ready model (as we used the homo sapiens metabolic model).
- The main challenge would be to construct arbitrary networks within the Operations Research framework. Therefore, different categories of constraints such as technical constraints, logistic constraints, physical and chemical constraints, economical constraints, and performance-indicator based constraints need to be quantified carefully in this framework.

Thank you for your attention.