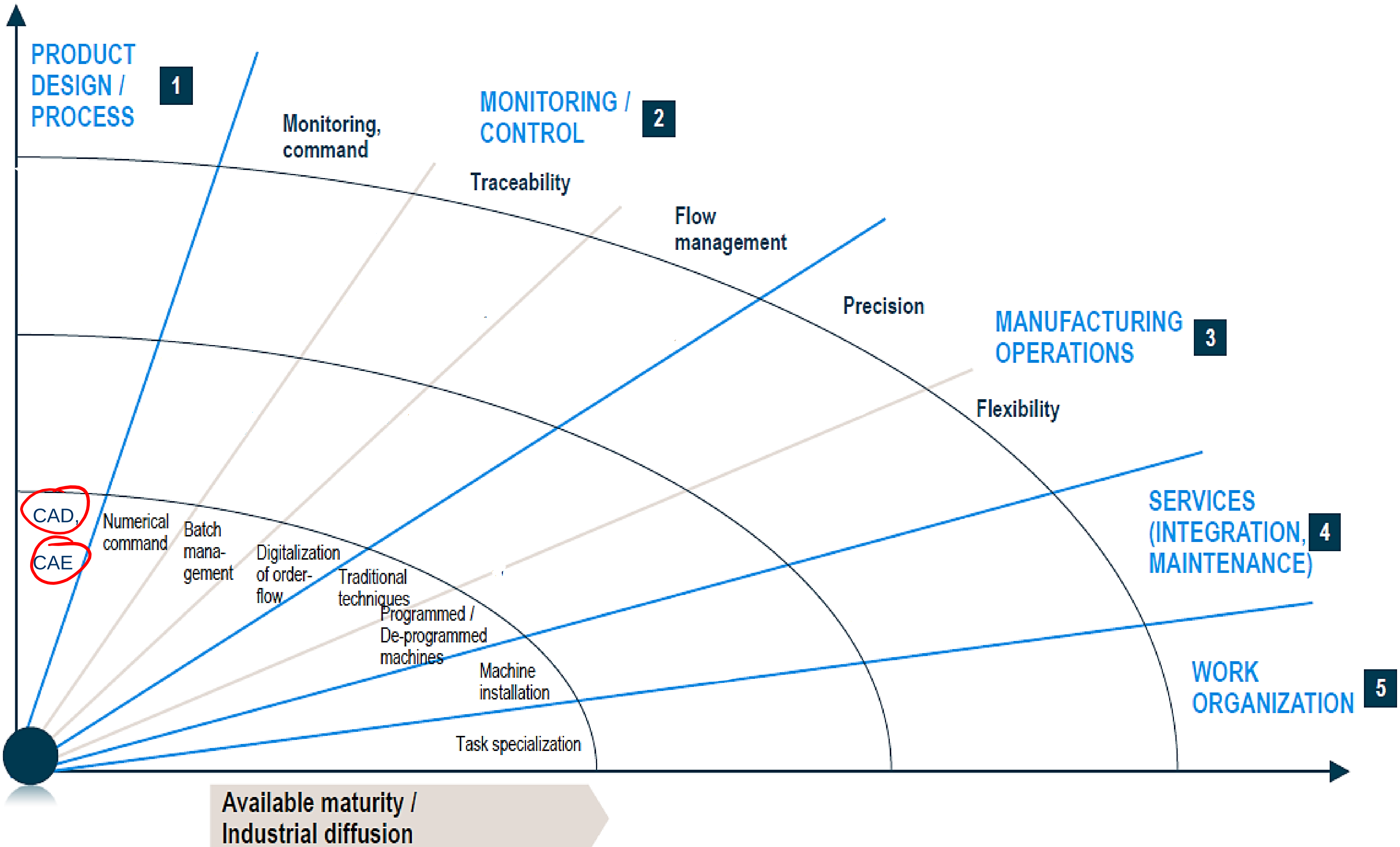
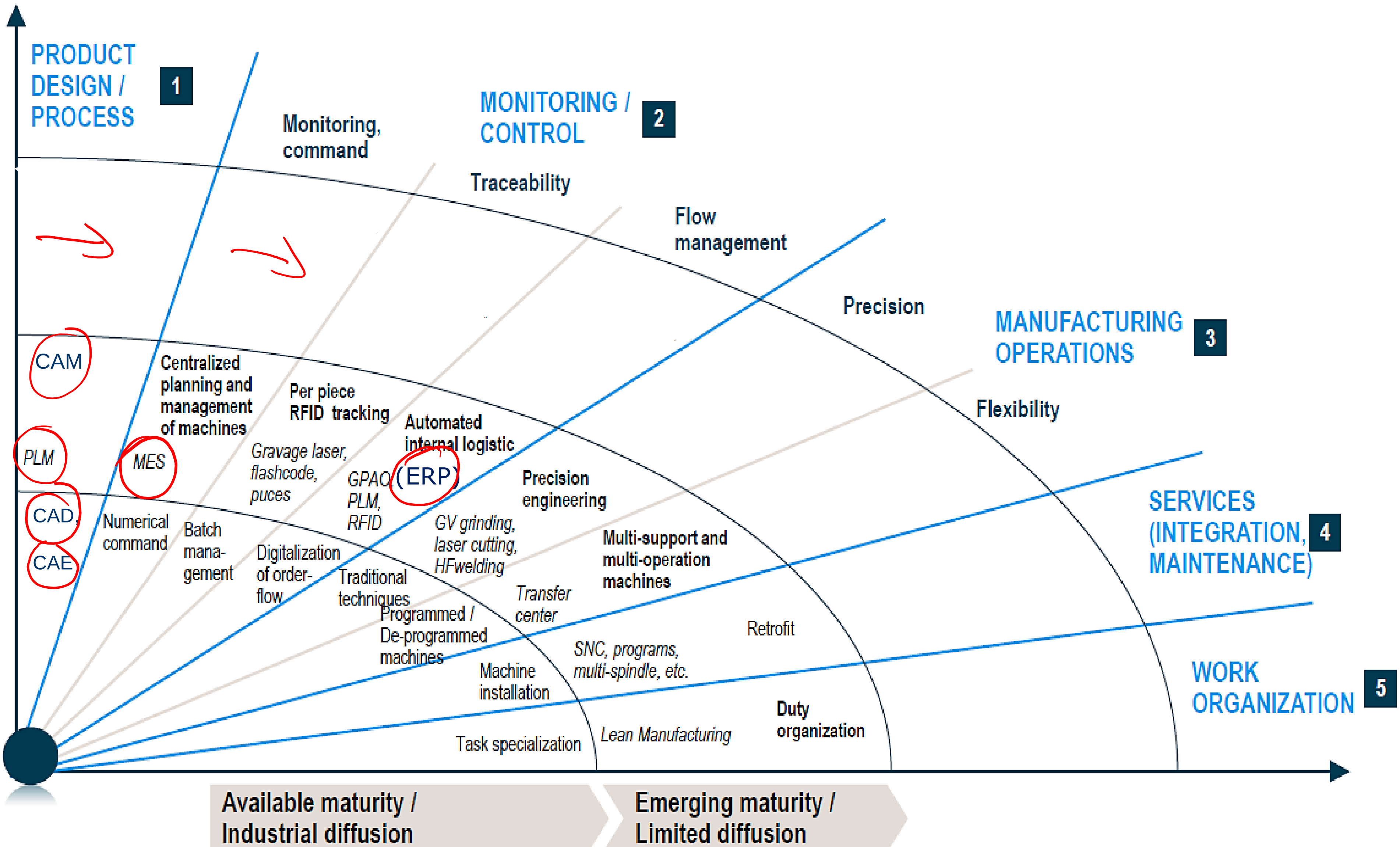
Disciplines, systems and technologies for I4.0

Industry 4.0 and smart factories rely on a wide range of known and new technologies



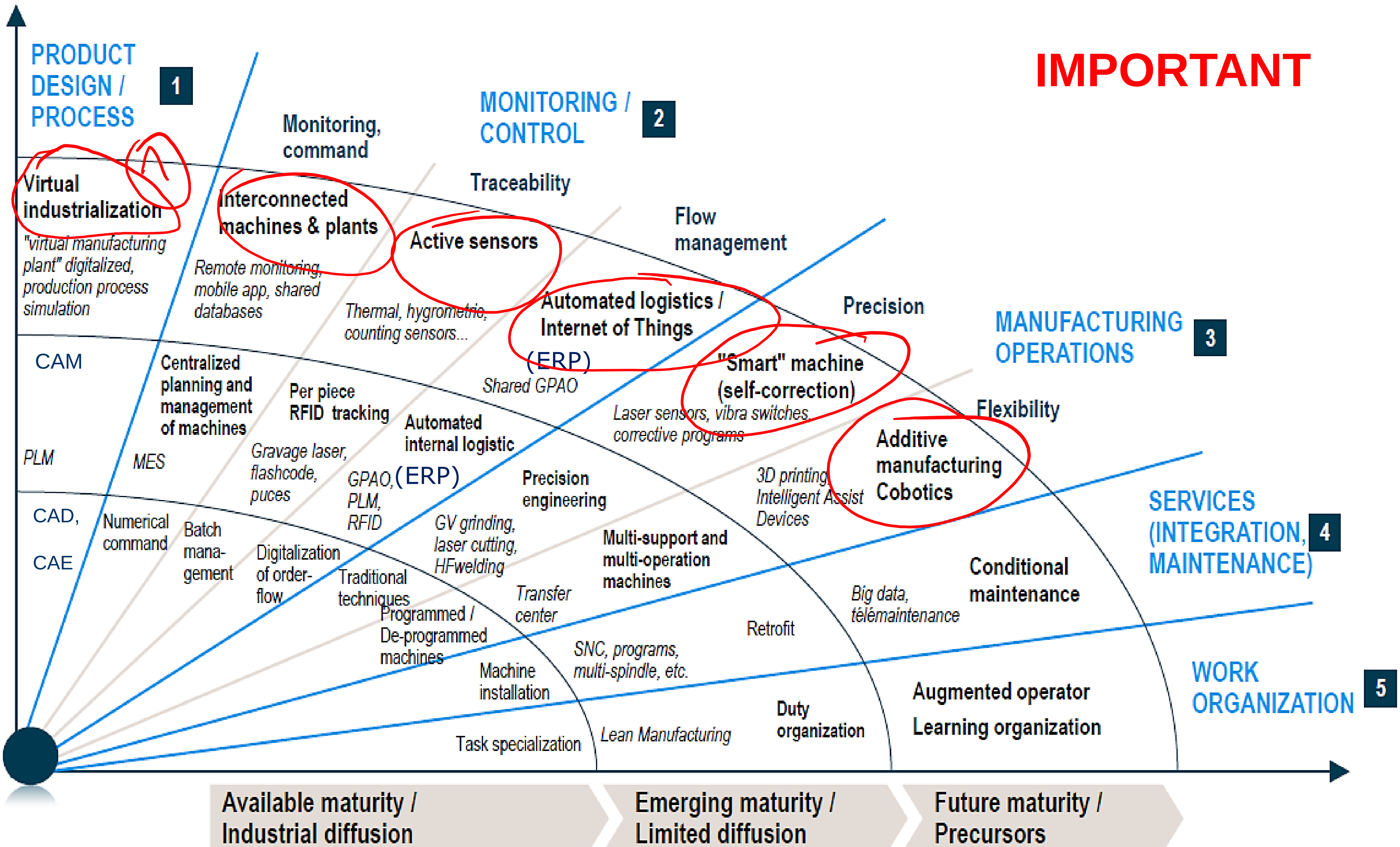
Source: Roland Berger

Industry 4.0 and smart factories rely on a wide range of known and new technologies



Source: Roland Berger

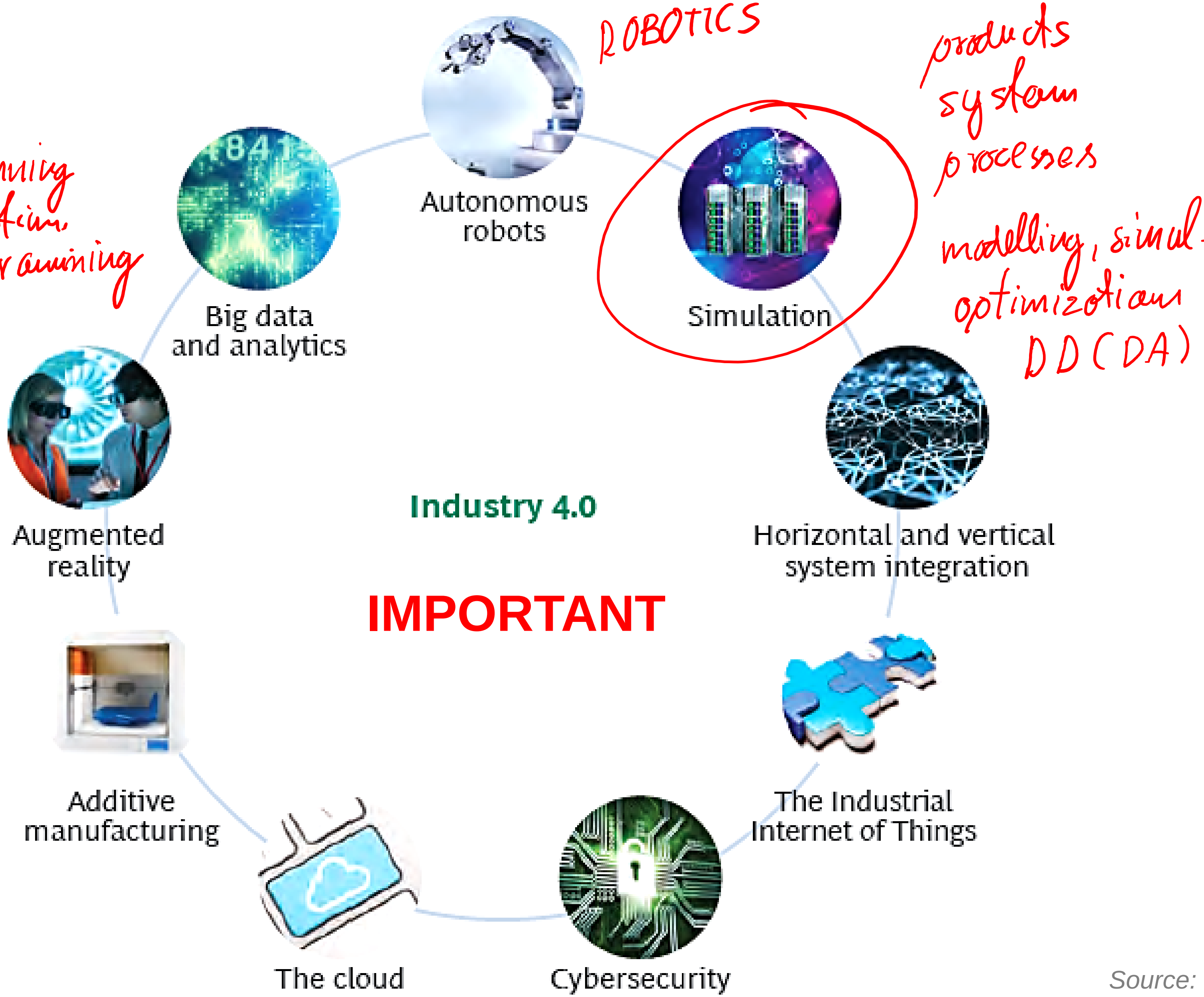
Industry 4.0 and smart factories rely on a wide range of known and new technologies



Source: Roland Berger

Key technologies for I4.0

Robotics:
- simul.
  - path planning
  - energy optim.
  - aut. programming
- sensors
  - security
  - MV machine vision



Source: BCG

Upcoming technologies I4.0

- Artificial intelligence (AI) and machine learning (ML) – LISP, Prolog, Python, C++, JAVA and other programme languages
- Blockchain technology
- New materials (for example graphene)
- Genetic and bio engineering, etc.
- New energy sources and energy storage technologies
- Quantum computing

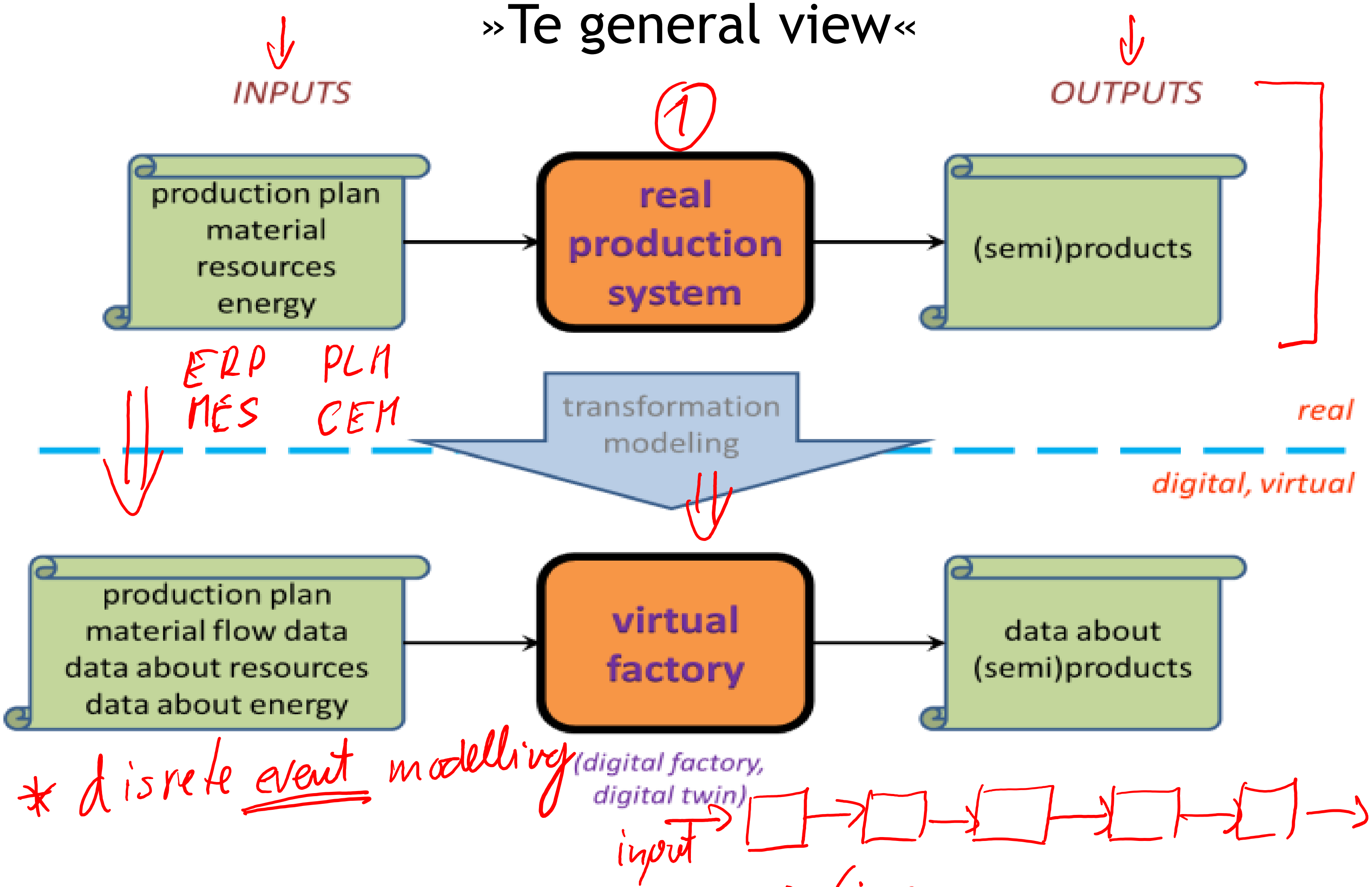
HPC => QC
heuristics
edge (local)

Modelling, simulation and optimization of production systems

IMPORTANT

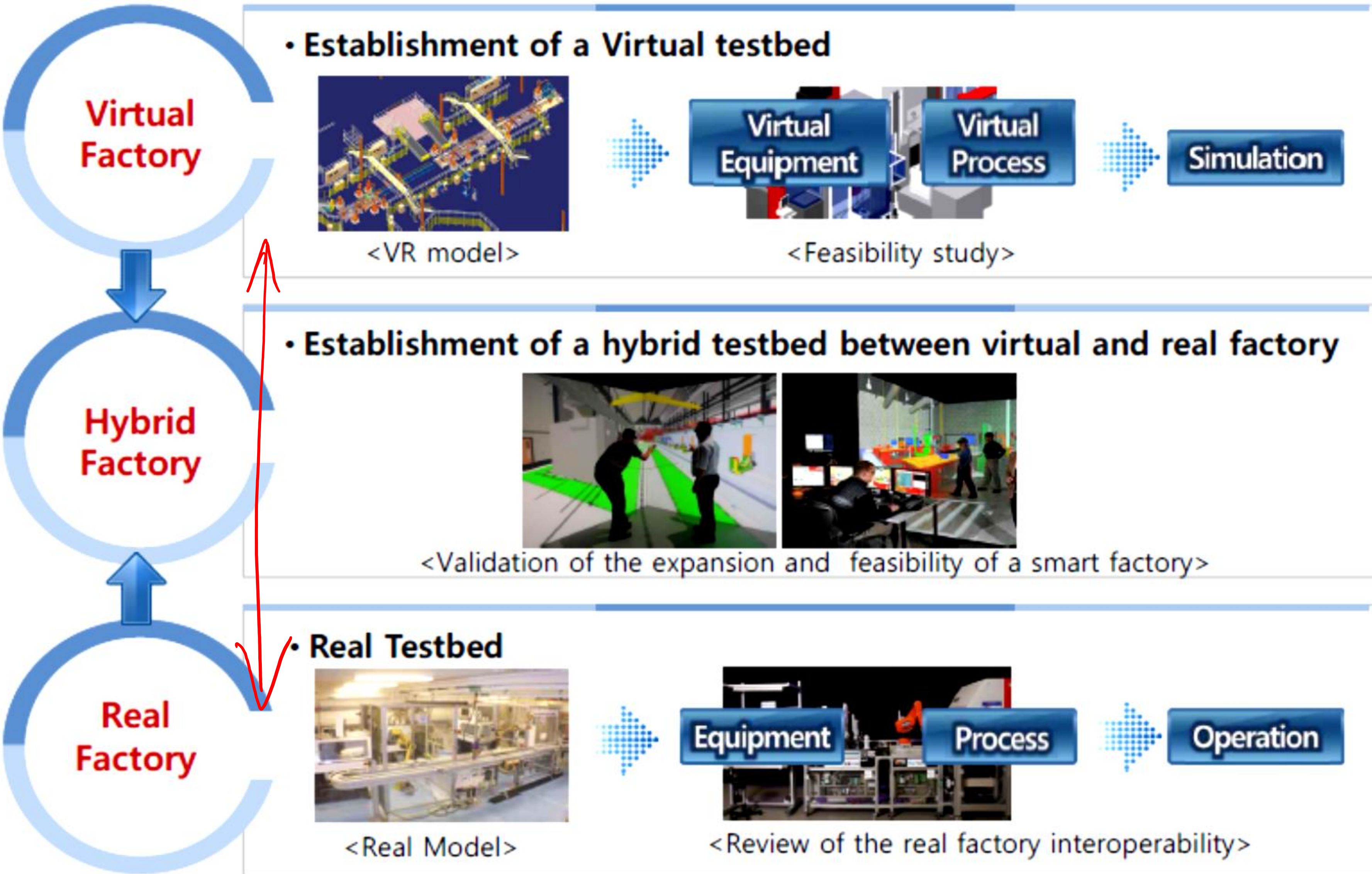
Optimization through modeling and simulation

»Te general view«



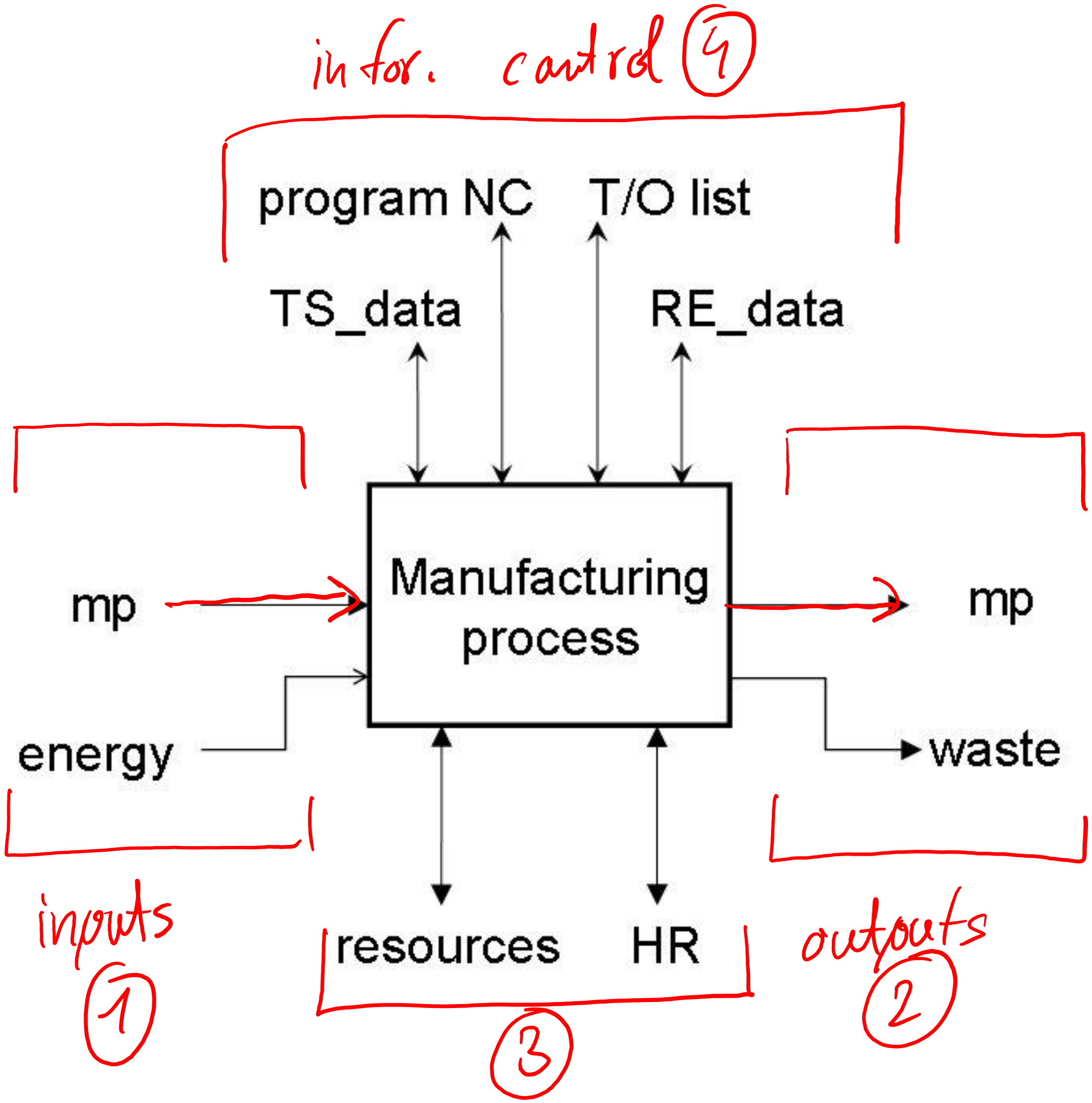
BASIC IDEA: to perform the scheduled production process in a computer in the same way as it performs in the real environment

DIGITAL TWIN



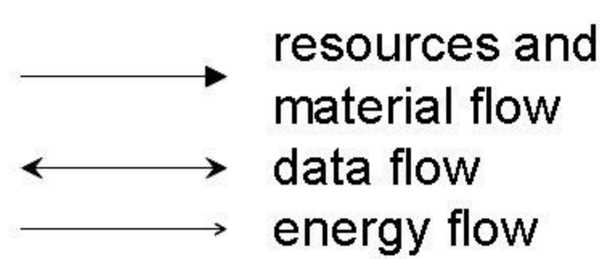
IMPORTANT

Production process (Assembly, Handling) – inputs and outputs

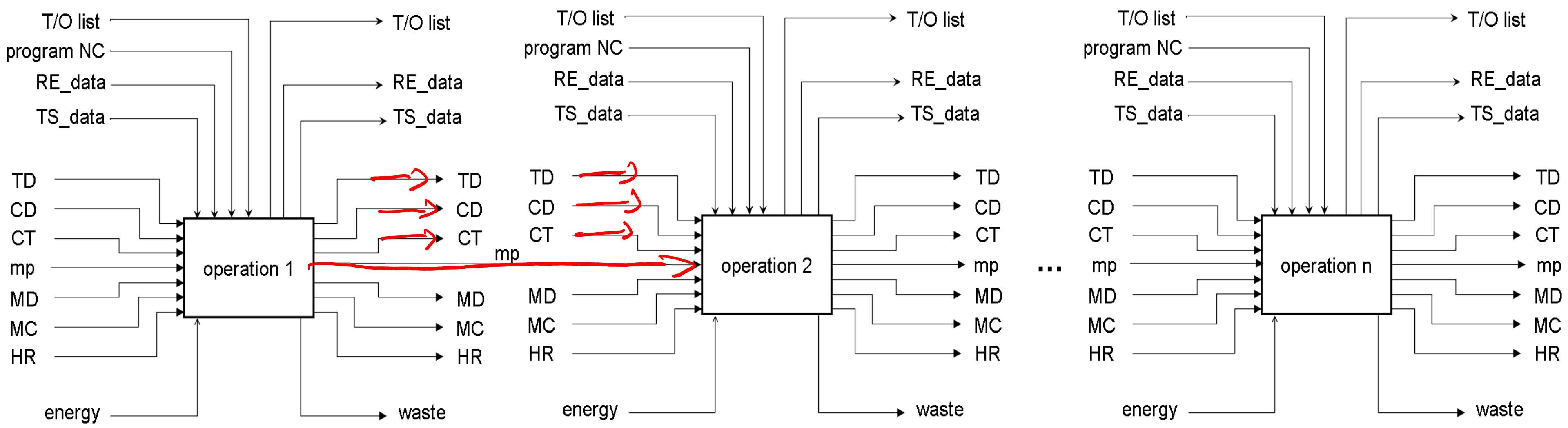


mp – machining part
HR – human resources

T/O list – technological list/ list of operations
RE_data – data of resources
TS_data – time schedule data



Production process (Assembly, Handling) – sequence of operations



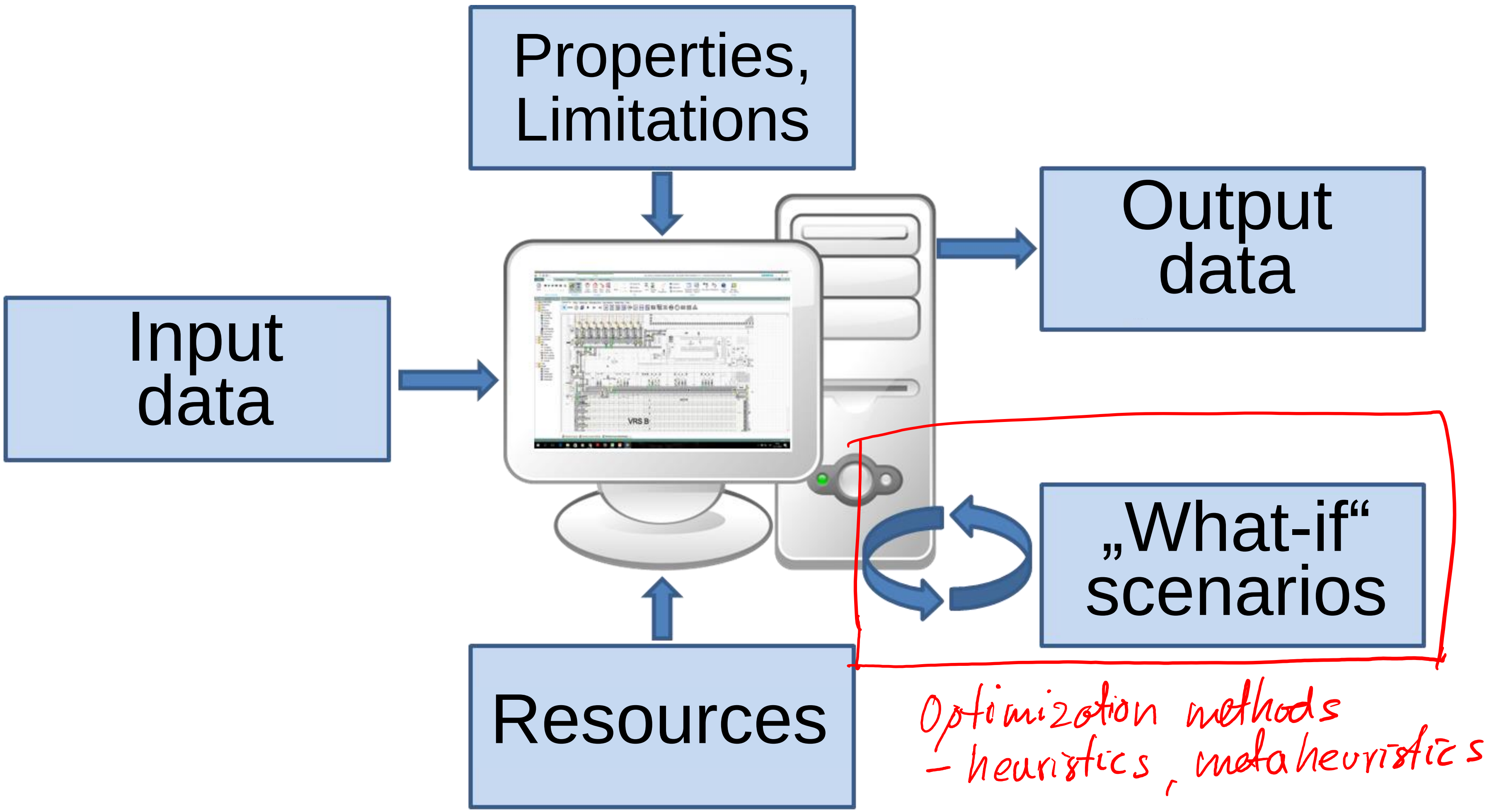
TD – transportation devices
CD – clamping devices
CT – cutting tools
mp – machining part
MD – measuring devices
MC – machining centre
HR – human resources

T/O list – technological list/list of operations
RE_data – data of resources
TS_data – time schedule data

→ resources and material flow
→ data flow
→ energy flow

IMPORTANT

Optimization through modelling and simulation

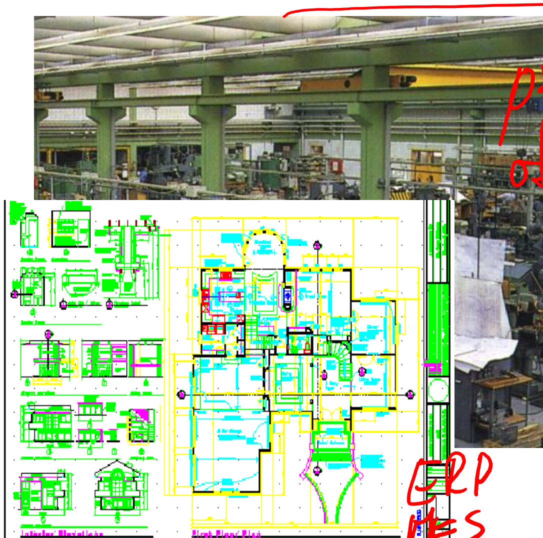


Simulation is the best tool for execution of the „What-IF“ scenarios.

IMPORTANT

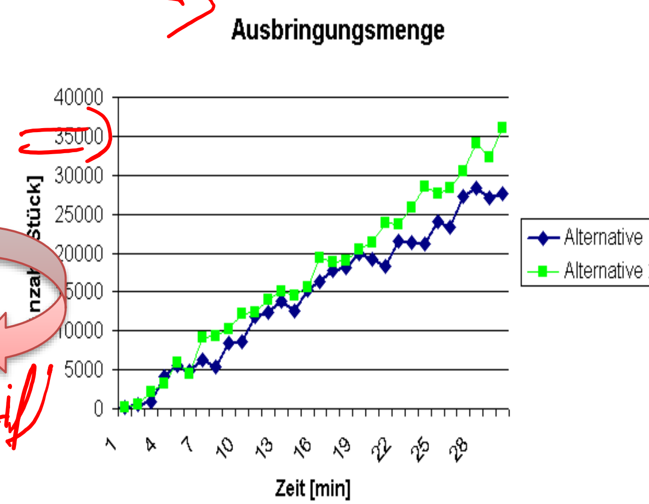
Principle of Production process simulation

Real System/Plan



Simulation Model

Simulation Result



preparation of data

ERP
MES

layout
data
structure
mat. flow

off-line simul

what-if

1

2

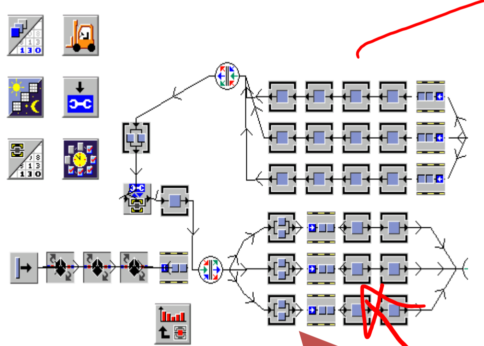
3

Source: Siemens PLM Software

Digital Factory - From simulation to optimization

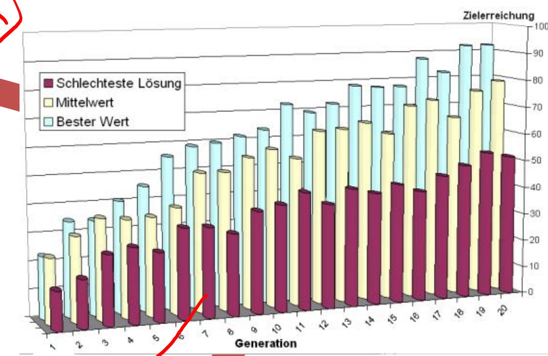
Optimization automatically generates improved results.

Simulation Model



Parameters 1:
e.g. Buffer size: 25
Skids: 100
AGVS Batteries 3
Loading stations 2

Simulation Results



Parameter
Buffer size 0-100
Skids 50-200
AGVS Batteries 1-3
Loading stations 1-5

Parameters n:
e.g. Buffer size 20
Skids 125
AGVS Batteries 2
Loading stations 2

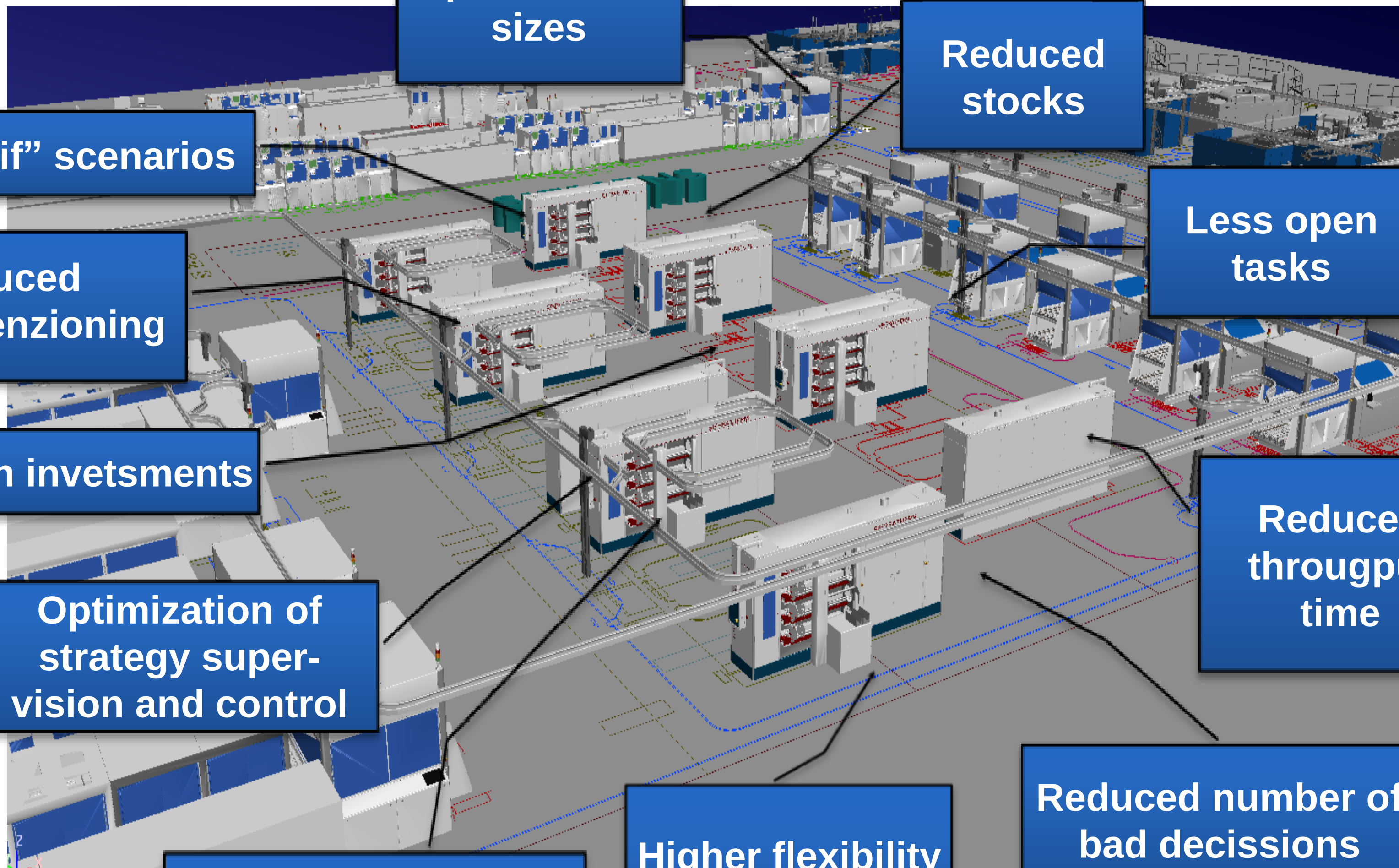
Results
e.g. Profit = Production quantity*Price-Production costs-Penalty for Delay in Delivery

Mechanism: Combine better solutions by using the good ones (Darwin).

Source: Siemens PLM Software

IMPORTANT

Digital factory – What the simulation makes possible

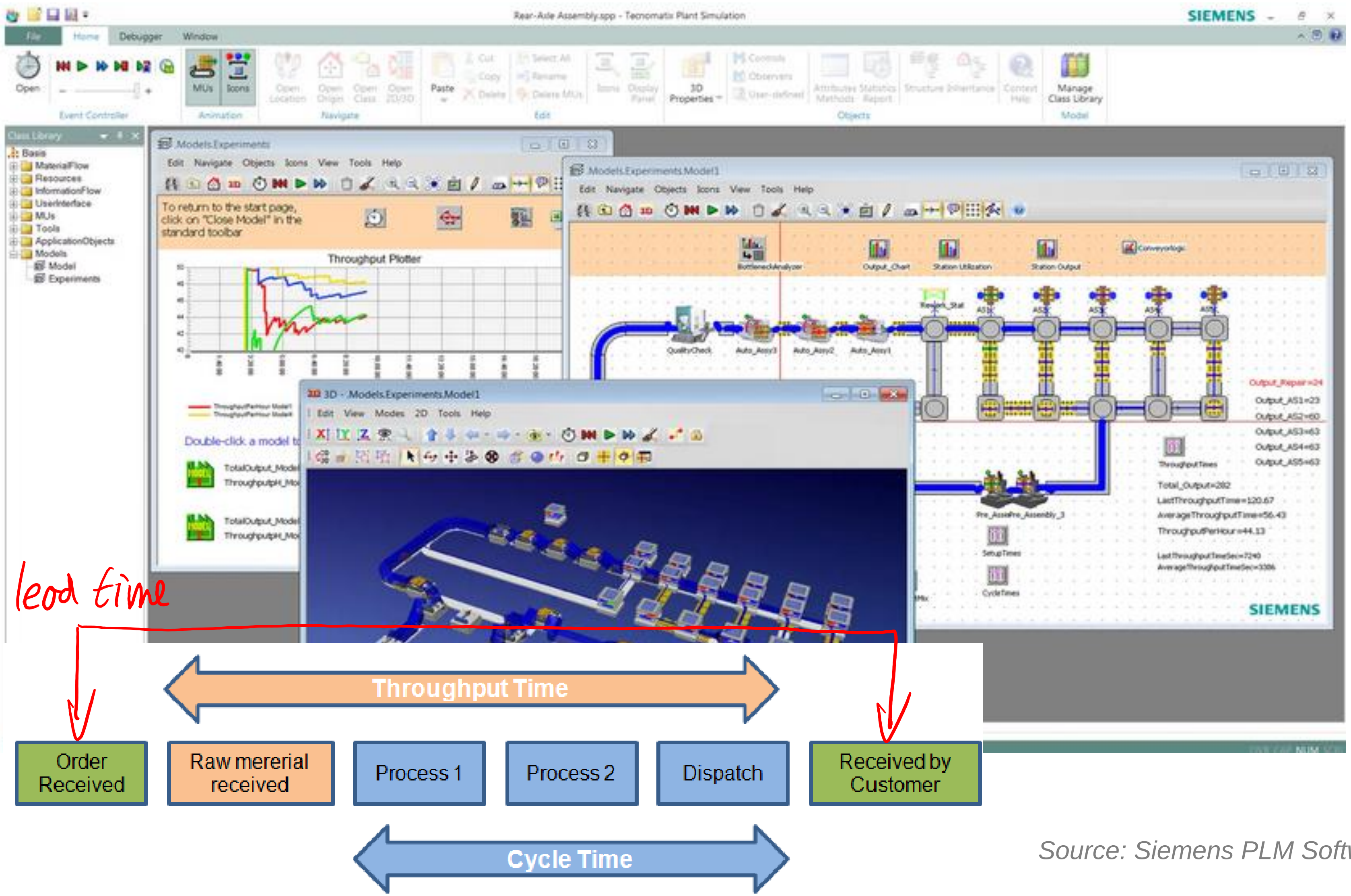


Source: Siemens PLM Software

Digital Factory - What Simulation Enables

IMPORTANT

Throughput Optimization

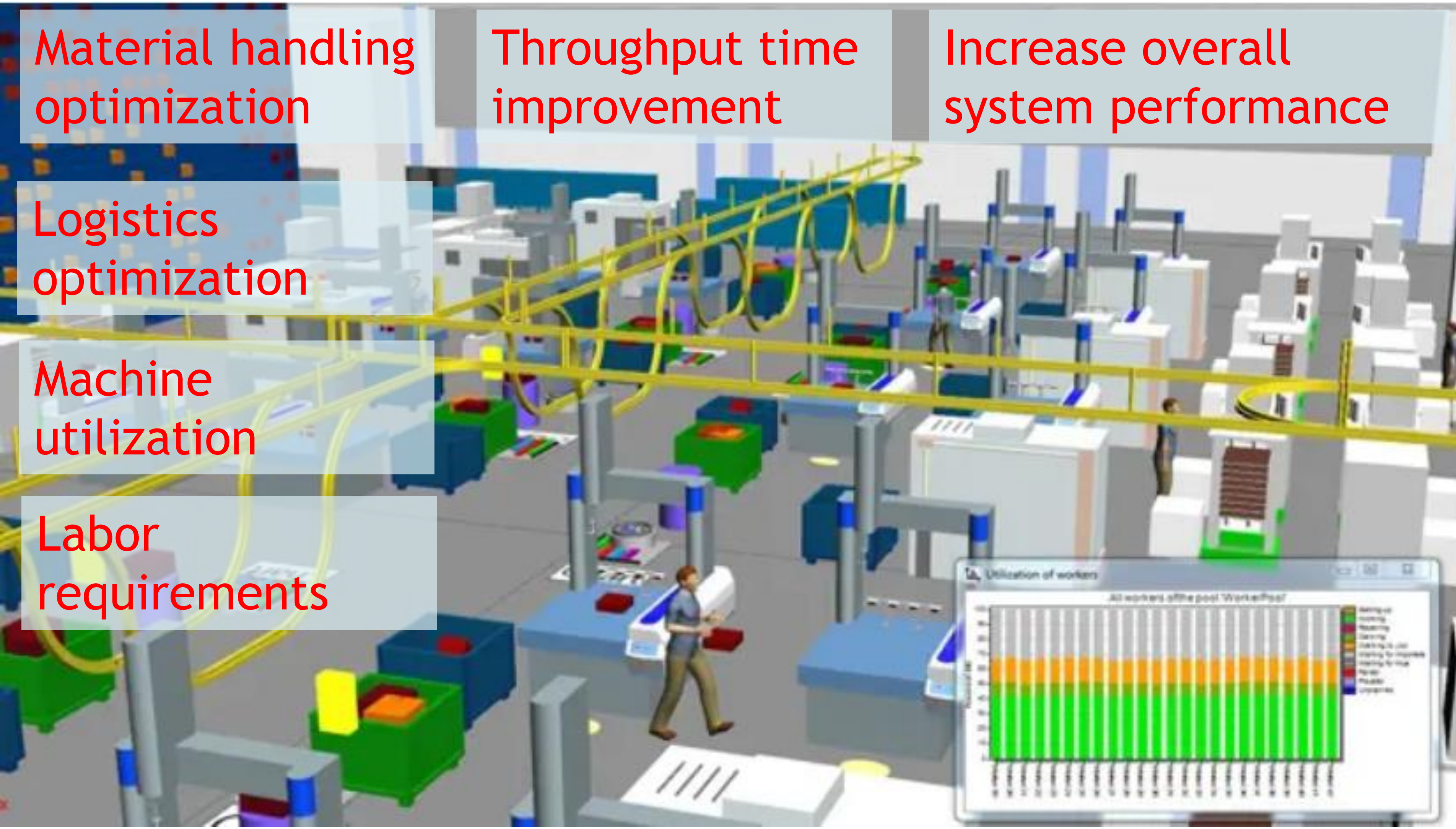


Source: Siemens PLM Software

IMPORTANT

Digital Factory - What Simulation Enables

Analyze Production Systems with 2D and 3D Statistical Simulation

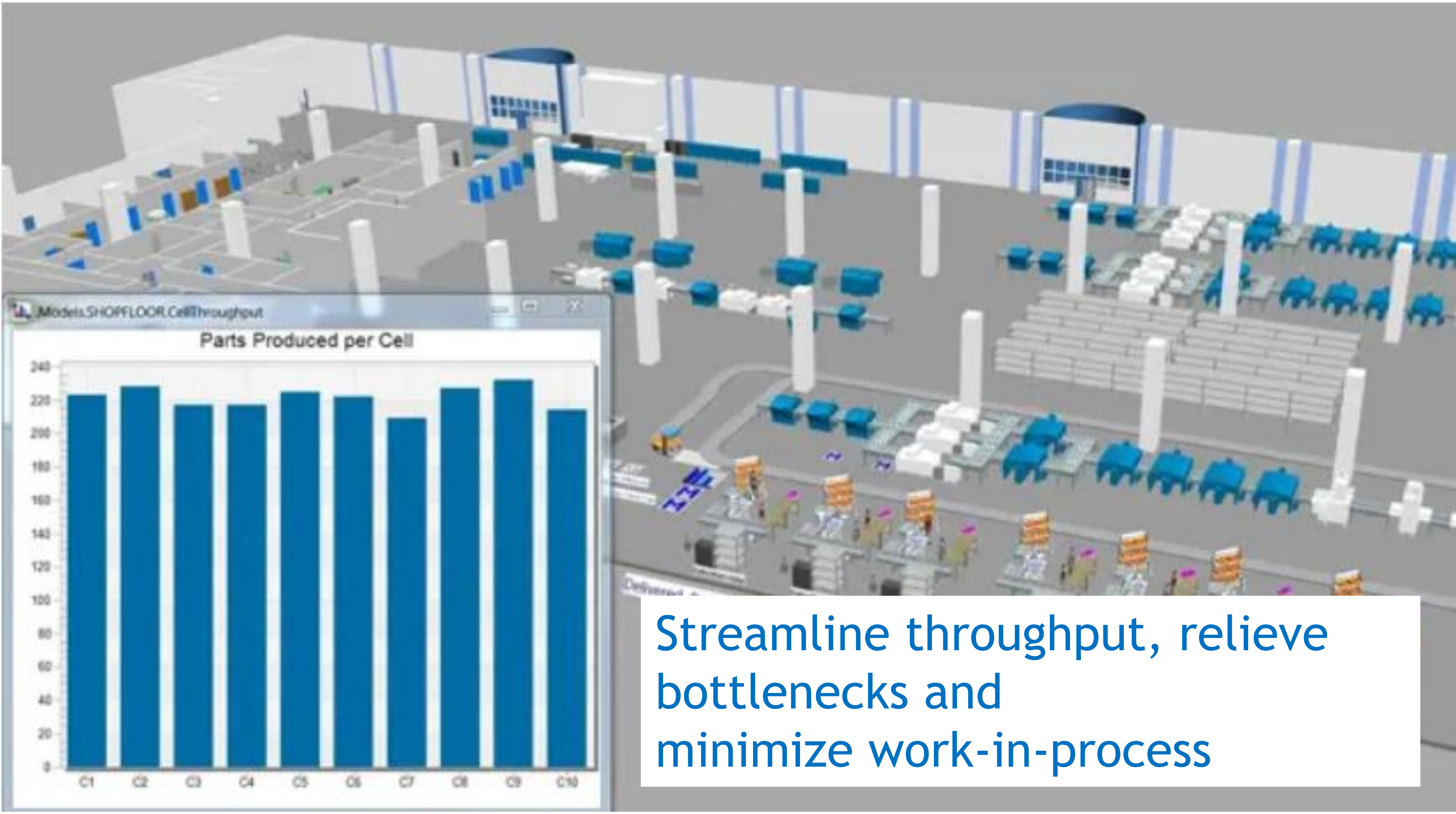


Source: Siemens PLM Software

IMPORTANT

Digital Factory - What Simulation Enables

Eliminate Bottlenecks and Streamline Throughput



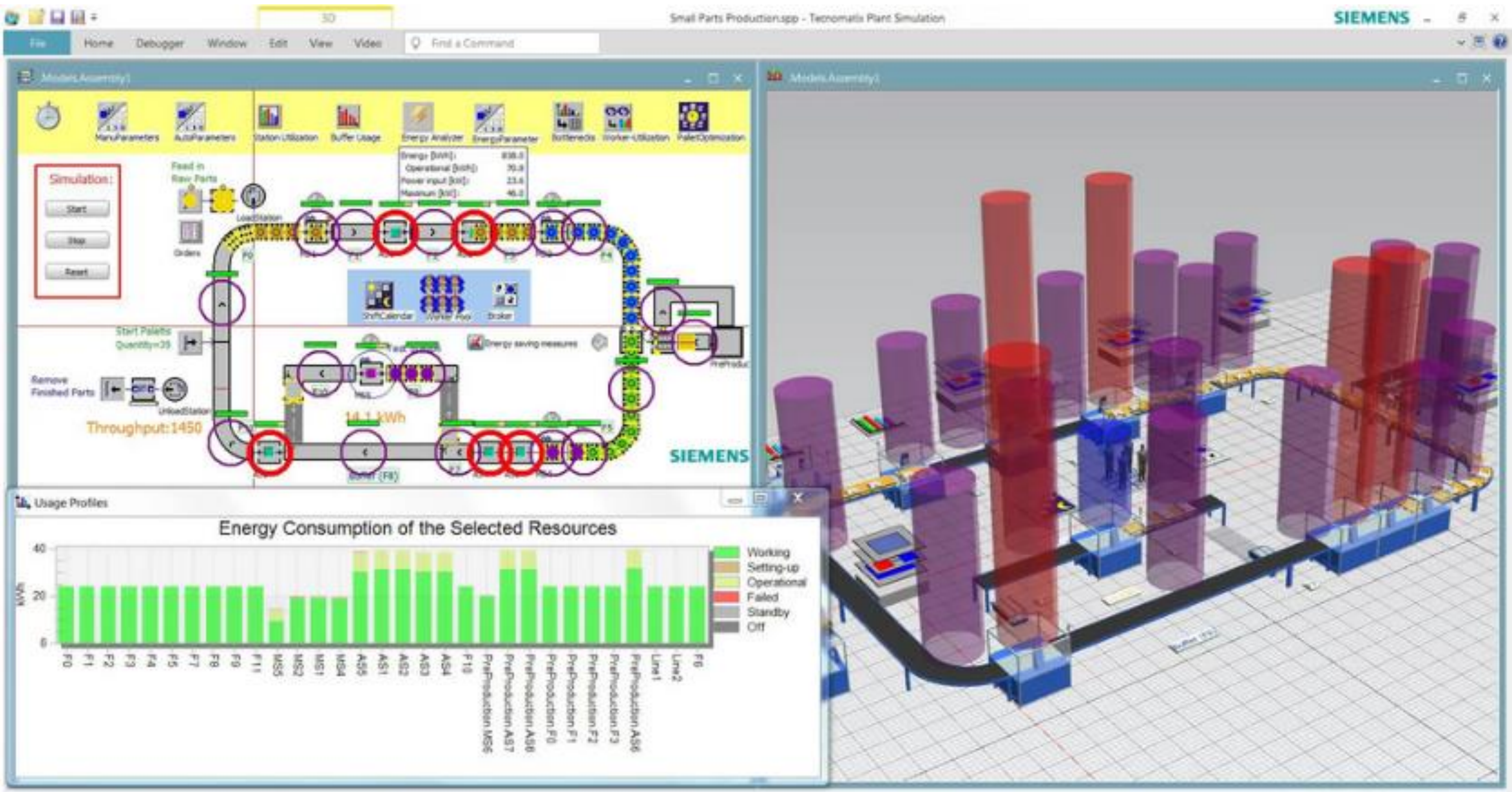
Streamline throughput, relieve bottlenecks and minimize work-in-process

Source: Siemens PLM Software

IMPORTANT

Digital Factory - What Simulation Enables

Optimize Energy Usage for Improved Performance



Source: Siemens PLM Software

IMPORTANT

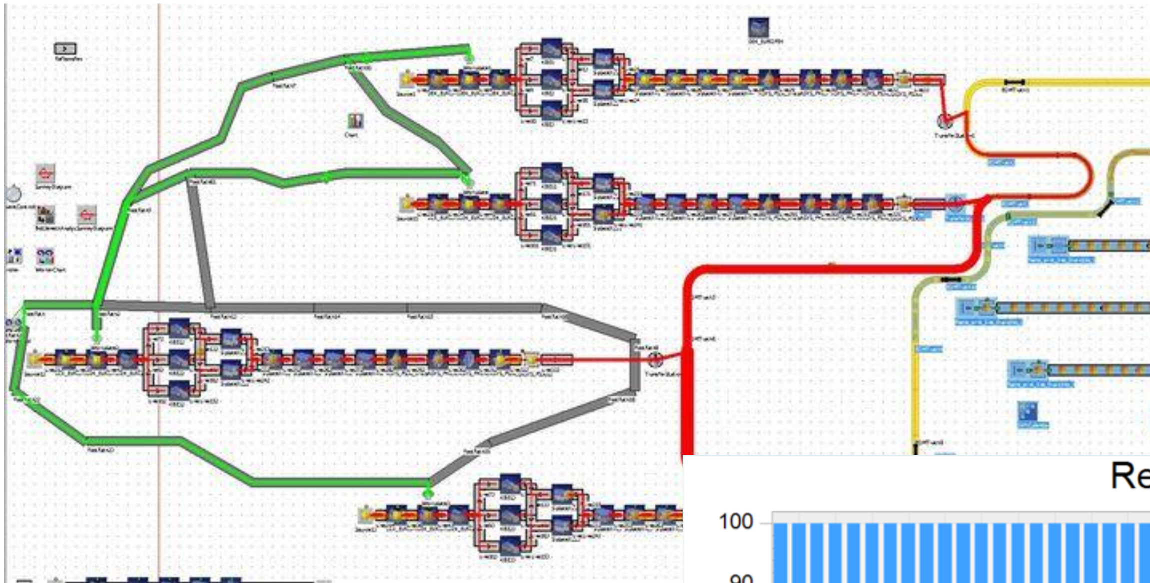
Digital Factory - What Simulation Enables

Virtually Commission Production Systems Prior to Startup

Virtual model of the plant linked to real plant control to simulate actual production

Source: Siemens PLM Software

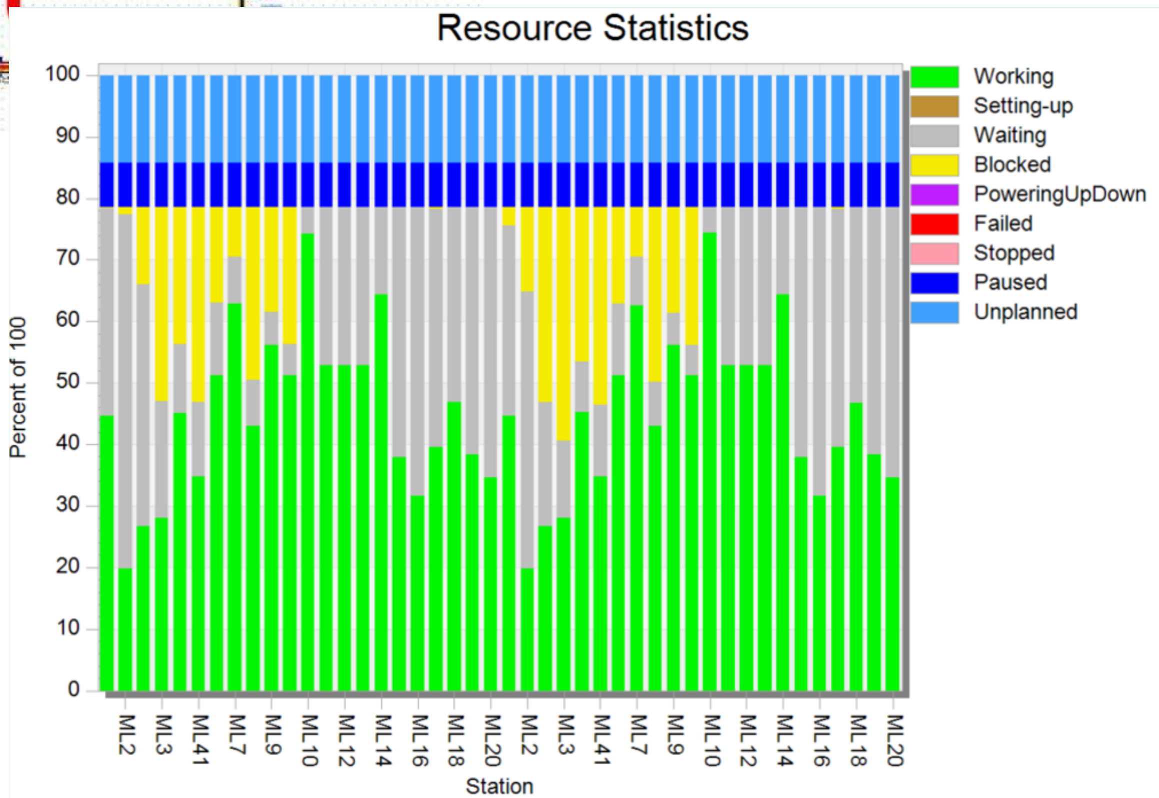
Visualization



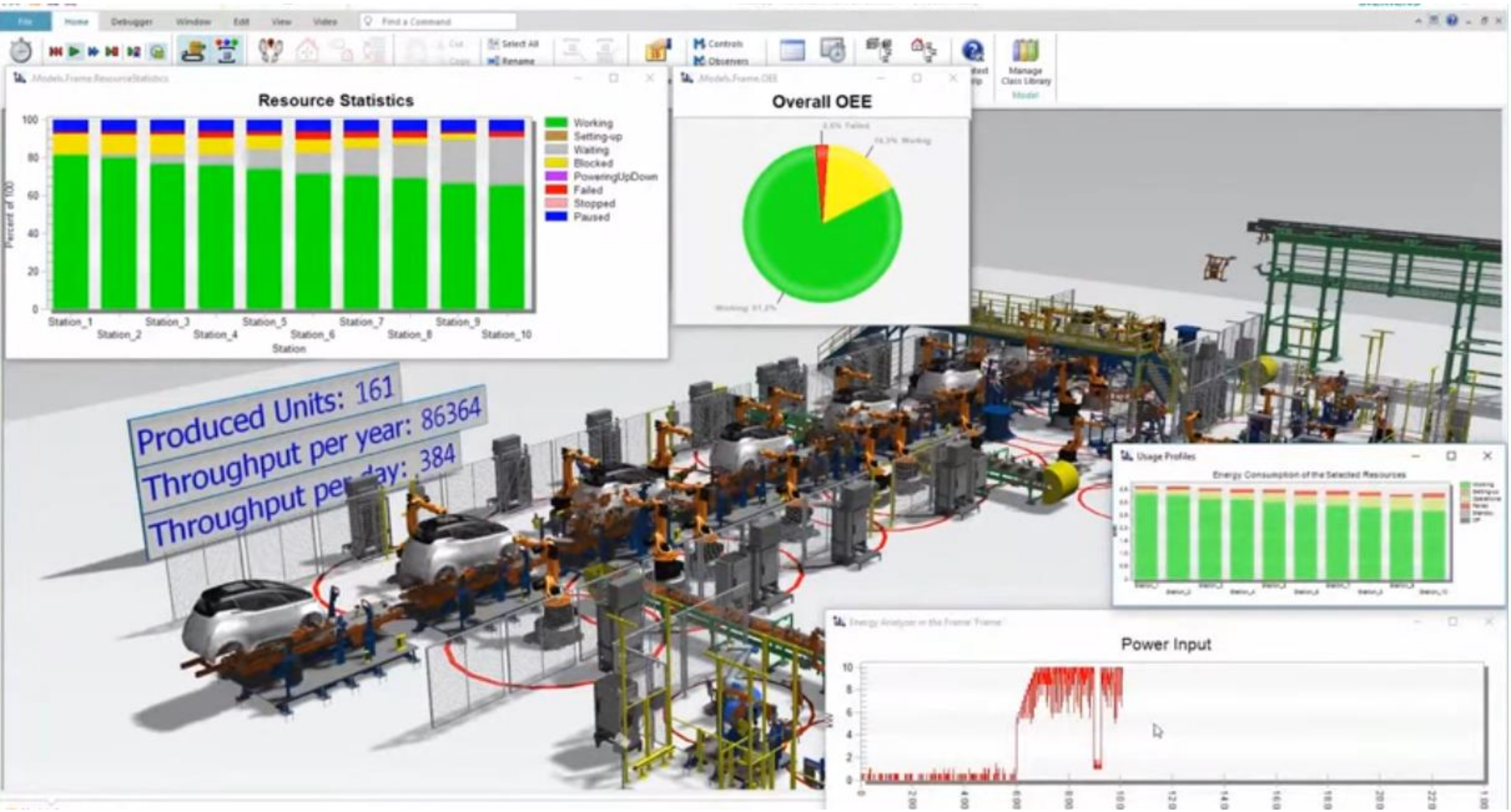
Material flow density analysis

Sankey Diagram

Asset and resources occupancy analysis



3D visualization



https://www.youtube.com/watch?v=yI4sk27DYLI

IMPORTANT

Digital factory – main goals

- ✓ Production optimization in computer
- ✓ Optimization execution in advance - before the real and expensive corrections would be necessary in real production
- ✓ Minimization of start times of the real production
- ✓ **Maximization of productivity**

IMPORTANT

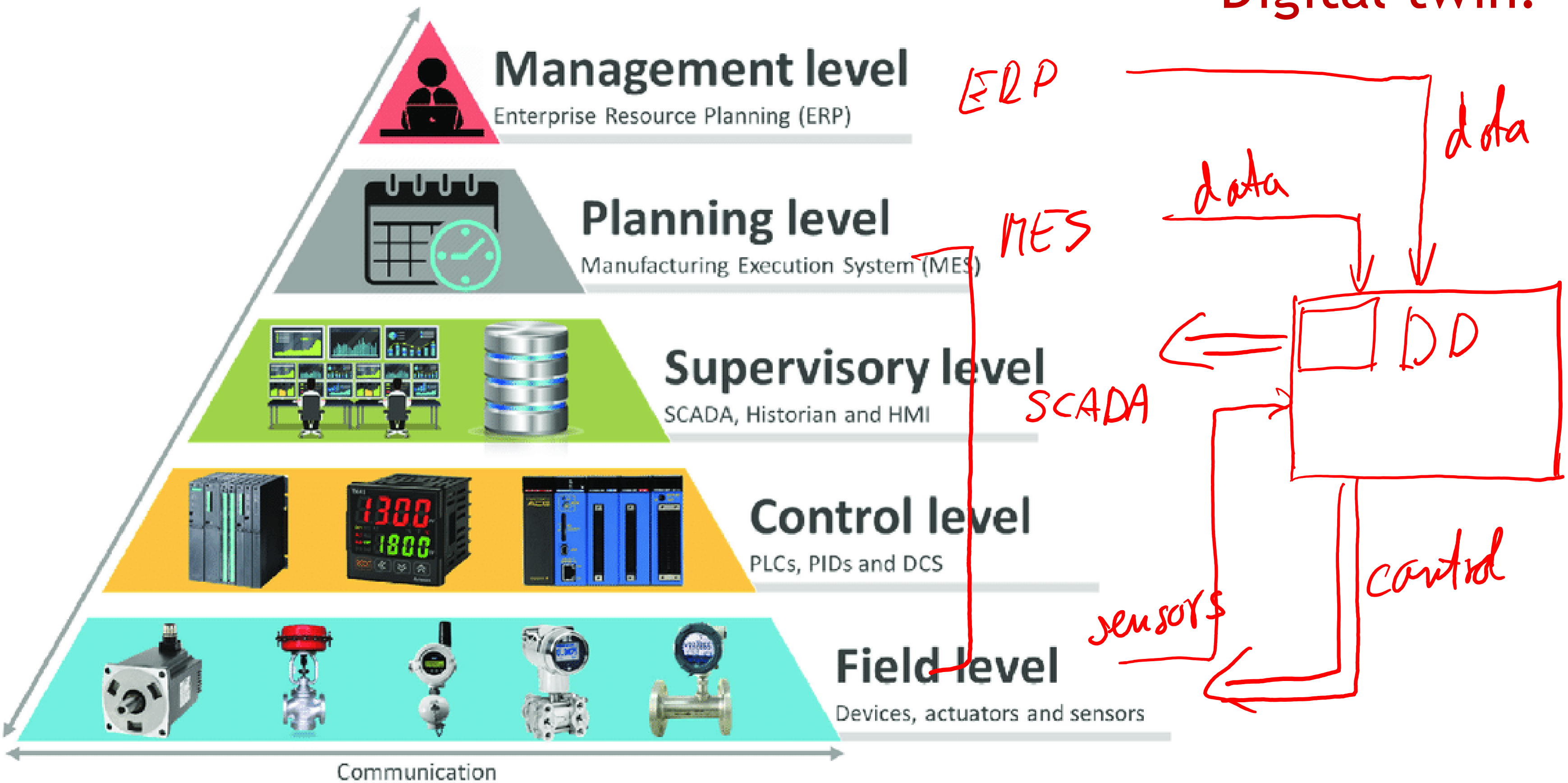
Digital factory – advantages and savings

- As much as **6% savings on investment cost** (VDI, Association of German Engineers)
- As much as **20% productivity** increase of existing systems
- As much as **20% reduced cost of new systems**
- As much as **60% decreased throughput time and inventory** (Average savings found in European market survey)

IMPORTANT

What the "virtual manufacturing„ technique enables?

Digital twin?



Automation pyramid

Distributed systems, local digital twins, local digital agents!

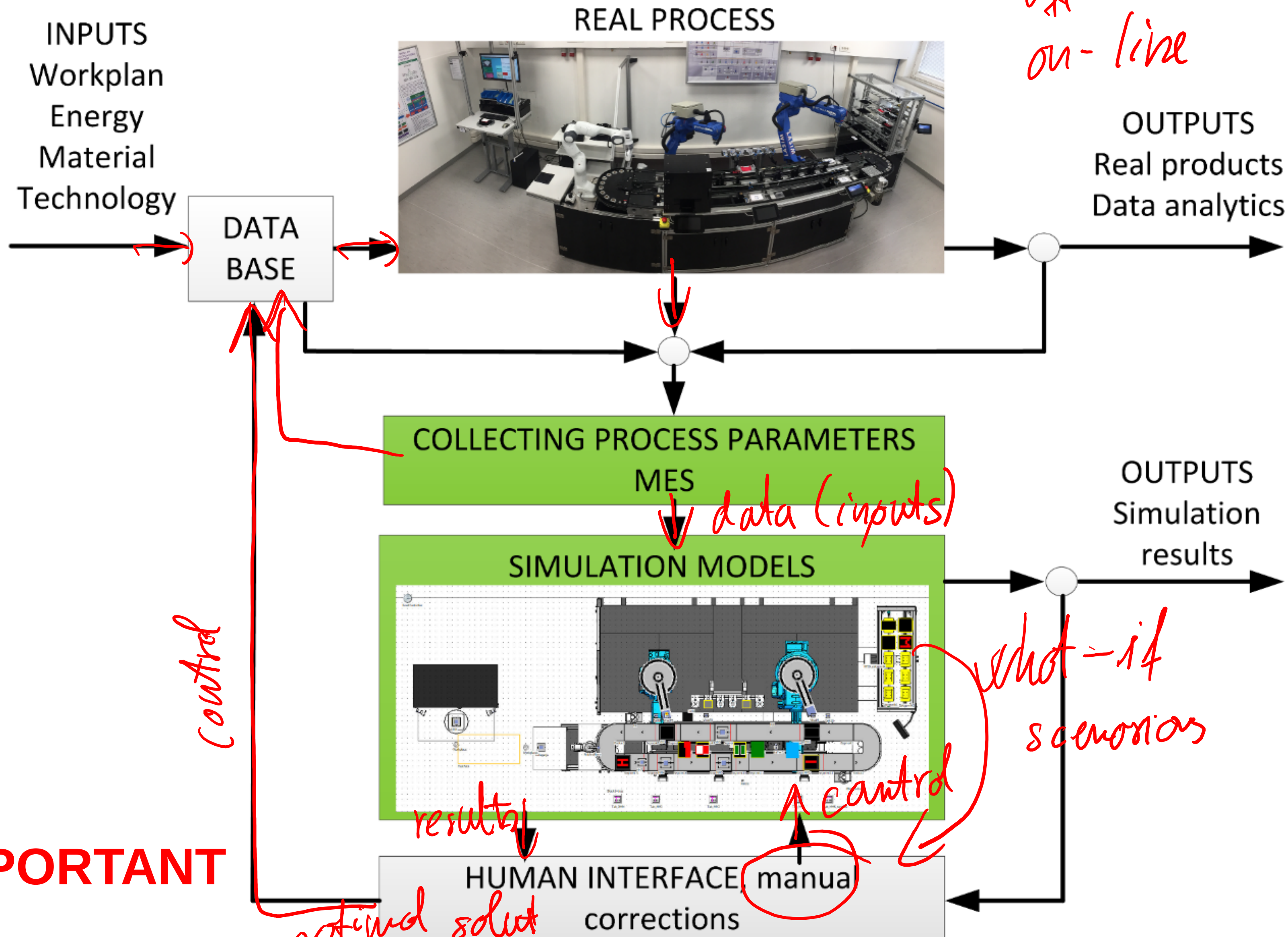
IMPORTANT

What the "virtual manufacturing„ technique enables?

- Faster and better adaptation of production to the needs of the market and orders
- A significant improvement in the efficiency of production, warehouses, logistics, etc.)
- Significant reduction of production time of individual products,
- Stock optimization
- Optimizing the supply chain
- Detecting the dangers of delays and bottlenecks in the virtual environment and eliminating them before real production begins
- etc.

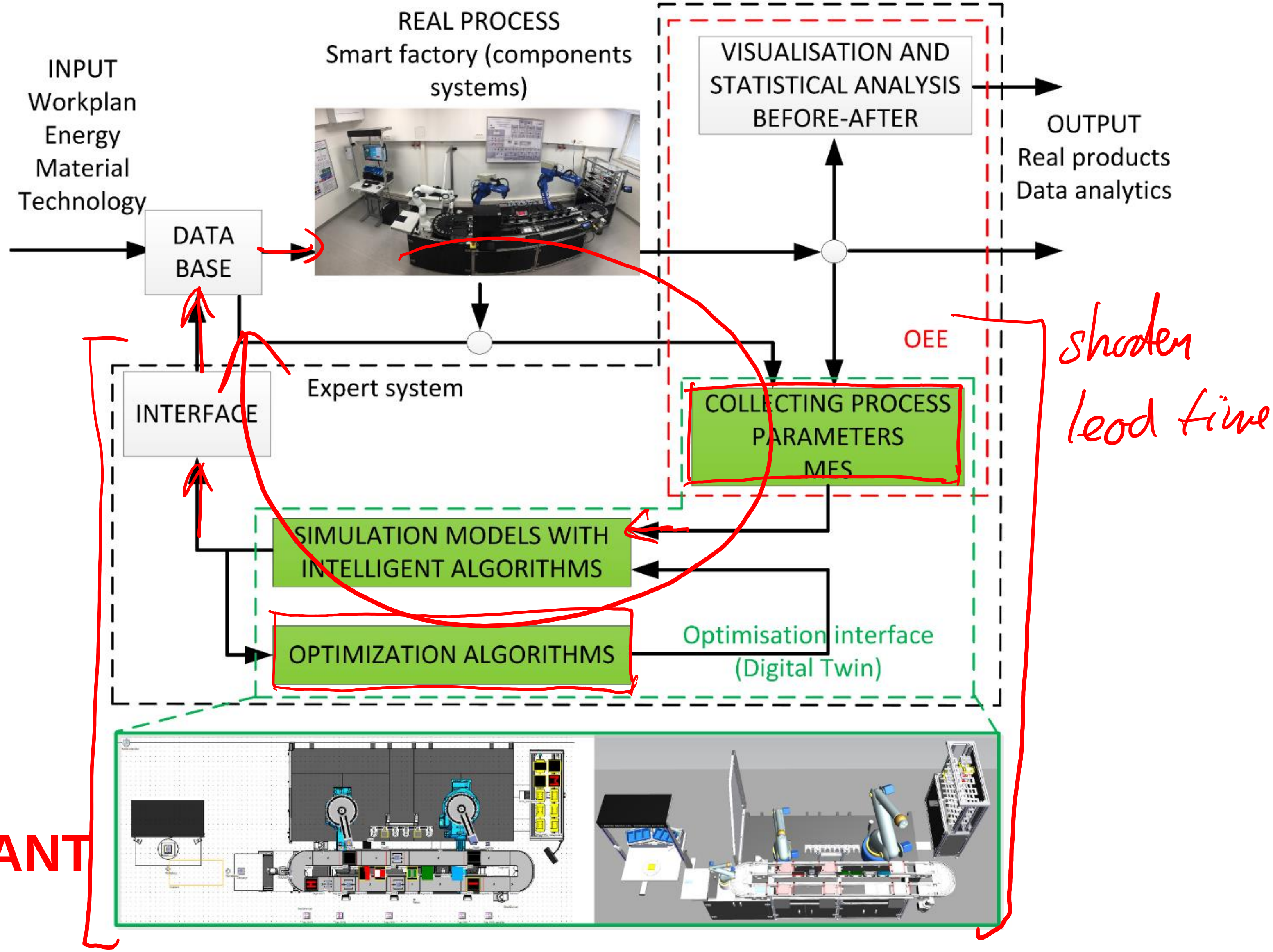
TODAY → "Off-Line" simulation

Important for understand
off-line
on-line



IMPORTANT

Future →Expert system with the simulation in "REAL time"

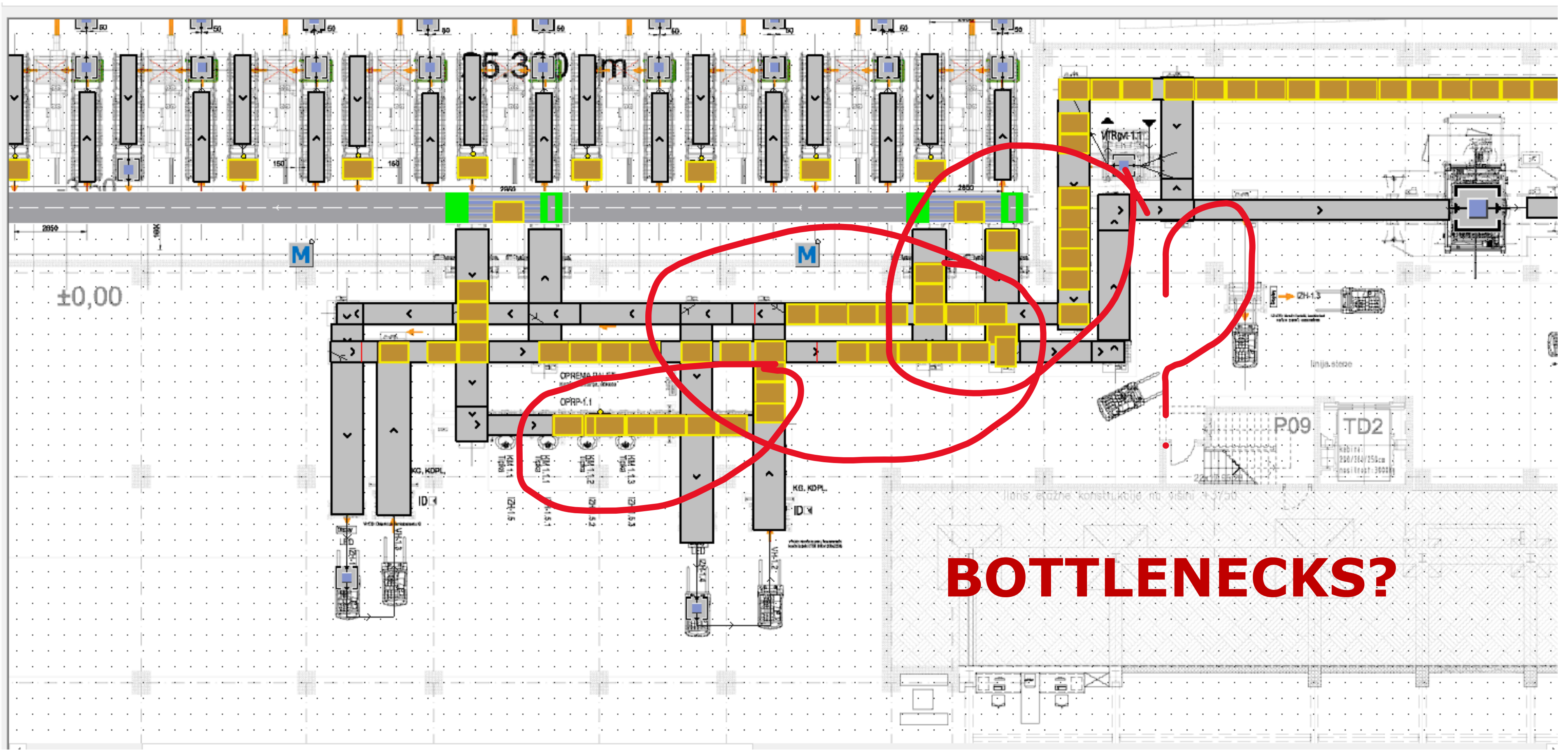


IMPORTANT

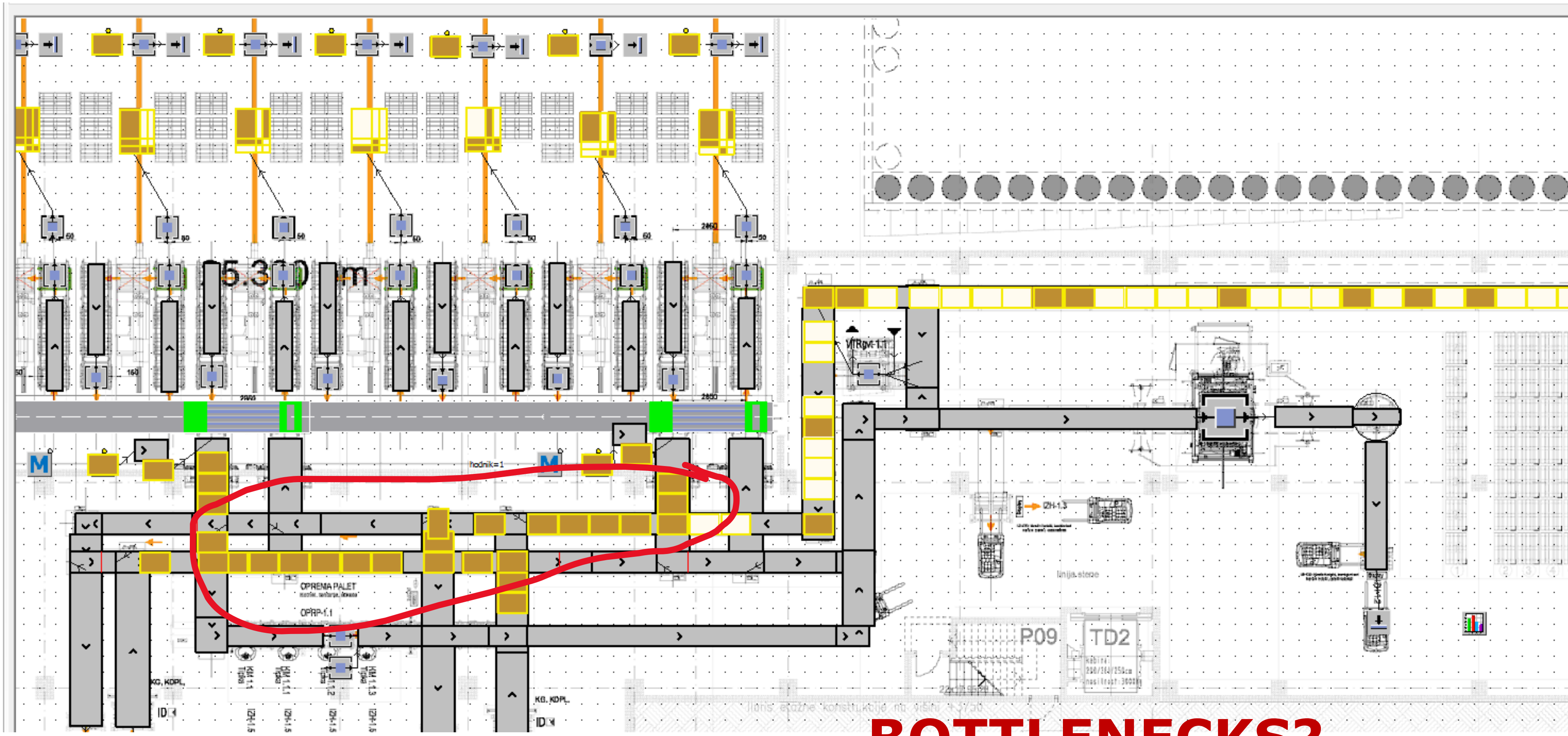
Understanding the difference between offline and real-time simulation, what is the difference between the model (simulation) and digital twin?

IMPORTANT

POST of Slovenia – real-time optimization

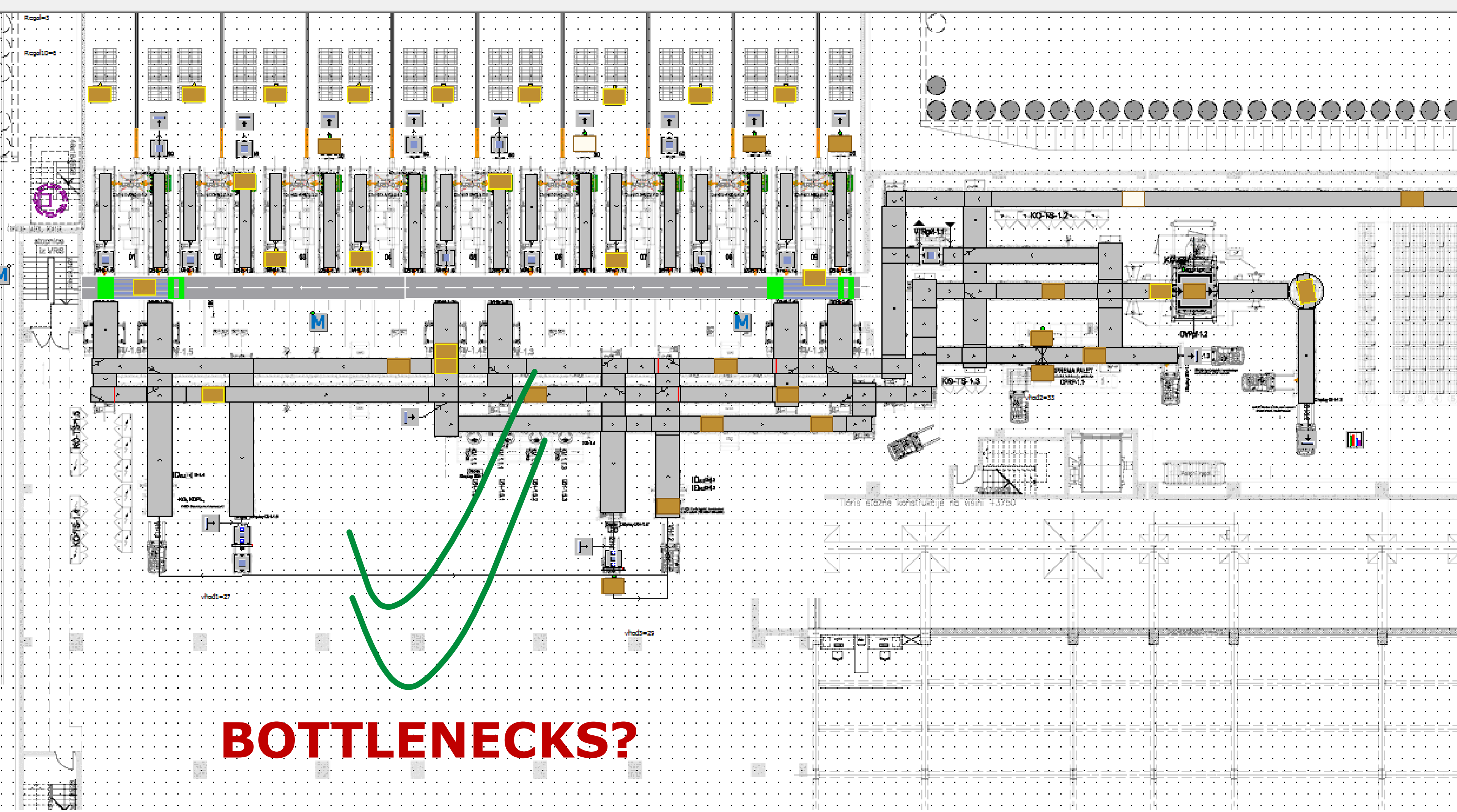


Post of Slovenia - additional line



BOTTLENECKS?

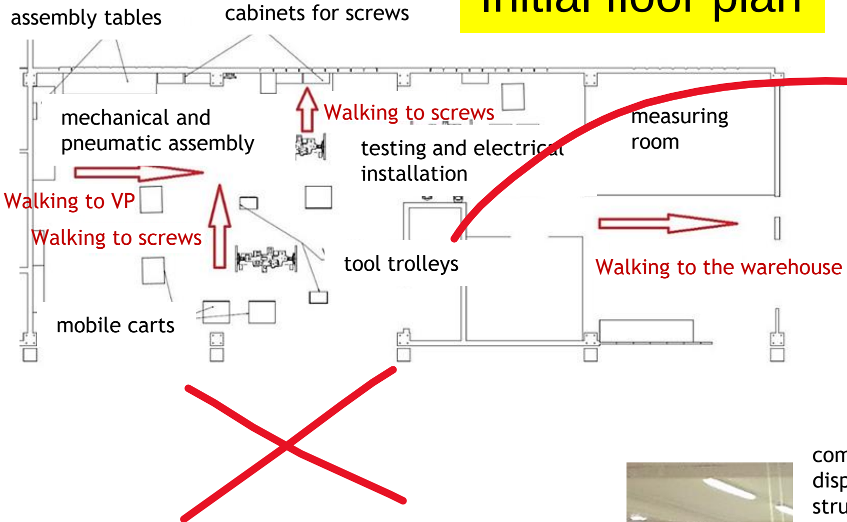
Post of Slovenia - Optimized ground floor



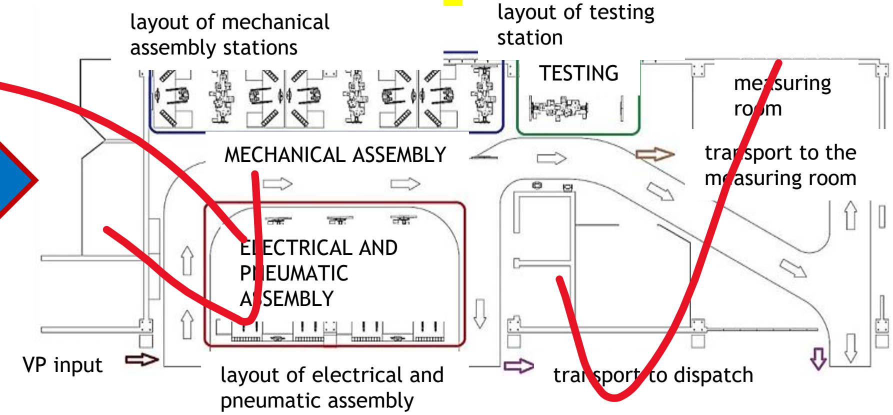
BOTTLENECKS?

Optimization by Digitization of Welding Equipment Production - Yaskawa Ristro

Initial floor plan

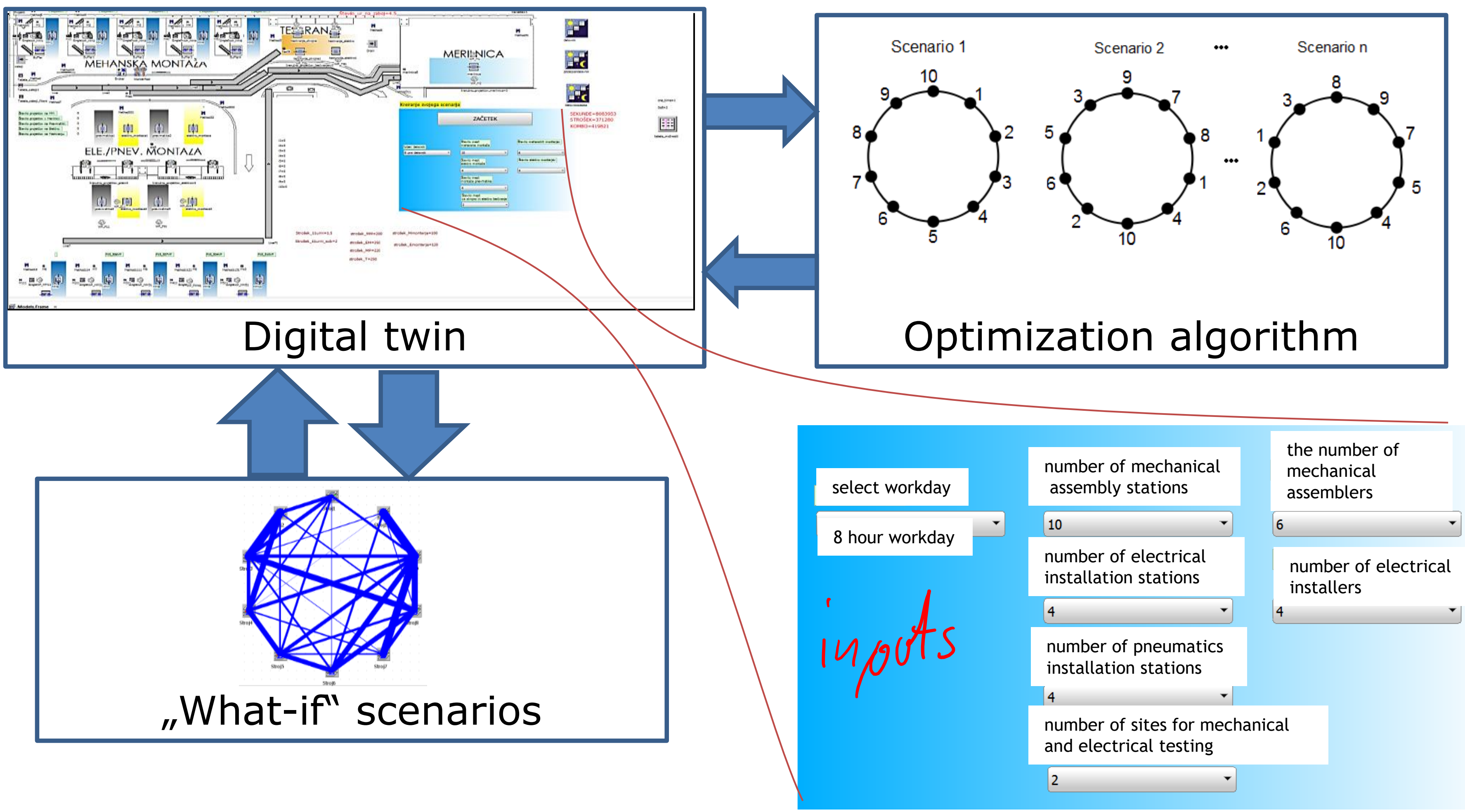


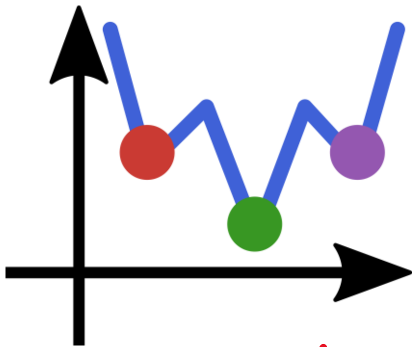
New floor plan



Ergonomically designed manual workstation

Digital twin of production of welding machines - optimal planning of production capacity, delivery times and required resources





Metaheuristics is an algorithmic way of solving combinatorial and optimization problem, in which we initially select a set of candidates for a solution and iteratively improve (depending on a predefined function of desirability) and return the best element from this crowd in sufficient steps.

IMPORTANT – discrete event simulation and heuristics approach

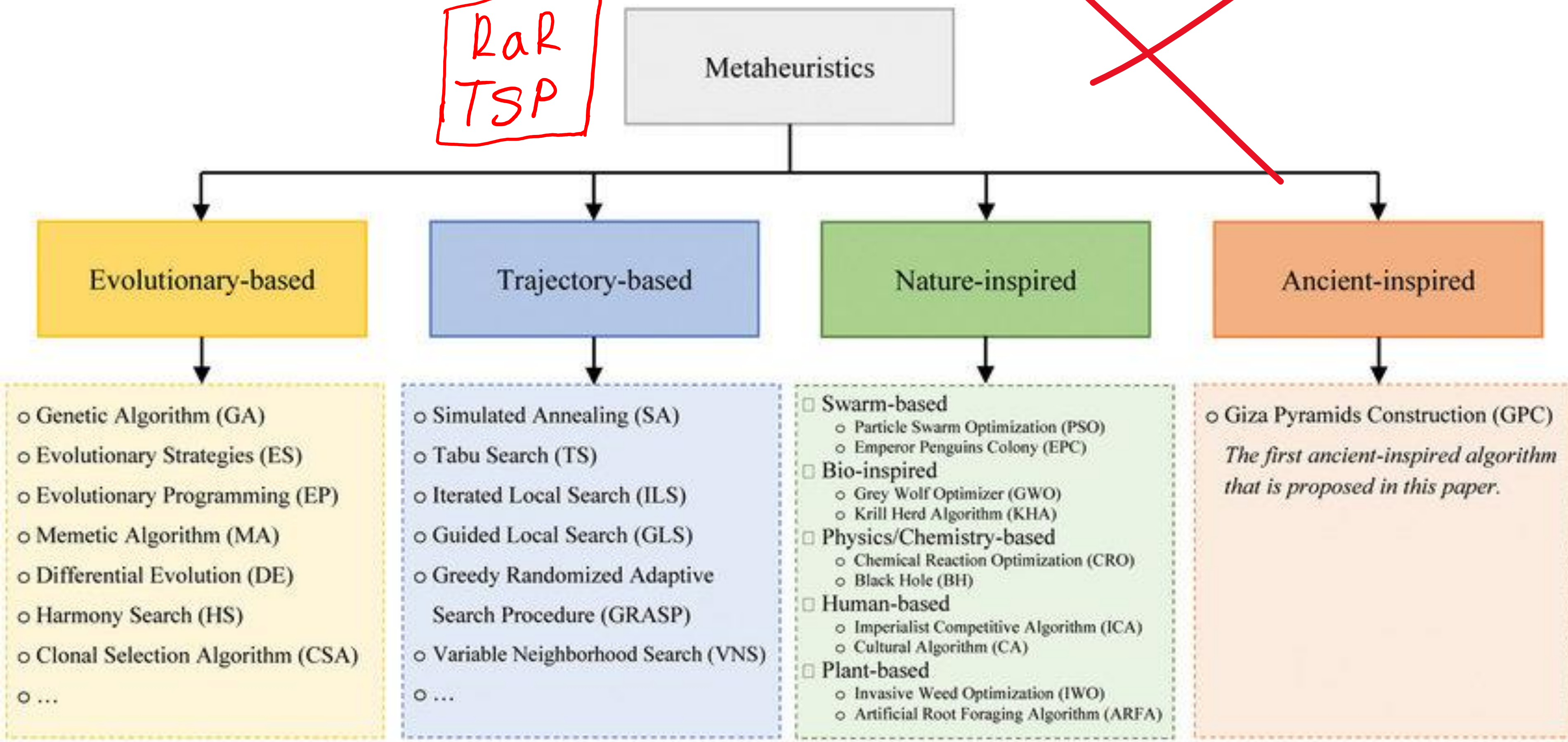
Metaheuristics therefore returns approximate solutions, but much faster than exact procedures.

https://www.youtube.com/watch?v=eekow29FSoc
https://www.youtube.com/watch?v=9ySShE2Wwoo
https://www.youtube.com/watch?v=cIZhNrscICA
https://www.youtube.com/watch?v=Ag2Cth_Q5VE

Metaheuristic approaches

initial solutions + what-if scenarios +

RaR TSP



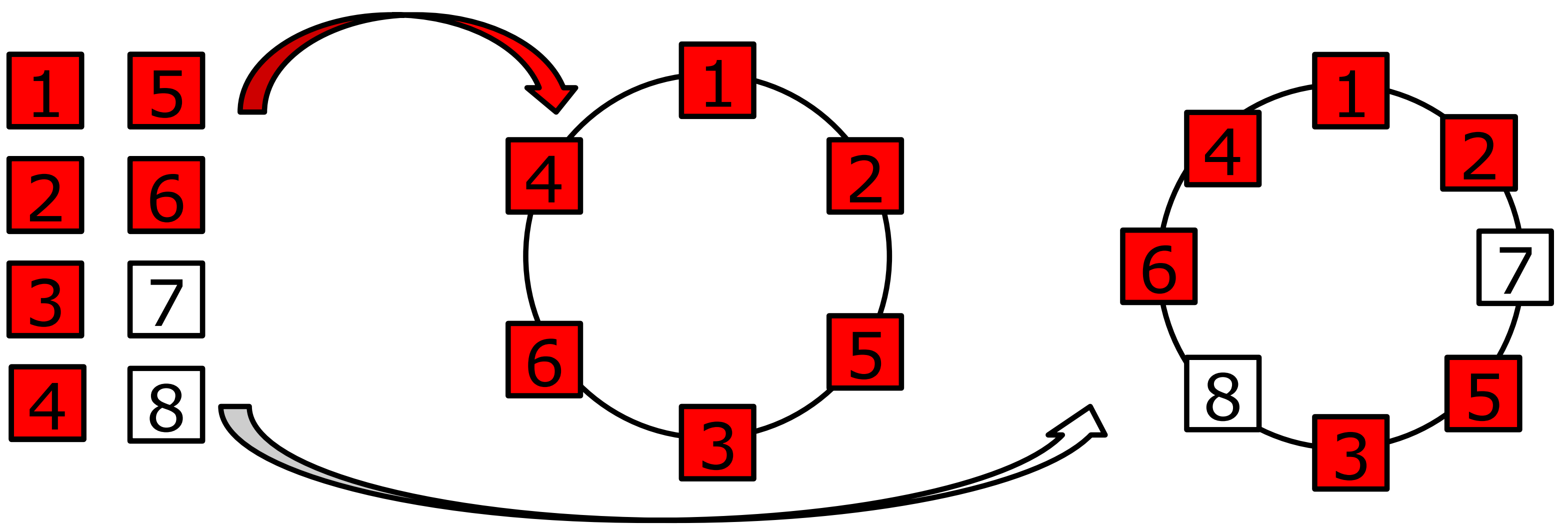
Source: Sasan Harifi

Metaheuristic RaR

RaR (Remove and Reinsert) can be considered as a hybrid metaheuristics, which consists of two phases: **generating an initial solution and iterative improvements**.

not so important -> just an example X

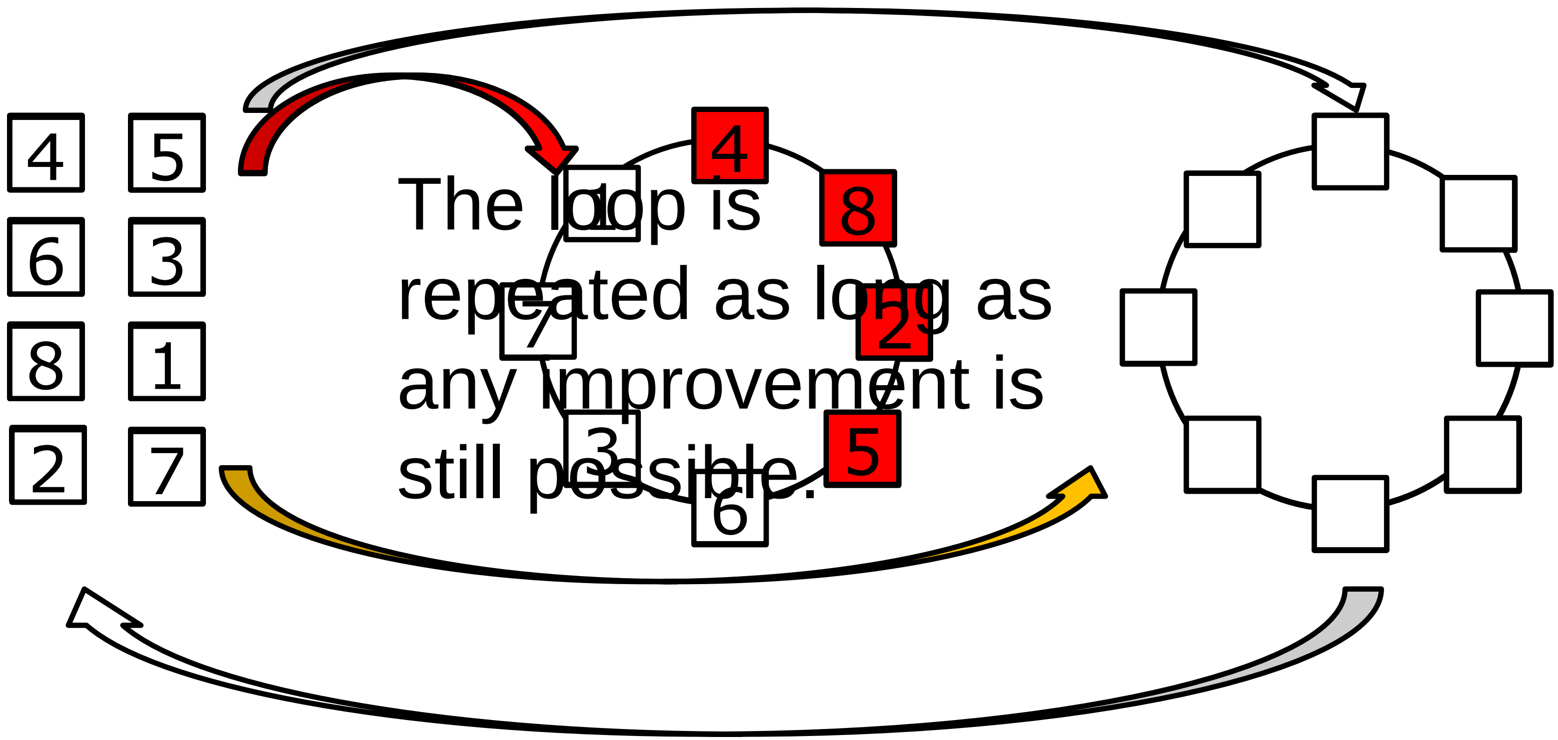
The iterative improvements phases remove some assembly devices/machines from the existing layout and re-insert them in the layout in a new, improved order.



Metaheuristic RaR

Let us assume that the initial layout status is given and let us focus on iterative layout improvements.

not so important -> just an example



The loop is repeated as long as any improvement is still possible.

New Yaskawa robotics factory in Kocevje

Layout optimization, material flow optimization, planning the factory in advance in virtual environment

New Yaskawa robotics factory in Kocevje - floor plan optimization

Input data

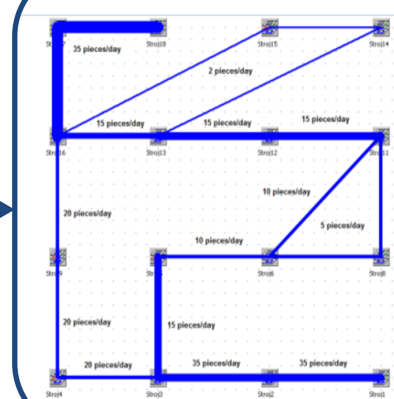
Digital Twin - SIMULATION

Result

+

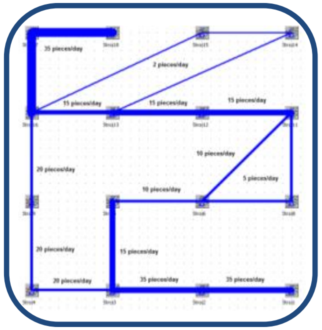
data from existing robot manufacturing plant in Japan

Simulation model +
an algorithm for determining
the optimal production plan



Sankey diagram

Floor plan optimization - Different variants



Sankey diagram

+

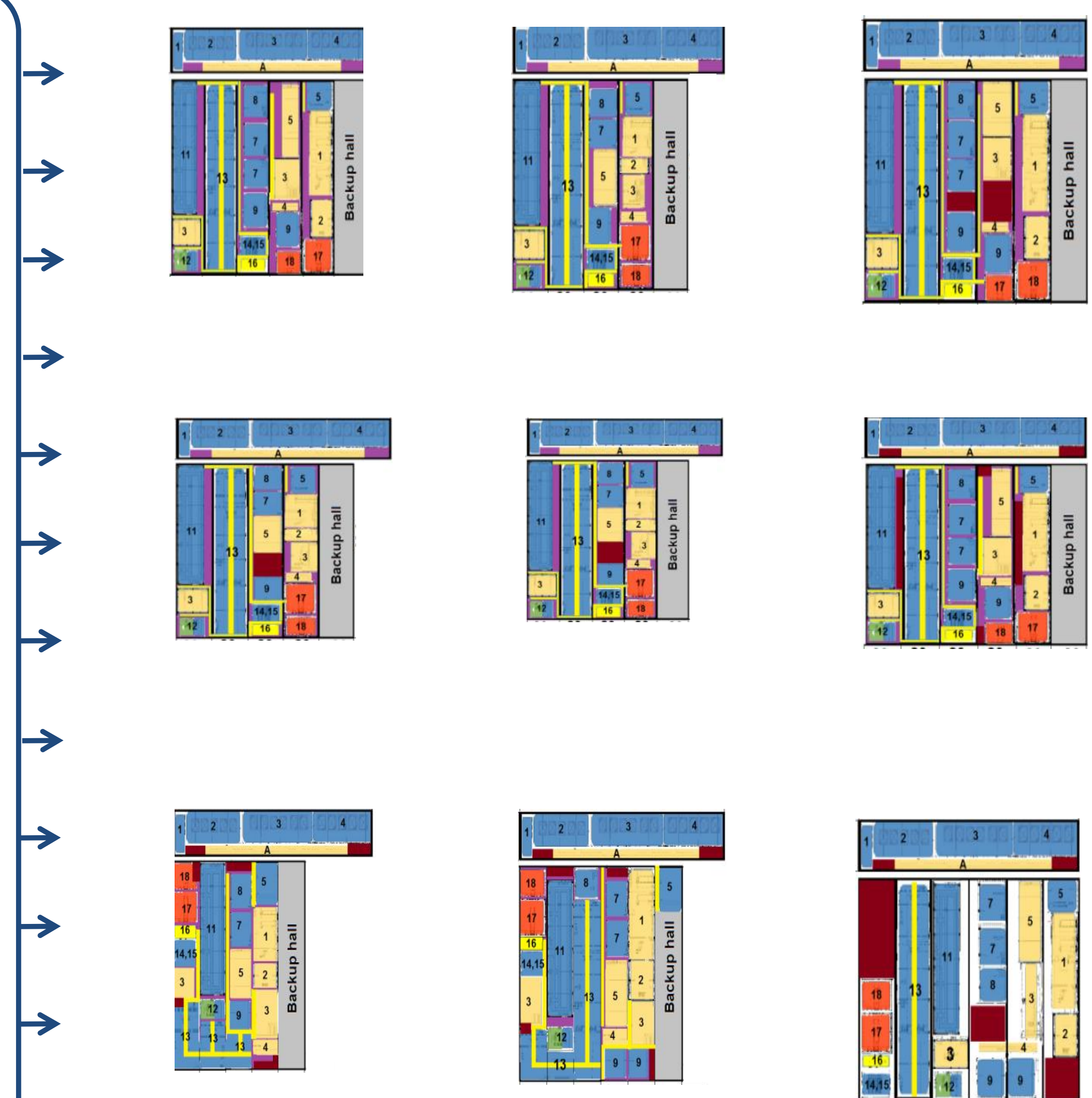
Dimensions of individual production segment

+

Number of shifts

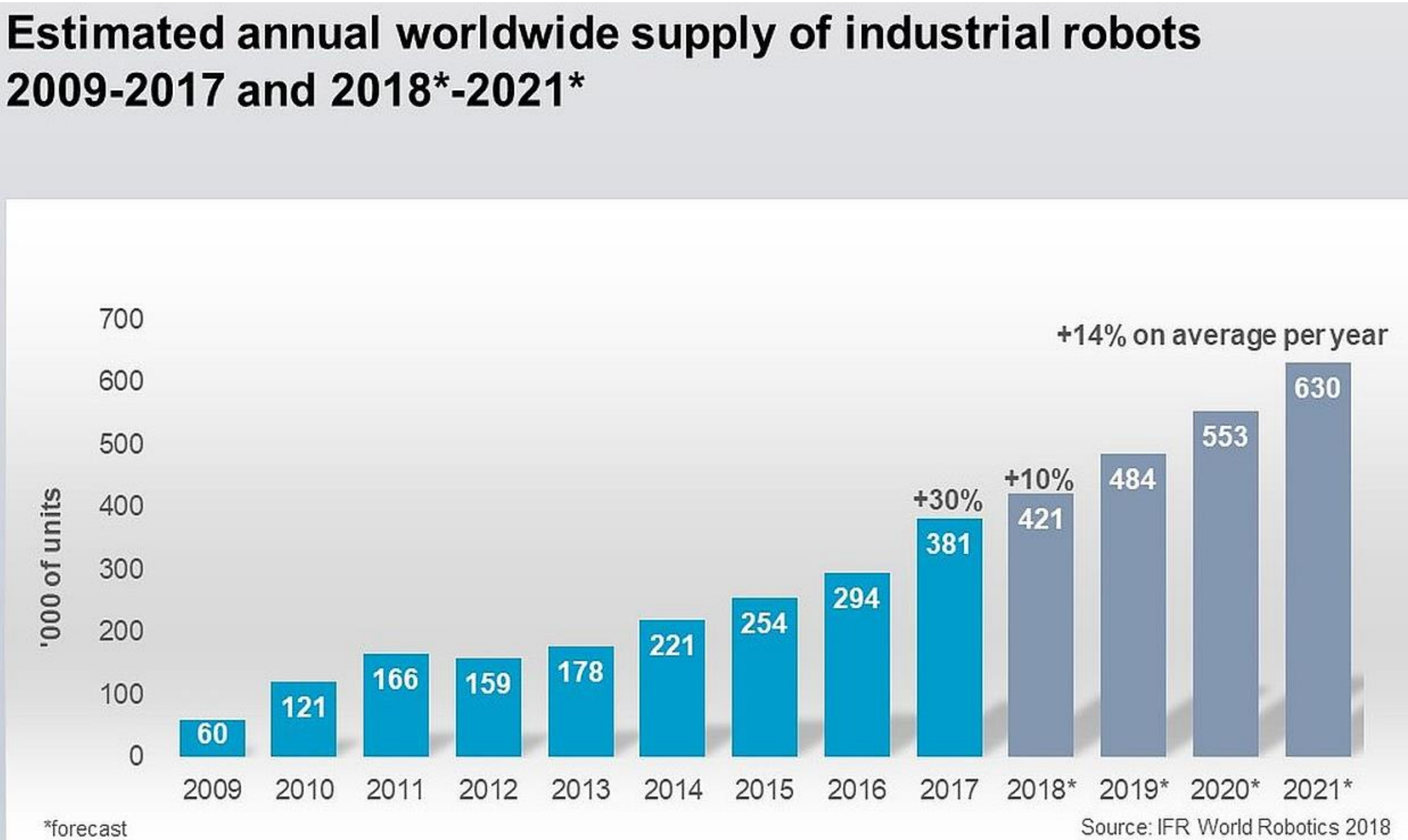
+

Production hall variants

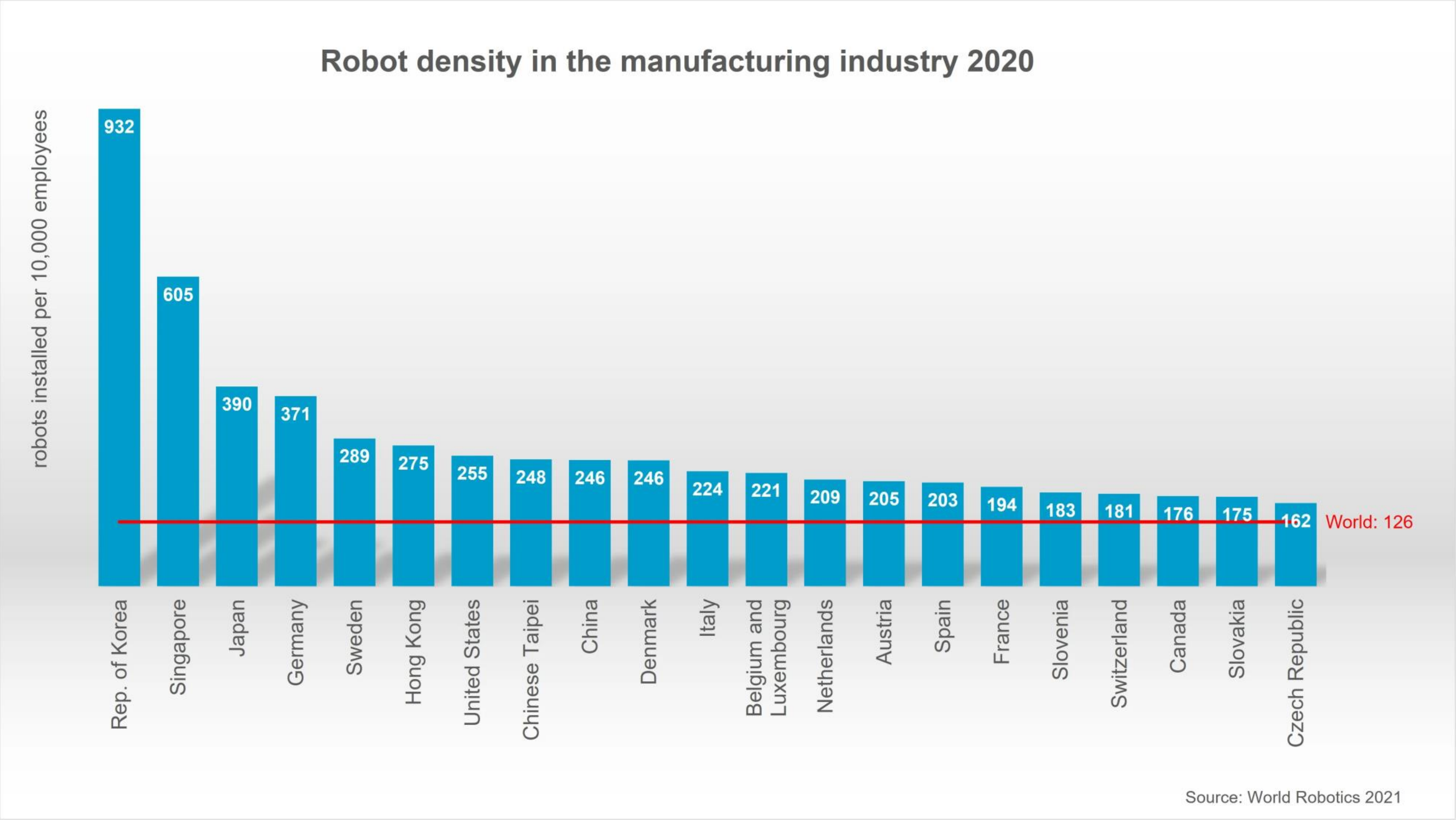


Robots in the production process and Programming of robots in the production process

The robot sales has doubled in the last 14 years



The degree of automation of production processes depends on the number of robots per 10,000 employees



Trends in robotics

- smaller robots with greater reach,
- use of light materials for robots and gripers,
- more intelligent machine vision,
- more integrated intelligence,
- simplification of control and programming,
- improved sensors and increased security,
- energy efficiency,
- increased flexibility of robots,
- more focus on the socio-economic impact of robots,
- Collaborative robots - human-robot collaboration,
- modular robotic cells,
- etc.

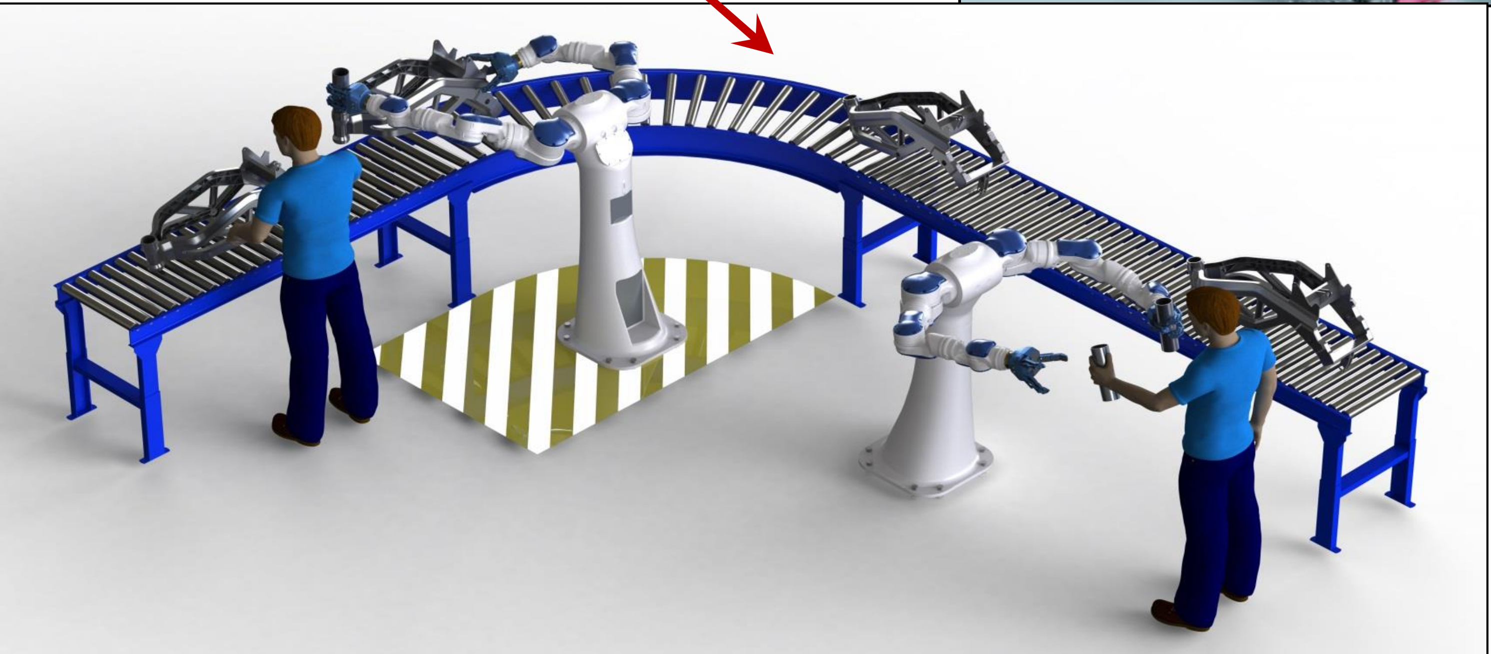
IMPORTANT

Source: Different sources

Trends in robotics

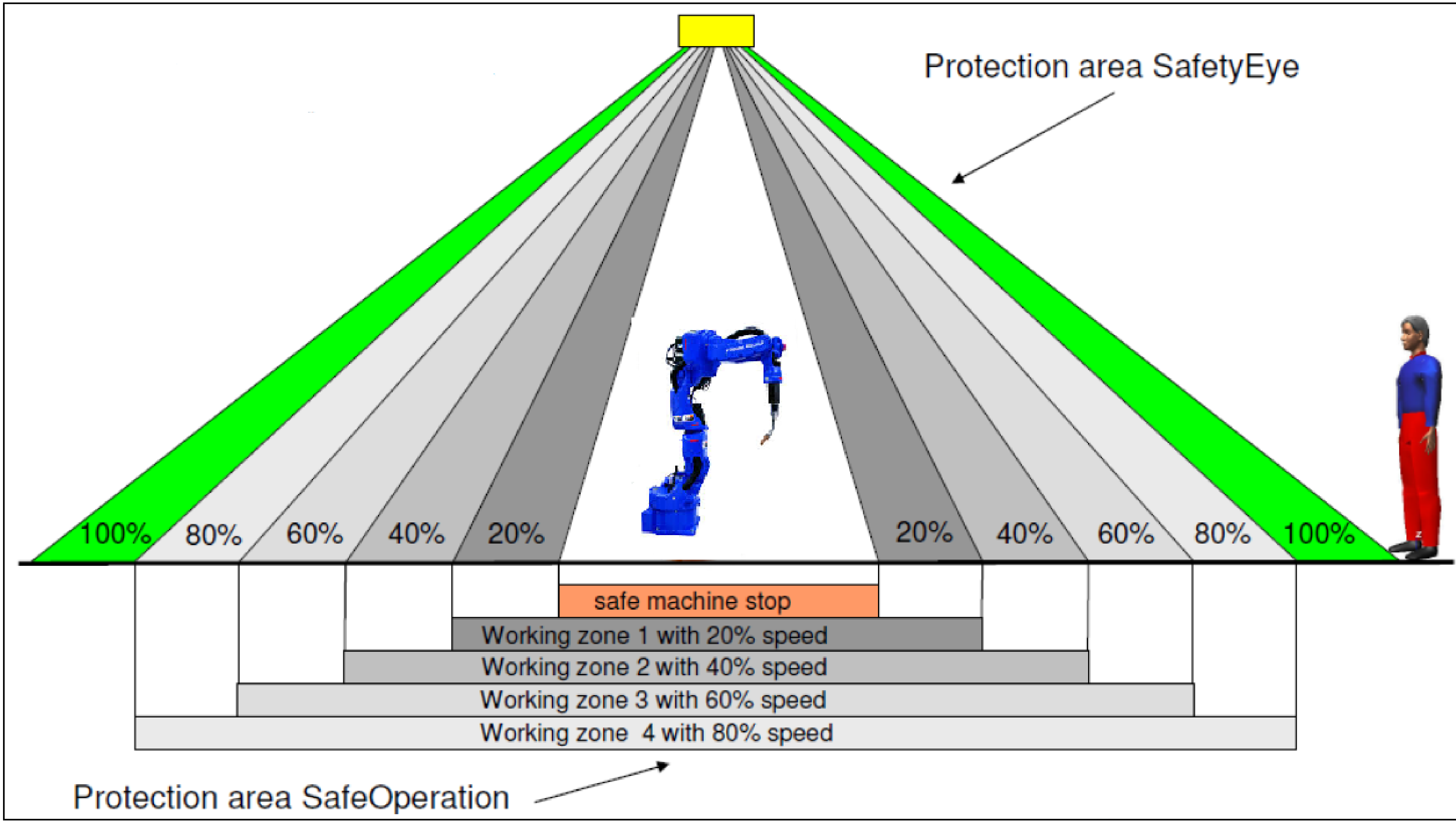
Example of the industrial robot use

Example of the use of collaborative robots



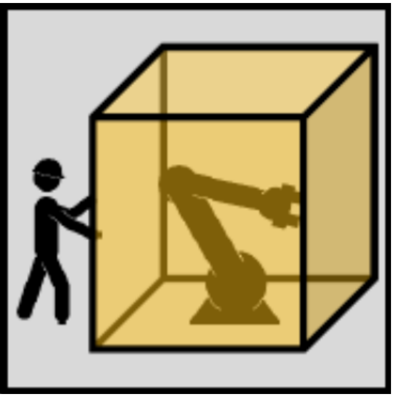
Source: Klemen Kastelec

Trends in robotics – space (area) control – use of industrial robot



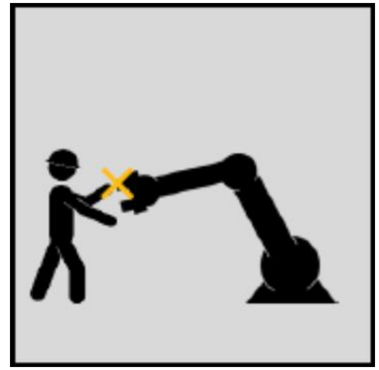
Source: M. Beaupre

Modes of robot operation in the presence of a person



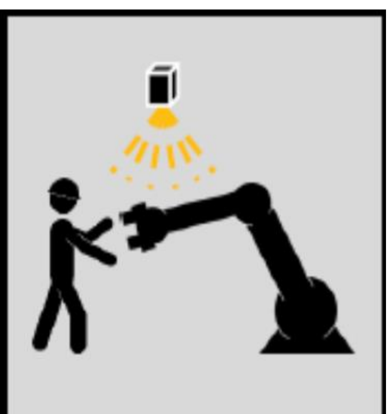
a.)

There is no movement of a robot when a person is inside a collaborative working space.



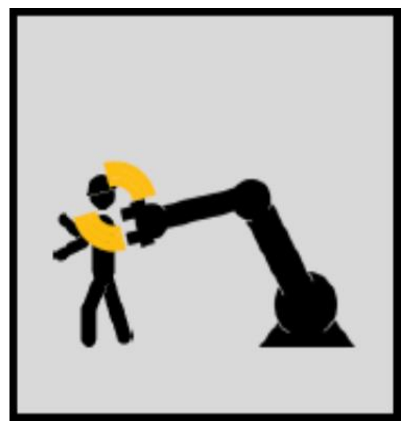
b.)

Movement of the robot through the direct manual operation of the operator.



c.)

Movement of a robot only in the case when a person is distant more than the minimum prescribed distance.



d.)

In the case of contact with a person, the robot can only cause limited static and dynamic forces.

Source: Klemen Kastelec

Collaborative robots – Cyber-physical systems –

Collaboration of a human, robot and the environment

IMPORTANT

The flexibility and variability of the assembly process requires close cooperation and the connection between the worker and the robot.

The worker is guiding, and the robot provides him with physical assistance, for which the accuracy of positioning is not enough - it is necessary to interact with a person.

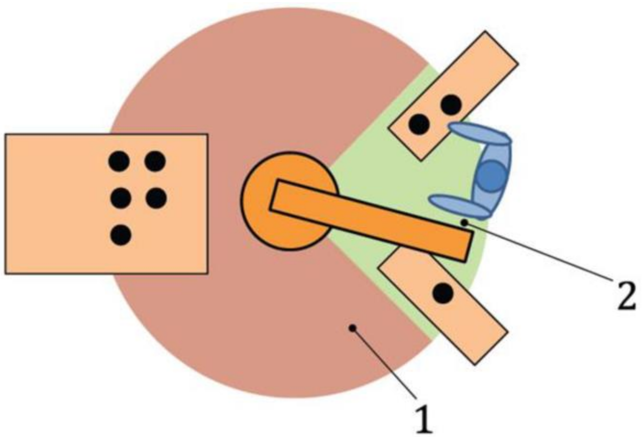
Source: robots.com

Source: Tech Briefs

Interaction human - robot

I.) Collaborative working space

The meaning of the phrase a *collaborative working space* is understood as a space within the entire working space, where the robot and man simultaneously perform work operations during the production process.



Legend:
1.Robot working space
2.Collaborative space

Collaborative working space according to ISO 15066:2016(E).

II.) Collaborative operation

The phrase *collaborative operation* means, when the robot and the man share a common working space.

Collaborative operation is used for/when:

- working conditions (operations) which are defined in advance,
- all security measures are assured,
- robots, which are used, support collaborative functions.

Source: Klemen Kastelec

Collaborative robots – Cyber-physical systems –

Collaboration of a human, robot and the environment

important

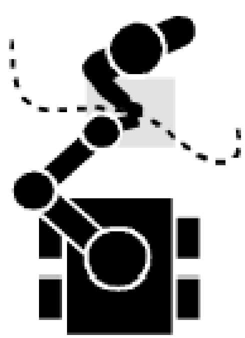
IMPORTANT

Goals:

- **Increasing the efficiency of work with the parallel or collaborative work of a man and a robot**
- **Reducing the cost of ergonomic job creation - robot flexibility with programming**
- **Increasing flexibility in changing work places, changing capacities, supporting people, adjusting the movement**

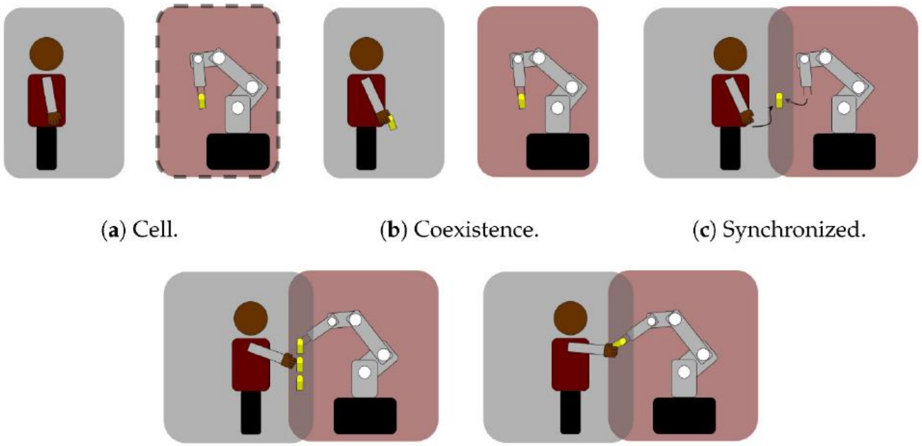
Duties:

- **Development of cooperation concepts**
- **Development of robots and grippers**
- **Human robot cooperation standards, security mechanisms, security concepts** ***ISO/TS 15066**
- **Development and use of sensors**
- **Planning the work of a robot and a man, a division of labour**



***ISO/TS 15066:2016**
Robots and robotic devices
Collaborative robots

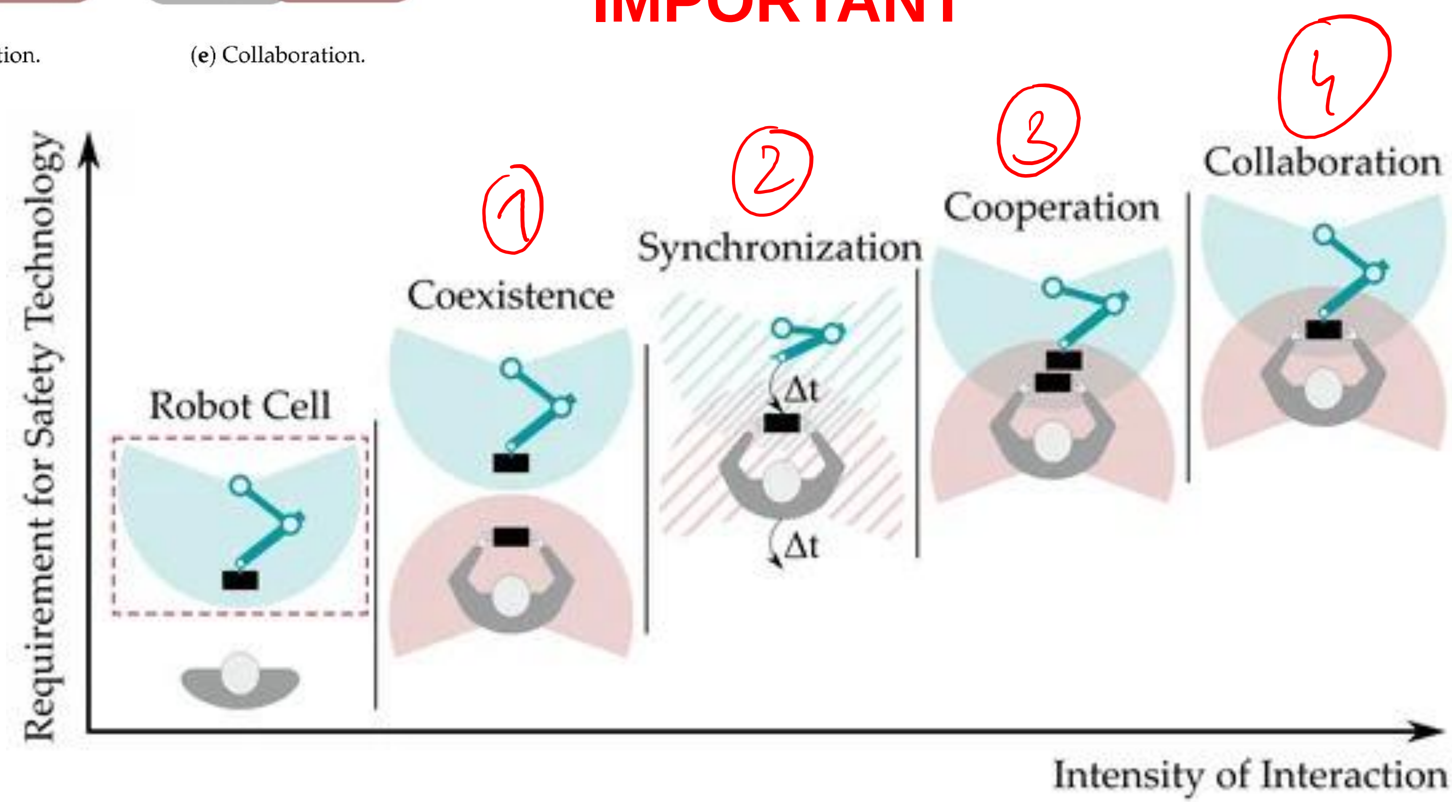
Cooperation principles



(a) Cell. (b) Coexistence. (c) Synchronized.
(d) Cooperation. (e) Collaboration.

https://www.youtube.com/watch?v=FRUmFhVUZHU

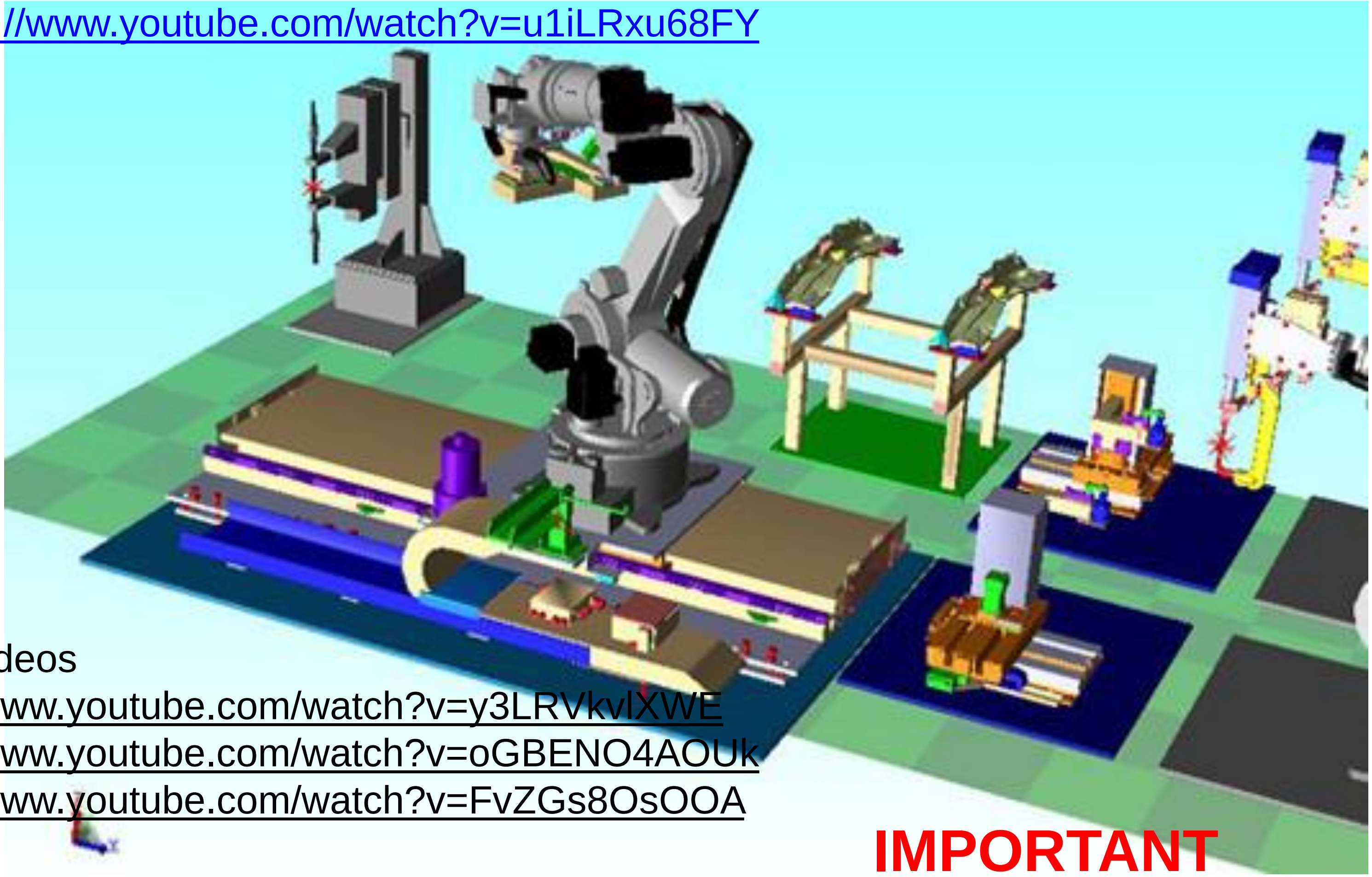
IMPORTANT



Self-configuration of robot cells

Reconfiguration of a robot cell, assembly and handling accesories, grippers, layout etc.

https://www.youtube.com/watch?v=u1iLRxu68FY



Other videos

https://www.youtube.com/watch?v=y3LRVkvlXWE

https://www.youtube.com/watch?v=oGBENO4AOUk

https://www.youtube.com/watch?v=FvZGs8OsOOA

IMPORTANT

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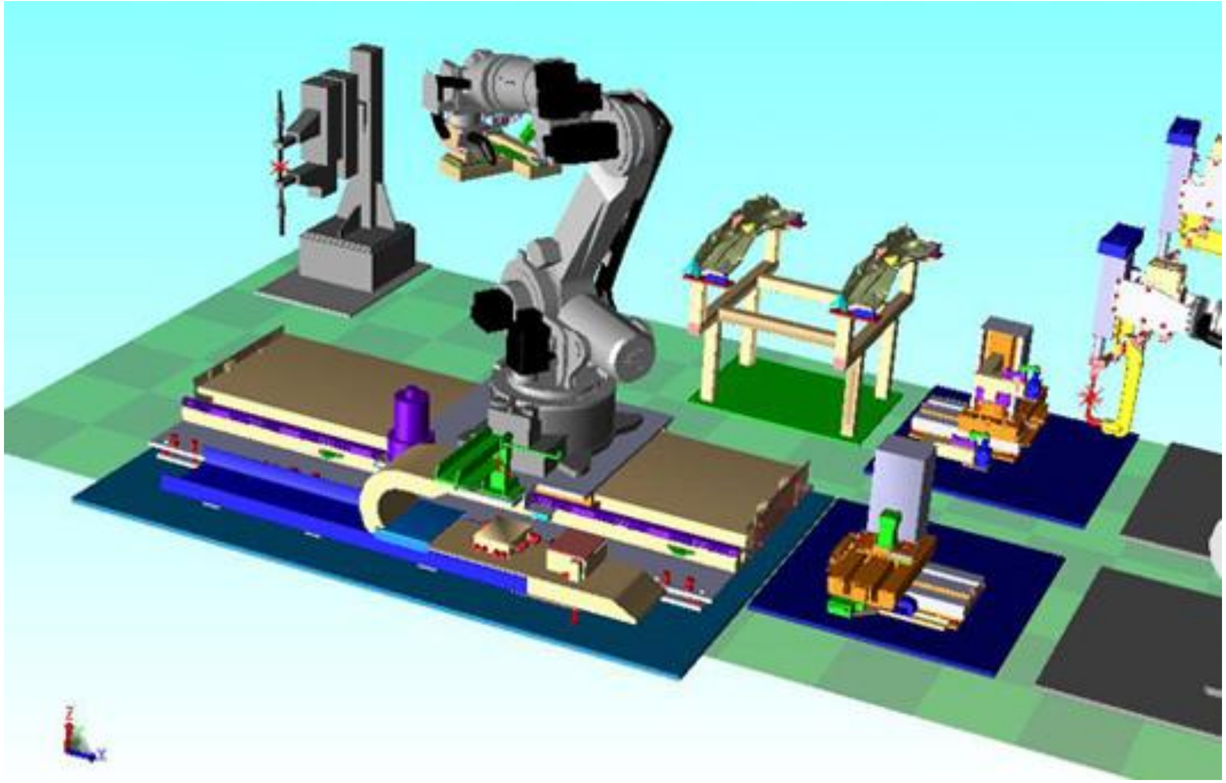
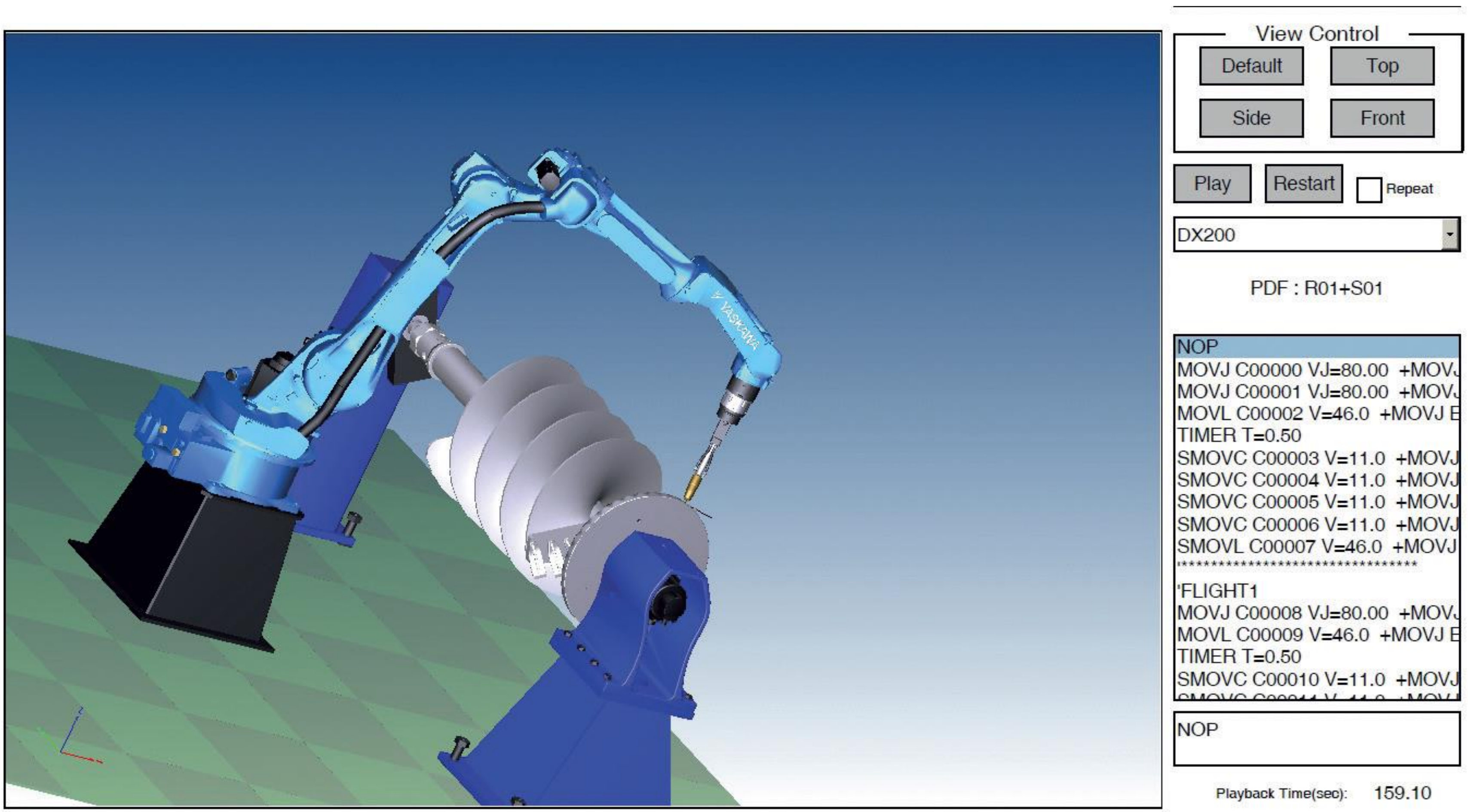
Robot programming in virtual environment

1. Making 3D model of robot cell (products, assembly devices, grippers, robot, storage containers)



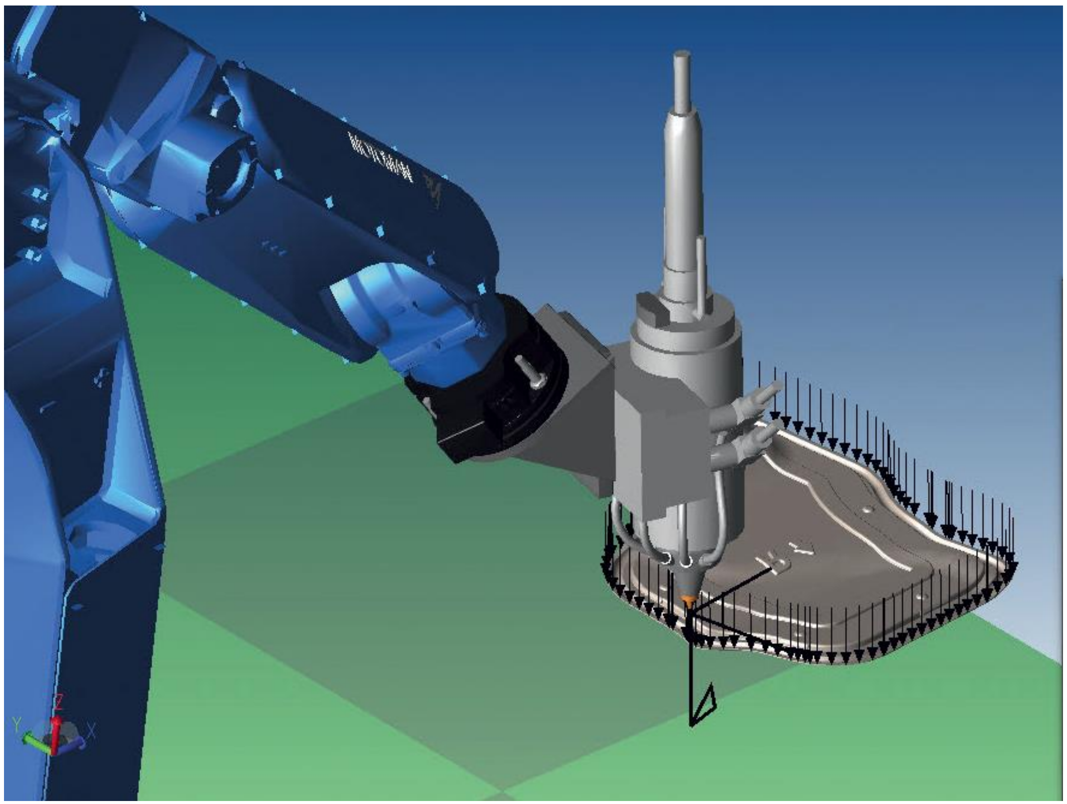
Robot programming in virtual environment

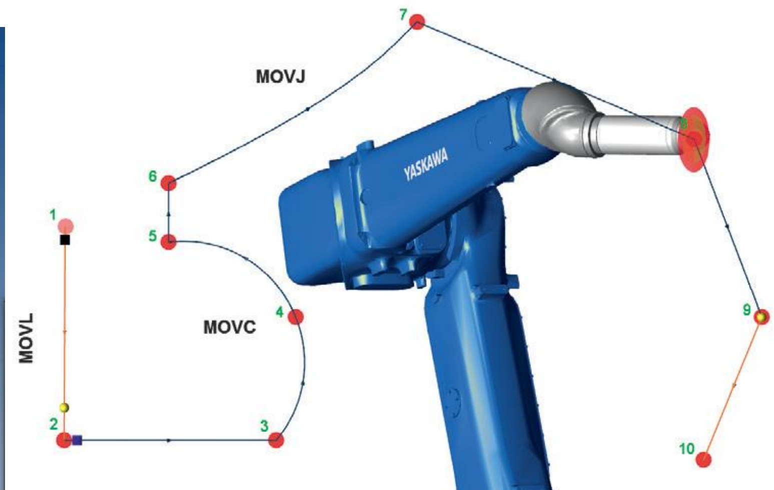
2. Input of the 3D model into the program for the simulation of robots (dependable on robot producer)

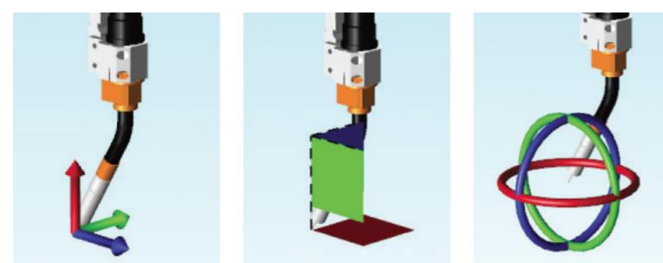


Robot programming in virtual environment

3. Generating and optimization of trajectories → defining of working cycles and the tact time of the system

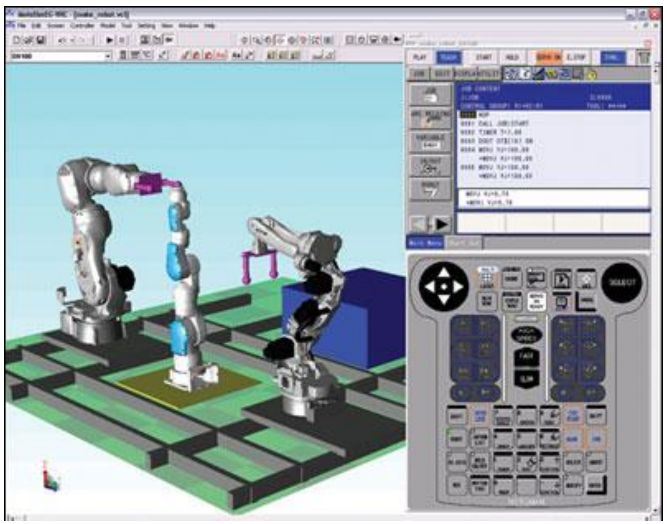


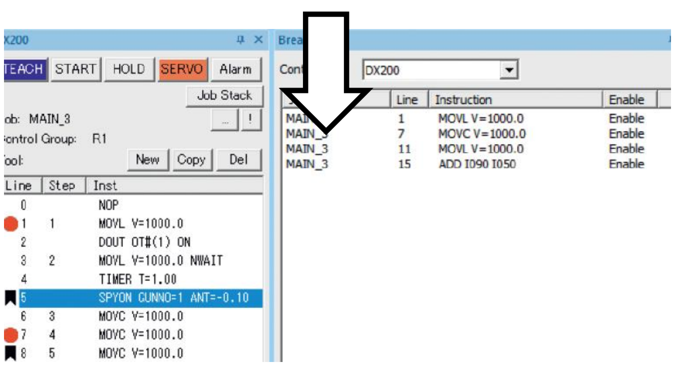


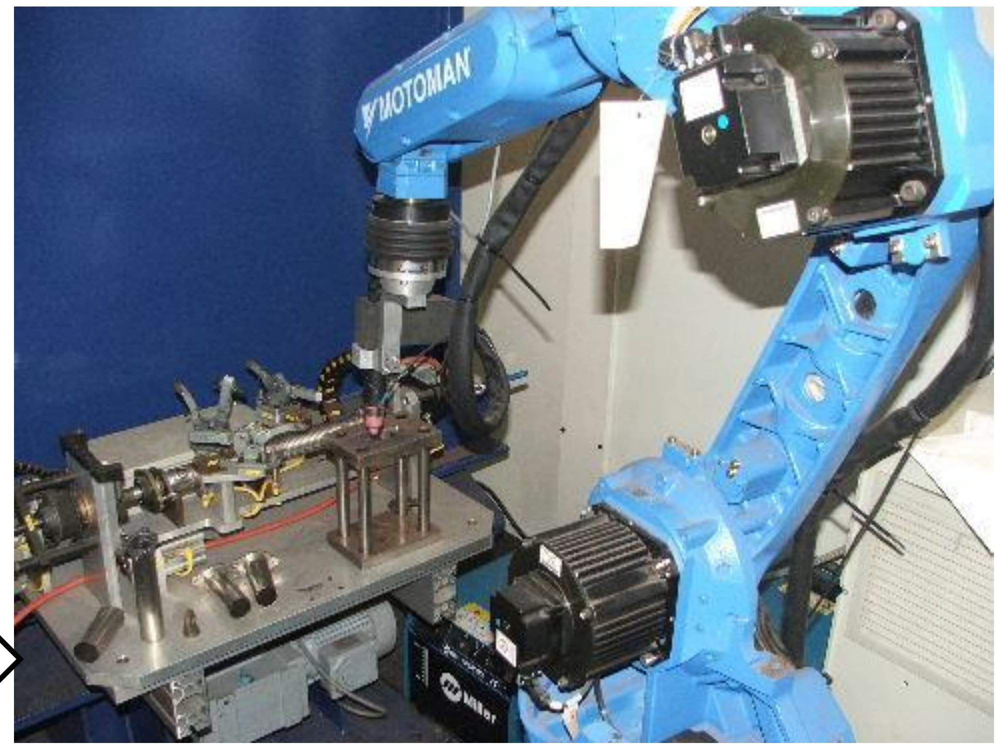


Robot programming in virtual environment

4. Generation of the program for robot movements and saving it on the physical robot controller through the cloud, internet/intranet, memory cards etc.





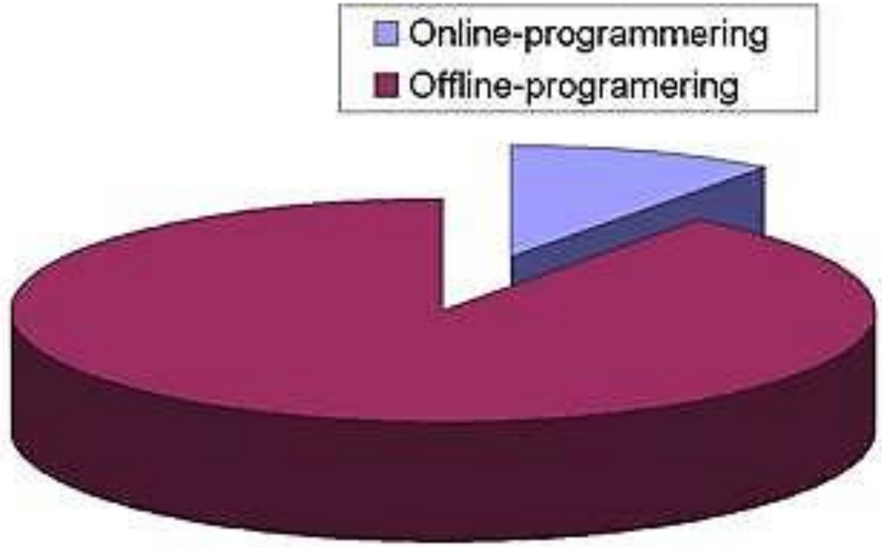


Robot programming

5. Adjustments of final positions of a physical robot and testing the system.

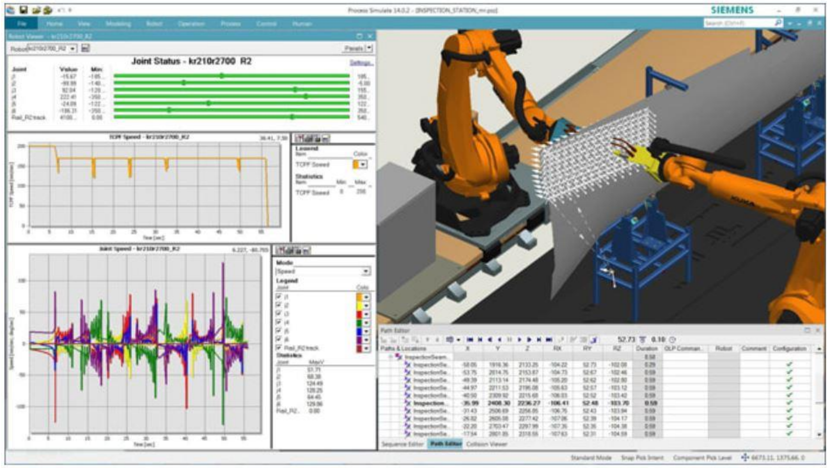
Robot programming

IMPORTANT



Programming: Online 100%

Programming: Online10%, Offline 90%



ROBOT grippers

Development of efficient and inexpensive grippers, as interfaces between the robot and the product will represent a challenge in the future research.

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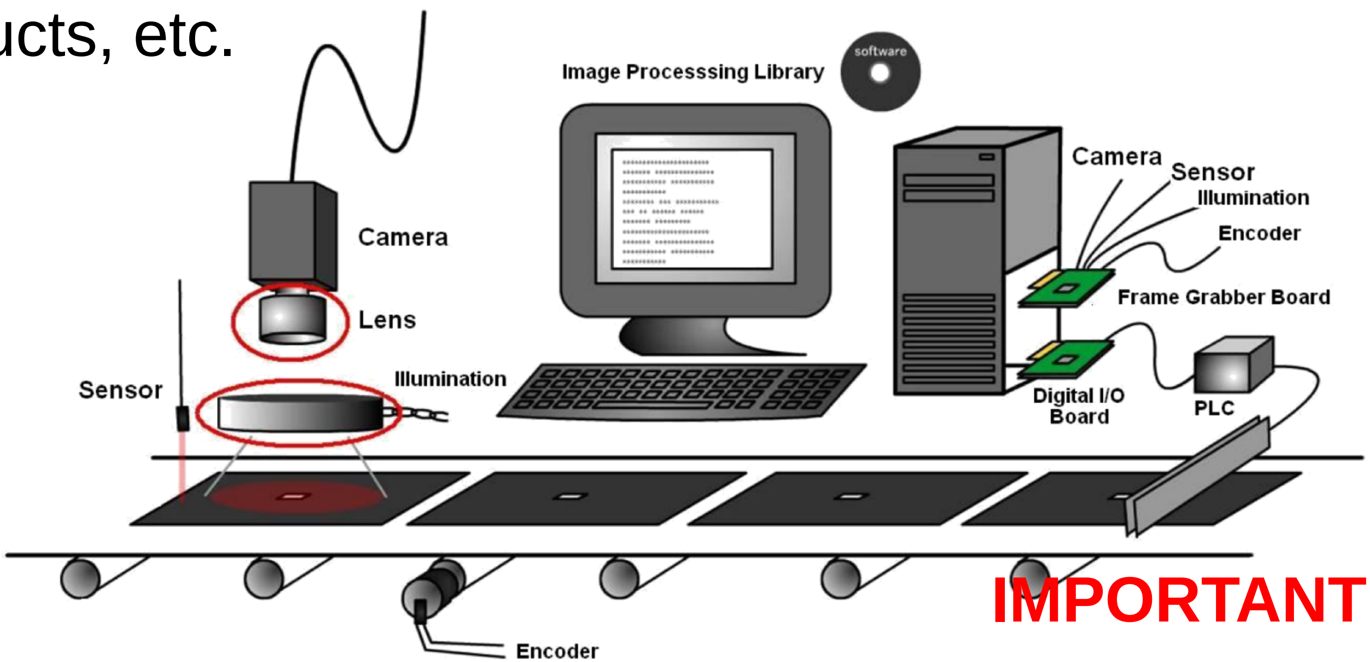
Source: Assembly

Machine vision systems

The Vision system will be more and more often used for robot control, for the final and intermediate control in assembly, for recognition of products, etc.



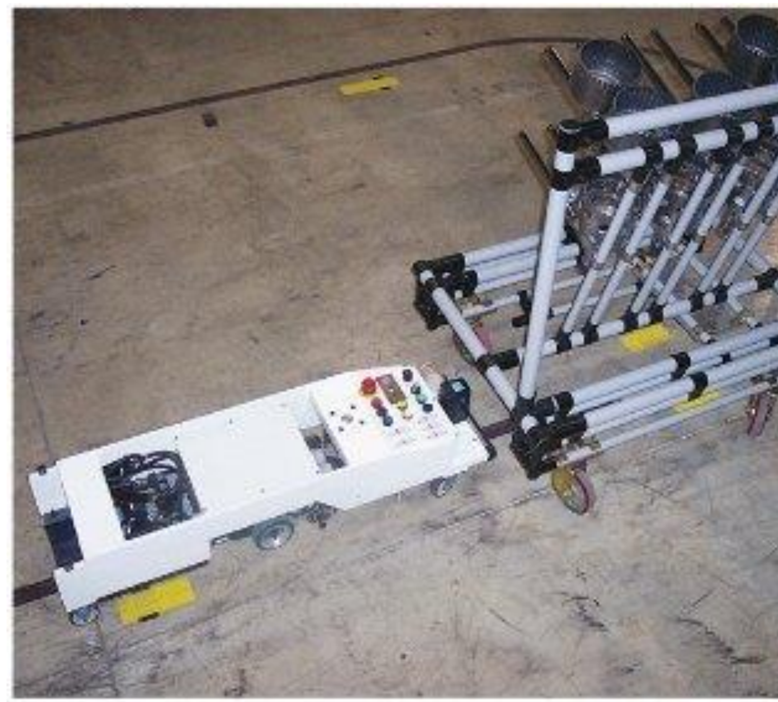
IMPORTANT

Trends in automation of handling and assembly

Flexible AGVs, AMRs

New technologies enable that AGVs get higher flexibility, agility, adaptivity and herewith higher usefulness in transport system of assembly.

Source: Assembly



IMPORTANT

Trends in automation of handling and assembly

https://www.youtube.com/watch?v=9mG1bgs_ND0

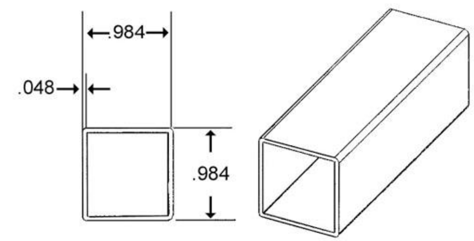
Automation, measuring systems: Machine vision – How to achieve „Zero defect“ with the process control

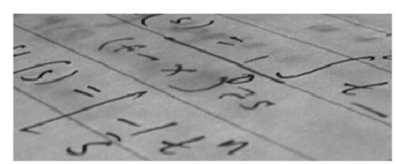
With Machine vision to „Zero defect“

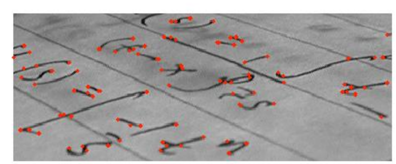
Analyses with the machine vision (standard today):

- Distance measurmenets
- Serial numbers reading
- Detection of the component presence
- Comparison of samples
- Analyses of connected points
- Letters and bar codes recognition
- Surface analyses
- Colour recognition

and analyses





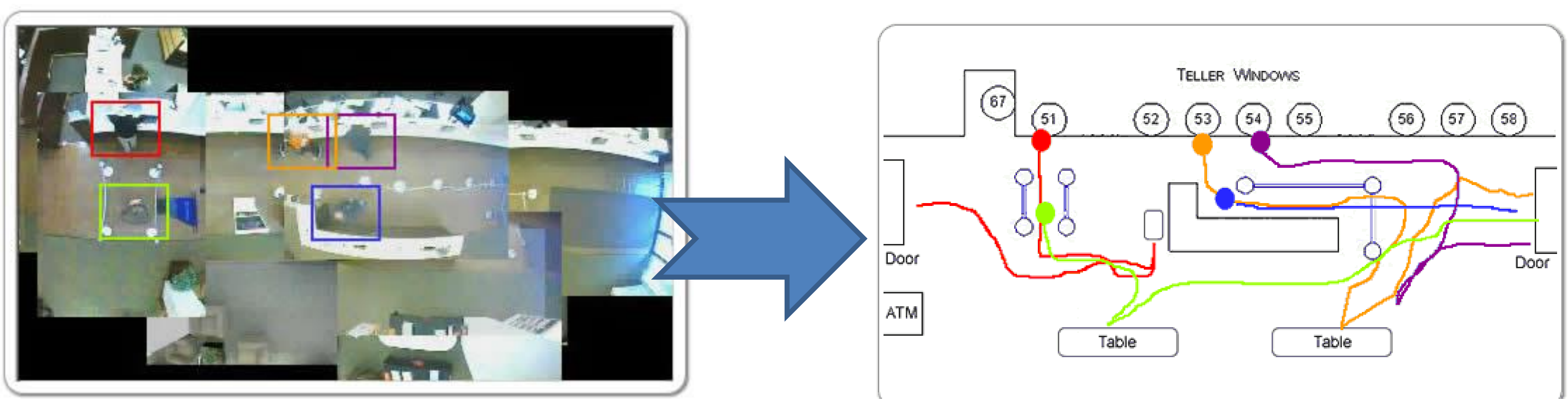


IMPORTANT

With Machine vision to „Zero defect“

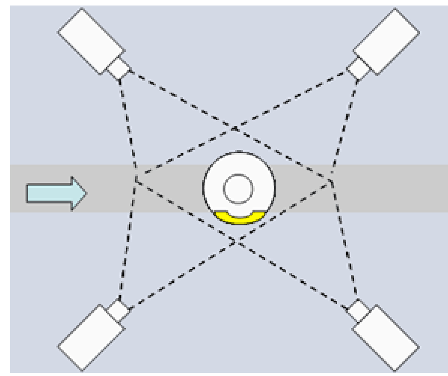
Analyses with the machine vision (new possibilities):

- The exchange of sensors with control cameras
  - The possibility of simultaneous presence and qouality control (more simultaneous functions)
  - Lower price (a few times) – when proper combination of hardware and software is used
  - Data saving on the server/cloud
- Workers‘ position/faces movements detection (tracking and optimization of assembly process)



Standard components of machine vision

- One or more cameras (more views or 3D vision)



- Optics (lenses, mirrors,…)
- Illumination
- Input/output (I/O) components
- Actuators
- Program (software)

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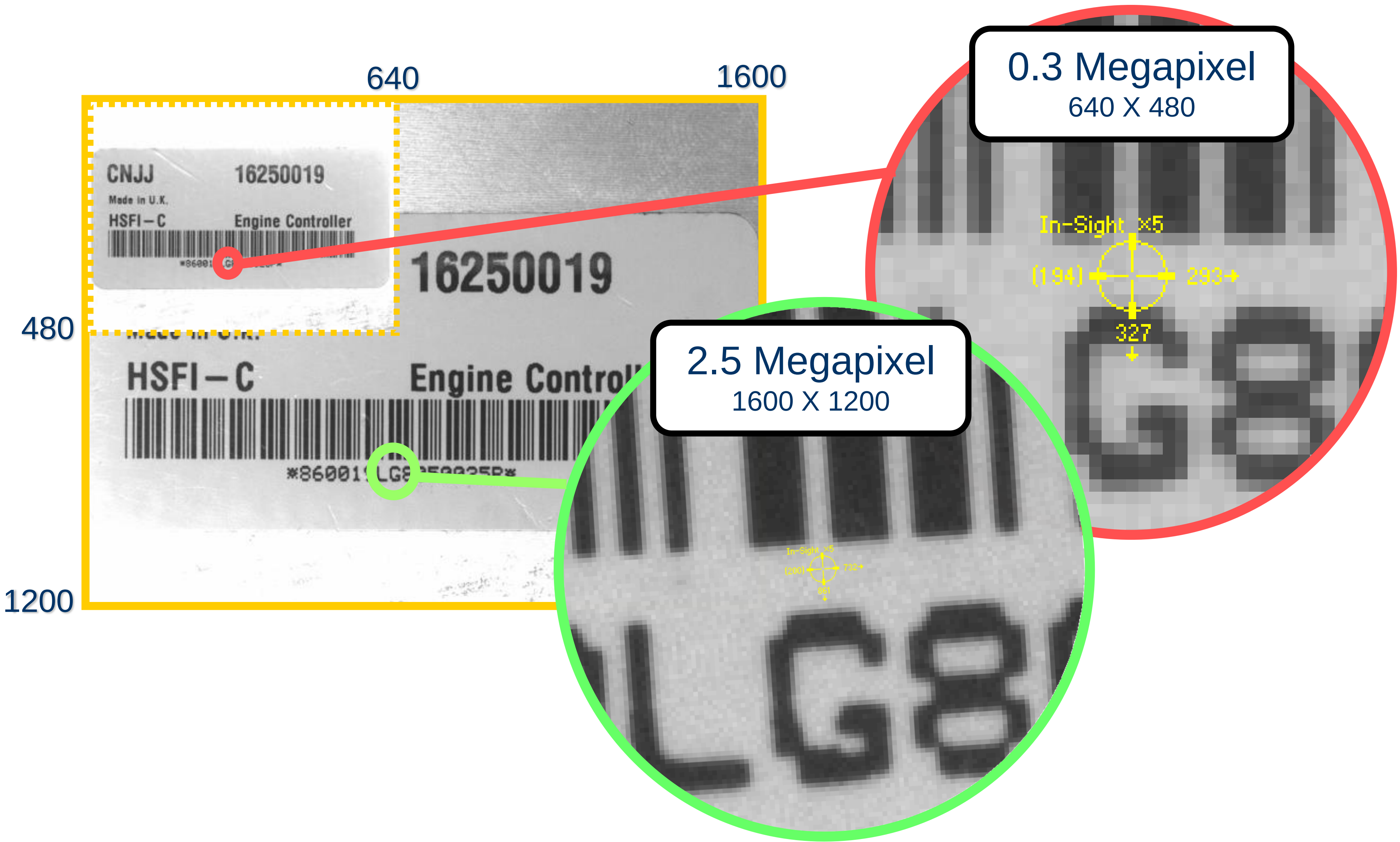
Different resolution for different applications



Hardware for machine vision

Standard cameras

- Wider possibility of use
- Higher price when using one camera (camera + controller)
- Lower cost when using more cameras
- Wide choice of lenses
- High resolution
- The processing speed depends on controller
- Required controller with I/O and vision program.

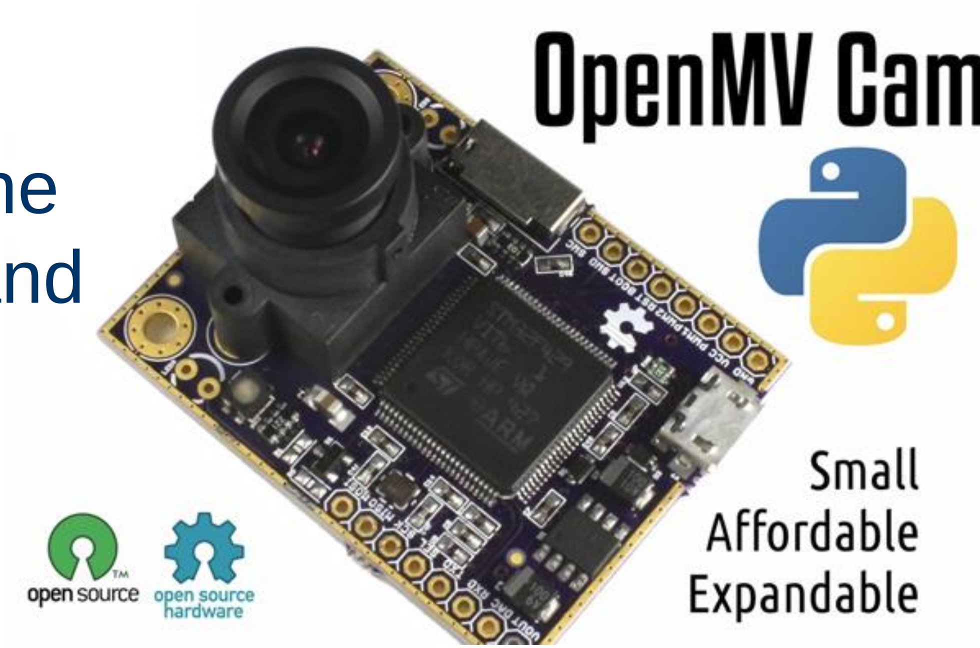
Smart cameras

- Lower price for 1 camera
- Integrated processor and program for analyses
- Integrated illumination option
- Integrated I/O module
- A simple interface
- Limited integration of more cameras
- Limitation of the resolution
- The rate of analysis depends on the processor in the camera

Low-cost camera modules

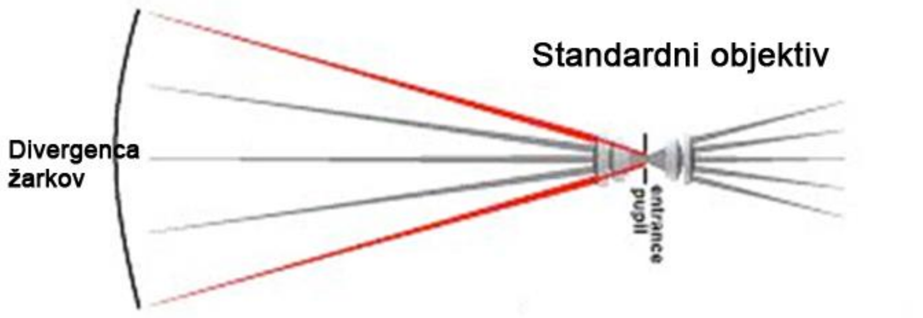
- Python program language
- Resolution up to 2MP (1920x1080)
- Serial, SPI, I2C and USB connection
- STM32F4 processor
- Libraries: OpenCV, Haar, FAST/FREAK Object/face detection
- Low cost solution

- Possibility to exchange the sensor and the camera and the lenses
- Possibility to shoot the video

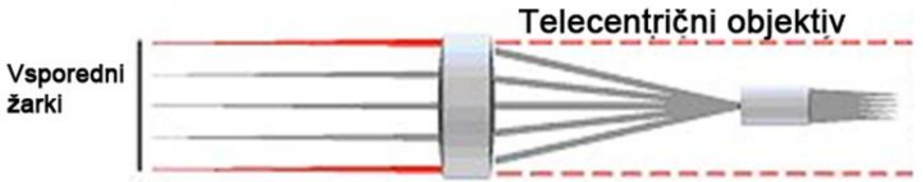


Lenses for the machine vision

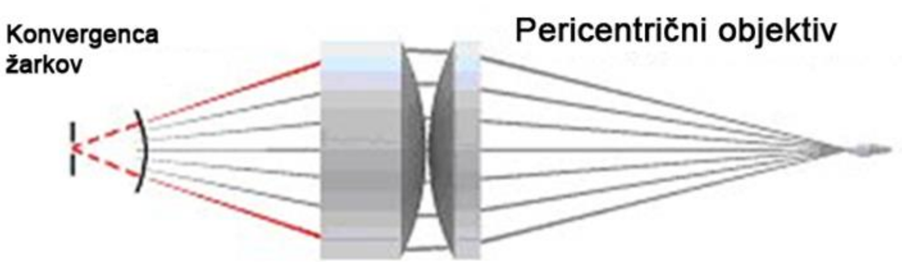
- Standard
  - zoom changes
  - image capture
  - perspective error



- Telecentric
  - front lens in the size of the housing
  - big and heavy
  - expensive



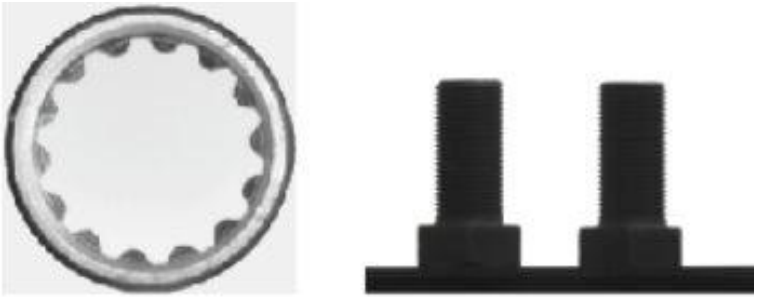
- Pericentric
  - possible to see one piece from more directions
  - high price



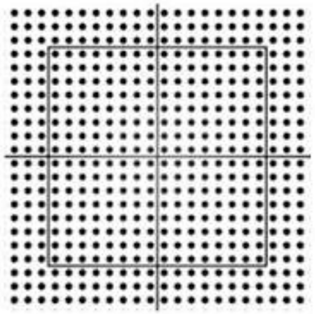
Telecentric lenses

- No zoom or it is standard
- No distortion
- No mistakes because of the perspective
- Higher resolution

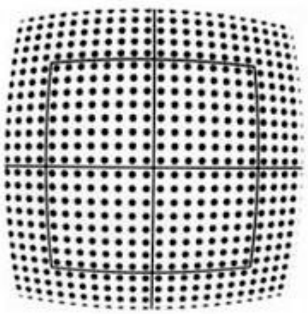
Telecentric lens



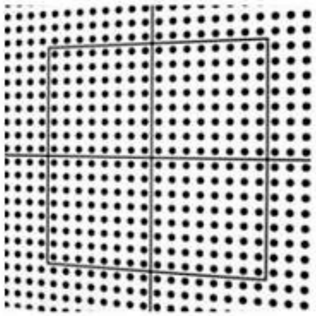
Standard lens



No distortion



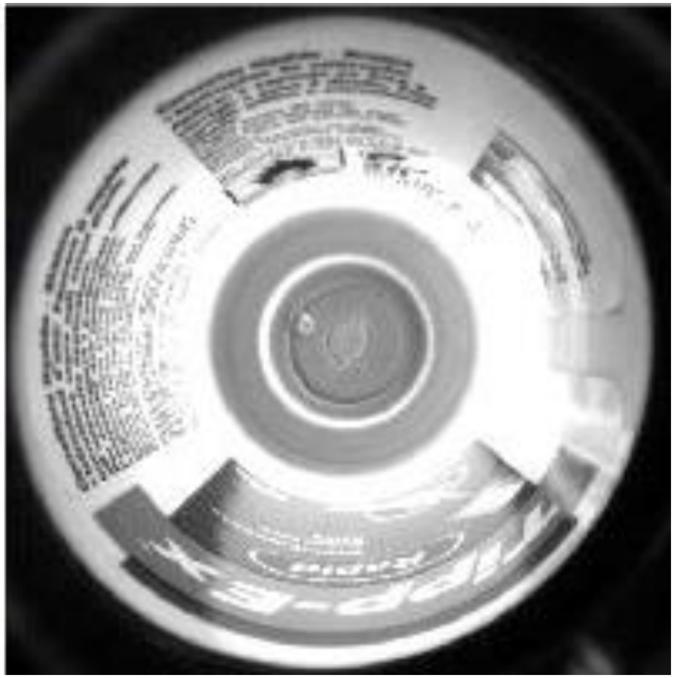
Radial distortion



Trapezoid distortion

Pericentric lens

- With 1 camera we make the work of more cameras
- Necessary to consider the distortion of the picture

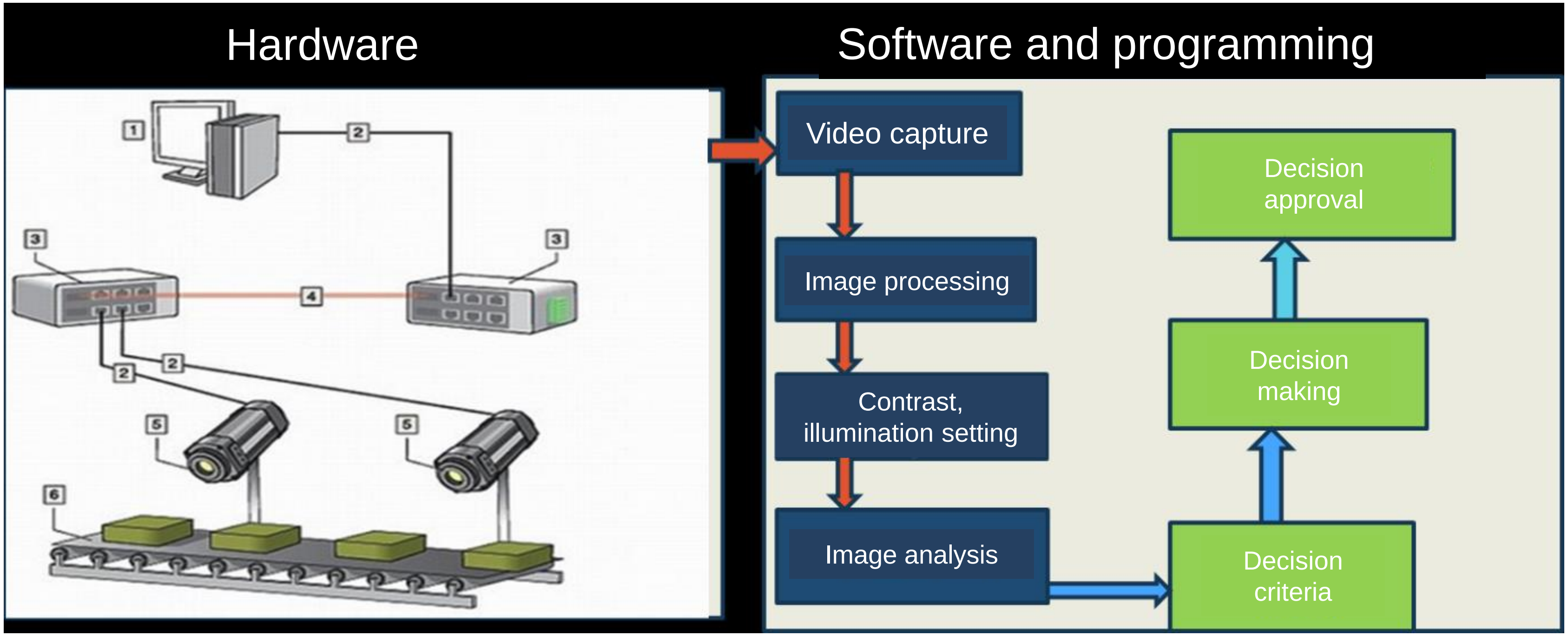



Different technologies to link the camera with the controller – and their properties

Connection	FireWire (IEEE1394b)	Gigabit Ethernet	USB 3.0	Camera Link
Transmission speed	80 MB/s	125 MB/s	400 MB/s	680 MB/s
Wire lengths	4.5 m	100 m	3 m	10 m
Integration complexity into the system	Moderte	Small	Small	Big
Power Delivery	45 W	15.4 W[1]	4.5 W	None
More cameras support	Excellent	Good	Excellent	Poor
Camera price	Middle	Middle	Low	Low

Programming for machine vision

- Image capturing, processing preparation
- Picture analysis
- Collection of results
- Decision criteria
- Writing the result of the analysis into the memory
- Sending the decision to the I/O component



Programming for machine vision

FoF

Comparison

Flexible solutions

- Development of an application with a generic program, which also enables the development of its own algorithms
- Solving specific problems with adaptive algorithms
- Low cost of equipment
- Flexibility of the system (changing settings according to customer's preferences) and the possibility of analysing different products
- Choosing the hardware based on a specific problem by considering the colour and material of the product, resolution, working cycle, processor power, and illumination.

Industrial solutions

- High price
- It is IMPOSSIBLE to solve non-standard measurements/detections - limited detection modules
- Rigid systems - designed for the exact specified product
- Closed system - you can not change the settings
- Smart cameras allow flexibility and change of settings, but they are expensive and the company must have an employee programmer for machine vision

Further trends, based on advanced sensorics

- Industry 4.0 – industry of the future,
- More RFID technology
- Internet of things – Cyber Physical Systems

The need to process a large amount of data → will require new sensor technologies, the integration of sensors, RFID and „e-grain“ computers (processors) integrated into a product, a system, etc.