Prescriptive System for Reconfigurable Manufacturing Systems considering Variable Demand and Production Rates

CATARINA BALTAZAR (up201406435@fe.up.pt)

JOÃO REIS (jpcreis@fe.up.pt)

GIL GONÇALVES (gil@fe.up.pt)

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Context and Motivation

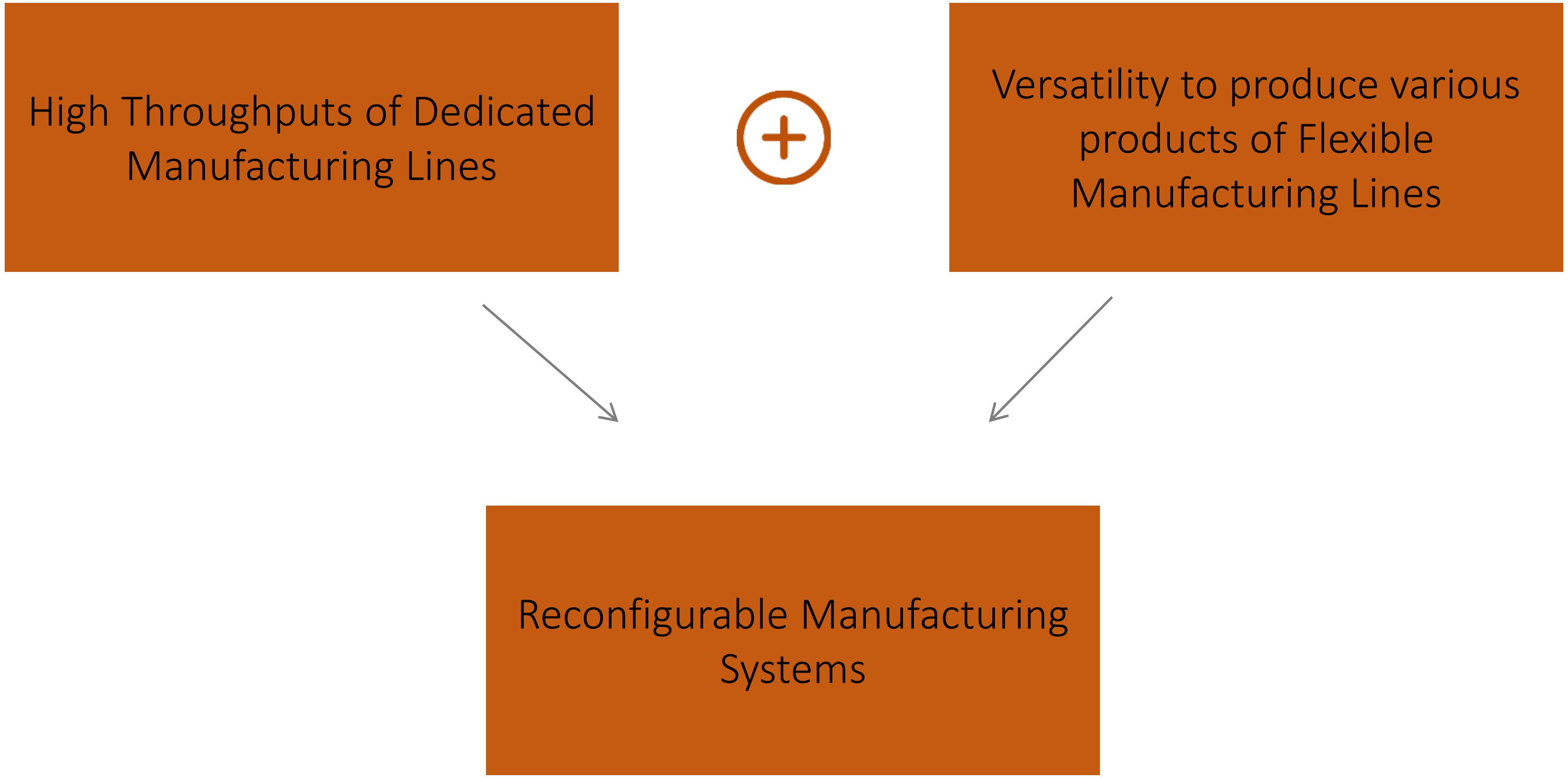
Challenges:

- Market Demand
- Market Competition
- Technological Revolution

Mass Production → Mass Customization

Context and Motivation

Why Reconfigurable Manufacturing Systems?



Context and Motivation

Prognostics and Health Management (PHM)

Diagnosis → **Prognosis** → **Decision-making**

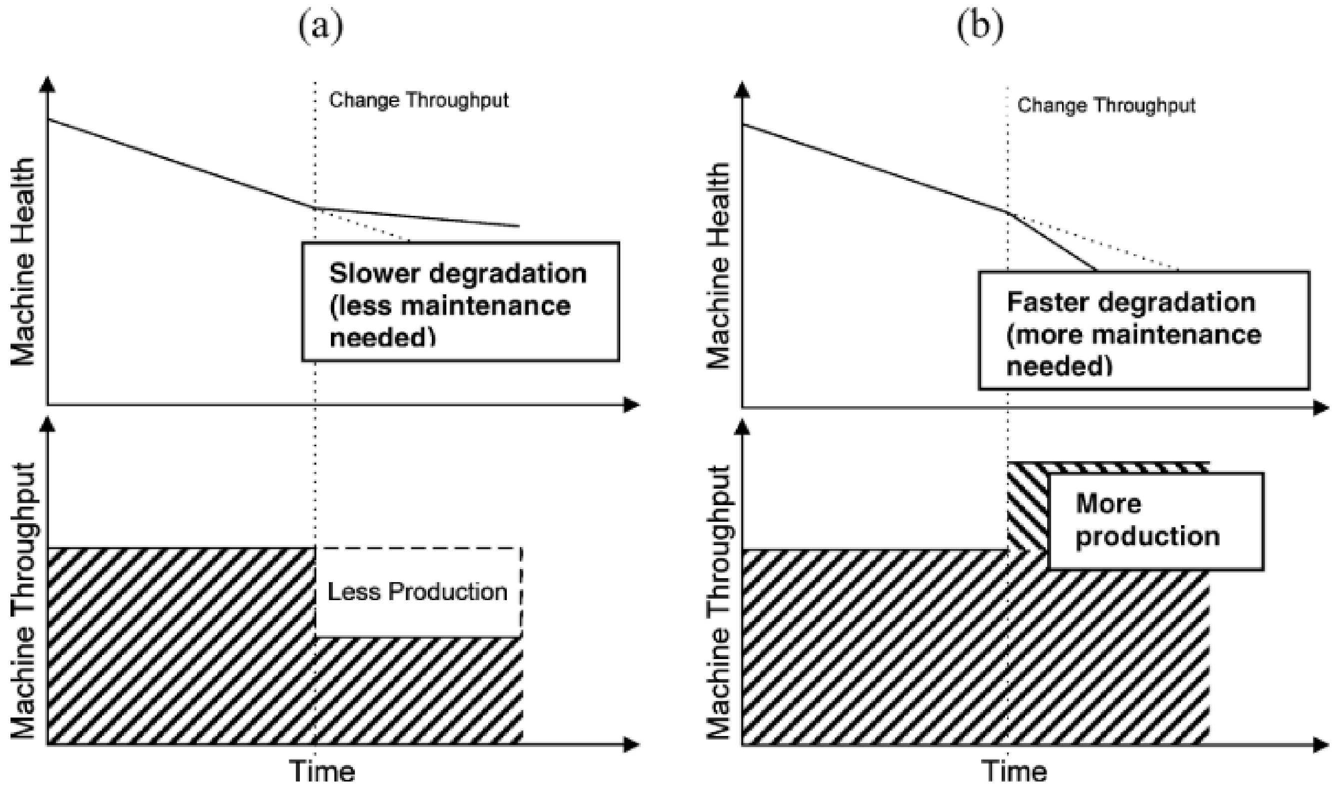
→ Improvements in reliability
→ Reduction of costs associated with maintenance costs

Goals

Development of a Prescriptive System that recommends a sequence of throughputs to be applied to determined machines taken into consideration:

→ Weekly Production Target
→ Degradation of equipment

In a **Reconfigurable Manufacturing System (RMS)** environment



Source: Z. Yang, D. Djurdjanovic, e J. Ni, «Maintenance scheduling for a manufacturing system of machines with adjustable throughput», *IIE Trans. (Institute Ind. Eng.*, vol. 39, n. 12, pp. 1111–1125, 2007.

Literature Review

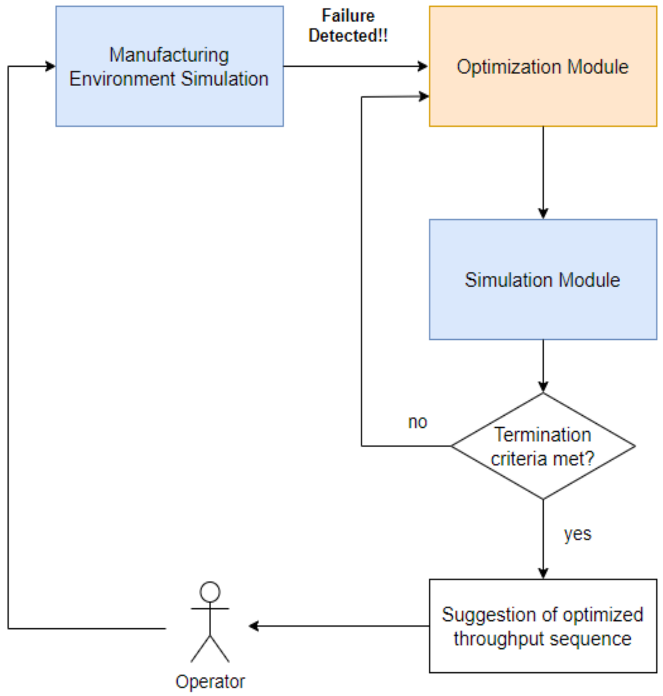
Prescriptive Systems can be understood as systems that recommend one or more courses of action.

→ Order Spare Parts
→ Scheduling
→ Life Cycle Optimization

Regarding implementation, **Evolutionary and Swarm Algorithms** are the most common ones.

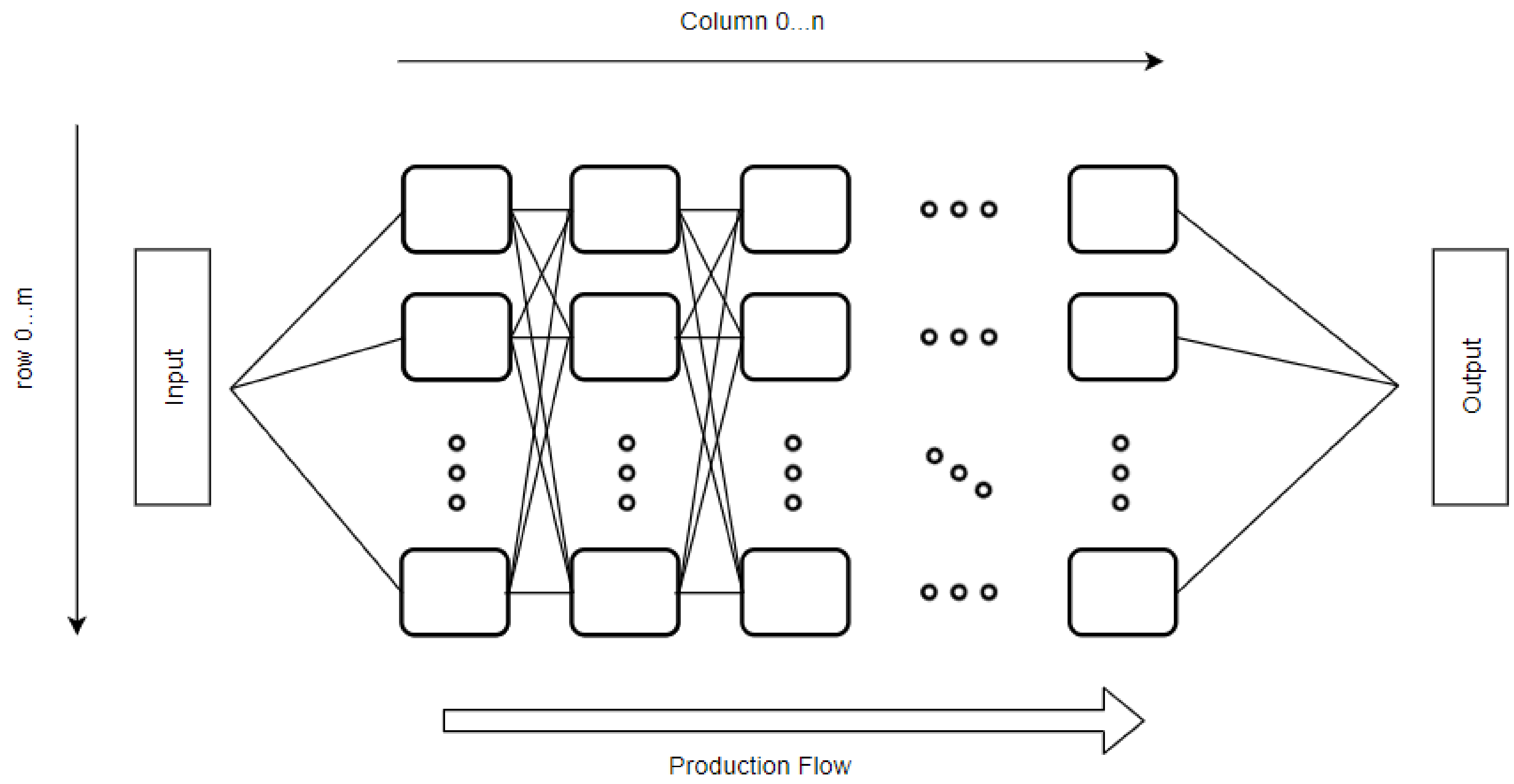
Implementation

Taking into consideration the main goal, the proposed Prescriptive System follows the general structure.



Implementation

- Simulation Module



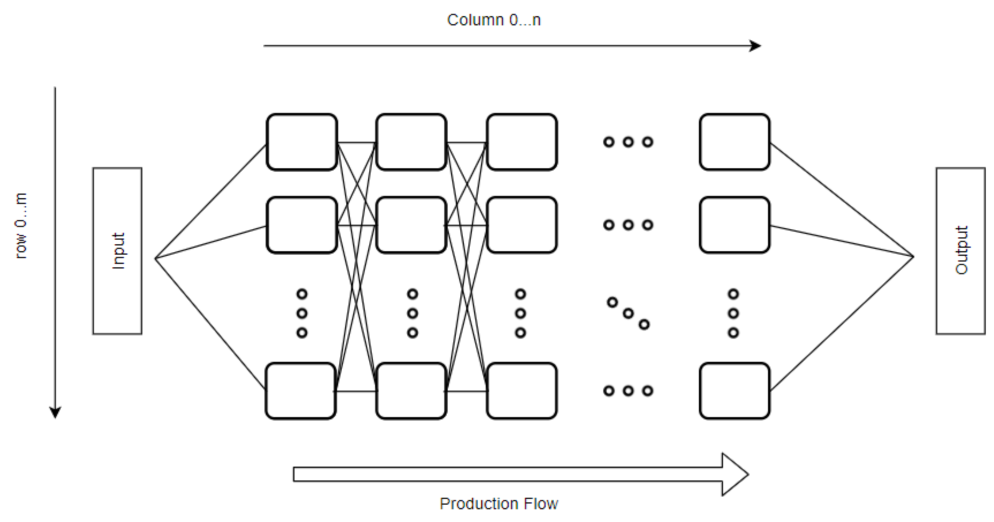
Implementation

- Simulation Module

Modeled based on Directed Acyclic Graphs

Advantages:

→ Quick and easy changes in layout
→ Flexibility
→ Readibility
→ Easy implementation



Implementation

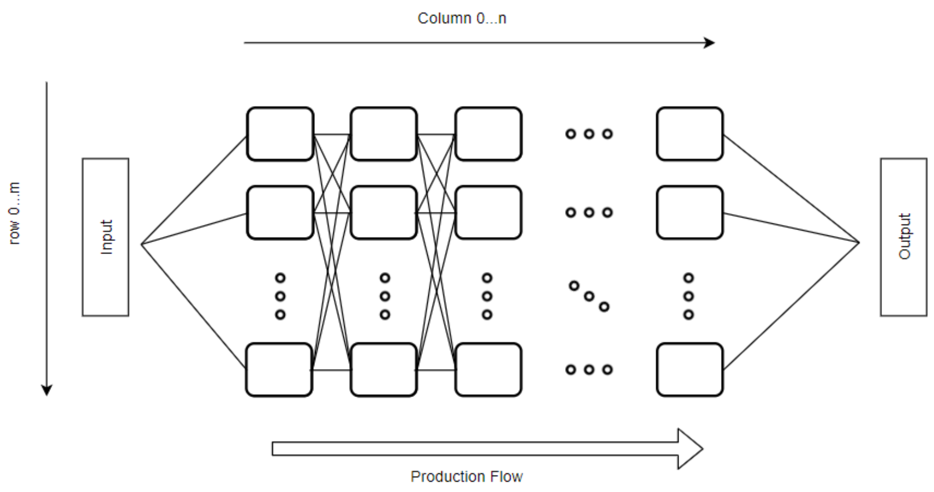
- Simulation Module

Node → Machine

Edge → Connections between machines

Each node is associated with an object of class Machine which saves several information regarding the equipment.

- → **Identifying Parameters**
  - → Age
  - → Machine ID
- → **Operation Parameters**
  - → Types of operations available
  - → Operation Mode
- → **Reliability-related Parameters**
  - → Mean Time To Repair (MTTR)
  - → Mean Time Between Failures (MTBF)



➡ This allows a high level of **parametrization** of the system

Implementation

- Simulation Module

✓ It is considered that probabilities of failure are known

✓ Failure detection is done based on time intervals

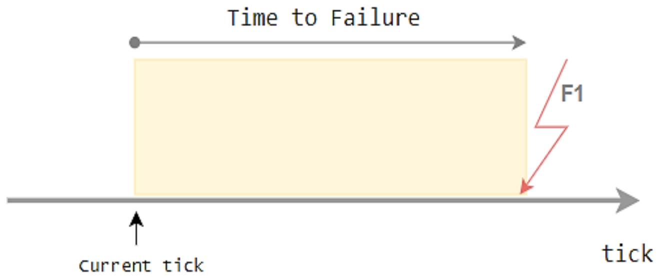
HOW?

The MTBF decreases each tick and once it falls below a certain threshold a failure is detected

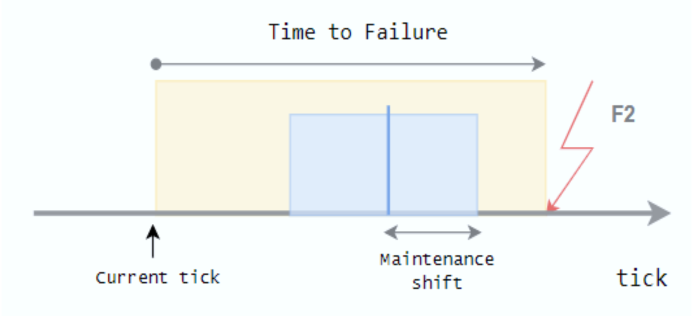
Implementation

- Simulation Module

The simulation module also allows the integration of maintenance shifts and those will affect how the optimization module is triggered.



Pending failure that will translate into an **Emergency Maintenance**



Pending failure that will translate into a **scheduling** of a Maintenance action

Implementation

- Optimization Module

The optimization module is key to the development of this Prescriptive System as it is responsible for the compensation in production losses due to machines’ downtime.

Genetic Algorithms

- Initial Population
- Fitness Function
- Selection
- Crossover
- Mutation

Implementation

- Optimization Module

Each gene of the chromosome represents the throughput of machine *i* at day *j*.

$T_{1,1}$	$T_{1,2}$	…	$T_{1,j}$	$T_{2,1}$	…	$T_{2,j}$	…	$T_{i,j}$

Depending on the days since the trigger of optimization module until the end of the week, and the number of machines, the size of the chromosome varies and is equal to *i x j*

Implementation

- Optimization Module

$$F = \min\left[K_p(W-P)^2 + K_{sm}\sum_{i}^{N} F_{sm_i} + K_{em}\sum_{i}^{N} F_{em_i} + K_{nw}\sum_{i}^{N} F_{nw_i} + K_{ch}\sum_{i}^{N} C_{ch_i} + K_{sd}\sum_{i}^{N} S_i\right]$$

W – target

P – pieces produced

F_{sm} – number of scheduled maintenances

F_{em} – number of emergency maintenances

F_{nw} – number of new maintenances in the following week

C_{ch} – number of changes in throughput different from baseline

S – Standard Deviation of throughputs of the week per machine

$K_p = 10$

$K_{sm} = 900$

$K_{em} = 1000$

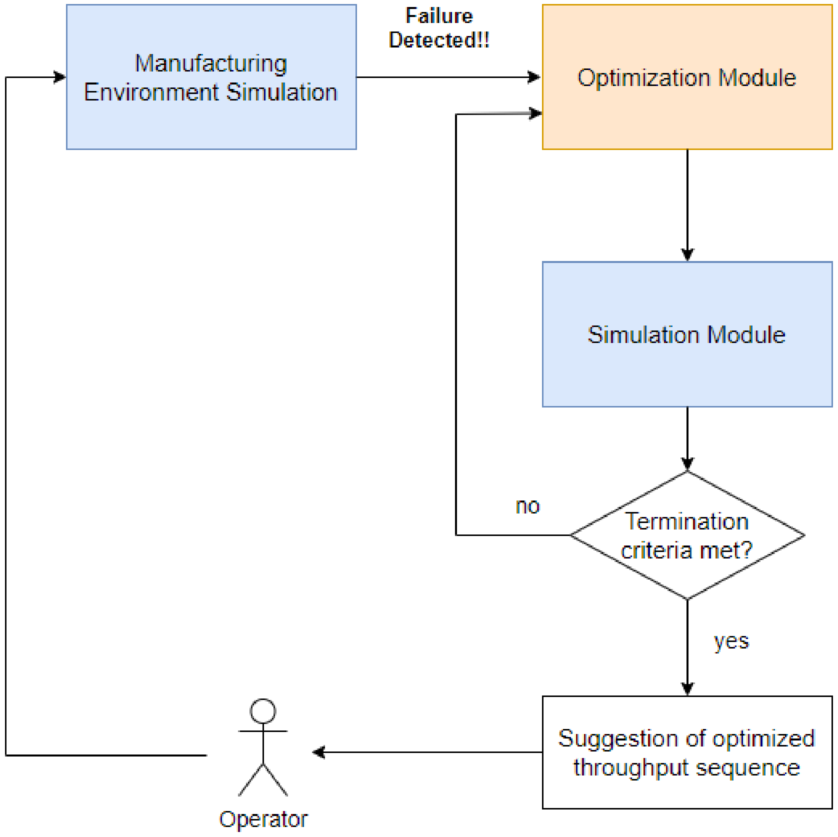
$K_{nw} = 300$

$K_{ch} = 300$

$K_{sd} = 400$

Based on sensitivity analysis

Implementation



System Validation

$$Differential\ (\%) = \left(\frac{pieces\_produced}{theoretical\ number\ of\ pieces} - 1\right) \times 100$$

$$Availabiliy_{system} = \frac{total\_operation\_time \times N - \sum_i^N downtime_i}{N(total\_simulation\_time\ - total\_shift\_time)}$$

Parametrization of GA:

→ Population Size = 100
→ Maximum Generations = 100
→ Mutation Rate = 0,2
→ Selection Method: Elitism

Simulation Time: 1 week

System Validation

Configuration	Number of maintenances	Normal Production	Pieces Produced	Target	Test Name
3x3	1	1194	1113	1194	Test1a
				1433	Test1b
4x4	2	1532	1412	1532	Test2a
				1838	Test2b
7x7	5	1554	1490	1554	Test3a
				1865	Test3b
10x10	8	2030	1954	2030	Test4a
				2436	Test4b

Results

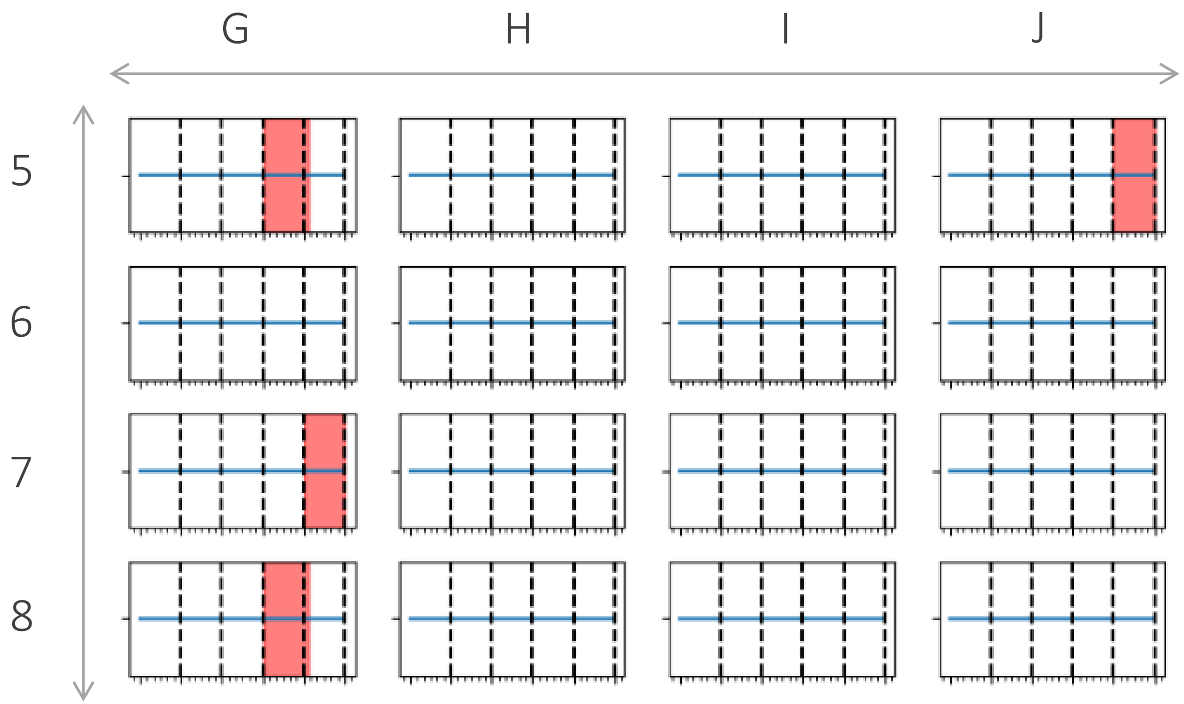
Tests	Pieces Produced	Differential	Differential σ	Availability	Processing Times
Test1a	1193	0 %	0,181 %	97,5 %	3,0 h
Test2a	1533	0,13 %	0,134 %	97,9 %	8,7 h
Test3a	1554	0 %	0,273 %	98,0 %	30,9 h
Test4a	2024	-0,279 %	0,203 %	98,7 %	71,3 h

Tests	Pieces Produced	Differential	Differential σ	Availability	Processing Times
Test1b	1434	0,07 %	0,057 %	97,5 %	3,1 h
Test2b	1838	0,108 %	0,112 %	97,9 %	9,7 h
Test3b	1864	-0,018 %	0,241 %	97,8 %	29,5 h
Test4b	2438	0,096 %	0,102 %	98,5 %	77,3 h

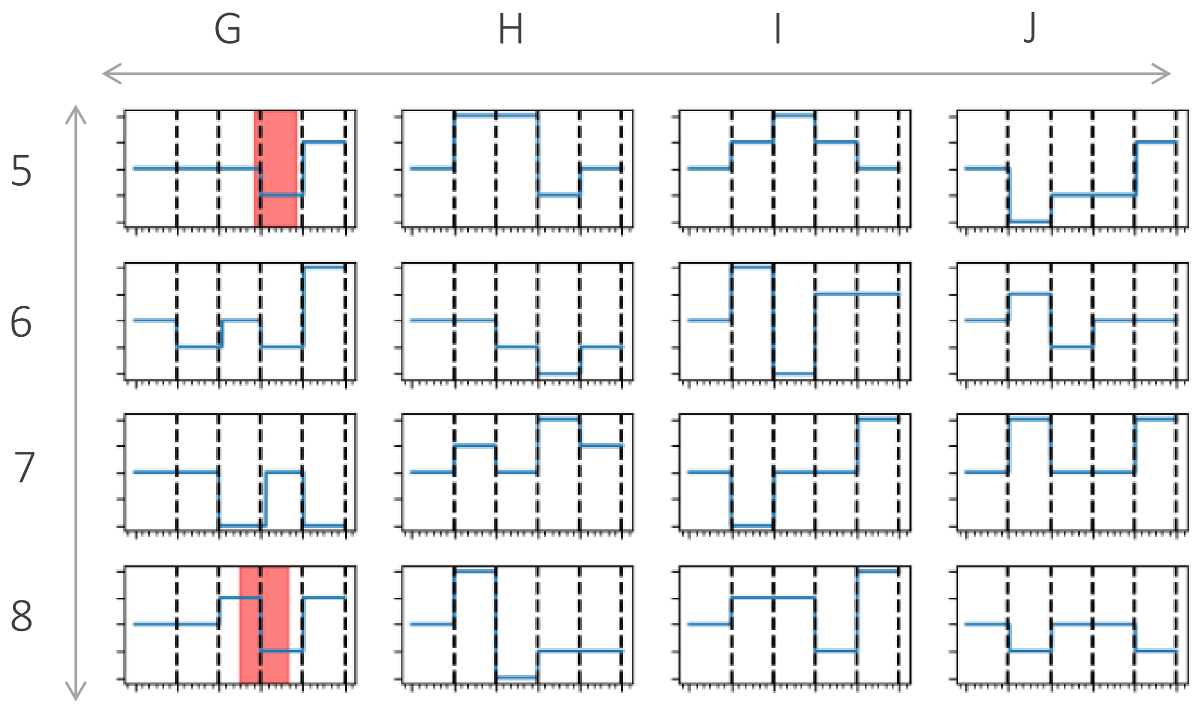
Results

Test4b – Run 1 – Configuration 10x10

Target	Pieces Produced	Differential	Availability
2436	2441 (+ 5)	0,205 %	98,8 %

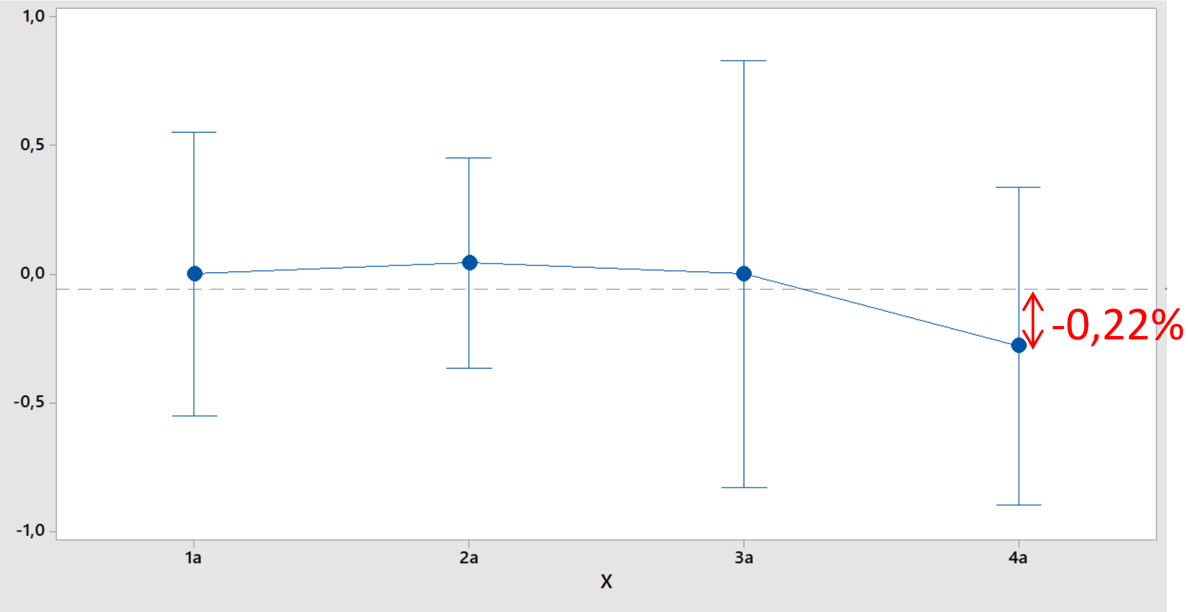


No optimizer

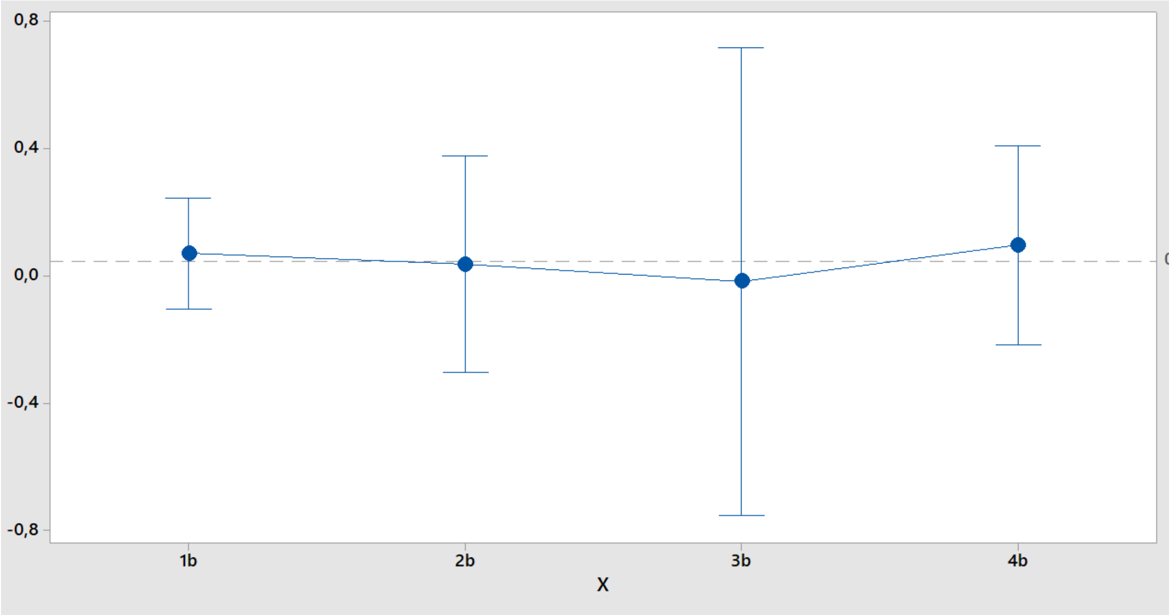


Proposed system

Results



Tests type A



Tests type B

Conclusion & Future Work

Conclusions

- → A Prescriptive System capable of adapting machines' throughput depending on weekly targets and machine degradation was presented
- → Several scenarios were tested and the results were consistent among them
- → The system was able to comply in situations where market demand was higher than the normal production

Future Work

- → Decrease processing times
- → More testing should be conducted in order to generalize results
- → Integrate prediction modules that model degradation of the equipment based on real-data

Thank you

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