Real-time prediction of employee workload in digital railway control rooms

Léon Sobrie[*], Marijn Verschelde[^] & Bart Roets[*§]*

[*]Ghent University, [^]IÉSEG School of Management, [§]Infrabel

Outline

1. Setting the stage
2. Research on workload
3. Implementation
4. Lessons learned
5. Future implications

1.Setting the stage

The current context

Current trends

- Increasing heterogeneity, complexity and interconnectedness of many business processes (Vasconcelos & Ramirez, 2011)
- Digitization of business processes (Davenport & Ronanki, 2018)
- The adoption of machine/deep learning in industry is still in its infancy (Kraus et al., 2020)

→ A need for data-driven decision support for management

Initiative

- European Commission: Industry 5.0

The control room

Control rooms

- The nerve center for real-time monitoring and intervention
- Manage and coordinate many environments: rail and air traffic, nuclear power plants, chemical production sites, ambulance, etc.

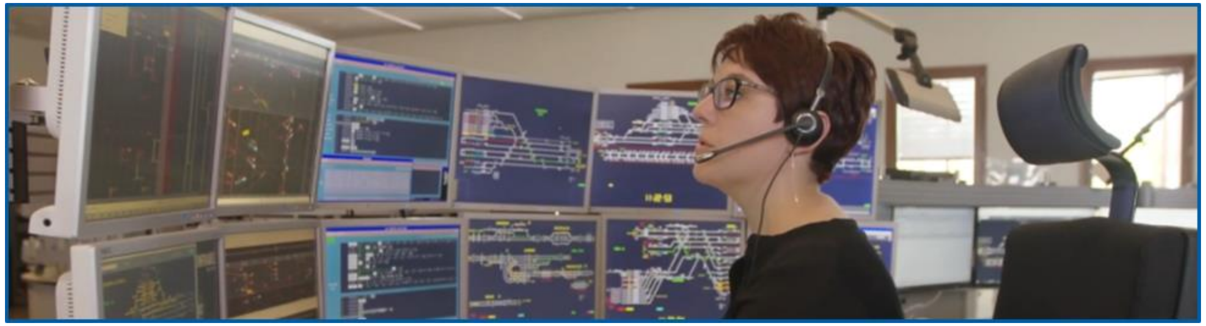
Characteristics

1. Real-time decision making
2. Highly variable workload
3. Safety-critical environment

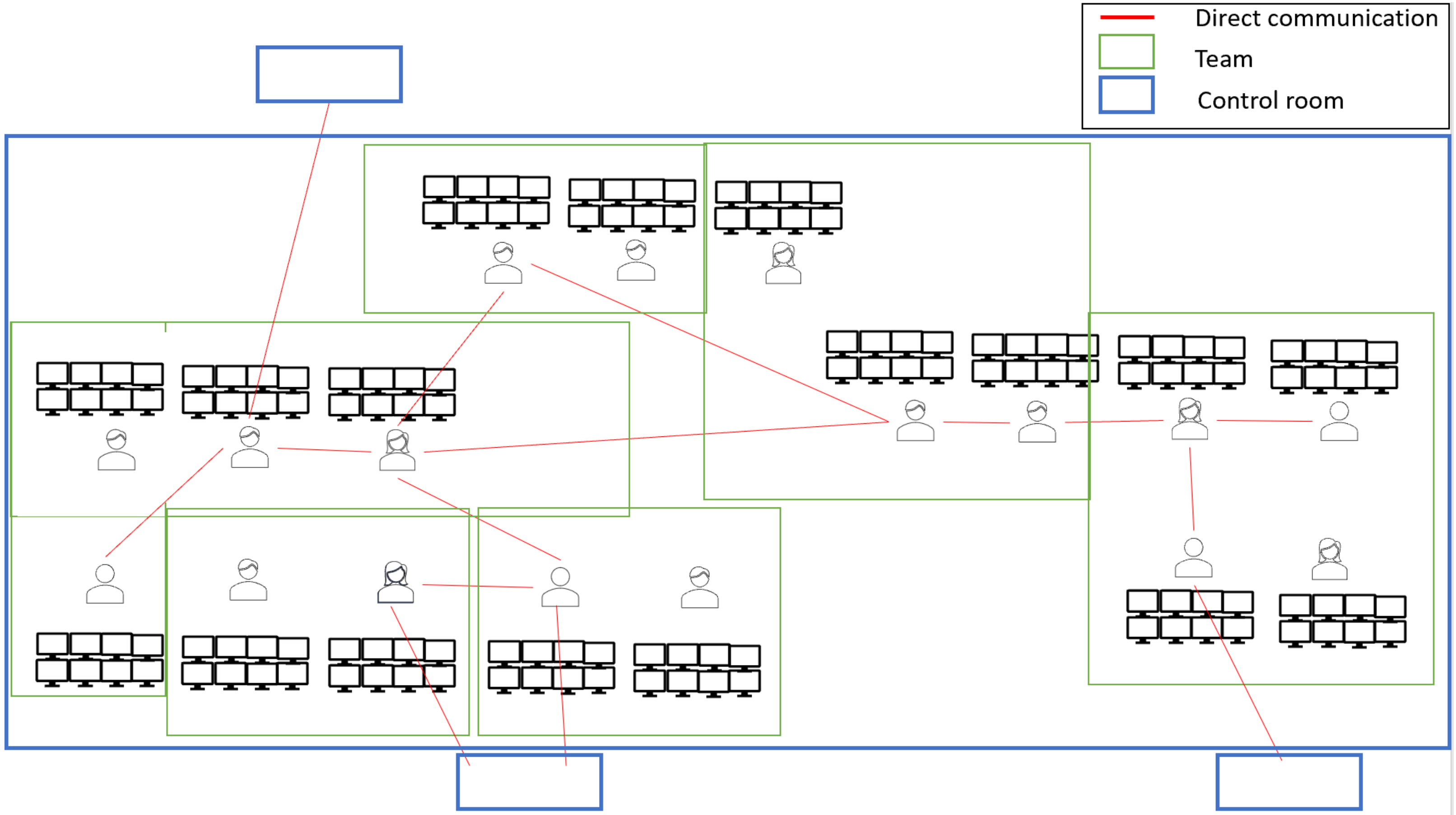
The control room

All Belgian railway traffic is managed in real-time by the control rooms of Infrabel

- Dense railway network
- Huge amount of events
  - Trains passing signals (50 million/year)
  - All actions taken by operators in control rooms (150 million/year)



Control room dynamics

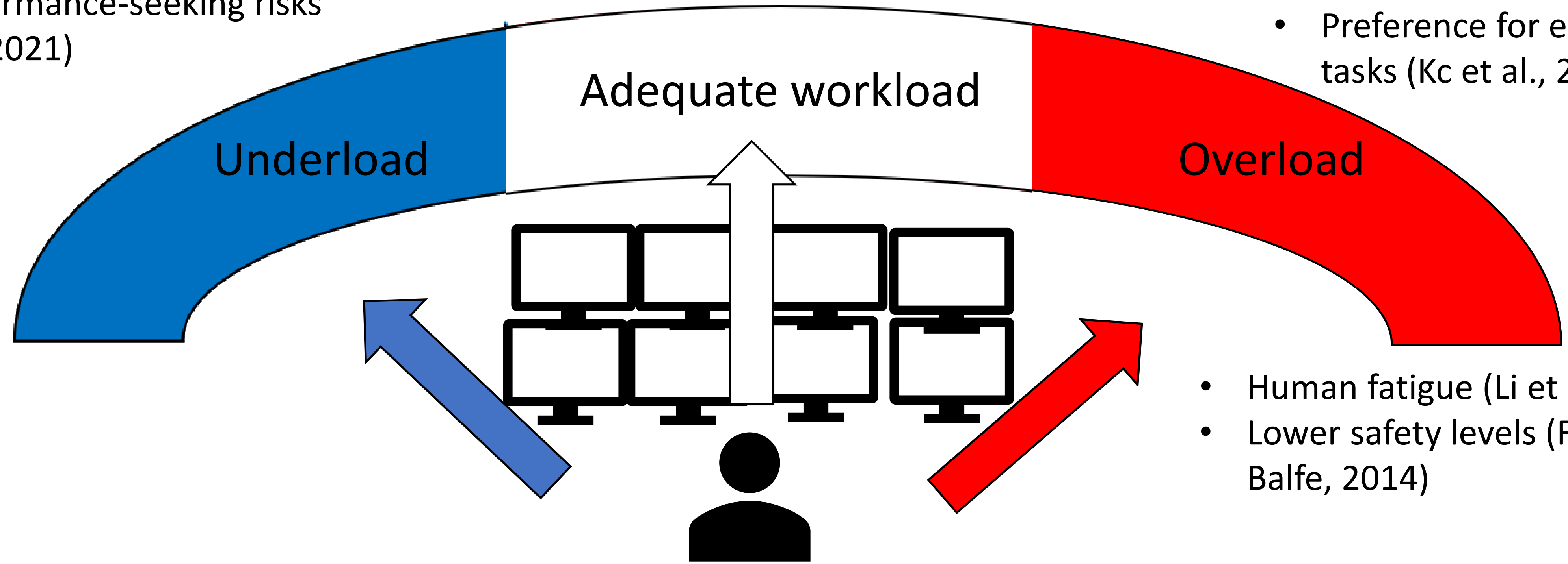


2. Control room operator workload

The importance of workload

- Lack of attention (Young, 2021)
- Extra performance-seeking risks (Xu et al., 2021)

- Lower well-being (Ilies et al., 2010)
- Preference for easier tasks (Kc et al., 2020)



- Human fatigue (Li et al., 2020)
- Lower safety levels (Fereira & Balfe, 2014)

The importance of balanced workload within and between operators (Inegbedion et al., 2020)

Contributions

1. Insights from a granular data structure containing all anonymized operator events
2. Empirical usefulness of the proposed model and insights into the importance of the different organizational & operational characteristics
3. Development of an application to provide decision-support for the control room manager

Input: operational and organizational characteristics

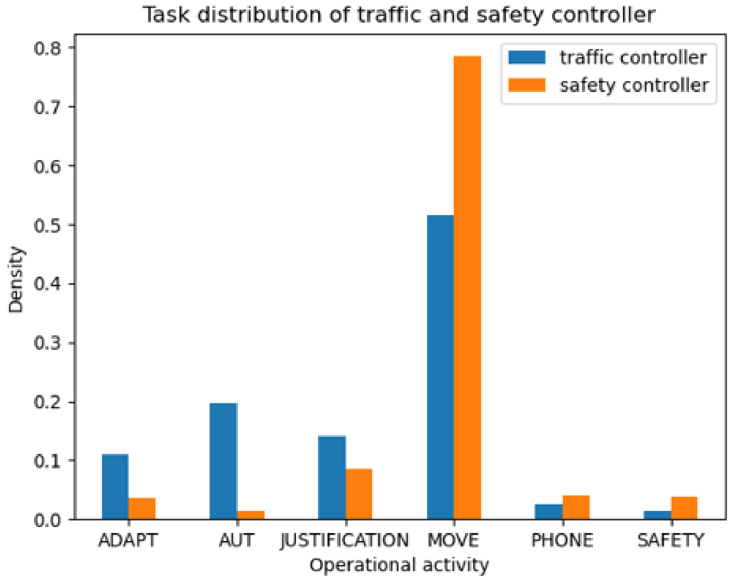
- Operational features
    - Experience
    - Railway operations
    - Time
    - Current workload

- Organizational features
    - Control room characteristics
    - Partner interactions

Output: Operational workload categories

- In line with the multi-attribute task battery for human operator workload (Comstock & Arnegard, 1992) = communication, resource management, automation, scheduling, monitoring and tracking

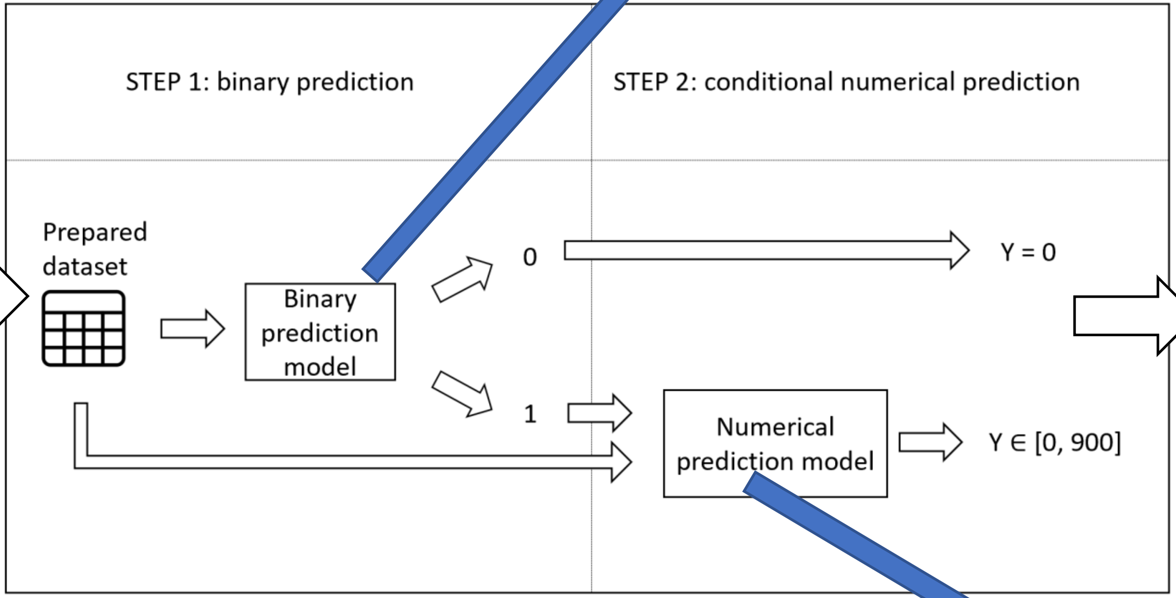
category	content
MOVE	proactively monitoring of railway traffic
ADAPT	changing tracks and station platforms
AUT	changing the automation
SAFETY	safety interventions
PHONE	phone calls between operator and driver
JUSTIF	justification of train delays

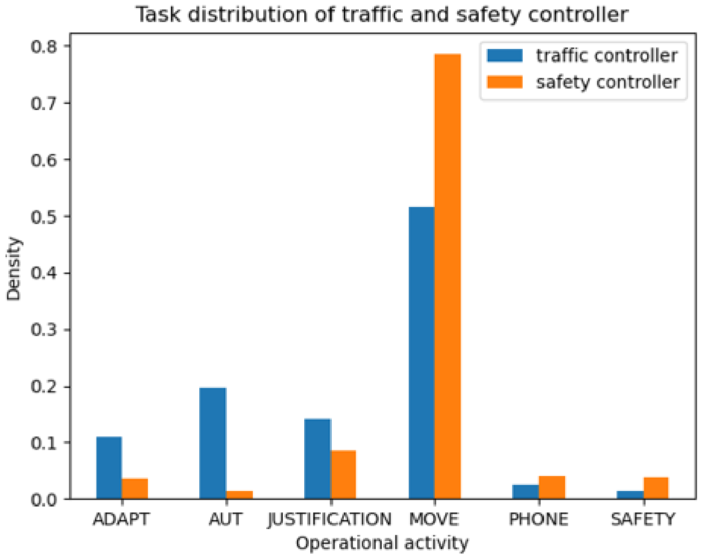


Model: linking characteristics with workload categories

Q1: To what extent can we predict whether the operator will have workload for a specific category?

Operational & organizational features

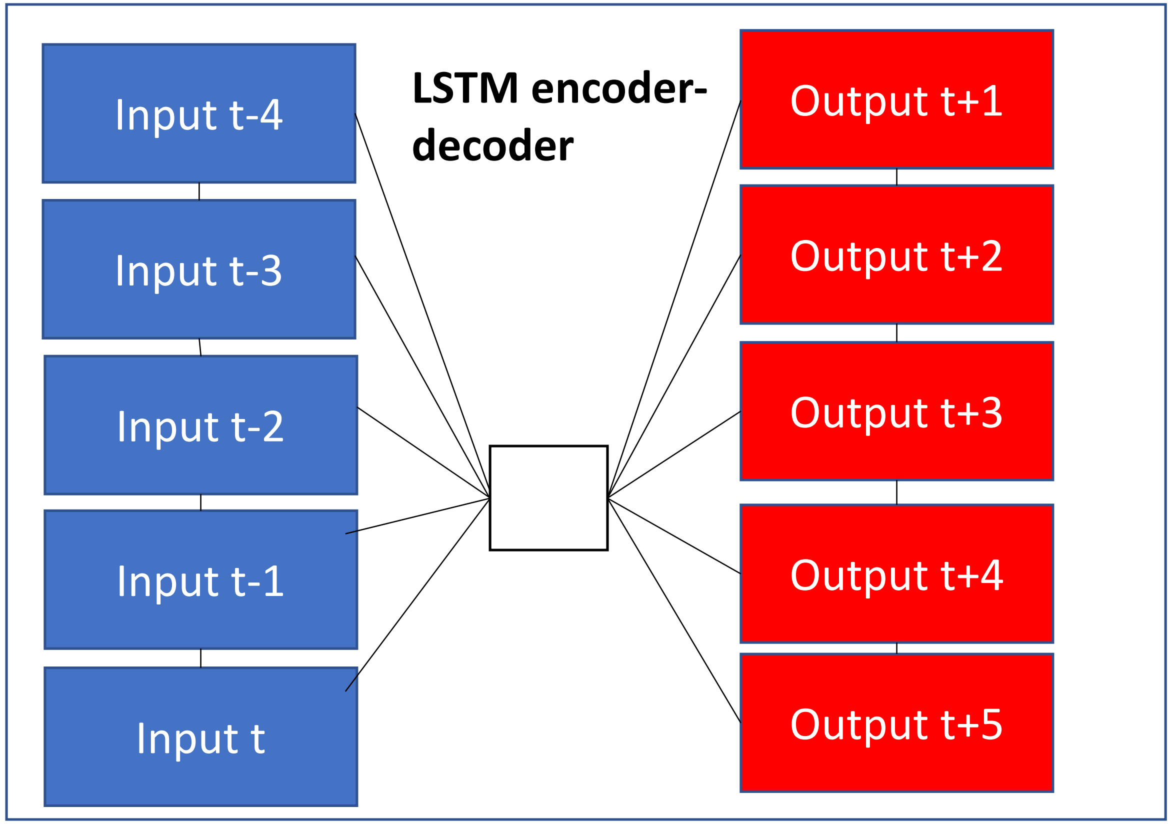




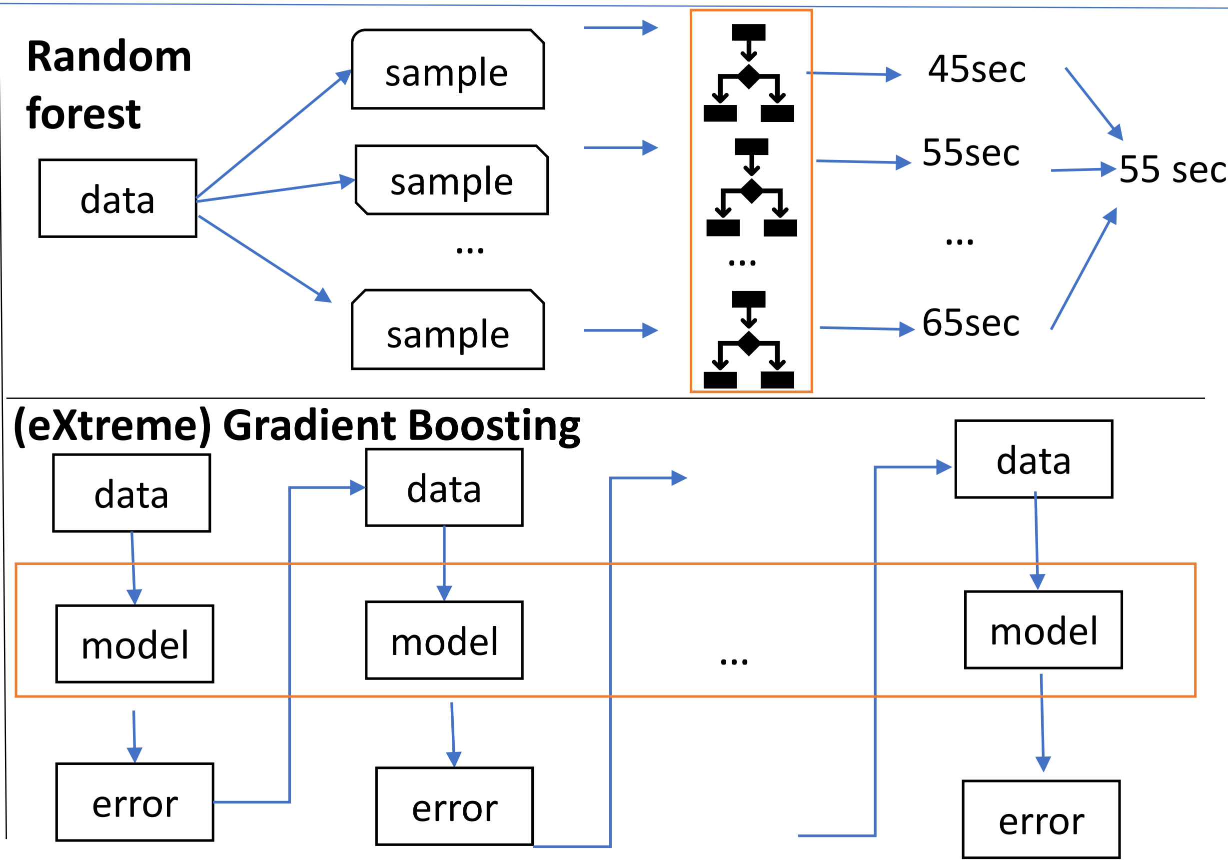
Q2: To what extent can we predict how much workload the operator will have for a specific category?

Model: linking characteristics with workload categories

Q1: To what extent can we predict whether the operator will have workload for a specific category?



Q2: To what extent can we predict how much workload the operator will have for a specific category?



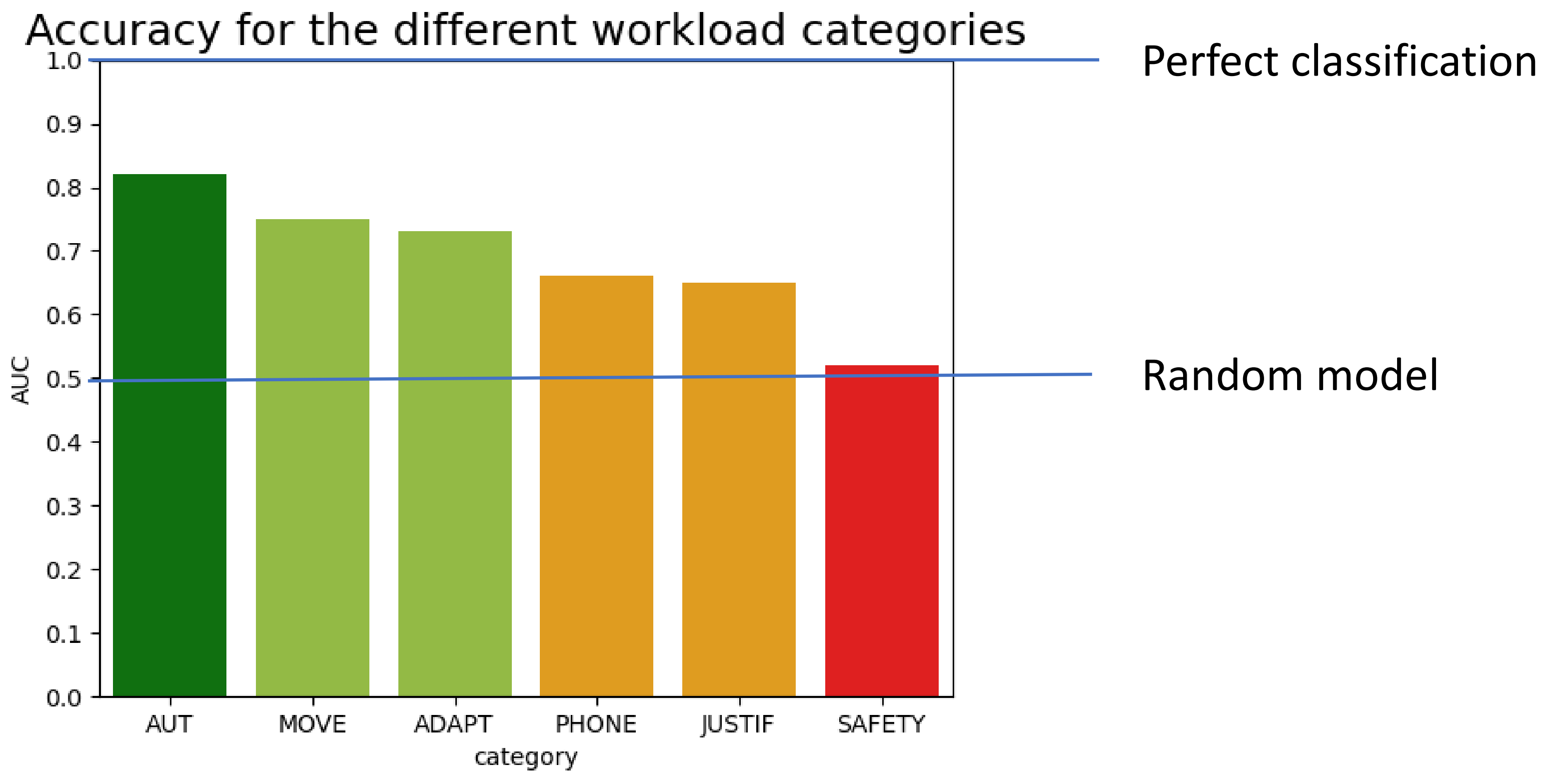
Managing model risk

- Different types of risk to be managed when modeling
  1. Data
  2. Specification
  3. Development
  4. Validation
  5. Operational
  6. Security
  7. Managerial

Source: ‘Managing model risk’ by Seppe Vanden Broucke & Bart Baesens

Results: classification ability

- Q1: To what extent can we predict whether the operator will have workload for a specific category in the next 15 minutes?



Results: error of prediction

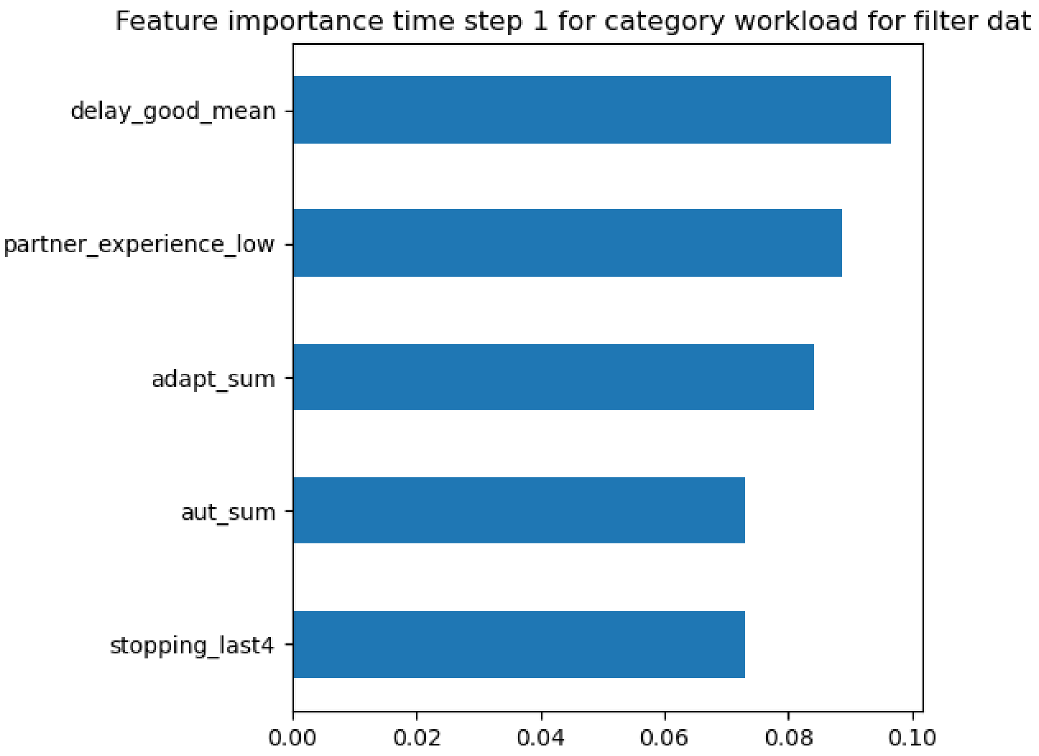
- Q2: To what extent can we predict how much workload the operator will have for a specific category in the next 15 minutes?

category	RF	XGB
MOVE	23s	22s
AUT	22s	20s
ADAPT	60s	54s
SAFETY	18s	18s
PHONE	70s	70s
JUSTIF	57s	57s

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(yi - \widehat{yi})^2}{N}}$$

Results: feature importance

Insights in the importance of features of random forest model



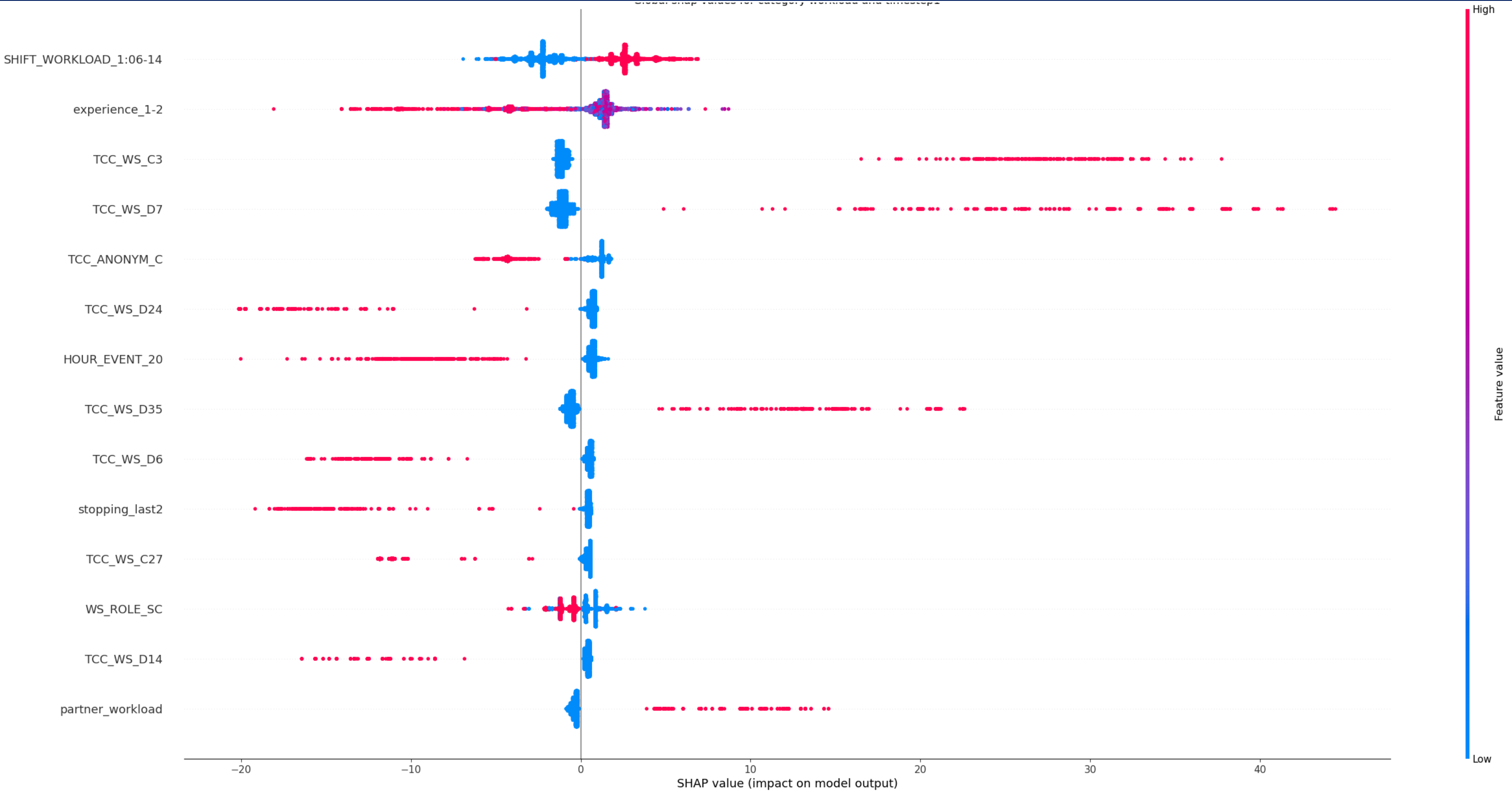
Delays

Partner interactions

Previous workload levels

End of shift

Results: SHAP values



Shift

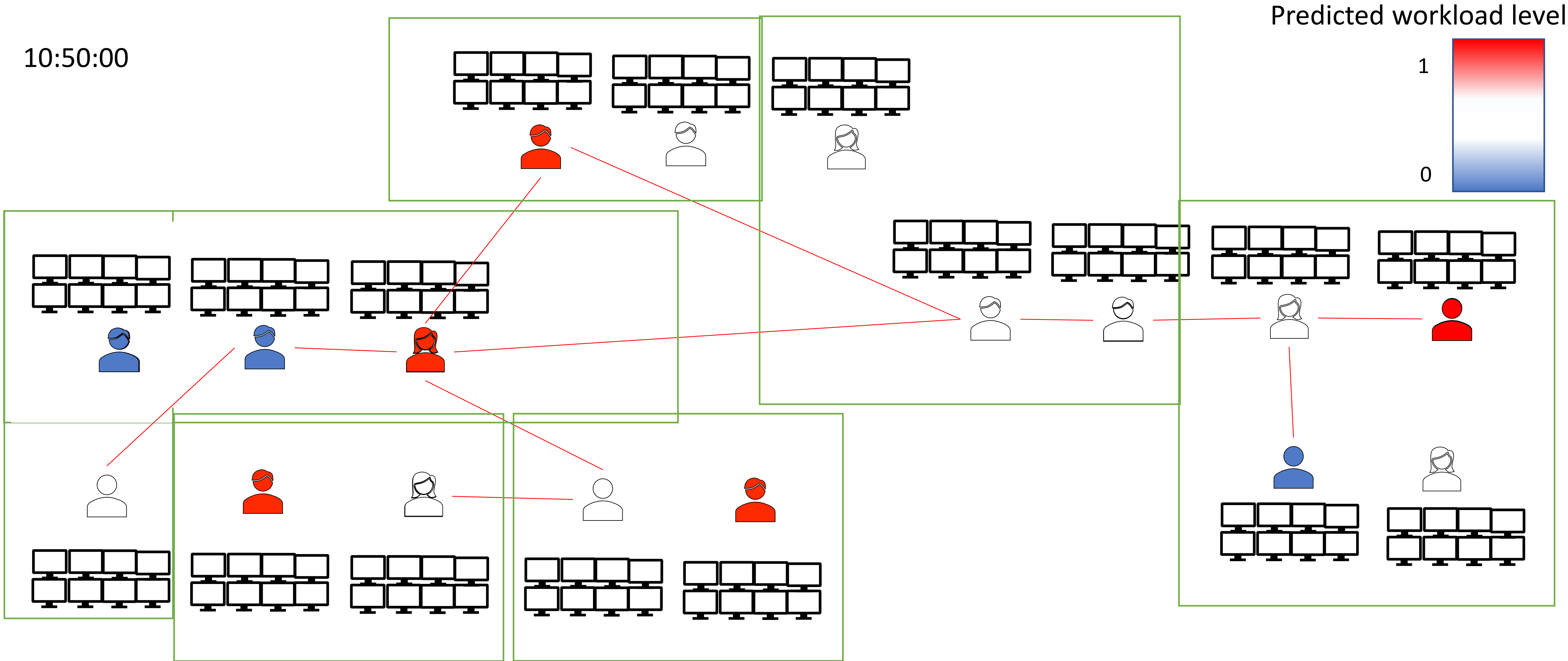
Specific workstations

Control room

Time of the day

Partner workload

Tool for management of workload



3. Implementation

Technology readiness level (TRL)

A compass for assessing how ready the technology is for the real-world (developed by NASA, originates from ’70s)

2 stage approach

→ using proofs of concepts

- Replay real-time simulation
  - Face validity
  - Flexibility

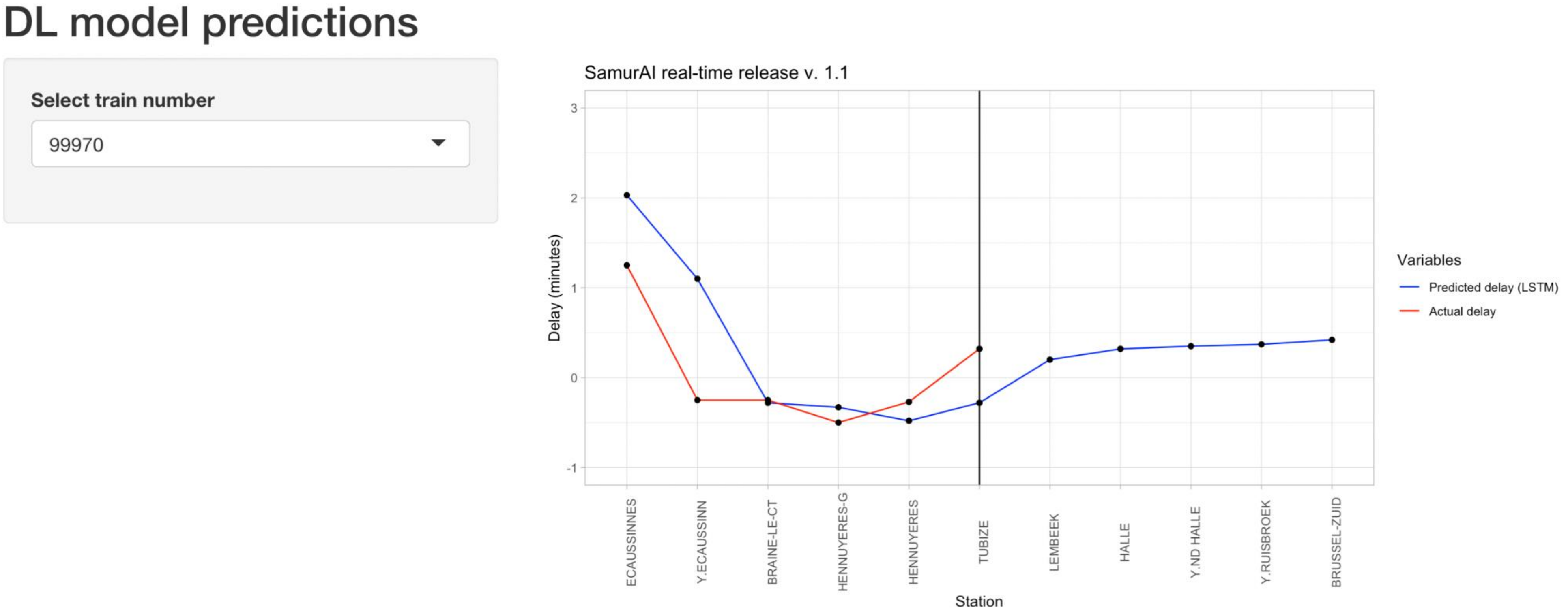
- Real-time implementation
  - R Shiny

TRL 9	System proven in operational environment
TRL 8	System complete & qualified
TRL 7	Integrated pilot system demonstrated
TRL 6	Prototype system verified
TRL 5	Laboratory testing of integrated system
TRL 4	Laboratory testing of prototype
TRL 3	Proof of concept established
TRL 2	Technology concept/ application formulated
TRL 1	Basic principles are observed

Implementation for management

Real-time implementation

Sobrie, Verschelde, Hennebel & Roets (2022) – Capturing complexity over space and time: An application to real-time delay prediction in railways



4. Lessons learned

Lessons learned

- There is untapped potential for machine learning in control rooms
  - Multidisciplinary approach required
  - Close collaboration between academia and practice
  - Learning iteratively: FAIL = first attempt in learning

- A roadmap towards implementation requires
  - Focus a practical issue
  - Construction of a real-time data flow
  - Model validation by operational testing

5. Future implications

Future research avenues

- Balancing the workload within and between operators
  - Research done in the BALANCE project of the On Track Lab
- Estimating the evolution of workload thresholds within a shift
  - Research done by the System Dynamics Lab of Virginia Tech
- More granular insights on the relationship between workload, delays, human errors and fatigue

Any questions?

Stay on track at https://ontracklab.com

Contact me at leon.sobrie@ugent.be

References

- Davenport, T. H., & Ronanki, R. (2018). Artificial intelligence for the real world. *Harvard business review*, *96*(1), 108-116.

- Ferreira, P. N., & Balfe, N. (2014, June). The contribution of automation to resilience in rail traffic control. In International Conference on Engineering Psychology and Cognitive Ergonomics (pp. 458-469). Springer, Cham.

- Ilies, R., Dimotakis, N., & De Pater, I. E. (2010). Psychological and physiological reactions to high workloads: implications for well-being. Personnel Psychology, 63(2), 407-436.

- Inegbedion, H., Inegbedion, E., Peter, A., & Harry, L. (2020). Perception of workload balance and employee job satisfaction in work organisations. Heliyon, 6(1), e03160.

- Kc, D. S., Staats, B. R., Kouchaki, M., & Gino, F. (2020). Task selection and workload: A focus on completing easy tasks hurts performance. Management Science, 66(10), 4397-4416

References

- Li, F., Chen, C. H., Zheng, P., Feng, S., Xu, G., & Khoo, L. P. (2020). An explorative context-aware machine learning approach to reducing human fatigue risk of traffic control operators. Safety science, 125, 104655.
- Kraus, M., Feuerriegel, S., & Oztekin, A. (2020). Deep learning in business analytics and operations research: Models, applications and managerial implications. *European Journal of Operational Research*, *281*(3), 628-641.
- Vasconcelos, F. C., & Ramirez, R. (2011). Complexity in business environments. *Journal of Business Research*, *64*(3), 236-241.
- Xu, Y., Tan, T. F., & Netessine, S. (2022). The impact of workload on operational risk: Evidence from a commercial bank. Management Science, 68(4), 2668-2693.
- Young, M. S. (2021, November). In Search of the Redline: Perspectives on Mental Workload and the ‘Underload Problem’. In International Symposium on Human Mental Workload: Models and Applications (pp. 3-10). Springer, Cham.