



# DIGI<sub>F</sub>LOW

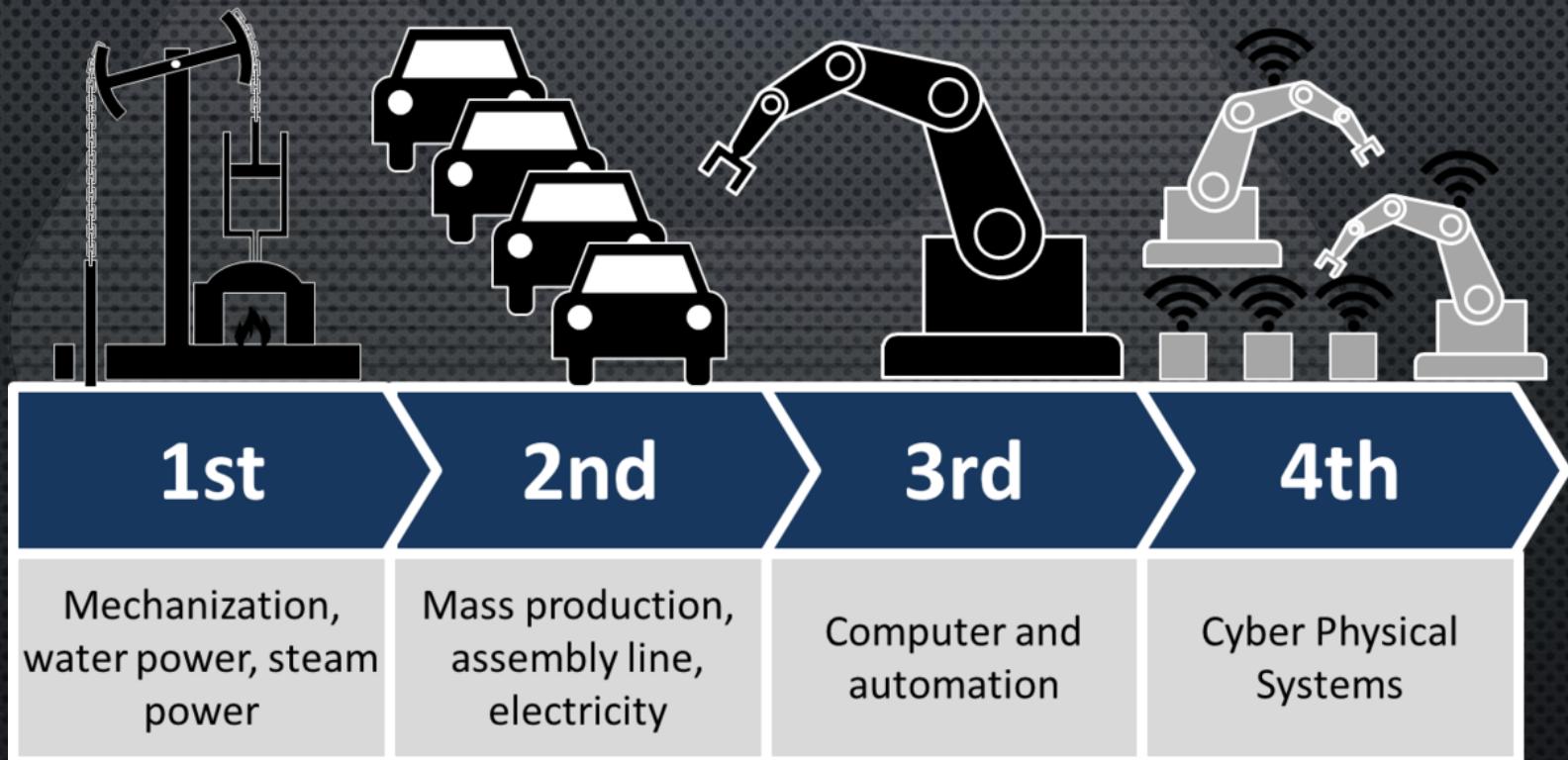
DIGITIZING INDUSTRIAL WORKFLOW  
MONITORING AND OPTIMIZATION

PETROS PAPAPANAGIOTOU

[pe.p@ed.ac.uk](mailto:pe.p@ed.ac.uk)

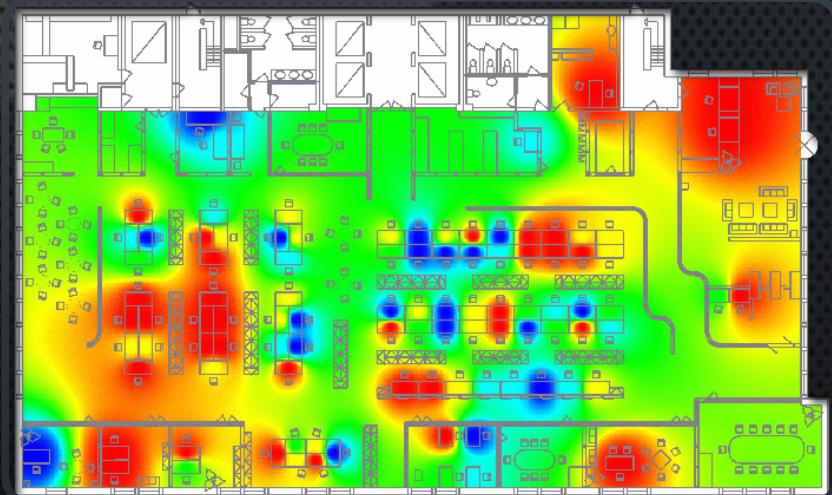


# INDUSTRY 4.0



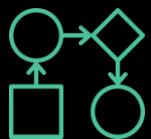
# IOT LOCATION-BASED SOLUTIONS

- TRACK MOVEMENT
- LIVE MONITORING
- HEATMAPS TO DETECT BOTTLENECKS
- ANALYTICS
  - TIMINGS
  - DELAYS
  - EFFICIENCY
- *BUT WHAT ABOUT THE CONTEXT?*





IoT



Workflow



Cloud & Fog



Consultancy



DIGITFLOW

IDEA:  
WORKFLOW  
MANAGEMENT  
FOR INDUSTRY  
4.0

# PARTNERS



FONDATION  
BRUNO KESSLER

Activity  
Leader



Business  
Champion



DIGITFLOW

THE UNIVERSITY of EDINBURGH  
**informatics**

Technical  
Partner



Technical  
Subgrantee

# TEAM



# PILOT CUSTOMER: BESPOKE PEN MANUFACTURING



Since 1919,  
*Italian Passion, Sign of Distinction.*

WHO WE ARE PRODUCTS NEWS HALL OF FAME SHOP COLLECTORS CONTACTS

Home > Shopping >

### CATEGORIES

- > Pens [+]
- > Leather [+]
- > Paper [+]
- > Watches [+]
- > Refill [+]
- > Memorabilia [+]
- > Writing unit [+]

Order by Posizione ↑ Viewing Items 8 on page

Items 1 a 8 of 635 Totals 1 2 3 4 5 ... 80 >



RESTRICTED

Diamante

Add to cart



RESTRICTED NEW

preview

920-DB

Add to cart

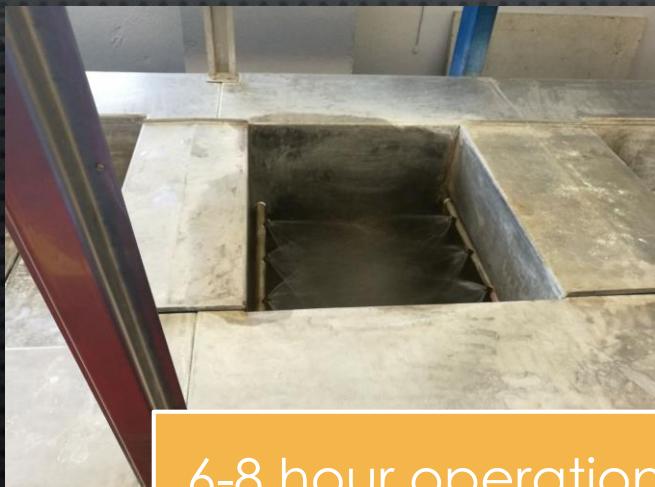
# CASE STUDY / CUSTOMER: BESPOKE PEN MANUFACTURING



Groups of machines



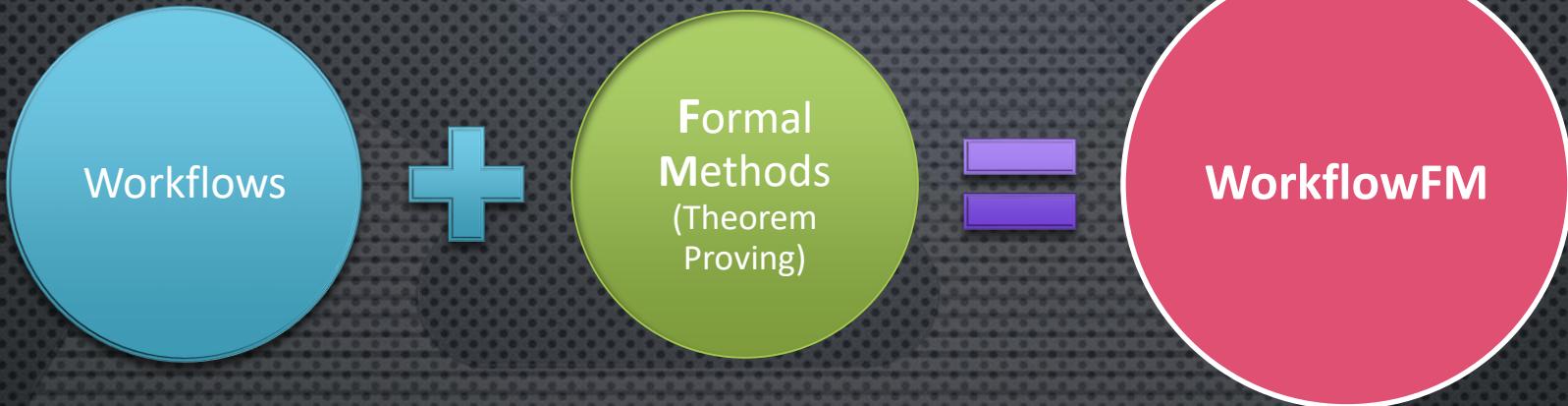
Manual scheduling  
and movement



6-8 hour operations

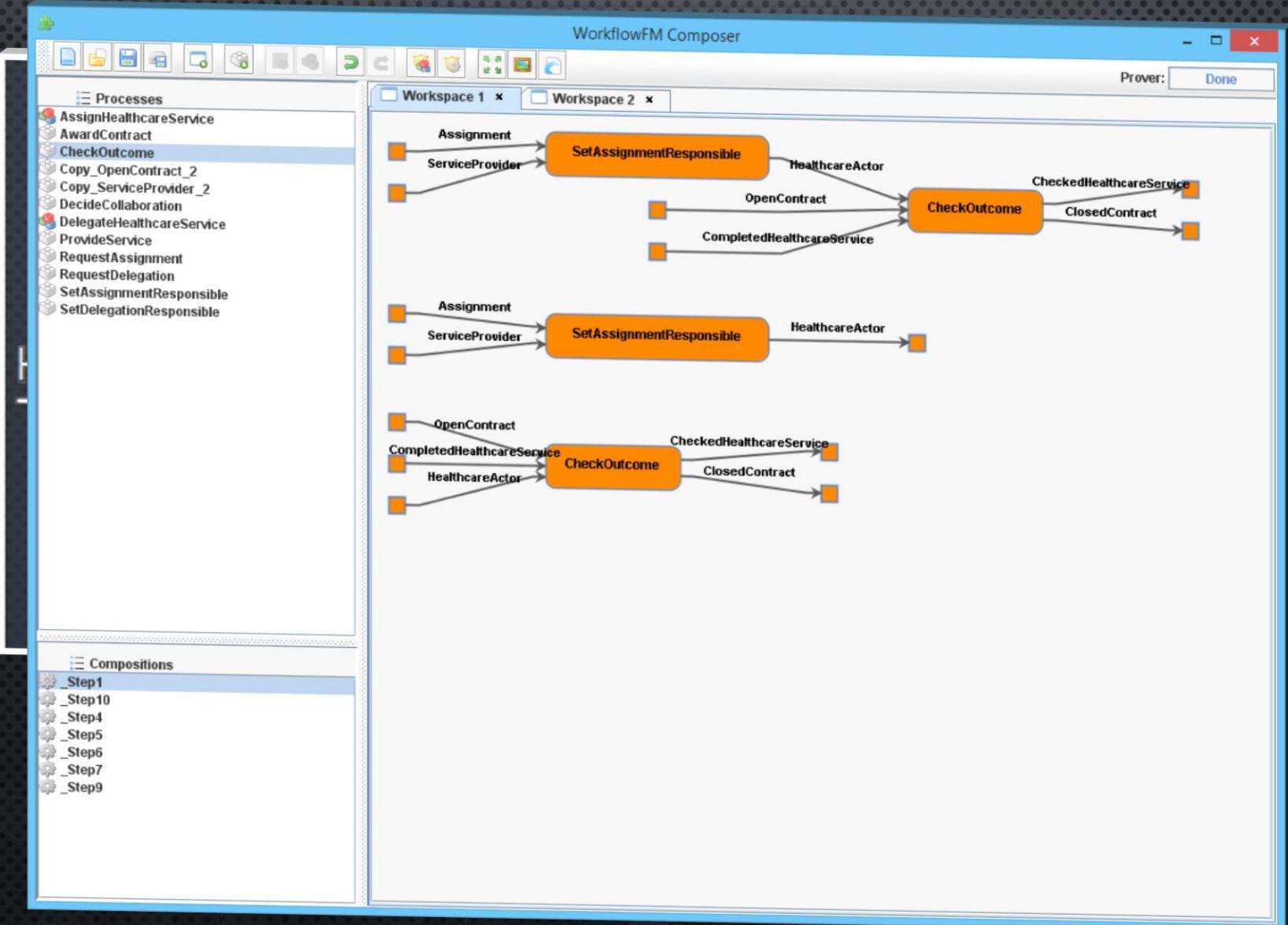


Orders sorted in  
production lots



- ✓ VISUAL, RESOURCE-BASED WORKFLOW MODEL
- ✓ CORRECT-BY-CONSTRUCTION DESIGN
  - ✓ CONSISTENCY & CONTINUITY GUARANTEED
  - ✓ SYSTEMATICALLY TRACKED RESOURCES
  - ✓ RECORDED EXCEPTIONS & VARIANCES
- ✓ PUSH-BUTTON DECENTRALISED ASYNCHRONOUS EXECUTION

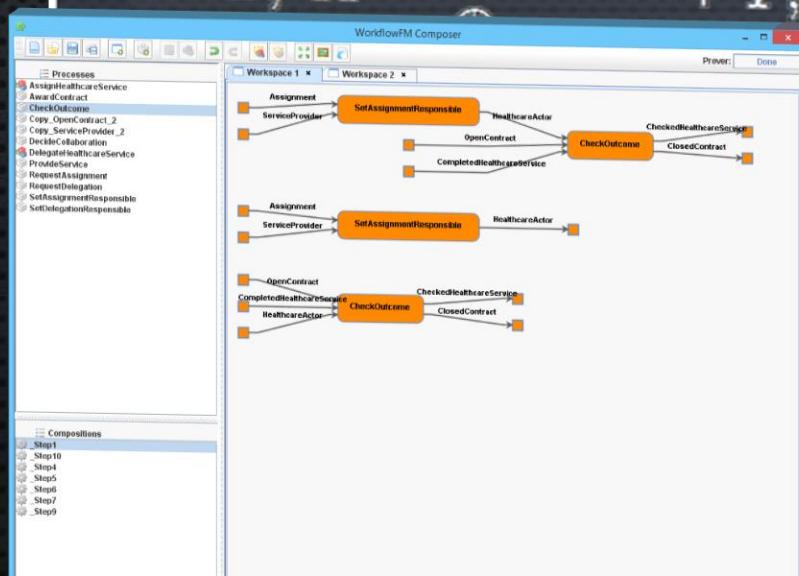
# WorkflowFM



$$\frac{}{\vdash A, A^\perp} Id$$

$$\frac{\vdash \Gamma, A \quad \vdash \Delta, B}{\vdash \Gamma, \Delta, A \otimes B} \otimes$$

$$\vdash \Gamma, A$$



$$\frac{\vdash \Gamma, C \quad \vdash \Delta, C^\perp}{\vdash \Gamma, \Delta} Cut$$

$$\frac{\vdash \Gamma, A, B}{\vdash \Gamma, A \wp B} \wp$$

$$\frac{\vdash \Gamma, B}{\vdash \Gamma, B \oplus_R}$$

$$\frac{\vdash \Gamma, A \quad \vdash \Gamma, B}{\vdash \Gamma, A \& B} \&$$

Papapanagiotou, Fleuriot. **A Pragmatic, Scalable Approach to Correct-by-construction Process Composition Using Classical Linear Logic Inference**, 128th International Symposium on Logic-Based Program Synthesis and Transformation (LOPSTR) 2019 (To appear)

# PROOFS-AS-PROCESSES

LOGICAL PROOFS

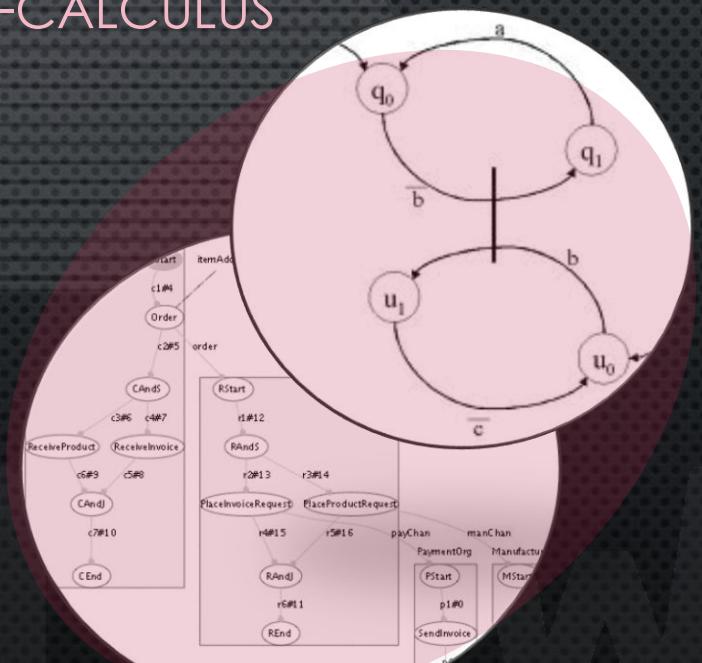
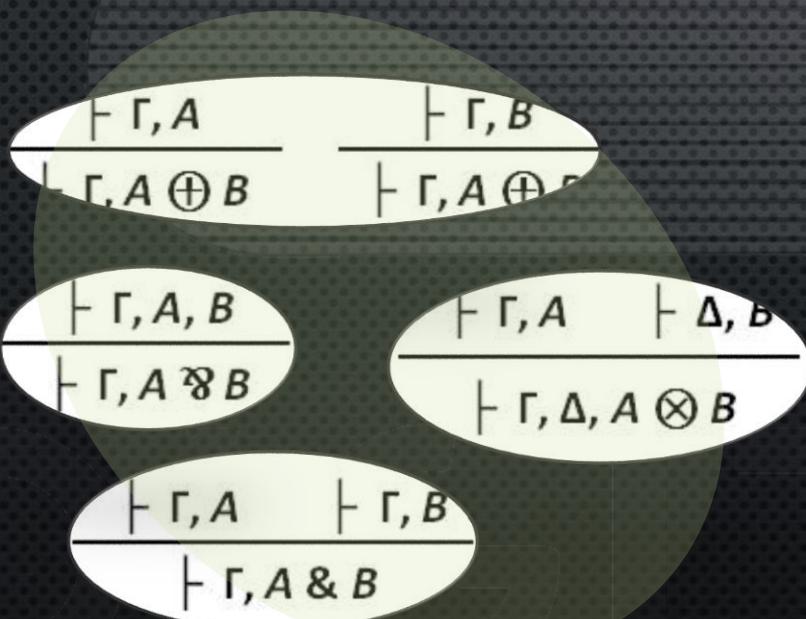


CONCURRENT PROCESSES

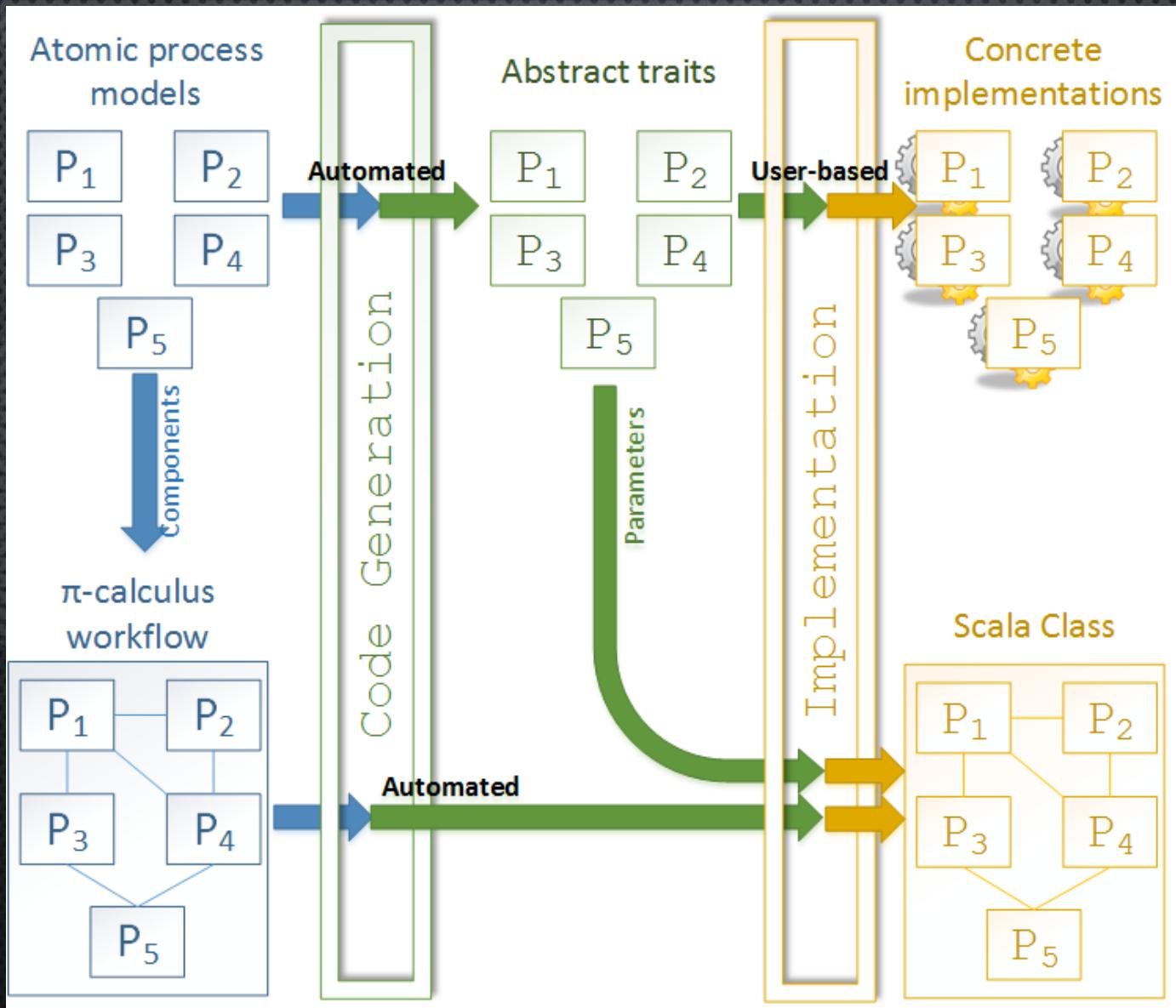
CLASSICAL LINEAR LOGIC



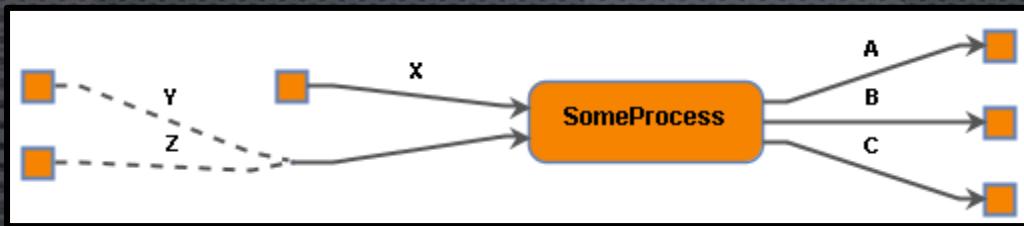
$\Pi$ -CALCULUS



# WorkflowFM



# EXAMPLE ATOMIC PROCESS



```
package com.workflowfm.example.instances

import scala.concurrent._
import com.workflowfm.example.ExampleTypes._
import com.workflowfm.example.processes._

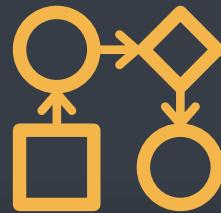
class SomeProcessInstance extends SomeProcess {
    override def apply( arg0 :X, arg1 :Either[Y,Z] ) :Future[(A,(B,C))] = {
        // TODO: Instantiate this method.
    }
}
```

**Process  
Mapping**

**Workflow  
Modelling**

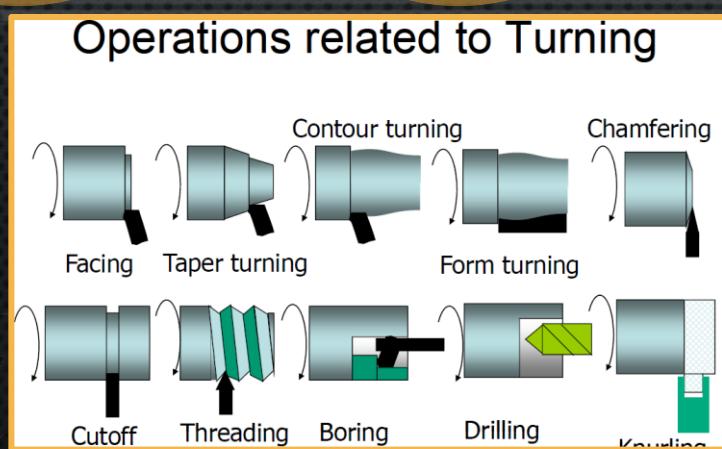
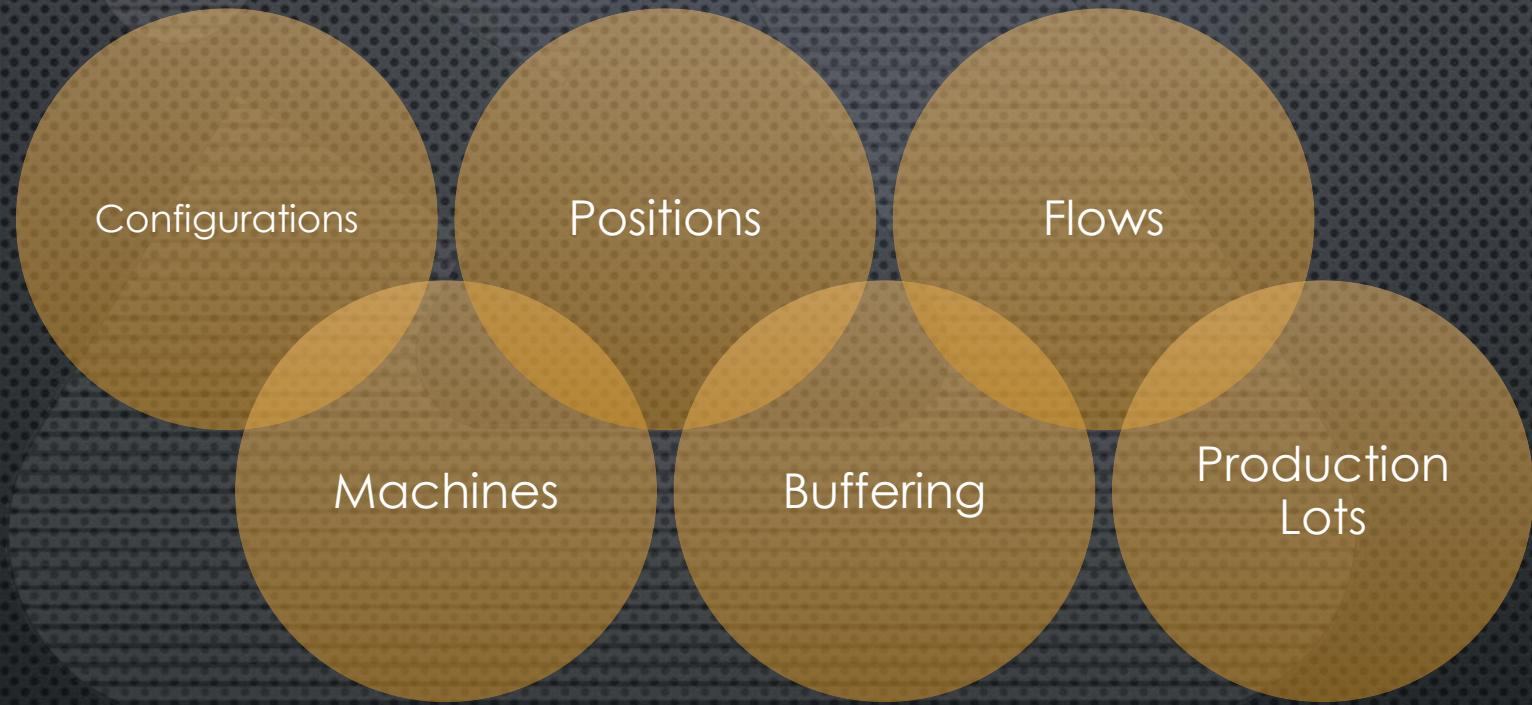
**Process  
Implementation**

**System  
Deployment**



# WORKFLOW METHODOLOGY

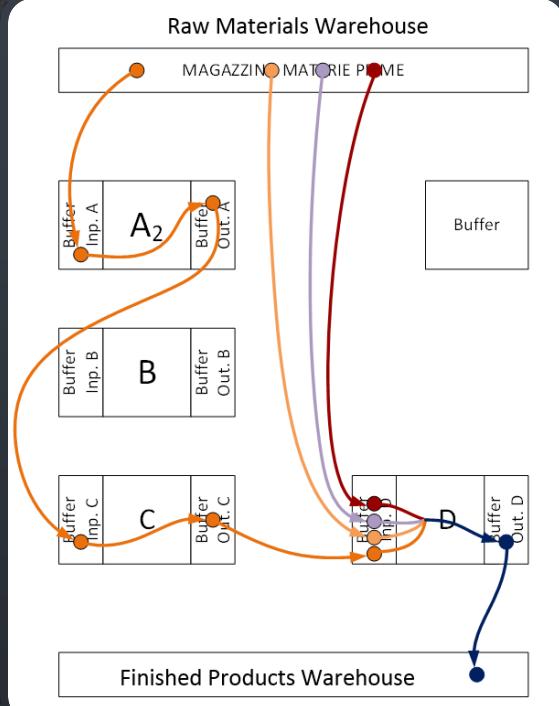
# 1. PROCESS MAPPING



# 1. PROCESS MAPPING

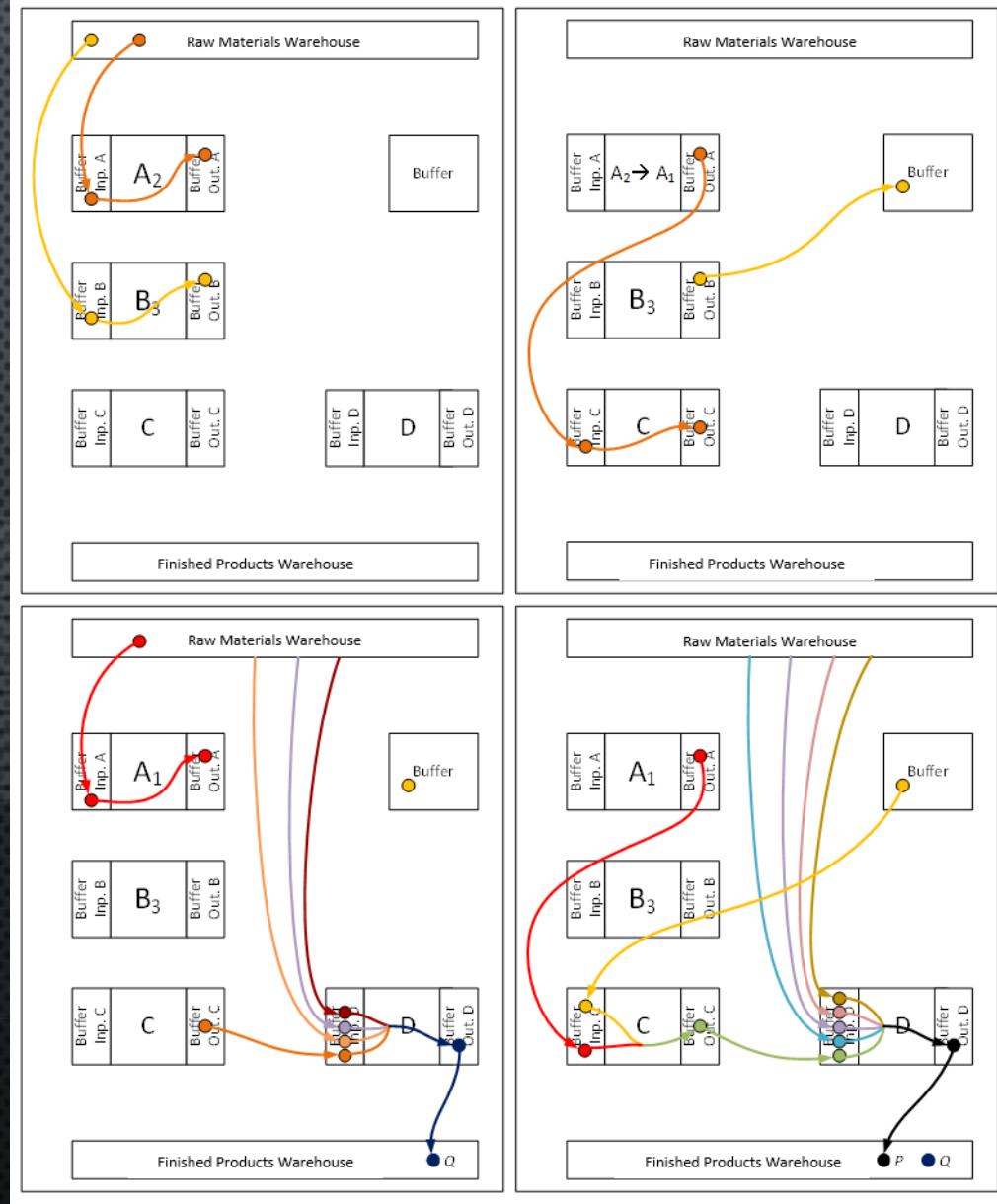
POSITION	POSITION NAME	OPERATOR NAME	ACTIVITY NAME	ACTIVITY DURATION
1	Raw-Material	Department Head	Input Interface	5 minutes
2A	Buffering before entering in process	Department Head	Entry into the process	N/A
2B	Turning - first working location	Turner	Turning	8 hour for lathing the whole production lot Turning of a single object: 1 minute
3	Idle station	employee	Temporary Idle station	N/A
4	Polishing	Polishing worker	Polish	2 hours
5	Washing	Washing worker	Washing	1 hour
6	Idle station	employee	Temporary Idle station	N/A
7	Turning - second working location	Turner	Turning	8 hour for lathing the whole production lot Turning of a single object: 1 minute
8	Turning - third working location	Turner	Turning	8 hour for lathing the whole production lot Turning of a single object: 1 minute
9	Idle station	employee	Temporary Idle station	N/A
10	pieces' testing	Tester	Testing	1 hour per lot
11	Output interface	Employee	Output interface	N/A

# Flows



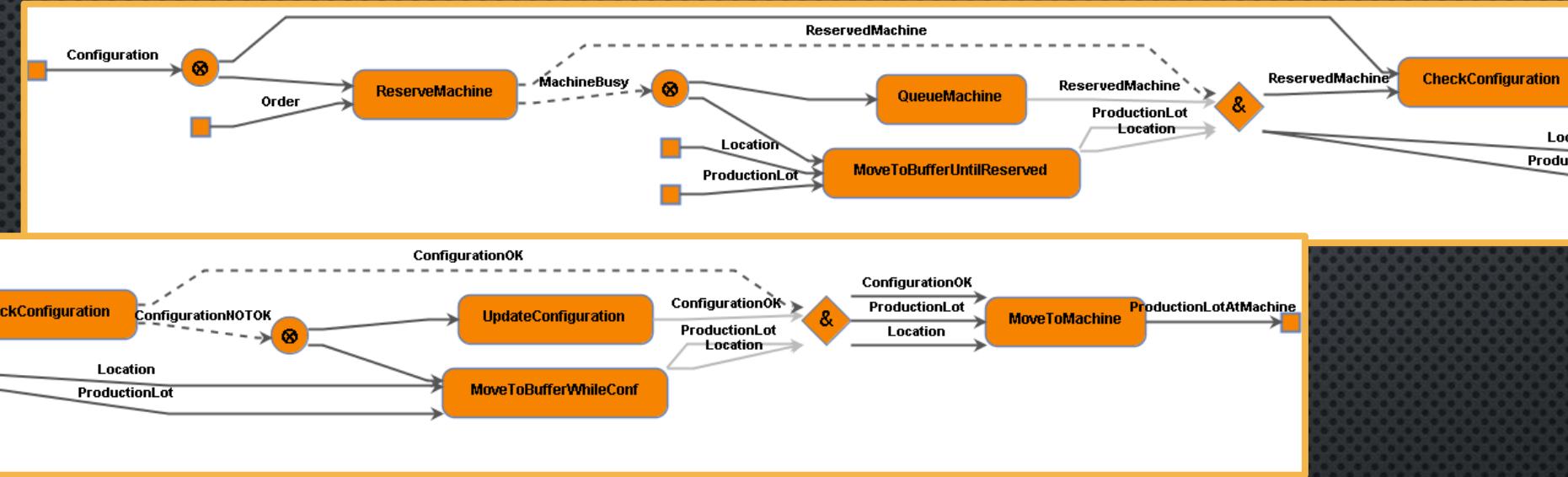
# Scenario

# 1. PROCESS MAPPING

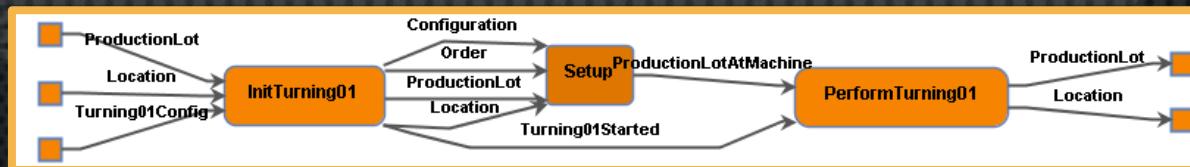


## 2. WORKFLOW MODELLING

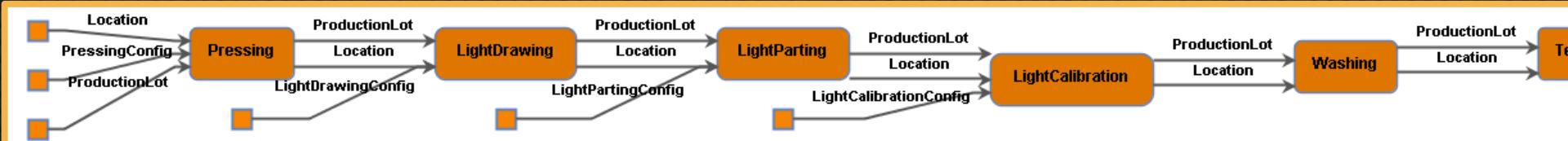
Setup



Single Machine



Full Flow



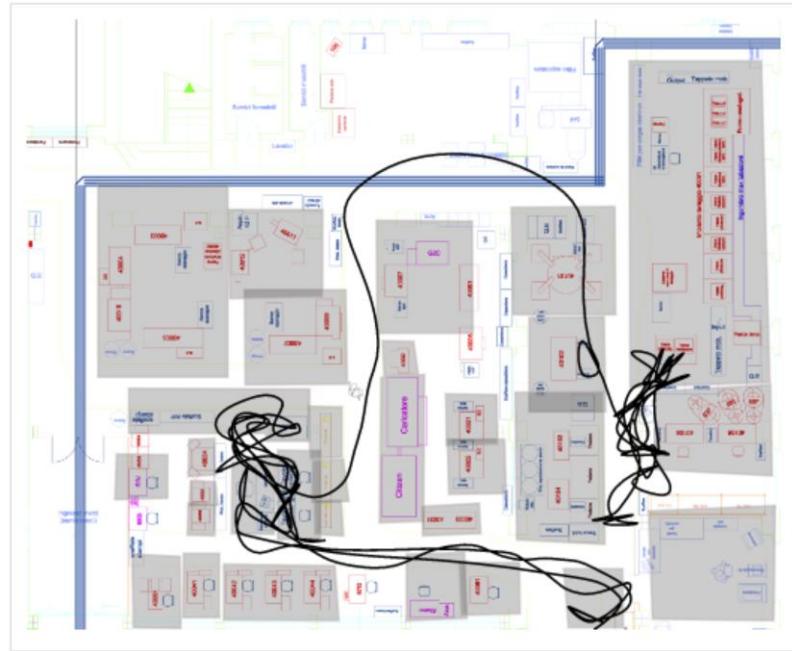
### 3. PROCESS IMPLEMENTATION

#### SIMULATION

- VIRTUAL RESOURCES: Machines, Queues
- VIRTUAL ASSETS: Production Lots
- REALISTIC DATA: Durations, Costs
- SIMULATION: Configurations & Flows
- CONCURRENCY: Parallel scenarios
- SCHEDULING: Realistic decisions
- ANALYTICS: Various metrics, Timeline
- DECISION SUPPORT: What-if? scenarios

#### LIVE MONITORING

- REAL RESOURCES: Floormap
- REAL ASSETS: Tags on Production Lots
- REAL DATA: Location & Geo-Fencing
- REAL SCENARIOS: Orders
- PERSISTENCE: Recovery from reboots
- SCHEDULING: Inferring decisions
- ANALYTICS: Real-time metrics & Timeline
- DECISION SUPPORT: Live, Contextual Info

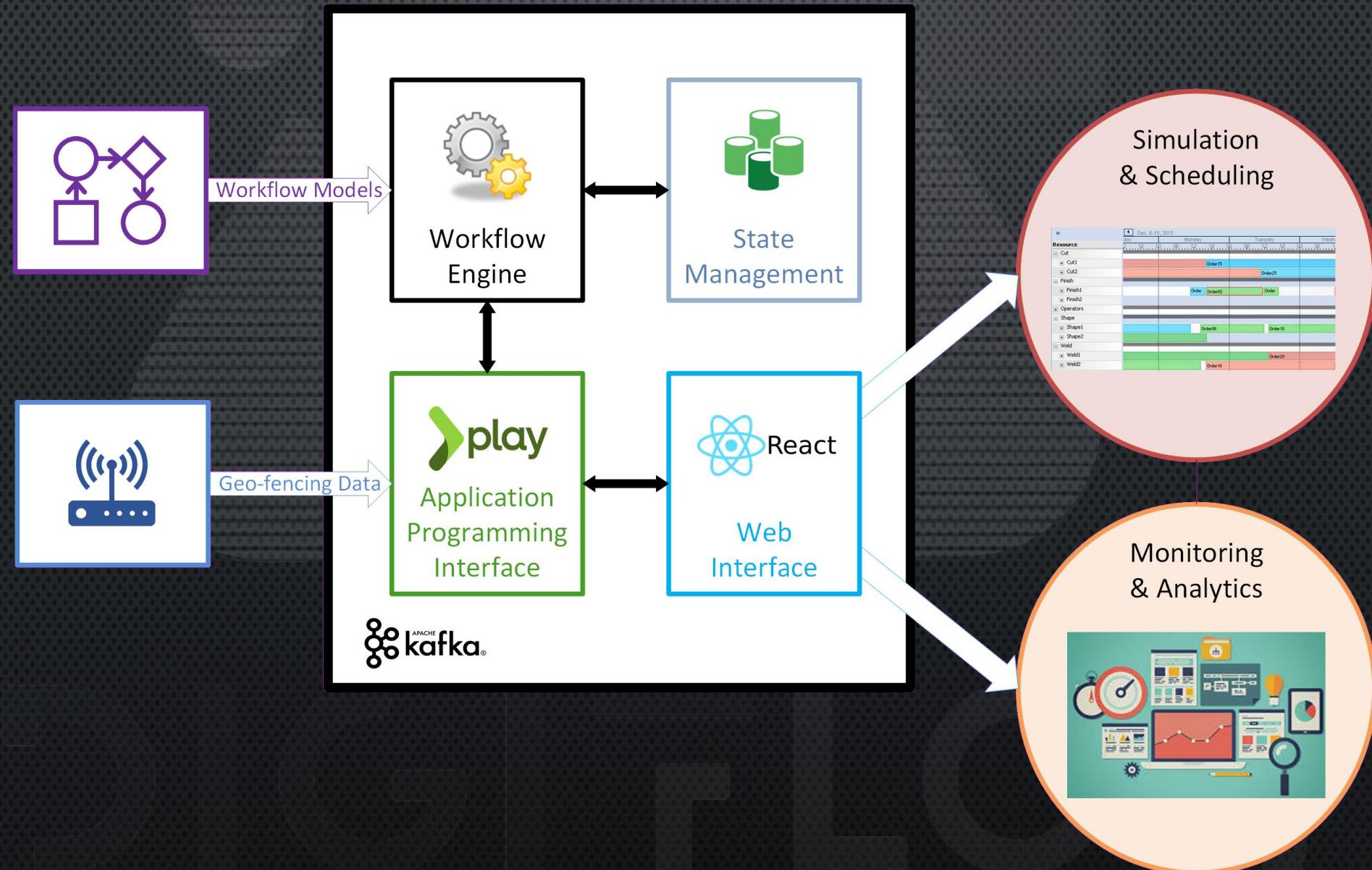


# IN PRACTICE

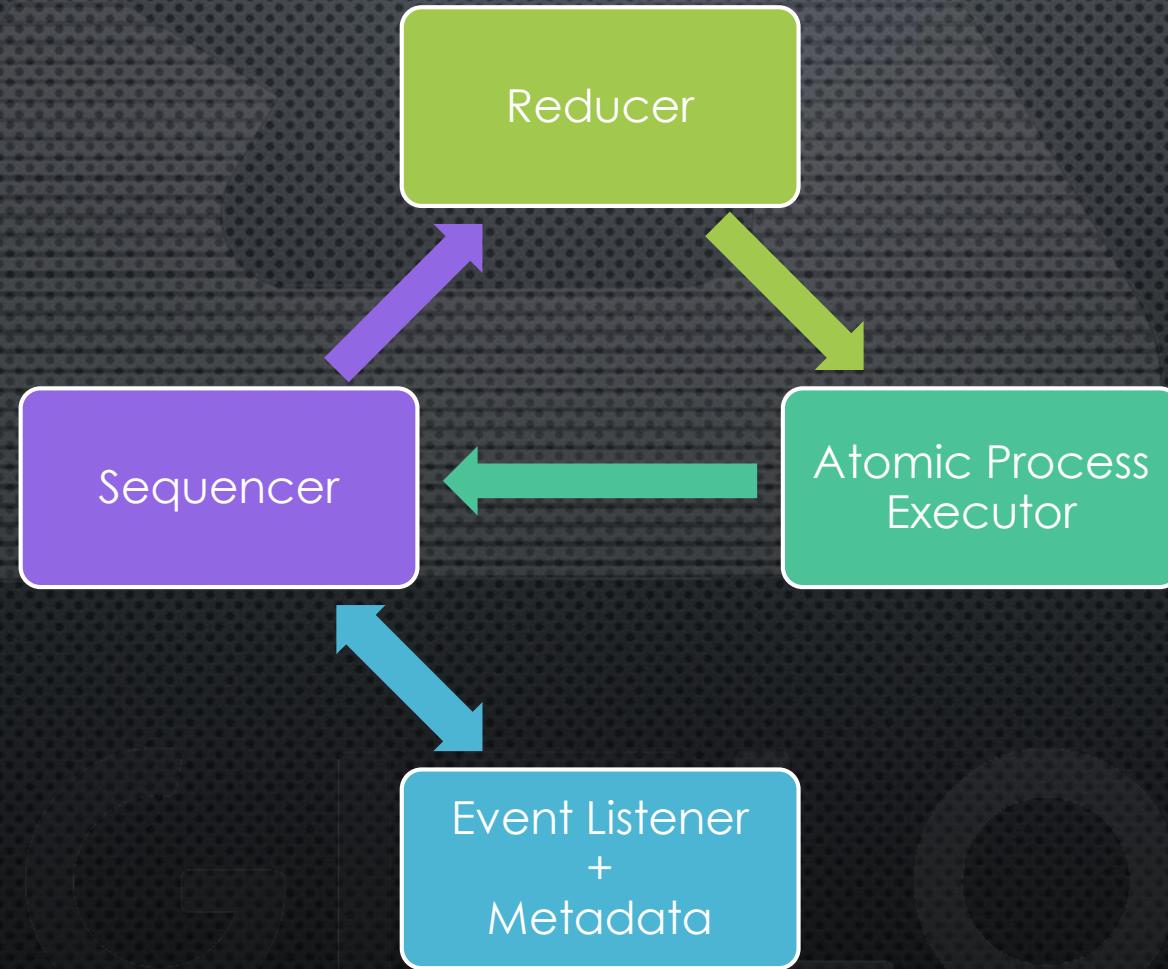
	action_type	entrance_timestamp	id_asset		id_settings	id_zone	metadata.customKey	timestamp
3	accessing	1542088816232	517	15398183895bc7c395d4c294.07482959	961			2018-11-13 06:00:16.232
6	accessing	1542088865641	517	15398183895bc7c395d4c294.07482959	962			2018-11-13 06:01:05.641
	action_type	entrance_timestamp	id_asset		id_settings	id_zone	metadata.customKey	timestamp
4	accessing	1542038550360	519	15398183895bc7c395d4c294.07482959	950			2018-11-12 16:02:30.360
5	accessing	1542089022815	519	15398183895bc7c395d4c294.07482959	942			2018-11-13 06:03:42.815
44	accessing	1542104608120	519	15398183895bc7c395d4c294.07482959	975	buffer_1		2018-11-13 10:23:28.120
43	abandoning	1542038550360	519	15398183895bc7c395d4c294.07482959	950			2018-11-13 10:23:34.811
47	abandoning	1542089022815	519	15398183895bc7c395d4c294.07482959	942			2018-11-13 12:35:55.732

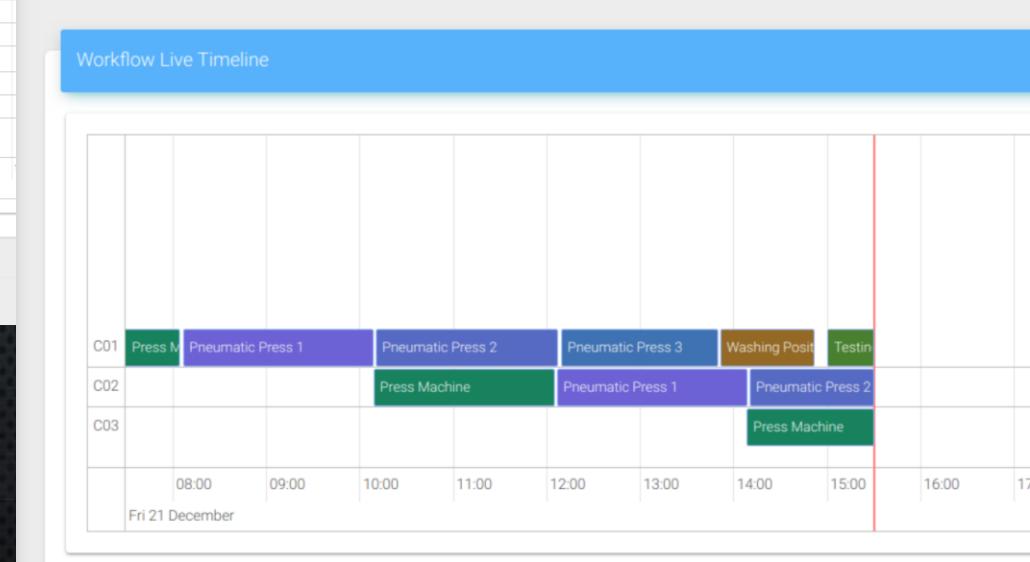
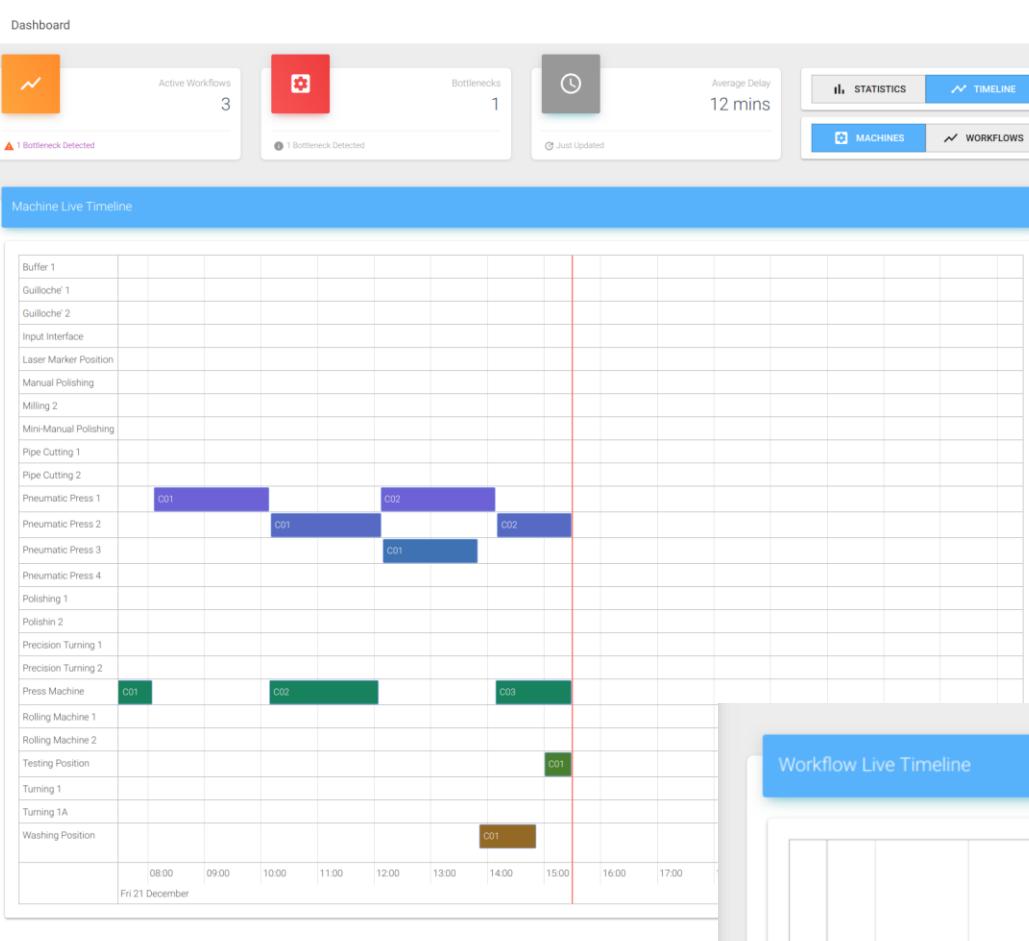
# IN PRACTICE

# 4. SYSTEM DEPLOYMENT



# PERSISTENT EXECUTION OF WORKFLOWS (PEW): KAFKA EXECUTOR







Active Workflows

3

⚠ 1 Bottleneck Detected



Bottlenecks

1

⚠ 1 Bottleneck Detected



Average Delay

12 mins

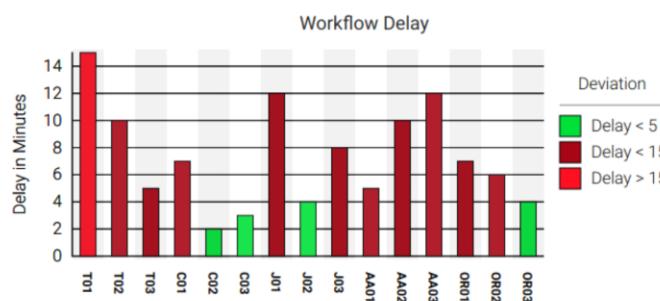
🕒 Just Updated

STATISTICS

TIMELINE

MACHINES

WORKFLOWS



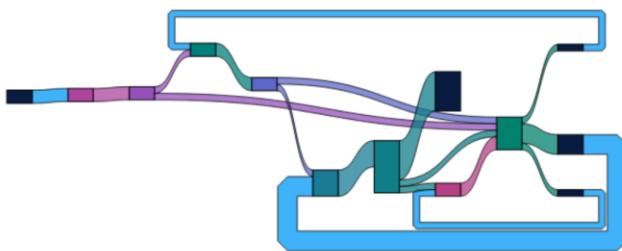
## Machine Events

- ⓘ Washing Position is 10% more efficient than its average. 02:29
- ⓘ Pneumatic Press 01 Machine is 10% less busy than expected. 02:28
- ⚠ Bottleneck detected at Pipe Cutting Machine. 02:27
- ⓘ Polishing Machine is Idle. 02:26

## WorkflowEvents

- ⓘ Workflow C03 Started. 02:29
- ✓ Workflow C01 Finished. 02:28
- ⚠ Workflow C01 is exceeding its average duration by 10%. 02:27
- ⓘ Workflow C02 Started. 02:26

## Sankey Chart



Workflow	Type	Start Time	Currency Stage	Estimated Completion
J01	Junction Insert	7:00 AM	Turning 03	5 hours
C01	Clip Processing	7:00 AM	Light Calibration	7 hours
T01	Tube Processing	7:00 AM	Milling	6 Hours
J02	Junction Insert	7:15 AM	Turning 02	6 hours
T02	Tube Processing	7:15 AM	Pipe Cutting	7 Hours
C02	Clip Processing	7:20 AM	Light Parting	7 hours

Rows per page: 6 ▾ 1-6 of 20 | < < > >|

# LIVE WORKFLOW ANALYTICS

Dashboard

Workflows

Run

Timeline

Flows

Machines

Configurations



Active Workflows

3

⚠ 1 Bottleneck Detected



Bottlenecks

1

⚠ 1 Bottleneck Detected



Average Delay

12 mins

🕒 Just Updated

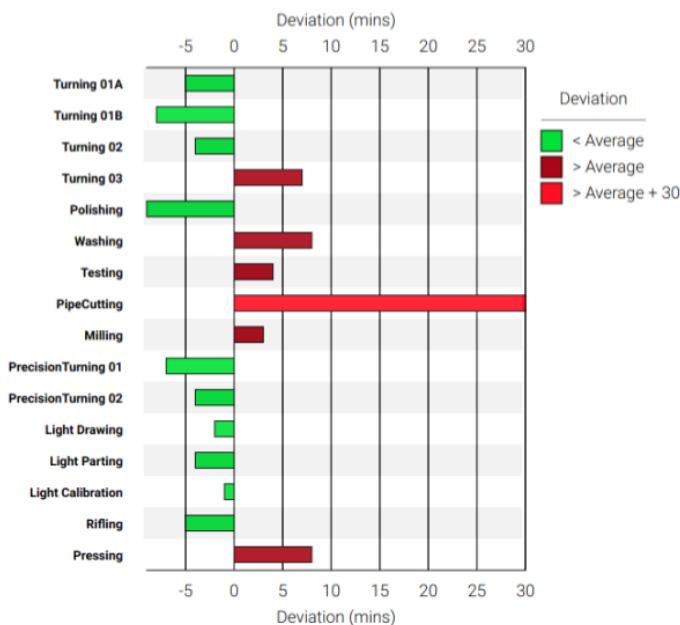
STATISTICS

TIMELINE

⚙ MACHINES

✓ WORKFLOWS

## Machines Efficiency



## Machine Events

- ⓘ Washing Position is 10% more efficient than its average. 02:29
- ⓘ Pneumatic Press 01 Machine is 10% less busy than expected. 02:28
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## WorkflowEvents

- ⓘ Workflow C03 Started. 02:29
- ✓ Workflow C01 Finished. 02:28
- ⚠️ Workflow C01 is exceeding its average duration by 10%. 02:27
- ⓘ Workflow C02 Started. 02:26

Machine	Status	Workflow	Queued	Estimated Completion
Pneumatic Press 1	busy	C03	1	1 hours
Pneumatic Press 2	busy	C02	0	1 hours
Pneumatic Press 3	busy	C01	1	2 hours
Washing Position	Idle	-	0	-
Turning 01 A	busy	T01	1	1 hours
Testing Position	Idle	-	0	-

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LIVE MACHINE ANALYTICS

C01

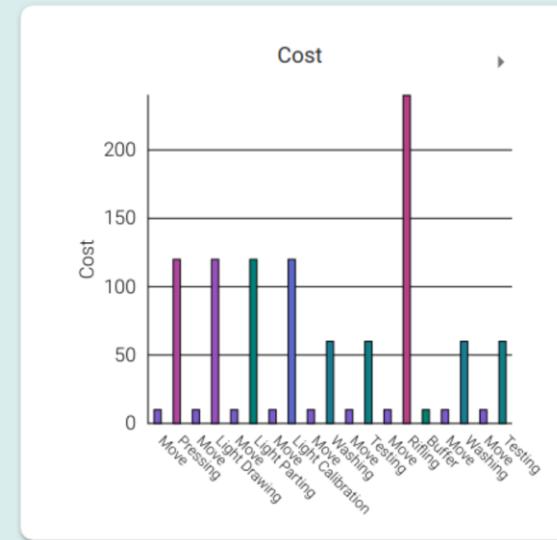
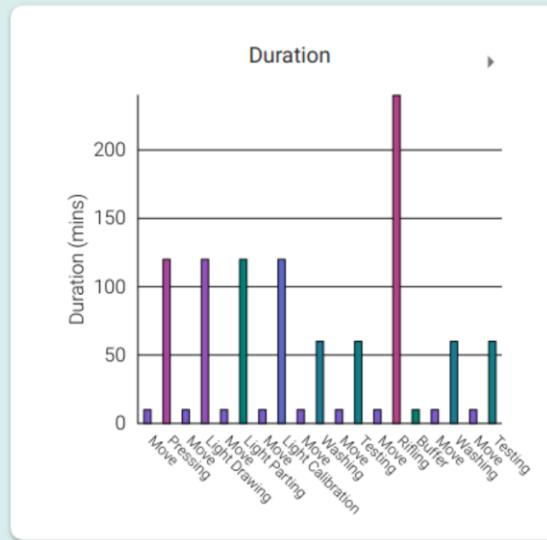
Finished

2 hours



Process	Start-time	end-time	cost
Move(C01)	08:00	08:10	0
Pressing(C01)	08:10	10:10	121
Move(C01)	10:10	10:20	0
Light Drawing(C01)	10:20	12:20	121
Move(C01)	12:20	12:30	0
Light Parting(C01)	12:30	14:30	121
Move(C01)	14:30	14:40	0
Light Calibration(C01)	14:40	16:40	121
Move(C01)	16:40	16:50	0

Rows per page: 9 ▾ 1-9 of 19 | < < > >|



C03

Testing(C03)

2 hours

# RETROSPECTIVE ANALYSIS REVIEW / AUDITING

# SIMULATION

Flow Instances

Select a workflow instance to edit or delete.

- J01
- J02
- J03
- T01

Flow

Select a configuration from the list.

Name: Jp4      Type of Flow: JunctionInsertSimulation

Polishing	Polishing
Turning01	Turning01
Turning02	Turning 02
Turning03	Turning03

**ADD FLOW**

Flow Instances

Drag and drop flow instances here to include them in the simulation.

No recent simulations selected

- J01 00:00 **X** **⊕**
- J02 00:00 **X** **⊕**

**RUN SIMULATION**

Available Flow Instances

Choose a flow instance from here to add to your simulation.

- J03
- T01
- T02
- T03
- C01
- C02
- C03
- A01

Machines

Drag machines here to use them in the simulation.

- Milling Machine
- Pipe Cutting Machine
- Turning 01 Machine A
- Turning 02 Machine
- Turning 03 Machine
- Polishing Machine

Available Machines

Here are all the machines you can pick from.

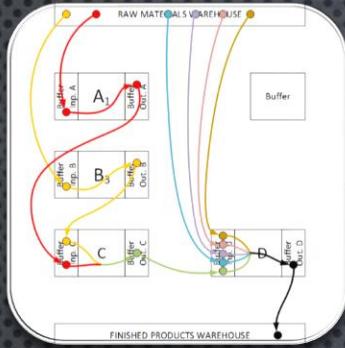
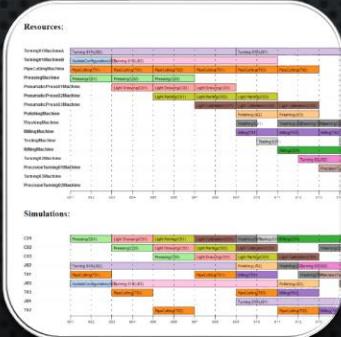
- Turning 01 Machine B
- Pressing Machine
- Testing Machine

## Machine Timelines

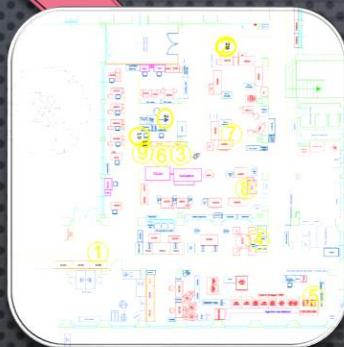
Turning 01 Machine B	UpdateConfiguration (J)	Turning 01B (J03)														
Pressing Machine	Pressing (C01)	Pressing (C03)	Pressing (C02)										Turning 01B (J03) [ID: 8] - cost: 481, delay: 00:00:00 10:10:00 - 18:10:00 (08:00:00)			
Turning 01 Machine A	Turning 01A (J01)				Turning 01A (J02)											
Pipe Cutting Machine	Pipe Cutting (T02)	Pipe Cutting (T03)	Pipe Cutting (T01)	Pipe Cutting (T02)	Pipe Cutting (T03)	Pipe Cutting (T01)										
Pneumatic Press 01 Machine		Light Drawing (C01)	Light Drawing (C03)	Light Drawing (C02)												
Rifling Machine			Rifling (C01)		Rifling (C03)								Rifling (C02)			
Polishing Machine					Polishing (J01)		Polishing (J03)									
Pneumatic Press 03 Machine						Light Calibration (C01)						Light Calibration (C03)				
Milling Machine							Milling (T02)	Milling (T03)	Milling (T01)							
Washing Machine								Washing (J)	Washing (C)	Washing (T)	Washing (J)	Washin				
Turning 02 Machine										Turning 02 (J01)						
Testing Machine											Testing (C0)					
Precision Turning 01 Machine													Precision Turning 01 (			
Pneumatic Press 02 Machine													Light Parting (C01)			
	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
	Mon 26 November															

# SIMULATED TIMELINE & ANALYTICS

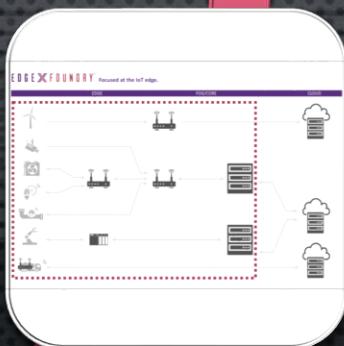
THANK  
YOU!



**DIGITIZATION OF MANUFACTURING WORKFLOWS**  
improve automation and efficiency



**INTEGRATION WITH IOT SENSORS**  
asset tracking  
across shop floors



**FOG AND CLOUD COMPUTING**  
flexible, robust,  
resilient management

**SIMULATION WITH REAL DATA**  
In-depth insights for optimisation