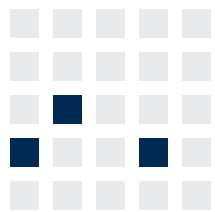


# Determinants of an appropriate degree of autonomy in a Cyber-Physical Production System

Univ.-Prof. Dr.-Ing. habil. Norbert Gronau  
Industry 4.0 Application Center, [ngronau@lswi.de](mailto:ngronau@lswi.de)



Chair of Business Informatics  
Processes and Systems  
*University of Potsdam*



# Agenda

- What is autonomy?
- How autonomy can be measured?
- What is the right degree of autonomy?
- How do we test our approaches?
- Further research

# Agenda

- **What is autonomy?**
- How autonomy can be measured?
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# What is autonomy?

- Freedom to act independently
- Capacity to make an informed, uncoerced decision
- Capacity of a system to make a decision about its activities without the involvement of another system or operator



A production system is autonomous, when it is capable to make a decision about its activities without the involvement of another system or operator

# When is autonomy advantageous?

New technologies

Kreimeier 2013

Challenging customer requirements

Gudszend 2002

Variable lot sizes

Kreimeier 2013

Higher degree of individualization and more dynamic markets

Meißner et al. 2013

Shorter ramp-up cycles

Heins et al. 2008

Frequent need for adaptation

Mersmann 2012

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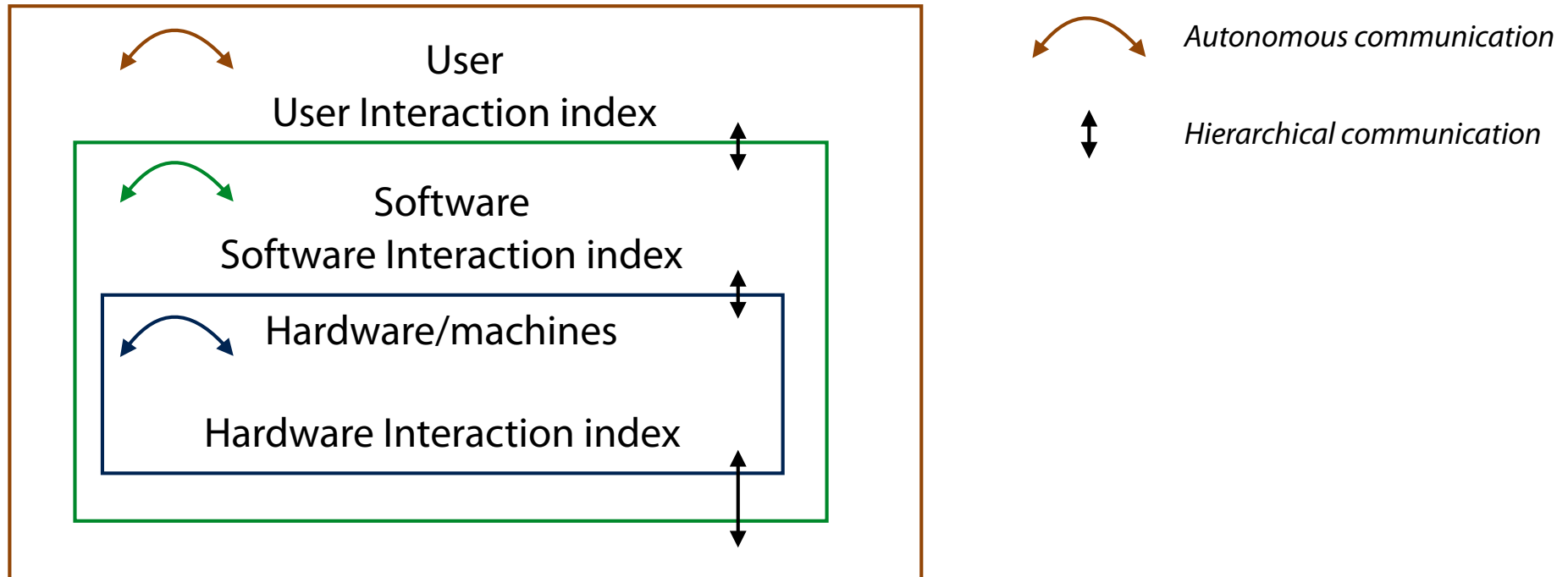
# Agenda

- What is autonomy?
- **How autonomy can be measured?**

Autonomy index

Market-based  
approach

# Measuring the autonomy index



$$\text{Autonomy Index } AI = \frac{DE_{\text{aut}}}{DE_{\text{all}}} = \frac{\sum_{z \in Z} \sum_{j=1}^m D_{zxj} + \sum_{i=1}^n D_{xxi}}{\left( \sum_{z \in Z} \sum_{j=1}^m D_{zxj} + \sum_{i=1}^n D_{xxi} \right) + \left( \sum_{z \in Z} \sum_{j=1}^m DN_{zxj} + \sum_{i=1}^n DN_{xxi} \right)}$$



# Communication of control center

- 
- 3,152 INFO ToolAdapter:300 - Curve PowerConsumptionreceived configuration Inductor Coil from Workingstep Heating through induction
- 
- 3,152 INFO ToolAdapter:300 - Curve Temperaturereceived configuration Inductor Coil from Workingstep Heating through induction
- 
- 3,152 INFO ToolAdapter:300 - Curve Noisereceived **configuration** Inductor Coil from Workingstep Heating through induction
- 
- 3,152 INFO ToolAdapter:300 - Curve Vibrationreceived configuration Inductor Coil from Workingstep Heating through induction
- 
- 3,152 INFO ToolAdapter:300 - Curve Noisereceived configuration Inductor Coil from Workingstep Clinch
- 
- 3,152 INFO ToolAdapter:300 - Curve Temperaturereceived configuration Inductor Coil from Workingstep Clinch
- 
- 3,154 INFO ToolAdapter:284 - Curve **Material Verschleissreceived** tool Schleifwerkzeug from Workingstep Schleifen Grob
- 
- 3,154 INFO ToolAdapter:300 - Curve Krnungsgradreceived configuration Schleifwerkzeug from Workingstep Schleifen Grob
- 
- 3,155 INFO ToolAdapter:300 - Curve Leistungsaufnahmereceived configuration Schleifwerkzeug from Workingstep Schleifen Grob
- 
- 3,155 INFO ToolAdapter:284 - Curve Oelspritzer Verschleissreceived tool Oelspritzer from Workingstep Schleifen Fein
- 
- 3,155 INFO ToolAdapter:300 - Curve Spritzdruckreceived configuration Oelspritzer from Workingstep Schleifen Fein
- 
- 3,155 INFO ToolAdapter:300 - Curve Leistungsaufnahmereceived configuration Oelspritzer from Workingstep Schleifen Fein
- 
- 3,155 INFO ToolHandler:247 - Content Curve Oelbehaelter von Maschine CNC Frse + Schleifer + Polierer wurde hinzugefgt
- 
- 3,157 INFO ADSFunctions:223 - PLCVar value: 0
- 
- 3,157 INFO ToolAdapter:284 - Curve Material Verschleissreceived tool Schleifwerkzeug from Workingstep Schleifen Grob
- 
- 3,158 INFO ToolAdapter:300 - Curve Krnungsgradreceived configuration Schleifwerkzeug from Workingstep Schleifen Grob
-

# Market-based approach

Optimization Dimension  
e.g. Time/Order

^

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Approximation

.

Supply of Environment

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Demand of CPS

· 0

Heteronomy

Optimum

100

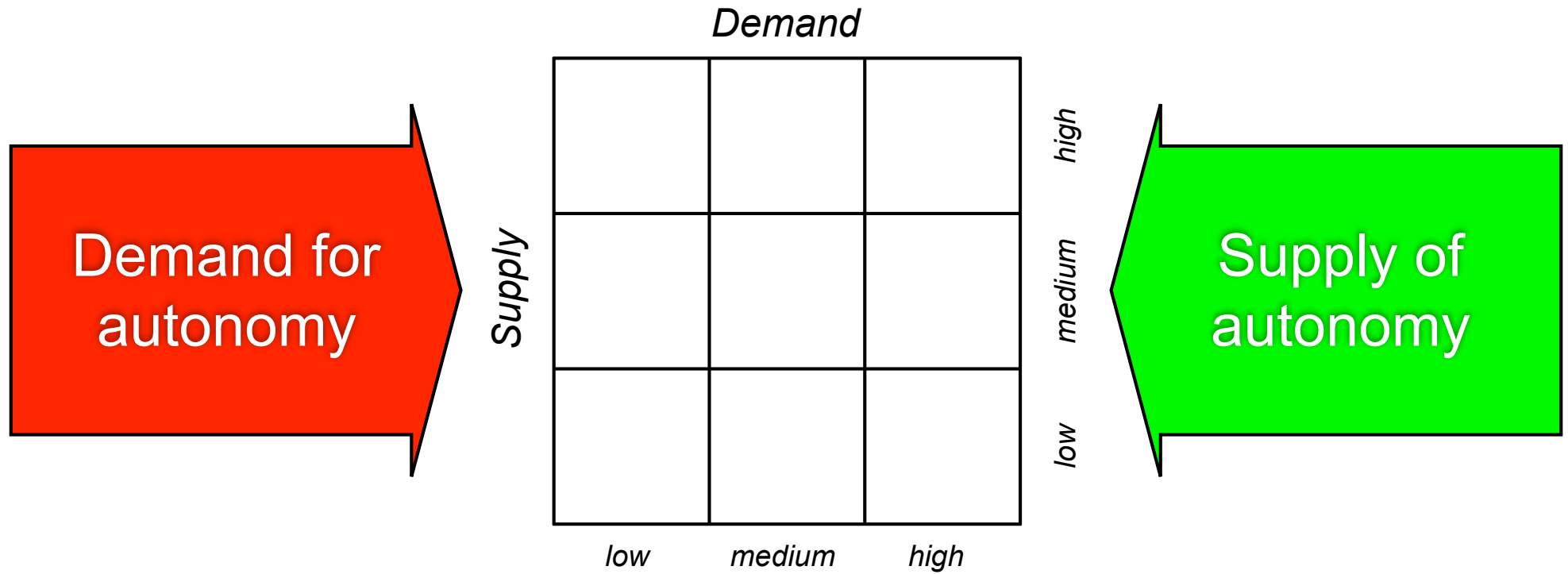
Autonomy

Degree of Autonomy

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# Demand and supply of autonomy



# Characteristics of a production system

<b>Product range</b>	Specification by customer	Serial products with customer-specific variations	Standard products with variations	Standard products without variations
<b>Product structure</b>	One-piece-product	Multiple-piece-products with simple structure	Multiple-piece-products with complex structure	
<b>Order trigger</b>	Manufacturing on demand with single orders	Manufacturing on demand with blanket orders	Manufacturing on stock	
<b>Disposition</b>	Following the customer's order	Mainly following the customer's order	Mainly MRP-based	MRP-based
<b>Demand planning</b>	No relevant external supply	Relevant external supply	Huge external supply	
<b>Manufacturing process</b>	Unique manufacturing	Unique and small lot manufacturing	Serial manufacturing	Mass manufacturing
<b>Manufacturing organization</b>	Construction site	Shop floor	Group-/ line assembly	Line production
<b>Share of self-manufactured parts</b>	Low	Medium	High	

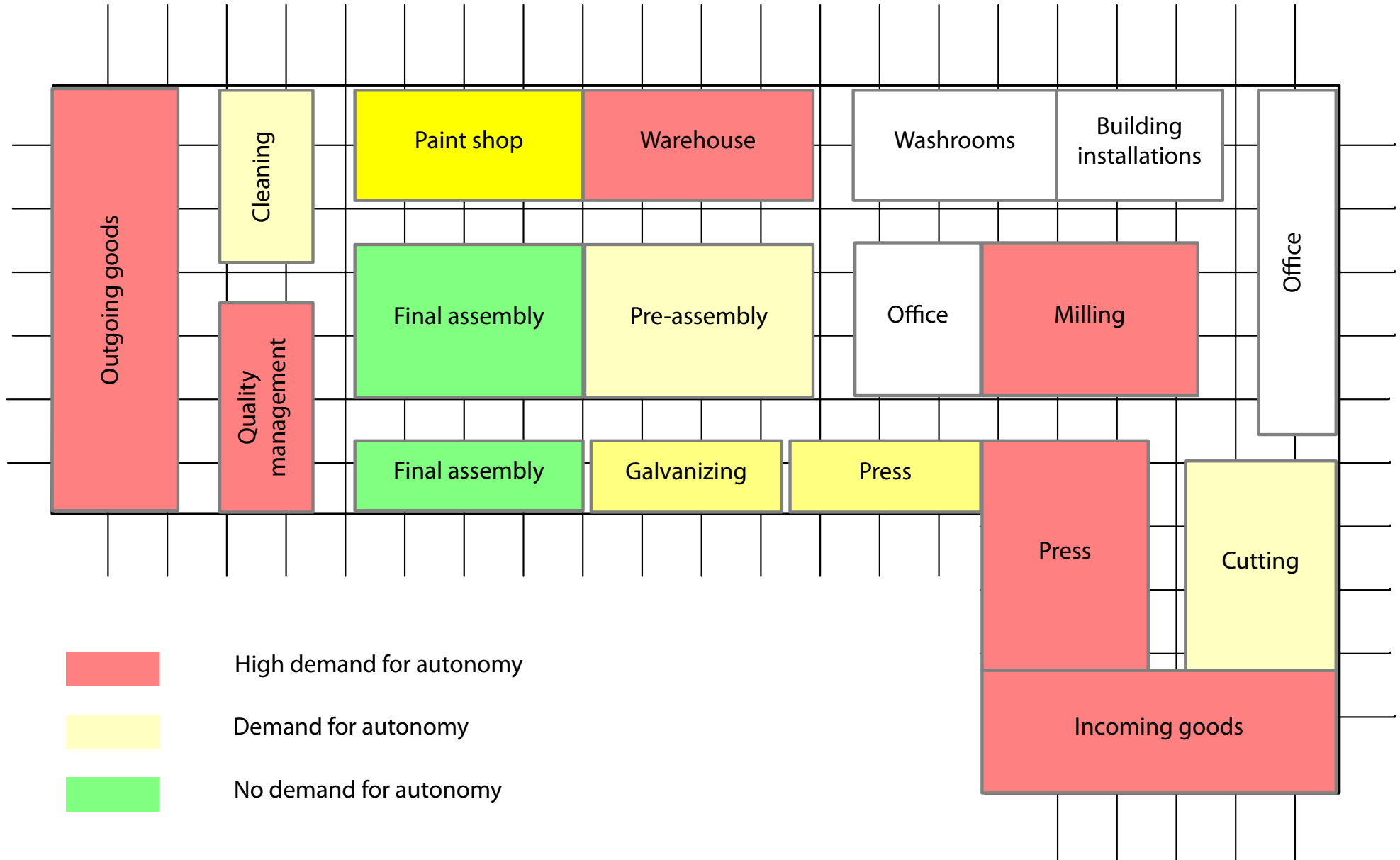
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# Example: Production of artificial knee joints

Attribute	Attribute values				Actual	Max
<b>Product range</b>	Specification by customer	Serial products with customer-specific variations	Standard products with variations	Standard products without variations		
<b>Need for autonomy</b>	++	+	o	-	0,33	1
<b>Product structure</b>	One-piece-product	Multiple-piece-products with simple structure	Multiple-piece-products with complex structure			
<b>Need for autonomy</b>	-	o	+		0,33	1
<b>Order trigger</b>	Manufacturing on demand with single orders	Manufacturing on demand with blanket orders	Manufacturing on stock			
<b>Need for autonomy</b>	++	+	o		0,66	1
<b>Disposition</b>	Following the customer's order	Mainly following the customer's order	Mainly MRP-based	MRP-based		
<b>Need for autonomy</b>	++	+	o	-	0,33	1
<b>Demand planning</b>	No relevant external supply	Relevant external supply	Huge external supply			
<b>Need for autonomy</b>	o	+	++		0,66	1
<b>Manufacturing process</b>	Unique manufacturing	Unique and small lot manufacturing	Serial manufacturing	Mass manufacturing		
<b>Need for autonomy</b>	++	+	o	-	0,33	1
<b>Manufacturing organization</b>	Construction site	Shop floor	Group-/ line assembly	Line production		
<b>Need for autonomy</b>	+	++	+	-	0,66	1
<b>Share of self-manufactured parts</b>	Low	Medium	High			
<b>Need for autonomy</b>	o	+	++		0,66	1
					3,96	8
				Autonomy demand	<b>49,5 %</b>	

# Example of an „autonomy heat map“





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# Modelling of fixed elements (e.g. machines)



Modeling only of the relevant properties



Cockpit



Communication

CPS

# Modelling of movable elements (e.g. workpieces)



Modeling only of the *relevant* properties



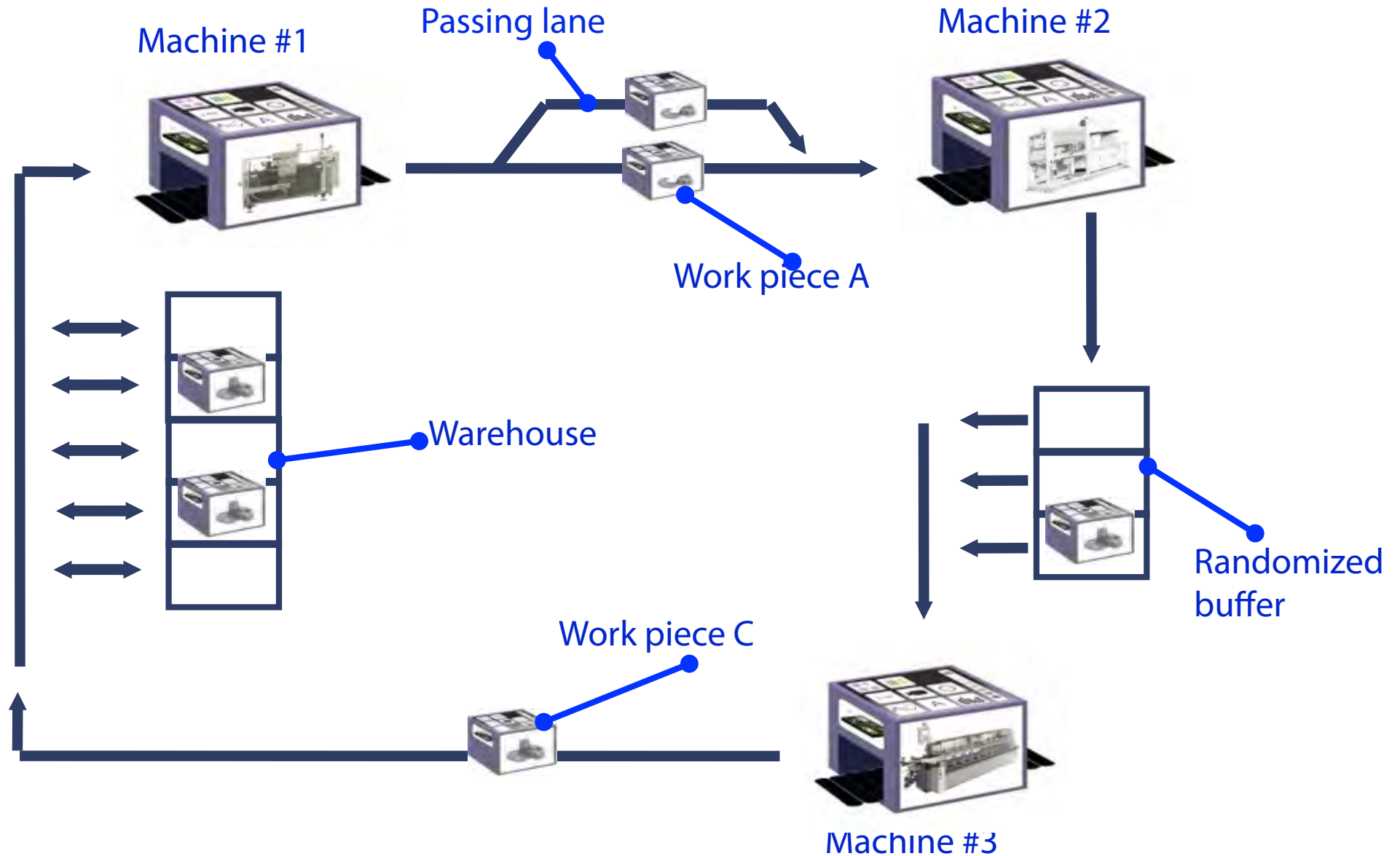
Cockpit



Communication

CPS

# Manufacturing and logistics processes in a factory





[www.industrie40-live.de](http://www.industrie40-live.de)

Part 4711 is missing

I need resupply!

Disturbance cleared in 50 min

New order: 50 pieces till Monday

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# Ongoing research

- How can we improve the adaptability of **existing** logistical and manufacturing processes?
- How do we mix human's and machine's autonomy?
- How can we improve the human-machine interface?

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