A CANON COMPANY

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Technische Universiteit **Eindhoven** University of Technology

How to Design the Paper Path of a Production Printer?

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Key Performance Indicators

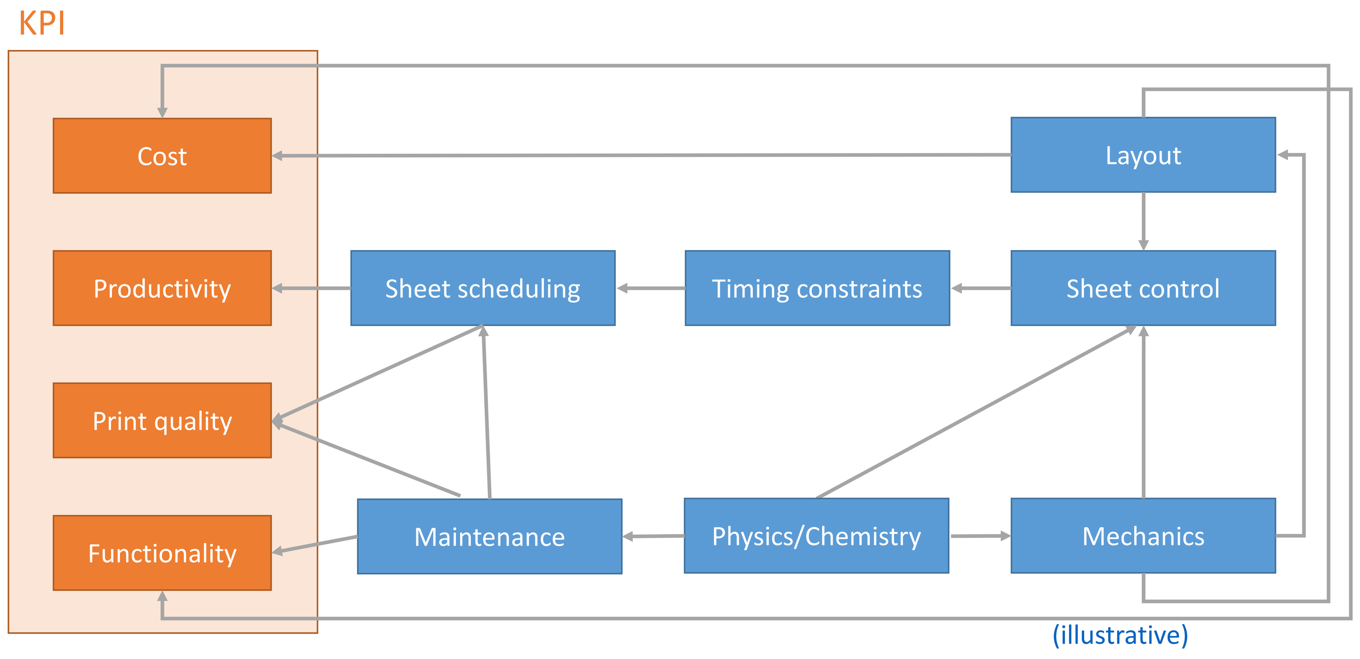

Figure 1. Paper path of a production printer

Designing and optimizing timing constraints

Sheet timing constraints

Simplex and duplex sheets flow from the Paper Input (PIM) to the Image Transfer Station (ITS) to the Finisher (FIN), in Figure 2.

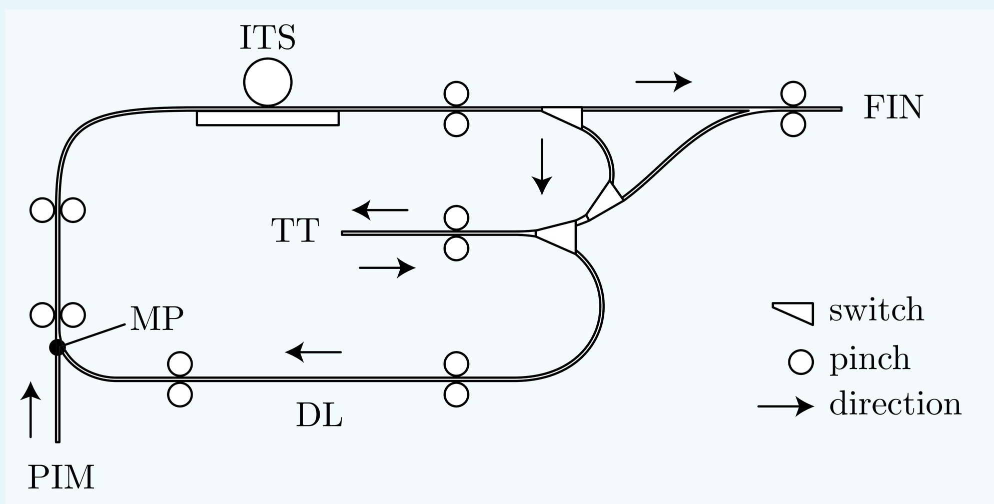

Figure 2. Schematic representation of a paper path (from [2])

Sheet timing constraints follow from many sources, for example:

- sheet position (piecewise second order polynomials, Figure 3)
- heating and cooling of printed sheets
- module reconfiguration times (e.g. ITS, PIM, FIN)

Sheet scheduling:

- determine sheet separation and buffer time
- avoid sheet collisions at the merge point (MP)
- allow enough time for reconfiguration of modules

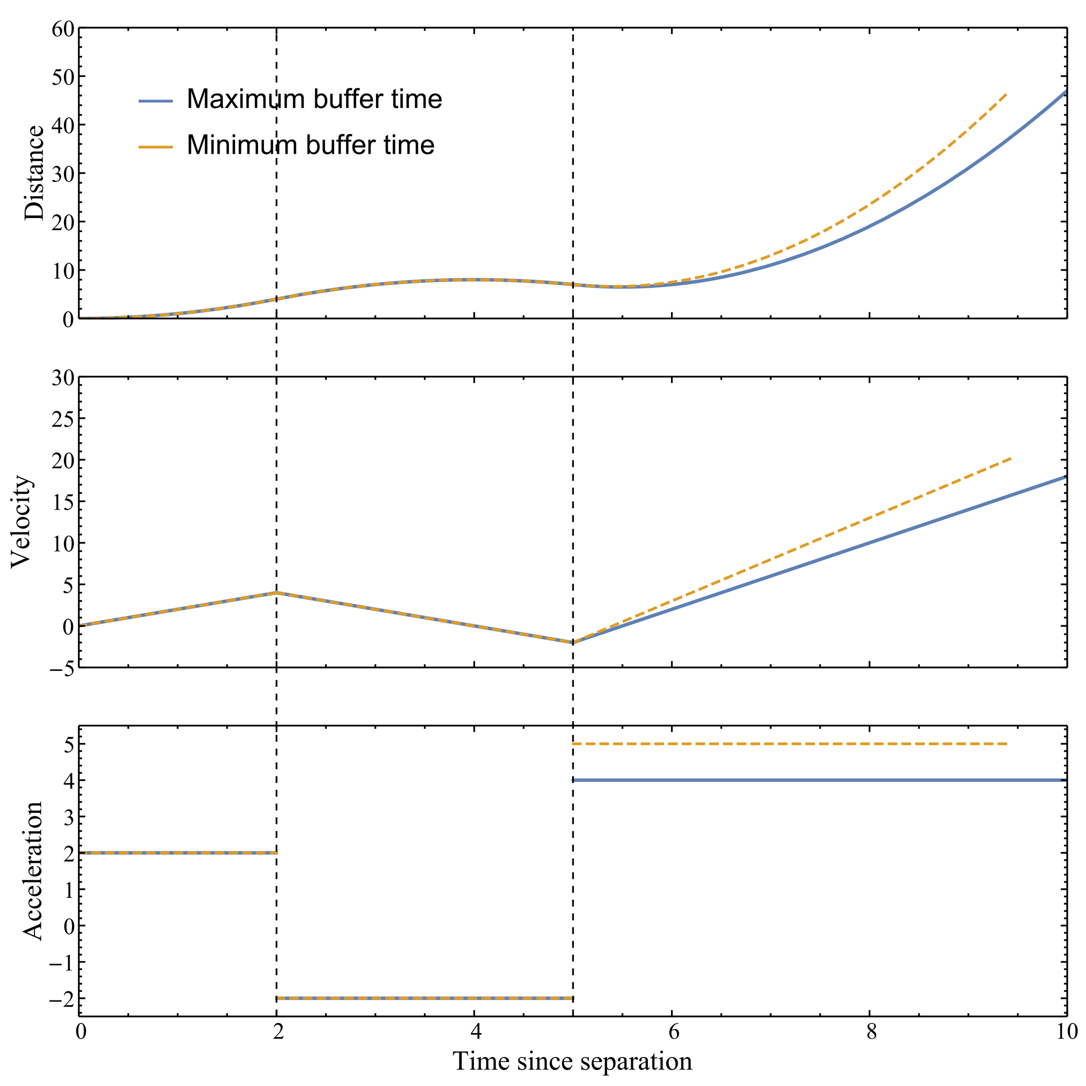

Figure 3. Example sheet position profile

Constraint domain model

Signal Temporal Logic (STL) [1] as semantic foundation

- sheet position profile interpreted as signals
- constraints are derived signals

Deflector switch requires at least T ms between first pass sheet A (pos_A at x) and second pass sheet B (pos_B at y):

$$\mathbf{G}(pos_A \leq x \Rightarrow (\mathbf{G}_{[0,T]}\ pos_B \leq y))$$

The resulting constraint signal is shown in Figure 4 (blue).

STL allows visualization and a quantative interpretation:

- minimum slack time negative; constraint violated
- minimum slack time positive; constraint conservatively met

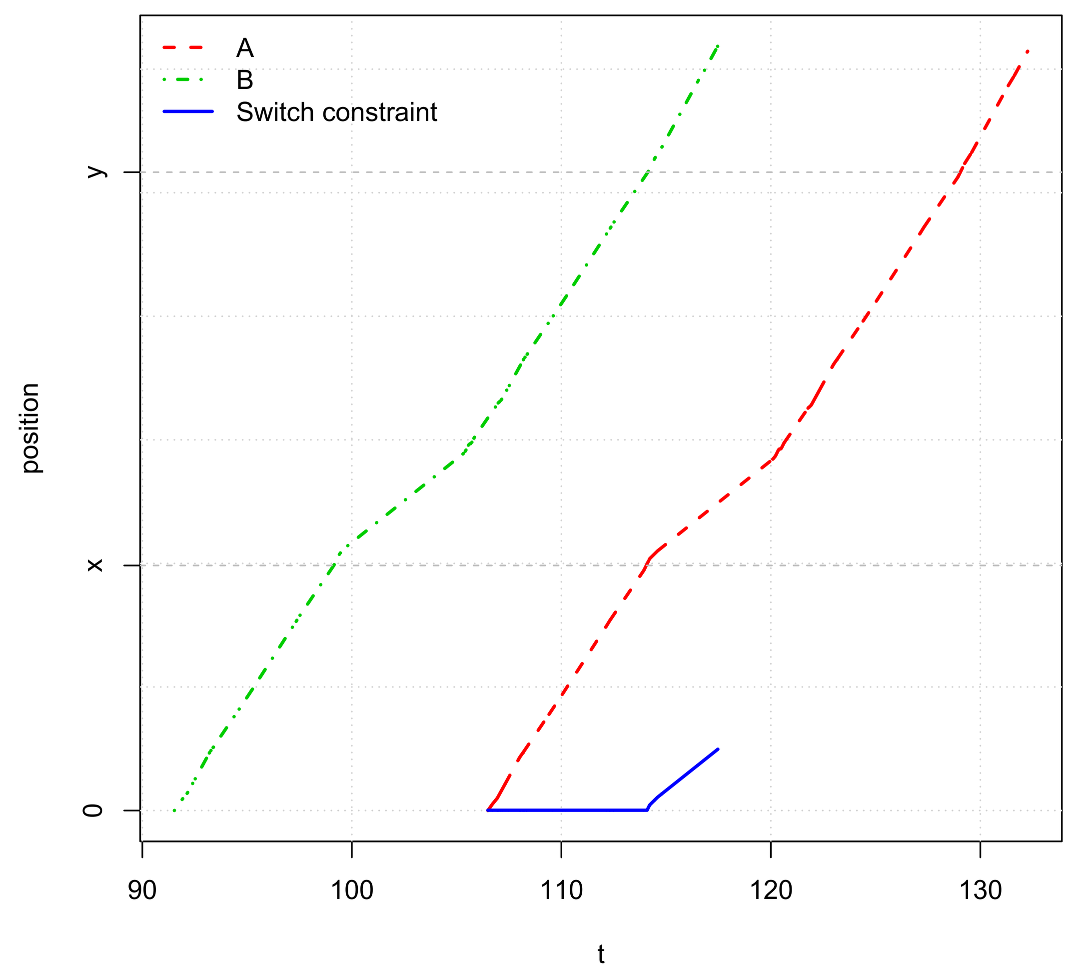

Figure 5. Example computation of a switch constraint using STL

Constraint-based scheduling

- capture scheduling requirements as a 2-reentrant flowshop
- constraint graph models events and timing constraints [3]
- freedom in sequencing the ITS operations (row 2,3, cyan)
- optimize performance, respecting constraints
- i.e. minimize critical path in the graph [3], [4]

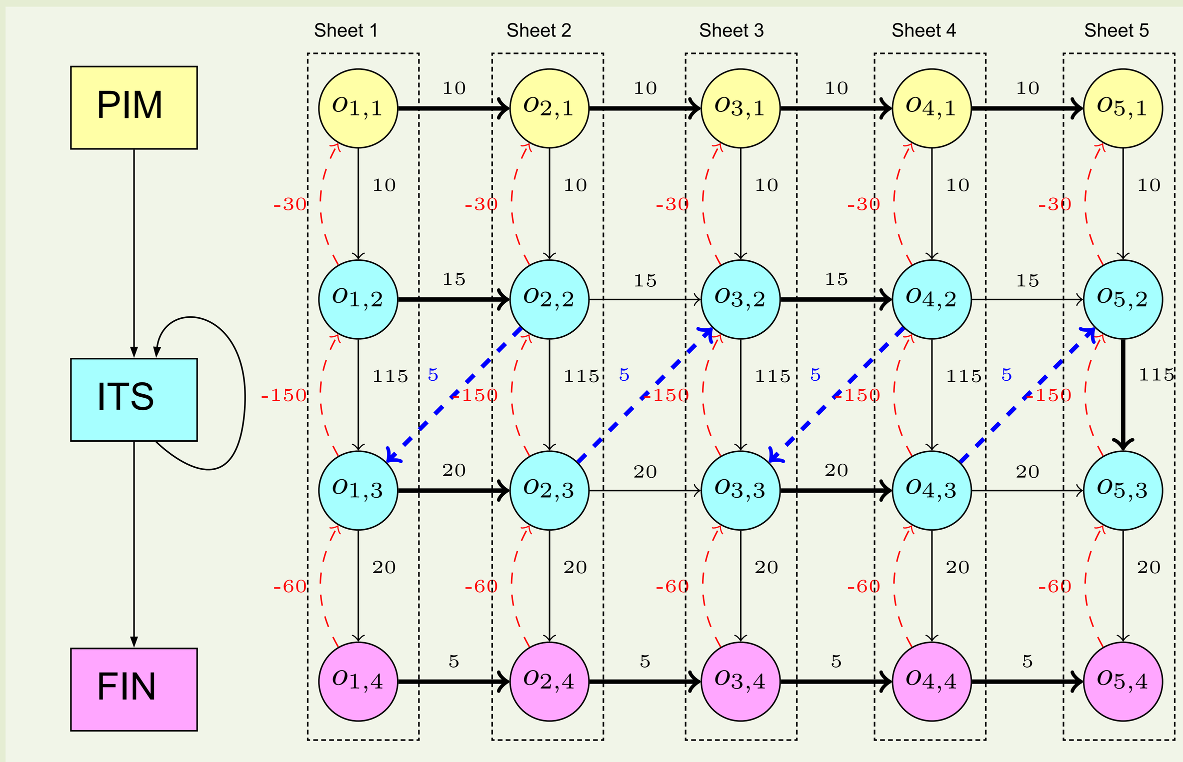

Figure 4. Constraint graph for five duplex sheets (from [3])

Parametric critical path analysis

Questions:

- how to improve the productivity of this print job?
- which constraints are most limiting?

Answers:

- parametric critical path analysis on the constraint graph
- simultaneous changing all instances of the same constraint
- identify performance expressions
- quantify the effect of changing parameters

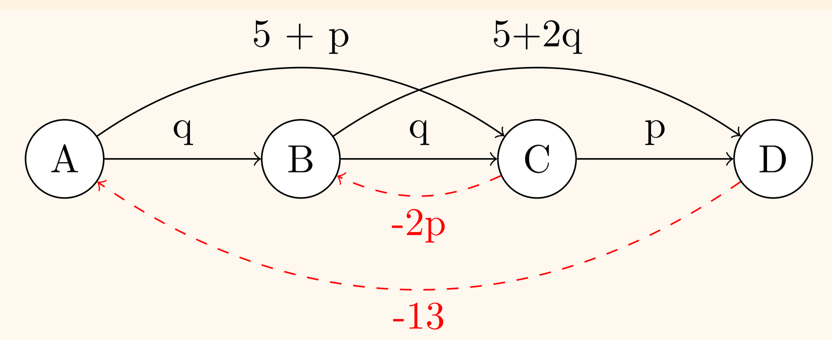

Figure 6. A graph representing events (A,B,C,D) and parameterized timing constraints between events

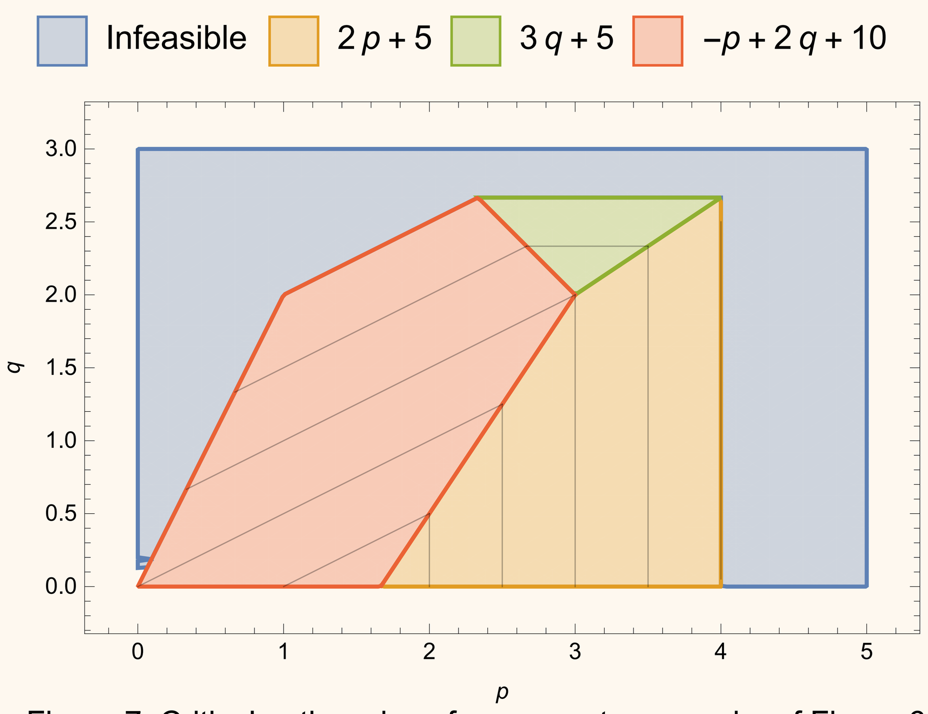

Figure 7. Critical path regions for parameters p and q of Figure 6.

References

[1] O. Maler and D. Nickovic, “Monitoring temporal properties of continuous signals,” in *Formal Techniques, Modelling and Analysis of Timed and Fault-Tolerant Systems.* 2004.

[2] L. Swartjes, et. al., “Simultaneous analysis and design based optimization for paper path and timing design of a high-volume printer,” *Mechatronics*, vol. 41, 2017.

[3] U. Waqas, et. al., “A re-entrant flowshop heuristic for online scheduling of the paper path in a large scale printer,” in DATE 2015.

[4] J.H.H. van Pinxten, et. al. *Online Schedulig of 2-Re-entrant Flexible Manufacturing Systems.* In CODES-ISSS, ESWEEK 2017

Outlook

Modelling

- define oncepts for the constraint domain model
- represent state-based constraints in the constraint graph

Design

- modularity and modular analysis

Verification

- intepretation of generic STL techniques and results.
- soundness and completeness

Synthesis

- automatic sheet timing synthesis from domain model