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Digital Factory

Factory critical points identification and suggestions for improvement

Module III: Digital factory analysis: From analysis to factory solutions

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Curriculum Development
of Master's Degree Program in
Industrial Engineering for Thailand Sustainable Smart Industry

Learning Outcome

Propose a digital factory platform of a case study factory in a virtual environment upon what have been learned (Design, Module III)

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Content

Case study in industrial

- Production line balancing
- Production bottlenecks
- Production and logistics processes
- Production scenarios
- Aircraft engine parts
- Tire Automotive
- Automated guided vehicles
- Human and Robot operation
- Human–robot collaboration (HRC)
- Ergonomics in Practice
- Digital Mock-Up for Mechanical products
- Spacecraft Collaborative Design Technology

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Concept of Digital Manufacturing

The digital manufacturing can be used in the following areas

❑ Manufacturing Planning

1. Define High-Level Manufacturing Processes
2. Process Planning (Assembly & Installation)
3. Define Work Instructions & Work Flow
4. Detailed Process Design & Analysis

❑ Detailed Resource Modelling & Simulation

1. Process Definition and Validation
2. 3-D Factory Layout
3. Equipment, Tool & Fixture Simulation
4. Ergonomic Simulation

❑ Validation & Virtual Commissioning

1. Control Logic Validation
2. Kinematic (Robotic) Validation
3. Quality Assurance/Process Improvement Validation
4. Sensor/Metrology Placement Validation
5. Virtual Commissioning/Validation of Automation Systems
6. Knowing that the Production System Works Prior to Launch: Priceless.

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Production line balancing

- **Case study for the optimization of the production line by using the balancing and discrete event simulation (2D) approach.**

- First the basic theory and steps for the production line balancing are presented.
- For the real production process, consisting of two production lines and an assembly workplace the simulation model is built and the initial results obtained.
- After balancing of the production process and improvement of its performance some further steps of the process optimization by using the improved simulation model are performed.

Zupan, 2015

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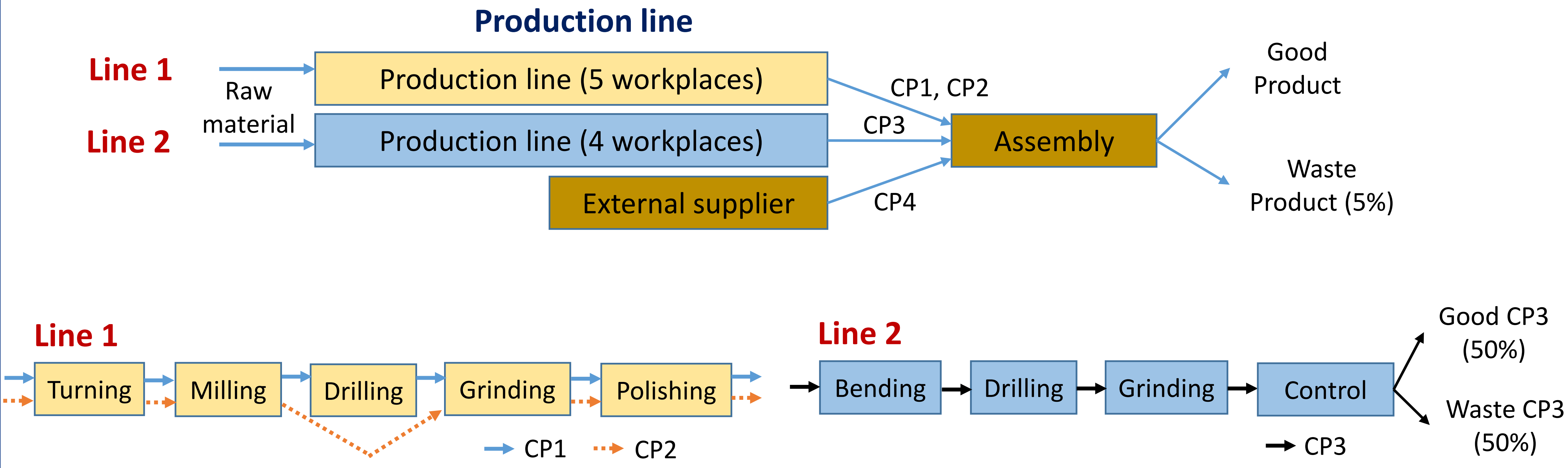
Production line balancing



Scheme of production process with assembly

Zupan, 2015

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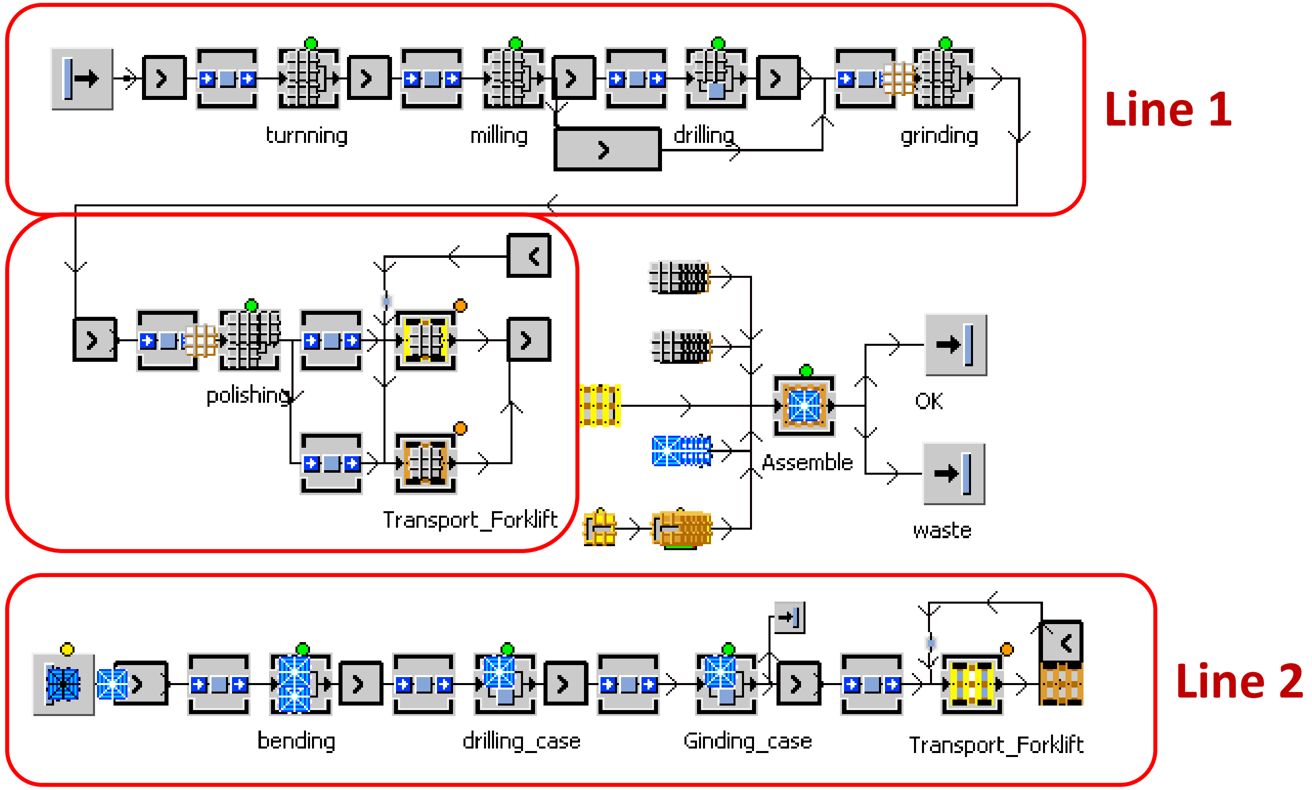
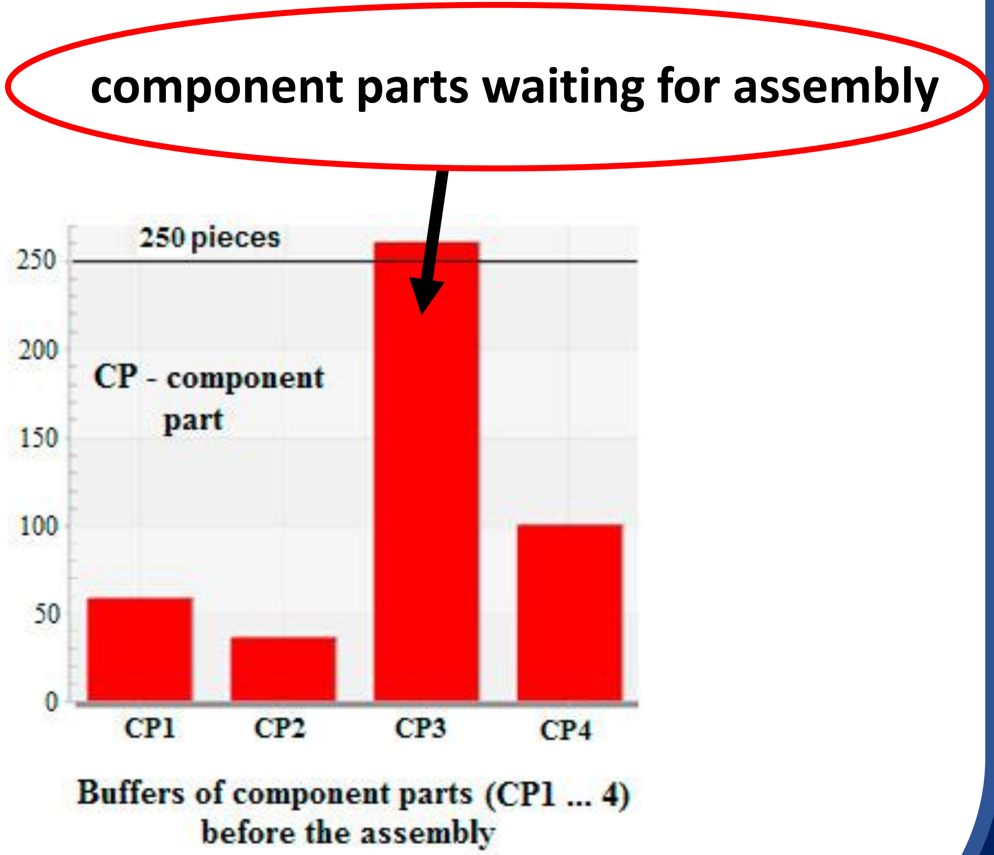
Production line balancing

Simulation model of the production line



Simulation model of assembly production (2D)

One of the indicators is the state of buffers



Buffers of component parts (CP1 ... 4) before the assembly

Zupan, 2015

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Production line balancing

Simulation model of the balanced production lines

- *bottlenecks appear – the forklifts transportation and intervals of raw material entering on both lines.*
- *The forklift is just not able to transport all of the new component parts from the 1st and the 2nd line to the assembly workplace.*

Improvement

- *By entering one additional forklift to each production line the first bottleneck can be removed.*
- *By adjusting the interval of raw material entering into the each production line the second bottleneck can be removed.*

Zupan, 2015

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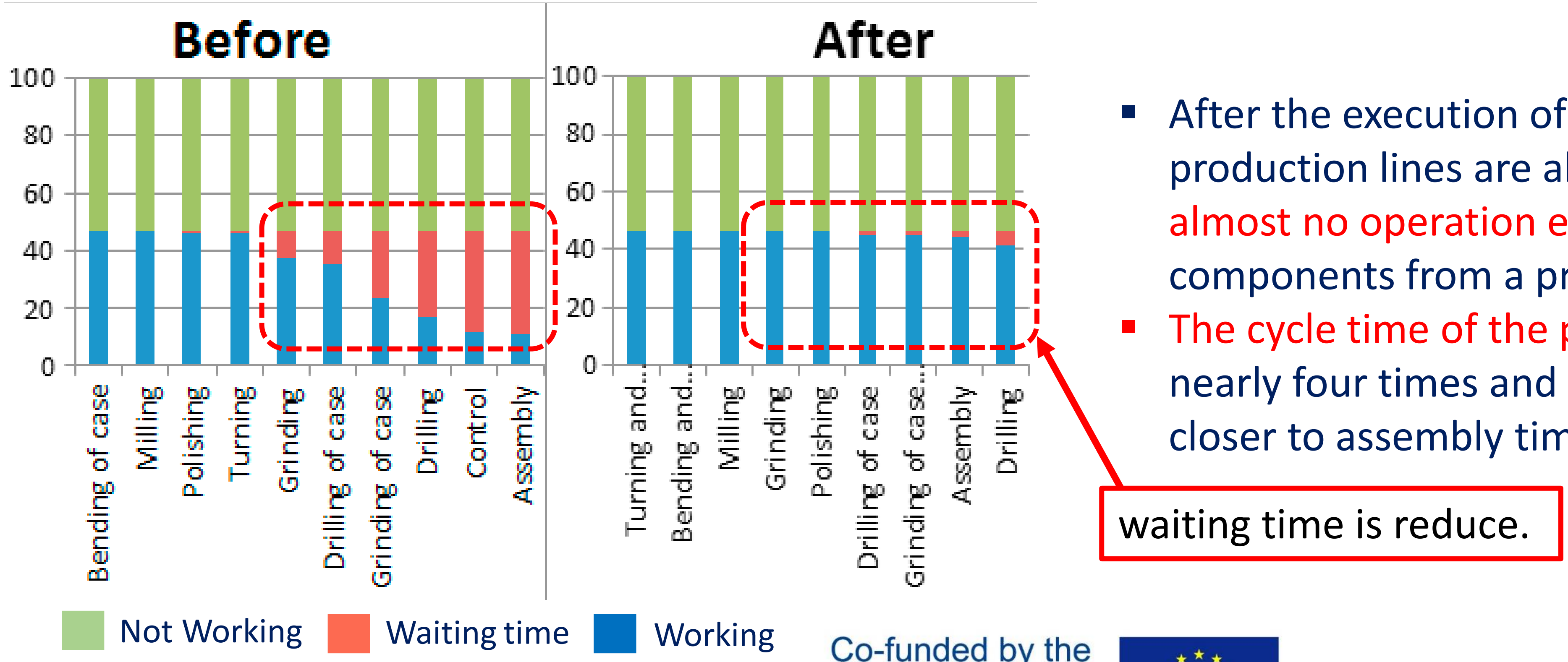
Production line balancing

Final results of the simulation model

The overview over the utilization time of machines in the both production lines where the state before and after the line balancing is presented.



- After the execution of line balancing the production lines are aligned in a way that almost no operation ever waits to the components from a previous operation.
- The cycle time of the production is reduced nearly four times and the cycle time is now closer to assembly time.

Zupan, 2015

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Production line balancing

Critical points identification	Bottlenecks appear – the forklifts transportation and intervals of raw material entering on both lines. The forklift is just not able to transport all of the new component parts from the 1st and the 2nd line to the assembly workplace.
Indicator	State of buffers, utilization time of machines.
Improvement	By entering one additional forklift to each production line the first bottleneck can be removed and adjusting the interval of raw material entering into the each production line the second bottleneck can be removed.
Result	No operation ever waits. The cycle time of the production is reduced.

Zupan, 2015

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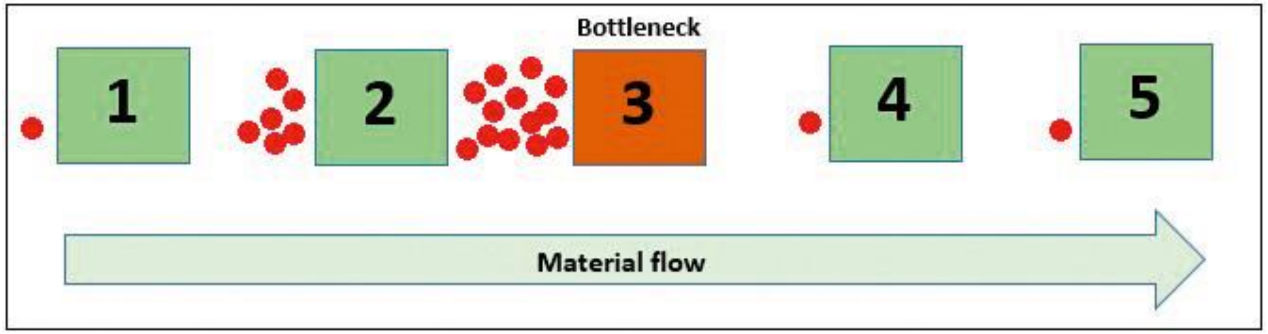
Production bottlenecks

- The article presents the analysis and assessment of the chosen production line in two versions. The studies facilitated an initial evaluation of the efficiency of specific elements in the process and the indication of its bottleneck.

- Simulation models allow evaluating different variants of production and their effectiveness. In addition, the simulation allows to use new strategies and procedures, verification of the production in the revised system, locate bottlenecks in the flow of materials, increase productivity while reducing inventory and reduce the cost of the implemented changes.



Idea of bottlenecks

Kikolski, 2016

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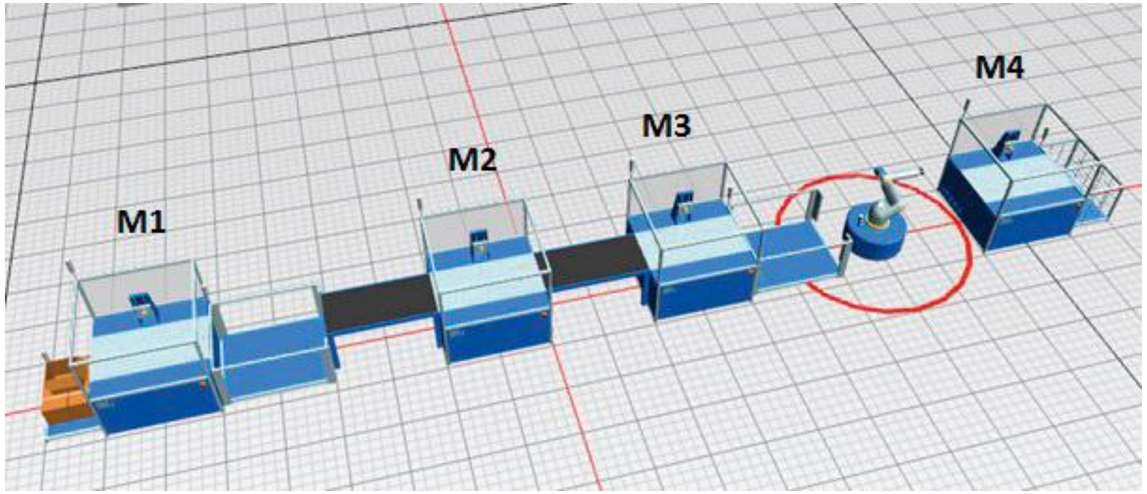
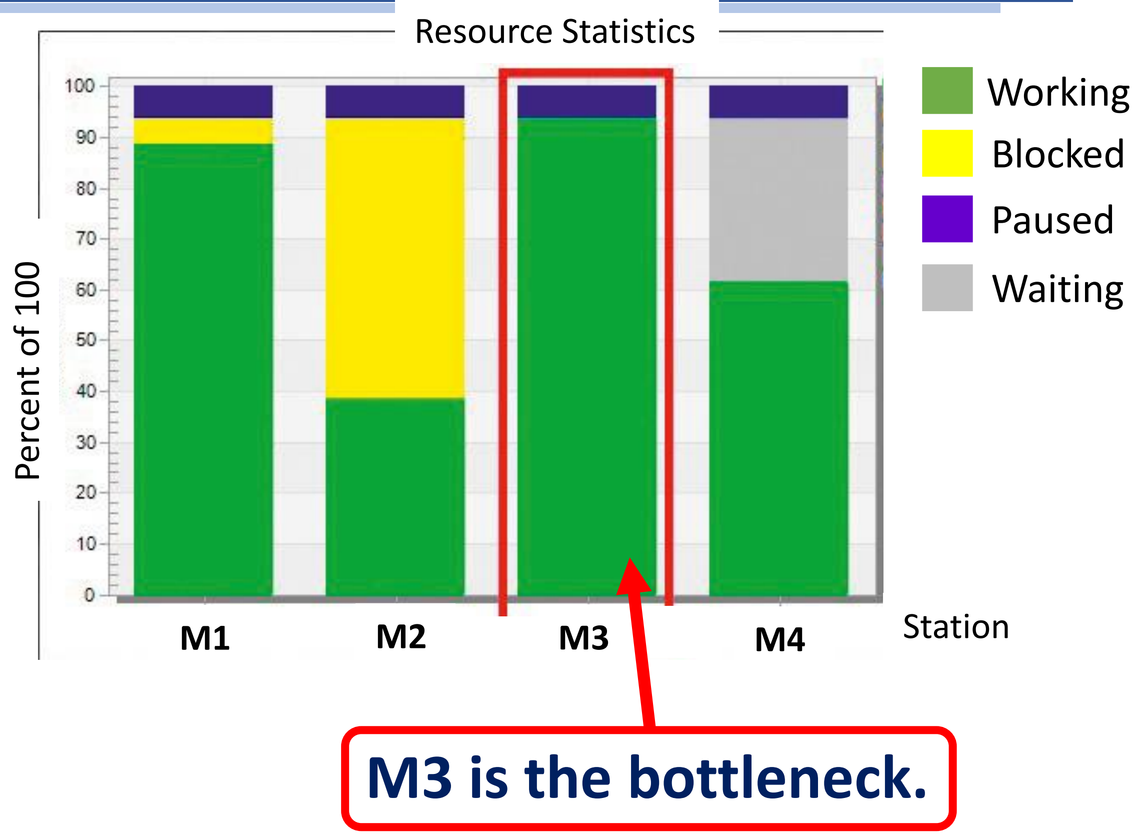
Production bottlenecks



Virtual 3D model of the analysed process

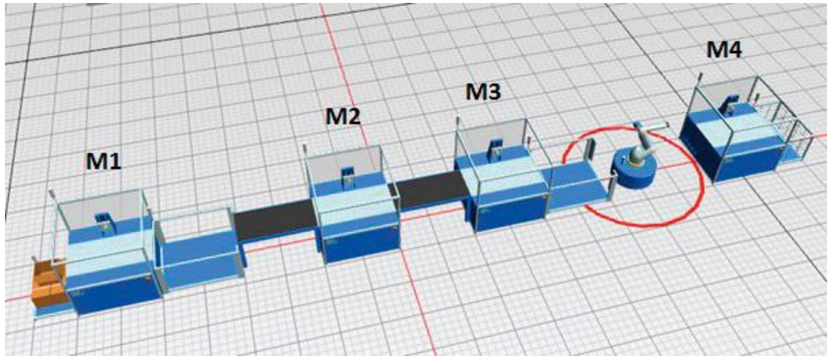


The input data are determined based on the known technological data of the process and the data concerning material flow during production.

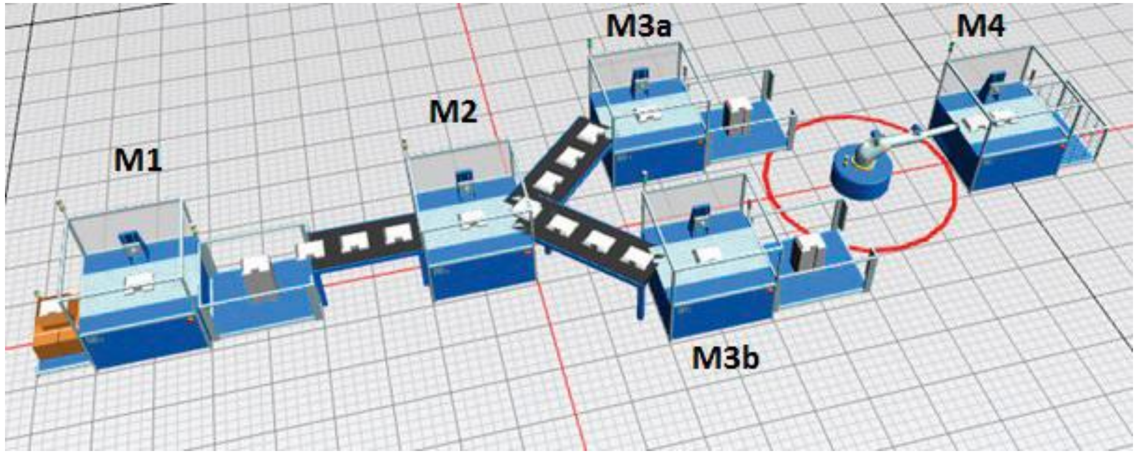
M1 and M3 have a high work coefficient.

Kikolski, 2016

Production bottlenecks



Virtual 3D model of the analysed process



Extended model of the analysed process

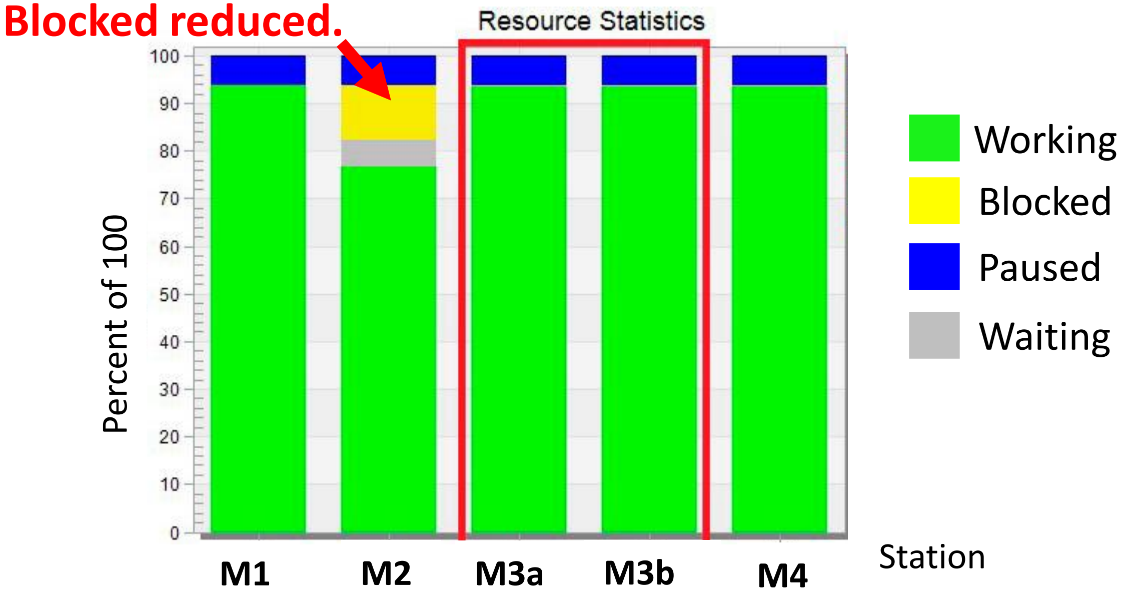


Chart of efficiency for extended model

Increase the production capacity of the process and the vast reduction of the time of locking at the station M2 and expectations for components at the station M4.
The analysed production line began to work smoothly.

Kikolski, 2016

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Production bottlenecks

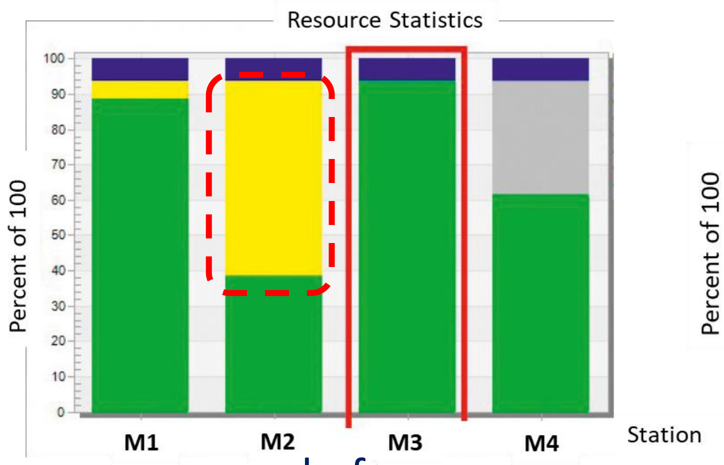
Detailed statistics in the basic model

Workplace	Working time [%]	Waiting time [%]	Blocked time [%]	Paused time [%]
M1	88.75	–	5.00	6.25
M2	38.29	0.18	55.28	6.25
M3	93.58	0.17	–	6.25
M4	61.22	32.53	–	6.25

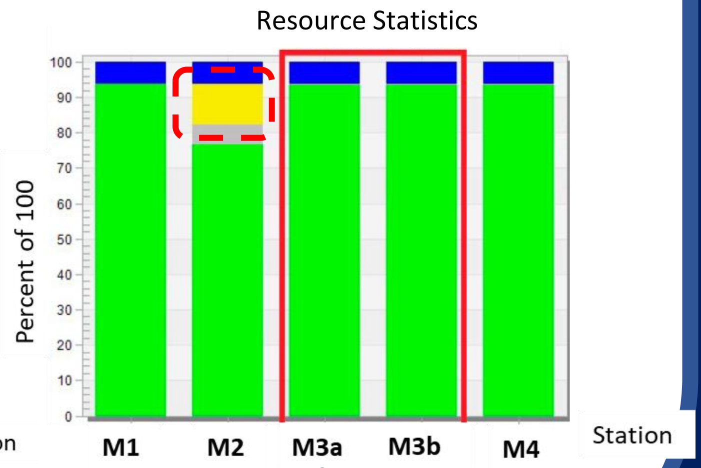
Detailed statistics in extended model

Workplace	Working time (percentage)	Waiting time (percentage)	Blocked time (percentage)	Paused time (percentage)
M1	93.75%	–	–	6.25%
M2	76.58%	5.59%	11.58%	6.25%
M3a	93.58%	0.17%	–	6.25%
M3b	93.49%	0.26%	–	6.25%
M4	61.22%	32.53%	–	6.25%

The introduced changes did not fully solve the problem of the bottleneck at the station M3, but they considerably improved the smooth operation of the entire production line.



before



after

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Production bottlenecks

Critical points identification	M3 is the bottleneck of the analysed process. The station M3 causes considerable standstills at the station M2. The waiting time for semi-finished products at the station M4.
Indicator	Resource statistics, working time, waiting time, blocked time, paused time.
Improvement	Expand parallel station of the work node M3, which is the bottleneck of the output process.
Result	Increase the production capacity of the process and the vast reduction of the time of locking at the station M2 and expectations for components at the station M4. The analysed production line began to work smoothly.

Kikolski, 2016

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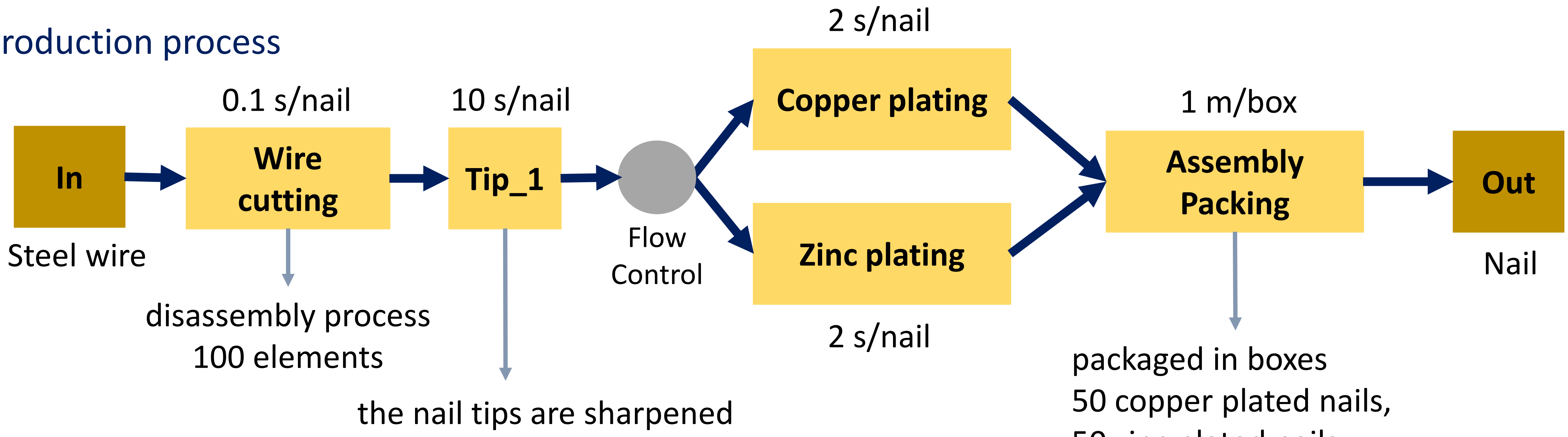
Production and logistics processes

- **Nails production**

  simulate discrete events and create digital models of logistic systems (e.g. production), optimize the operation of production plants, production lines, as well as individual logistics processes.

Nail production process



Siderska, 2016

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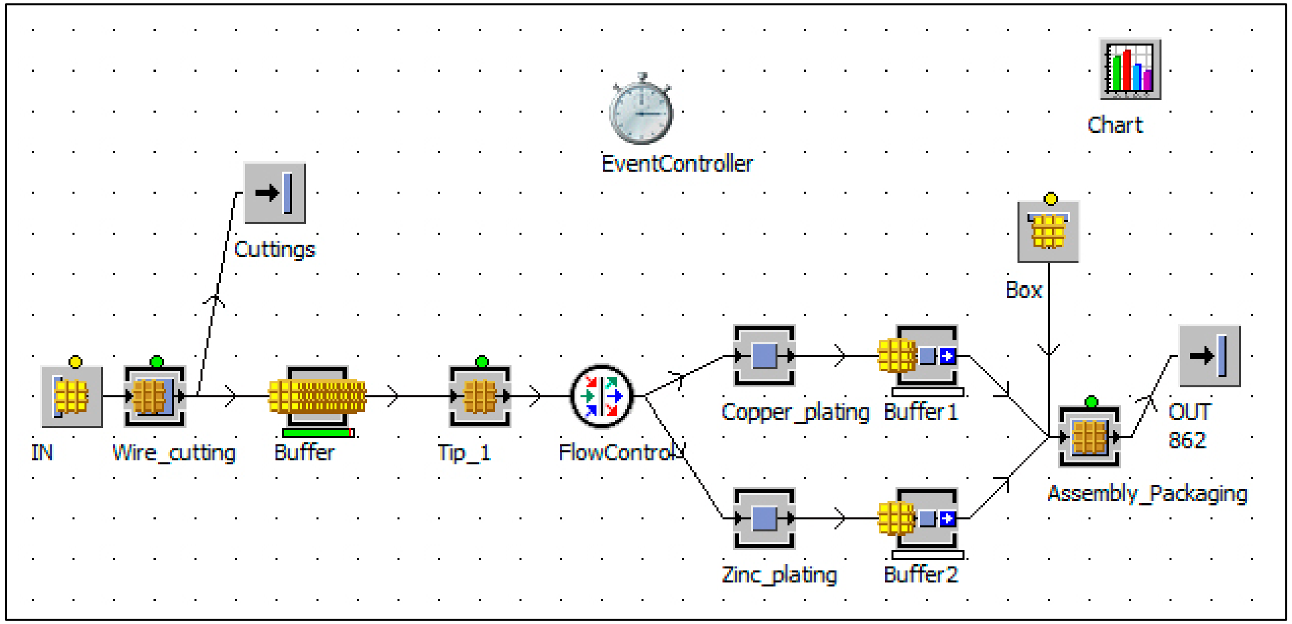
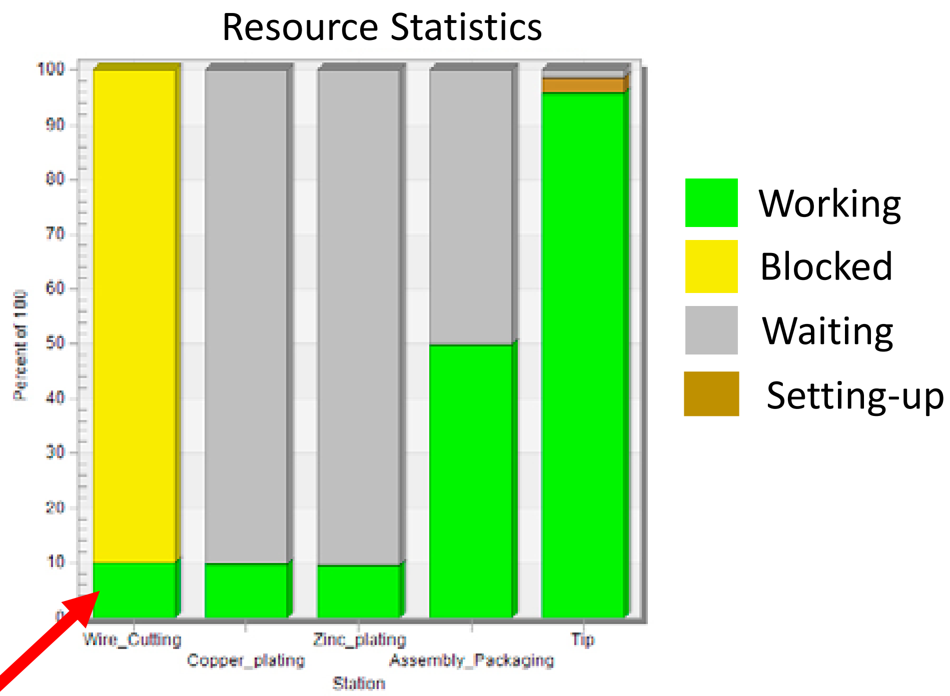
Production and logistics processes

Production process designed





What are the bottlenecks of the production process and how to increase the throughput of the plant ?

The wire cutting machine capacity was used only 10%. This station is blocked by the “Tip” machine, which is the bottleneck in this process.

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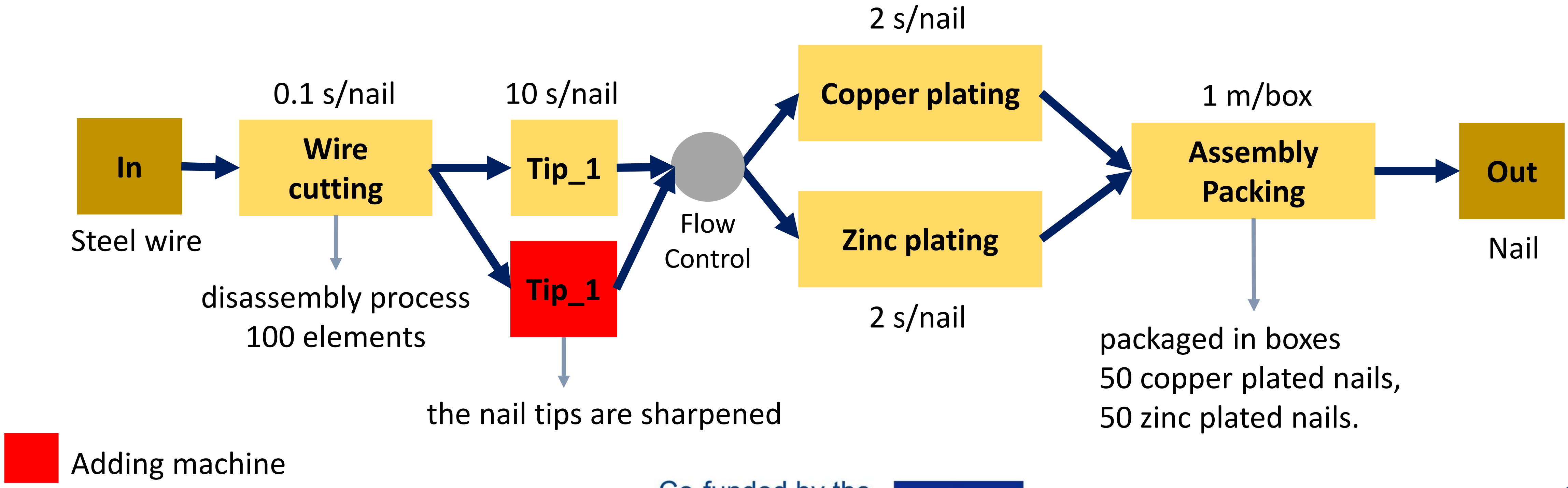
Siderska, 2016

Production and logistics processes

Adding another, parallel workstation for sharpening the cut nails.
Settings of the extra machine are the same as of the main one.

New nail production process



Siderska, 2016

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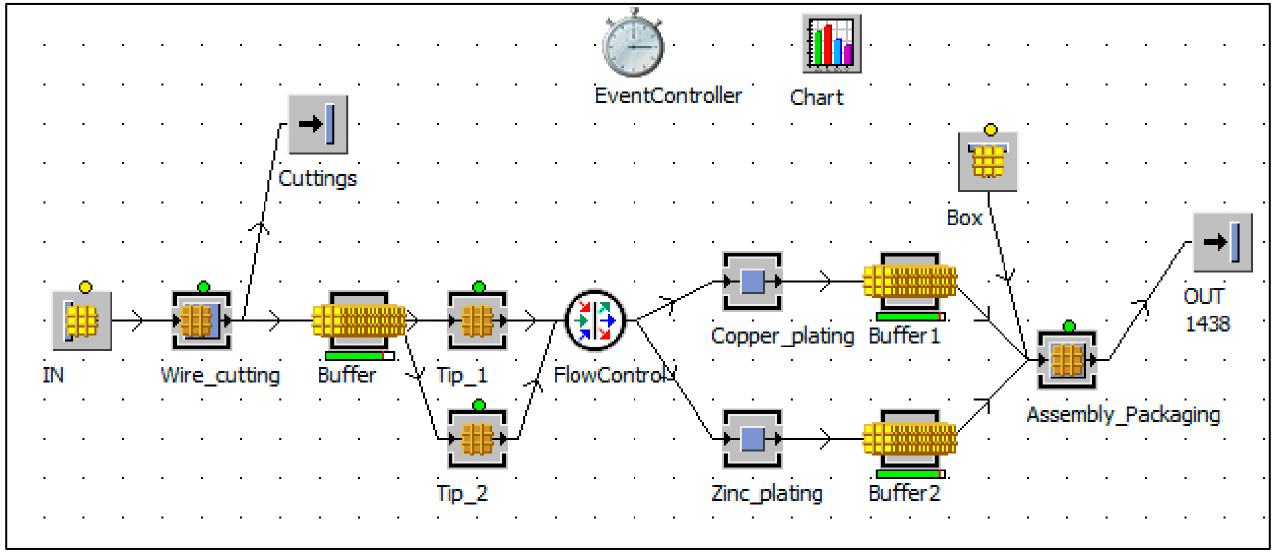
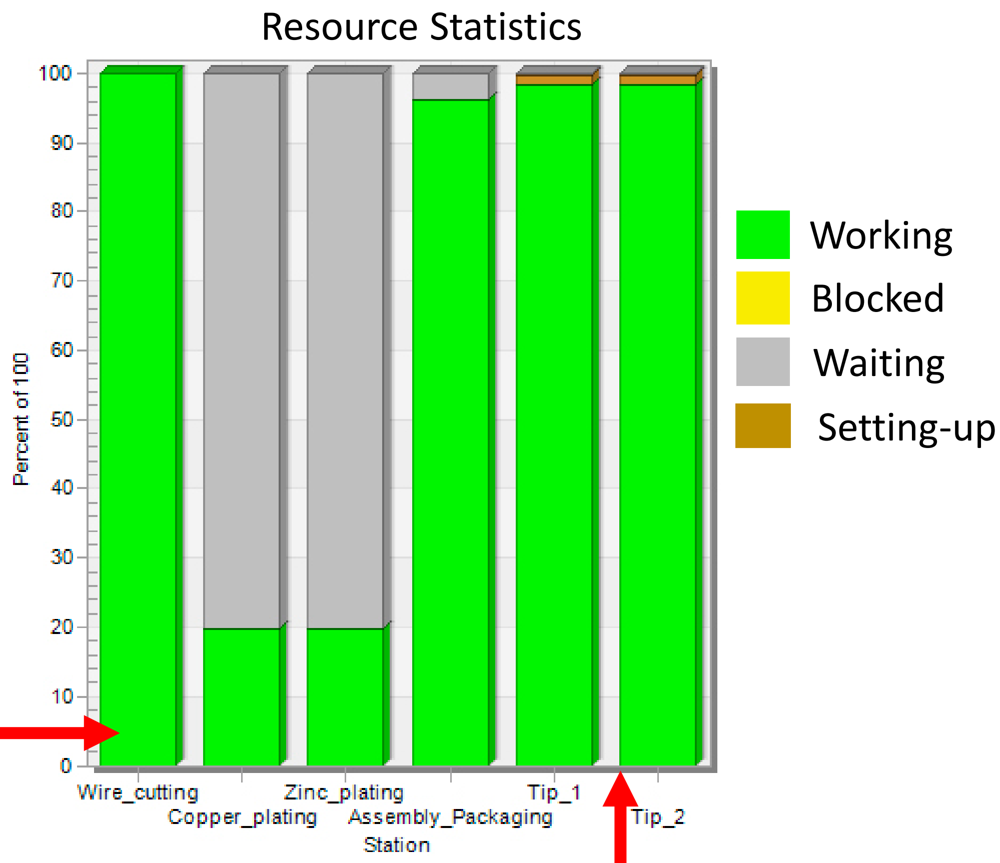
Production and logistics processes

Production volume after adding the “Tip” workstation





The wire cutting machine is working all the time now and 100% of its’ capacity was actually used.

This machine is not blocked by the “Tip” workstation any more.

Siderska, 2016

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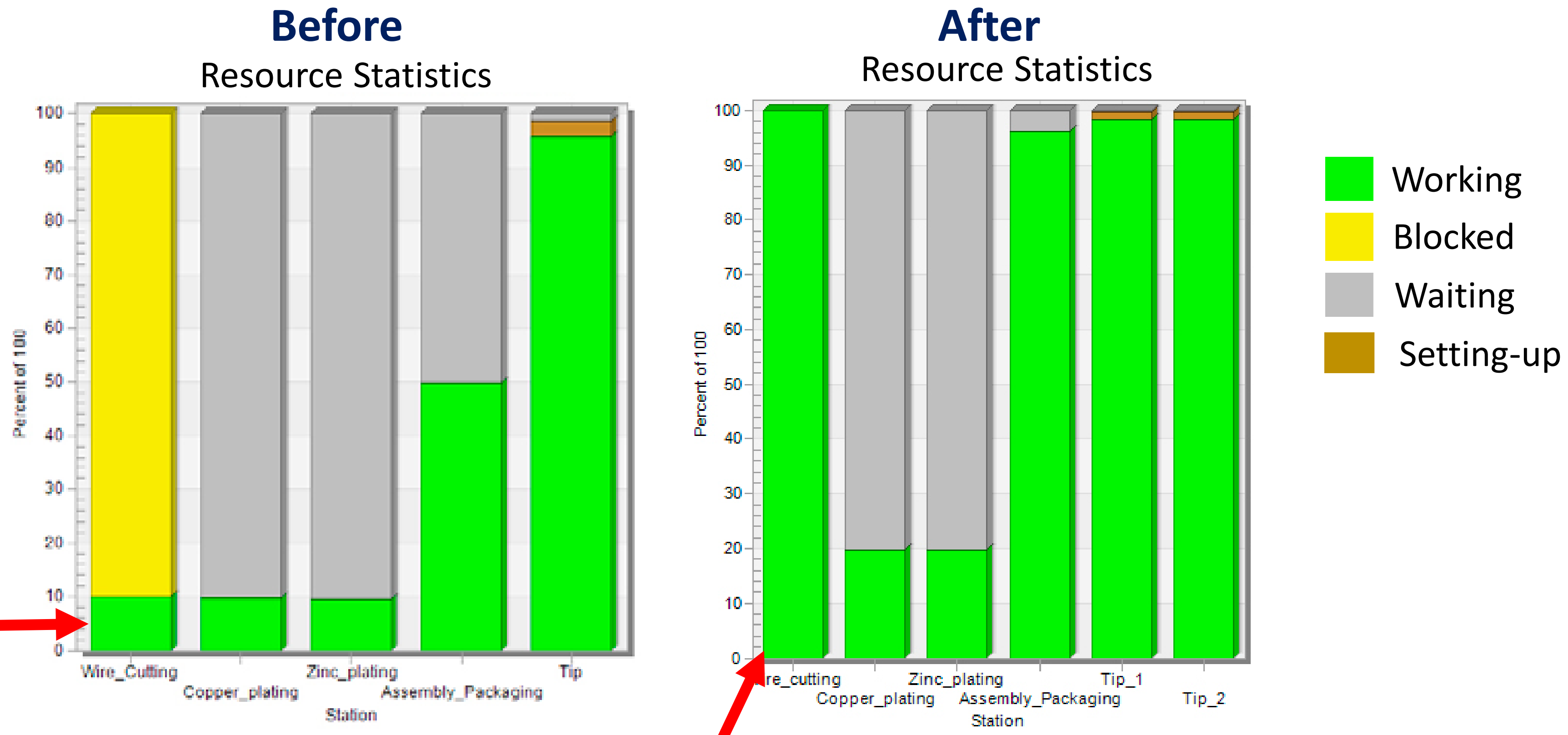
Production and logistics processes



The wire cutting machine capacity was used only 10%. This station is blocked by the “Tip” machine, which is the bottleneck in this process.

The wire cutting machine is working all the time now and 100% of its’ capacity was actually used. This machine is not blocked by the “Tip” workstation any more.

Siderska, 2016

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Production and logistics processes

Critical points identification	Optimize the operation of production plants, production lines, as well as individual logistics processes. This station is blocked by machine, which is the bottleneck in this process.
Indicator	Resource Statistics.
Improvement	Adding another, parallel workstation for sharpening the cut nails.
Result	The wire cutting machine is working all the time now and 100% of its' capacity was actually used. This machine is not blocked by the "Tip" workstation any more. The effect of shortening the time of assembly of one box from 60 to 30 seconds was also analyzed. This would make it possible to increase the production capacity even up to 1,726 pieces within 24 hours.

Siderska, 2016

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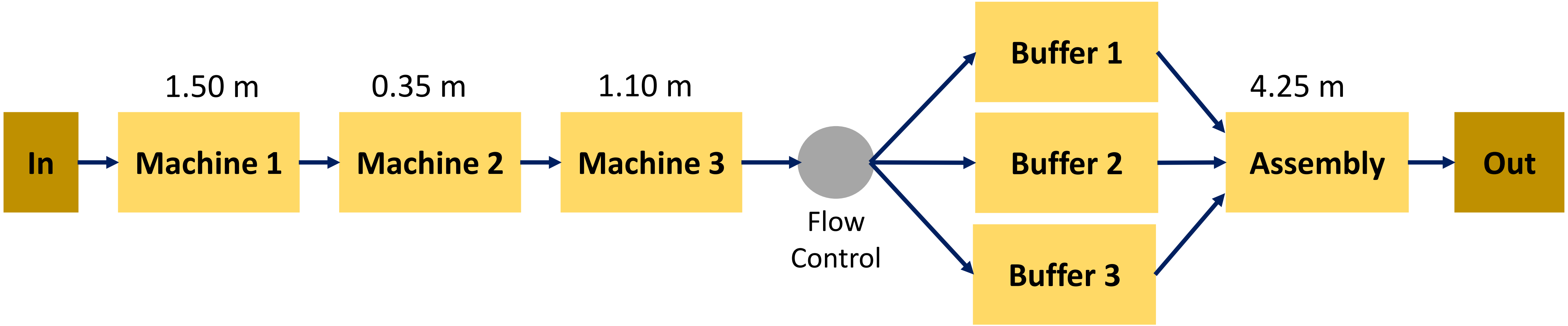
Production scenarios

- ❑ **Presents possibilities of applying computer simulation models in studying chosen production scenarios.**

Model of the analysed process



size of production batches, simulation times, performing specific operations and the availability of work stations.

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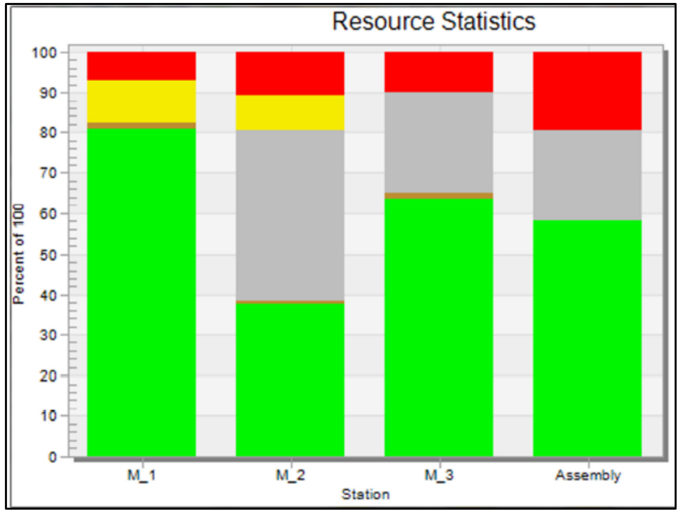
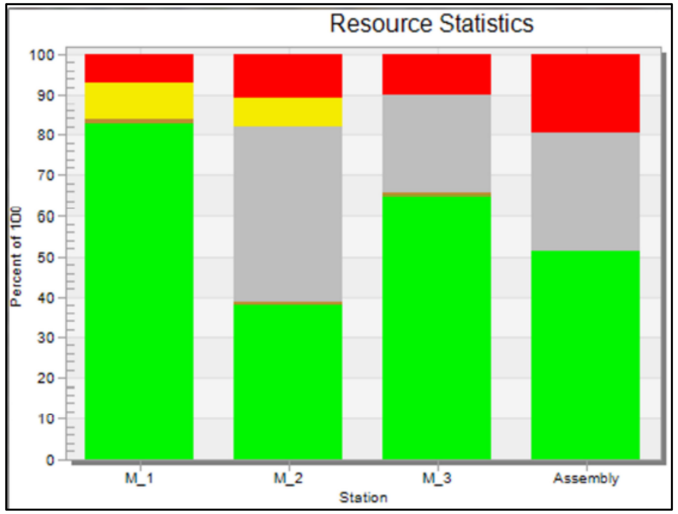
Production scenarios

Scenario 1 (currently), *30 items*



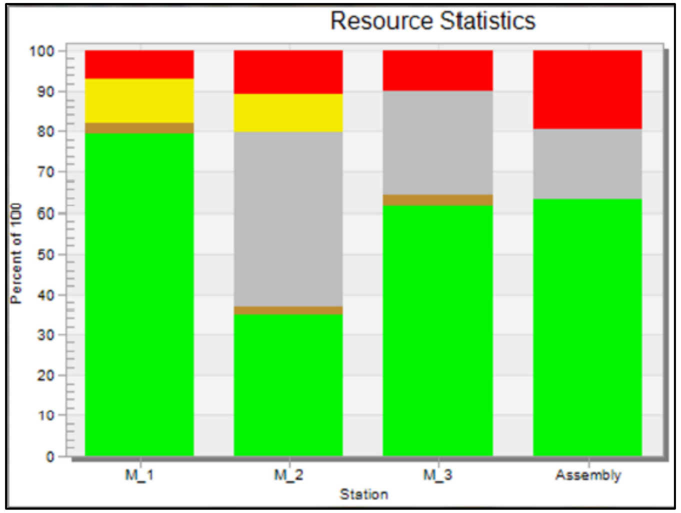
final products = 63 items

Scenario 2, *45 items*



final products = 56 items

Scenario 3, *15 items* (elements)



final products = 69 items

Working
Blocked
Waiting
Setting-up

- The simulation period assumed one 8-hour shift.
- The simulation analysis leads to the conclusion that the highest efficiency was reached within the system providing elements in 15-item batches.
- It appeared that increasing batches of entered components lowered production efficiency.

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Production scenarios

Critical points identification	Reduce the volume of stocks while ensuring the continuity of the production process.
Indicator	Resource Statistics, number of final products.
Improvement	The scenario analysis for number of items of each component into the system. Finally, chosen the best production scenarios is maximum final products .
Result	Reducing the batches entered into the system can increase its efficiency and flow of the transfers.

Kikolski, 2017

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Aircraft engine parts

- **Two case studies industrial scenarios, i.e. mass and small batch production, are simulated with the aim of improving specified performance measures related to manufacturing cells productivity, such as throughput or throughput time, and utilization of resources.**
  - **Small batch** in aerospace sector

Simulation models with the aim to analyse and possibly enhance the resources utilization and the batch throughput time, i.e. the time required to produce a whole batch of components.

Deburring or polishing, can often determine worker's injuries that could be avoided by introducing a higher level of automation based on devices such as robots.

Deburring or polishing

Caggiano, 2013

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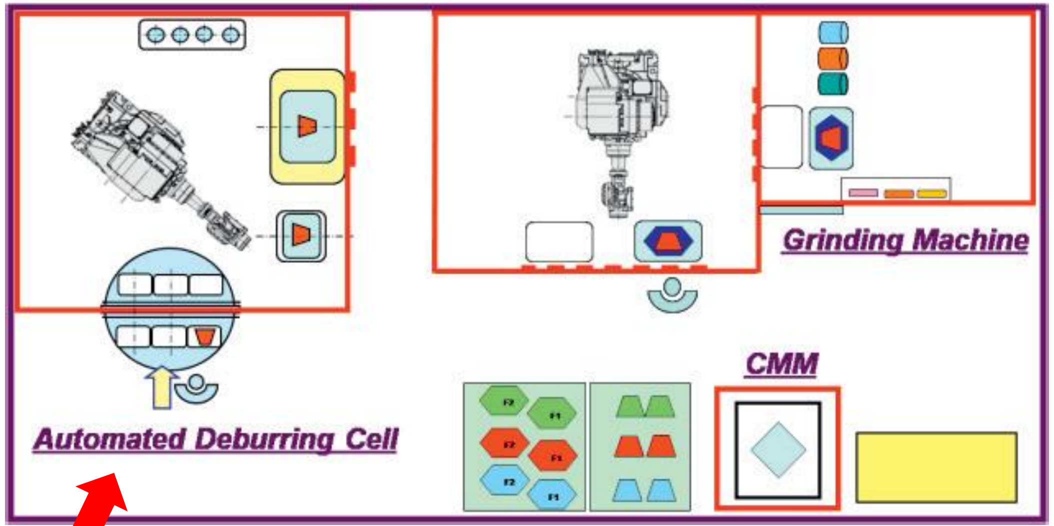
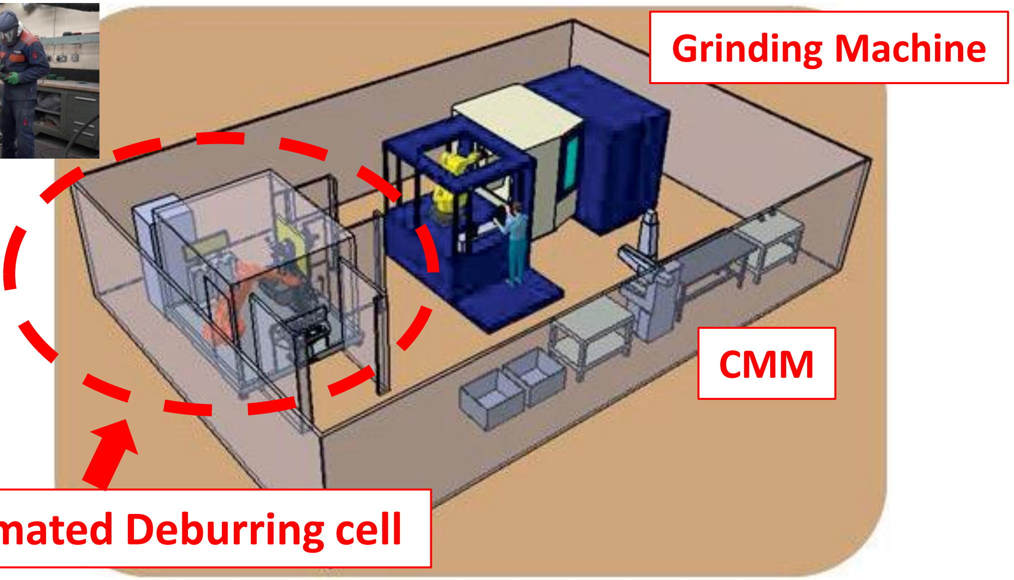
Aircraft engine parts

To reduce these risks and improve the manufacturing cell performance, a reconfigured manufacturing cell having an automated deburring cell provided with an industrial robot has been designed.



Layout of the reconfigured manufacturing cell

The 3D Motion Simulation model of the reconfigured manufacturing cell, including the machine tool, the Coordinate Measuring Machine (CMM) and the automated deburring cell.



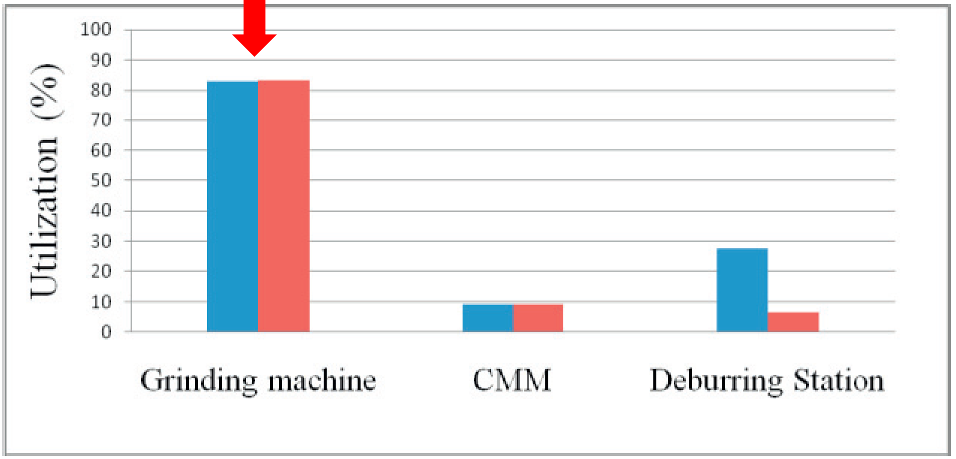
3D motion simulation

Caggiano, 2013

Aircraft engine parts

The automated deburring cell, deburring is performed only after both grinding processes.

Grinding machine is bottleneck around 83%.



Utilization of the manufacturing cell resources:
Existent manual cell   Reconfigured automatic cell

- as the handling/deburring robot is able to perform deburring faster than the human labor.
- However, the automated deburring cell has a production capacity which is higher than the one required by a single part number.
- *In order to increase the utilization of the automated deburring cell, a new scenario is simulated, where external part numbers are introduced into the cell only for deburring.*

Caggiano, 2013

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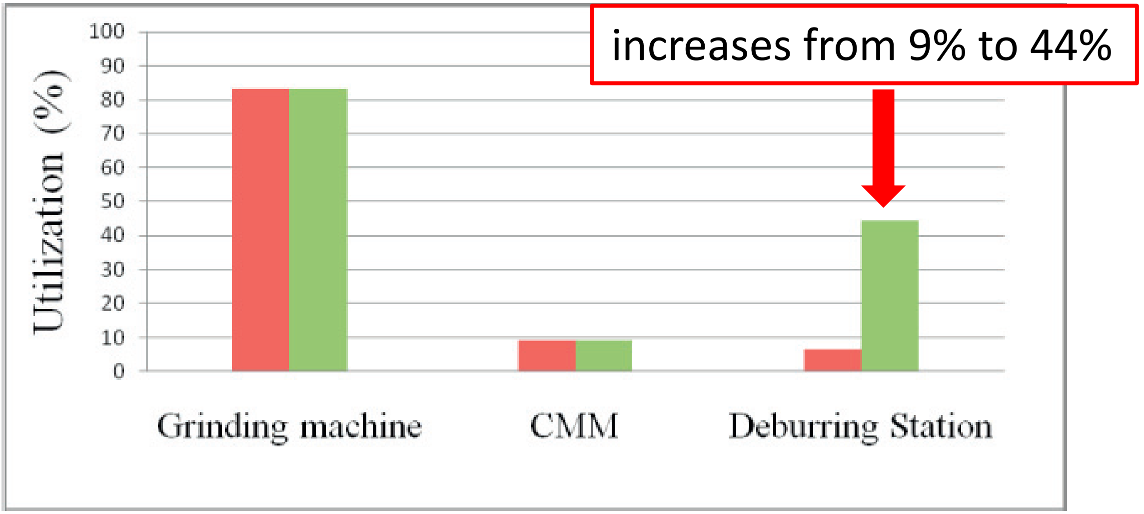
Aircraft engine parts

A new scenario is simulated, where external part numbers are introduced into the cell only for deburring.

- While the grinding machine processes the entire batch of the original part number, the automated deburring cell works on the external part number.
- As soon as the entire batch of the original part number has been completely ground and measured, little by little it is introduced in the deburring cell.



Utilization of the manufacturing cell resources:
Reconfigured cell Reconfigured cell with external part numbers.

- The deburring cell increases from 9% to 44%,
- The global throughput of the manufacturing cell is much increased as it includes a large number of external part numbers deburred.

Caggiano, 2013

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Aircraft engine parts

Critical points identification	Deburring operations are performed manually by a human operator following a procedure that requires large experience, manual ability and mind concentration. An inaccurate operation or human inattention can produce severe damages to the processed component.
Indicator	Utilization of the manufacturing cell resources.
Improvement	Deburring or polishing, can often determine worker's injuries that could be avoided by introducing a higher level of automation based on devices such as robots.
Result	Increase the throughput of the manufacturing cell by including external part numbers and to augment the utilization of the deburring cell from 9% to 44%.

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Caggiano, 2013

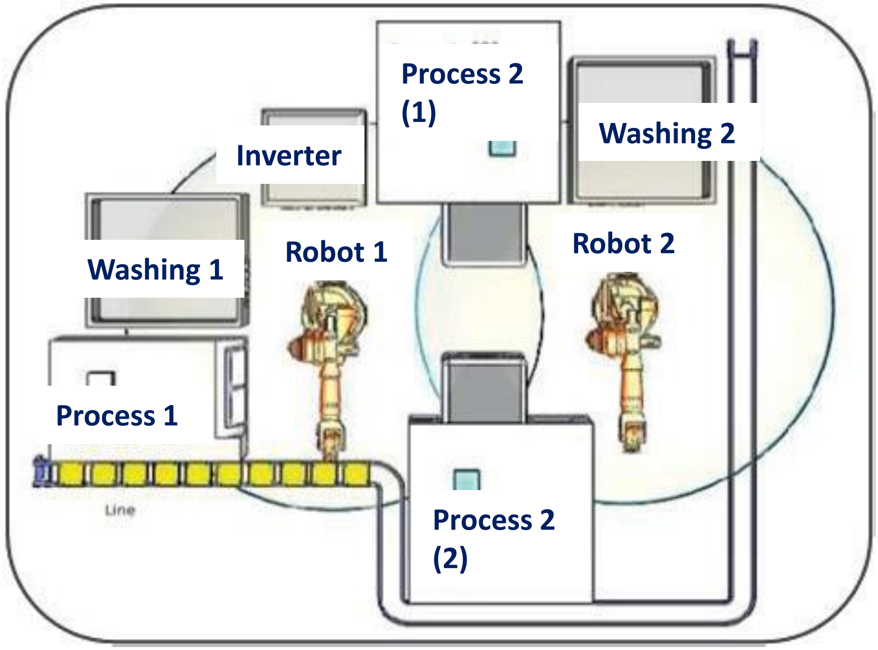
Aircraft engine parts

- **Mass Production**

Improve the efficiency of manufacturing cell by achieving the desired throughput level, expressed. In order to analyse the behaviour of the manufacturing cell and investigate how to achieve

A first simulation run is performed to obtain numerical results on current manufacturing cell throughput and utilization of resources, and to carry out bottlenecks analysis to identify the critical components.

Each one of these elements is characterised by two main parameters: **process cycle time** and **machine availability.**



Layout of the manufacturing cell DES model (Tecnomatix)

Caggiano, 2013

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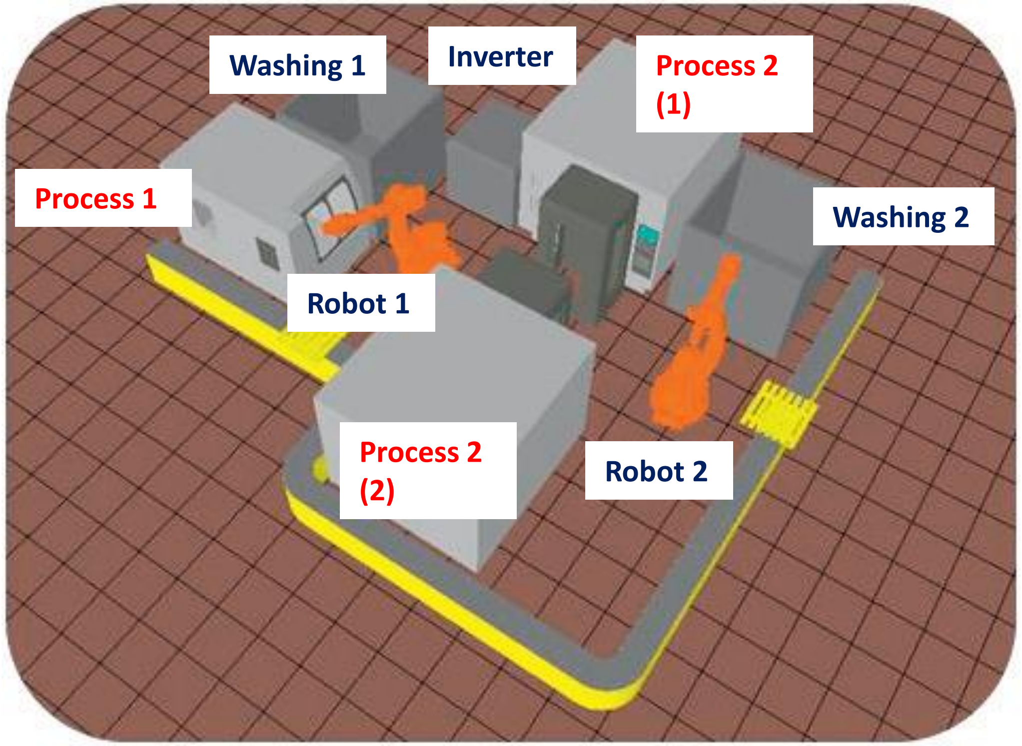
Aircraft engine parts



Layout of the manufacturing cell DES model (QUEST)

- The new simulation model set up with the values of the 6 parameters (process time and machine availability for each of the three machine tools). identified by the algorithm gives new results in terms of throughput (increased about 4%) and utilization of resources
- A multi-level experimental design with different combinations of the 6 previously defined parameters would require a very large number of experiments.

Caggiano, 2013

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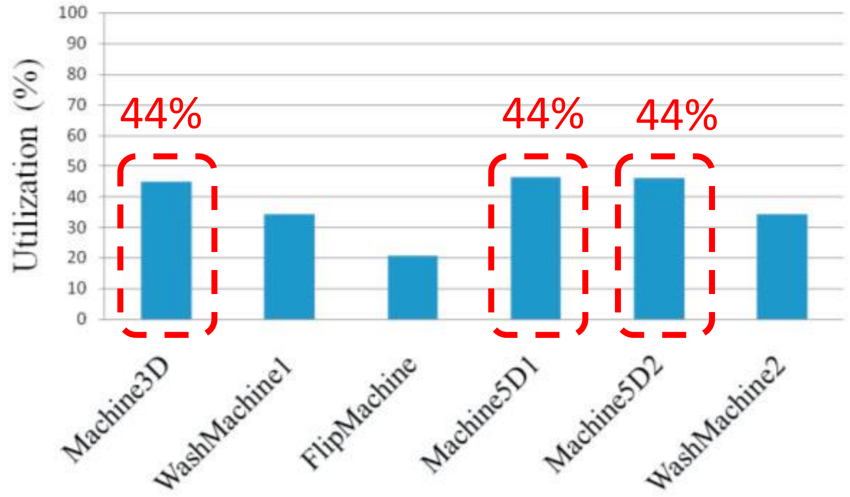
Aircraft engine parts

Elements utilization in the first simulation run and new model

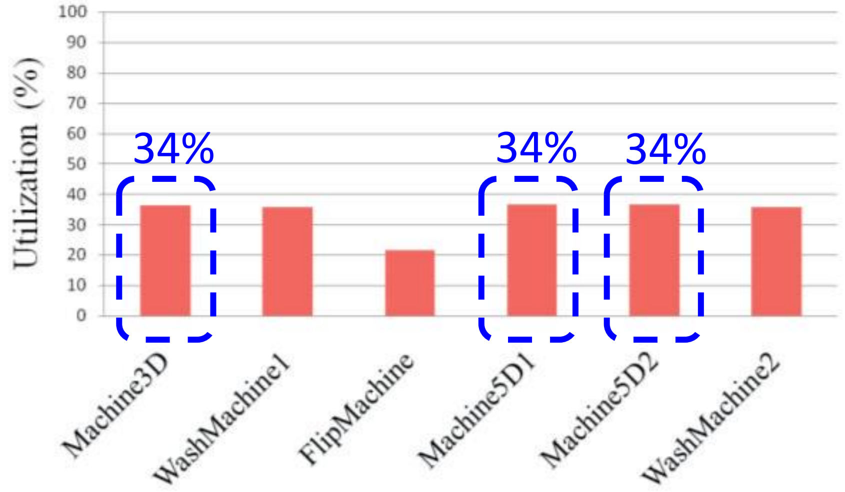
bottlenecks of the cell are represented by the three machine tools which have a very similar utilization.



the first simulation run

Tabu search solution

The algorithm gives new results in terms of throughput (increased about 4%) and reduce utilization of resources (from 44% to 34%).



new model

Caggiano, 2013

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Aircraft engine parts

Critical points identification	Improve the efficiency of manufacturing cell by achieving the desired throughput level, expressed as the number of produced units/day, giving information on the rate at which work can be handled by the system.
Indicator	Cycle time and machine availability.
Improvement	Set up with the values of the 6 parameters: process time and machine availability for each of the three machine tools.
Result	New results in terms of throughput (increased about 4%) and reduce utilization of resources.

Caggiano, 2013

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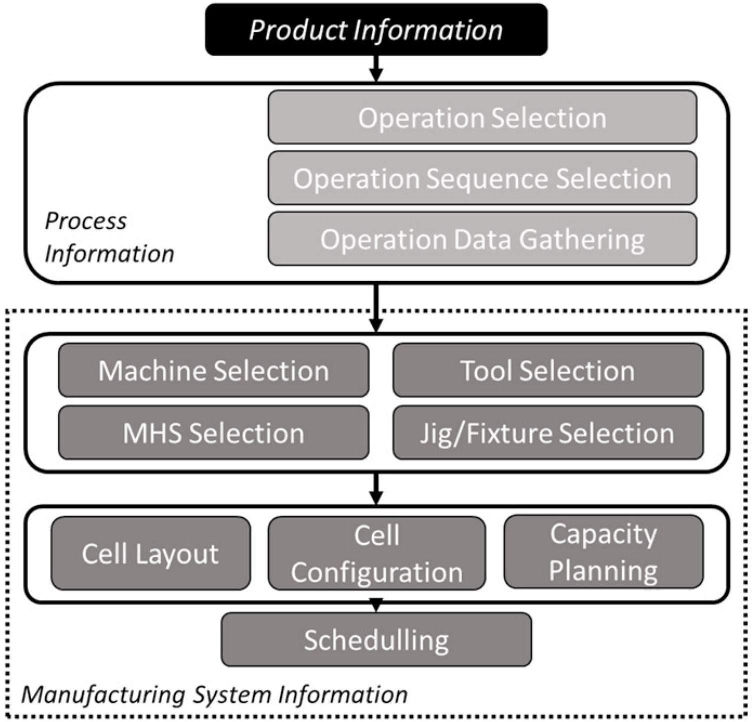
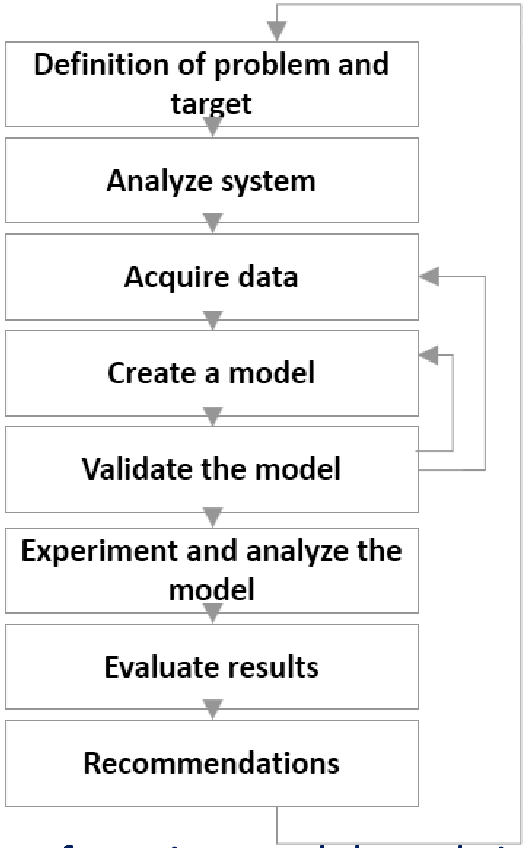
Tire Automotive

- A methodology to the guide development and improve the decision-making process to assist the plant design and operation using simulations.



Enterprise planning activities



Steps for using models and simulations as stated

Chavarria , 2018

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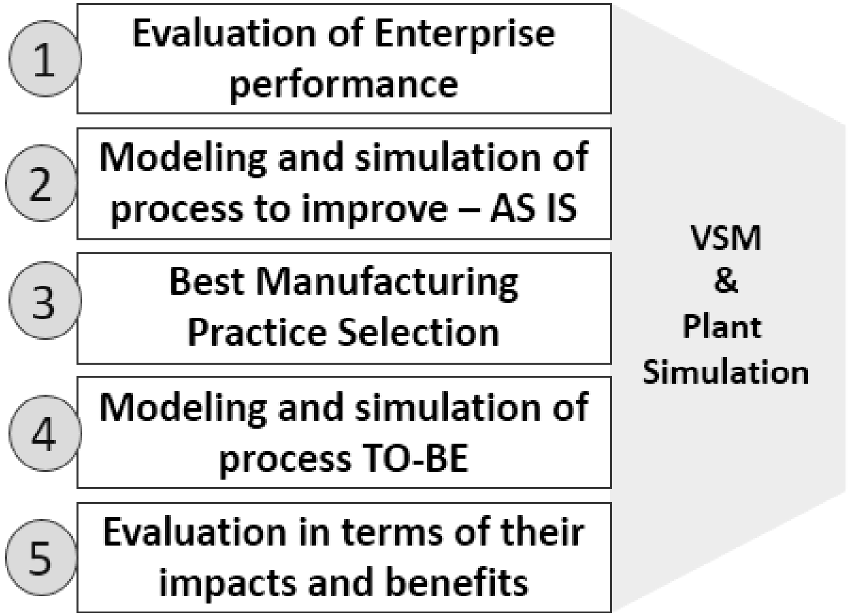
Tire Automotive



Methodology for evaluation of best manufacturing practices [Molina and Medina 2000].

Accordingly, the activities done at each action-research cycle become as follows:

- **Plan:** (1) define problem and target according to the set of enterprise planning activities, (2) establish a set of objectives (3) specify the decision criteria for analyzing the alternatives (objective measures), and (4) propose one or more alternatives of the manufacturing system.
- **Act:** (1) Determine the type of model according to a model typology, (2) Develop a model and validate it.
- Carry experimentation if necessary.
- **Observe:** (1) simulate the model and (2) evaluate the objective measures.
- **Reflect:** (1) Identify one or more courses of action according to the results of the observe step and restart the cycle if necessary.

Chavarria , 2018

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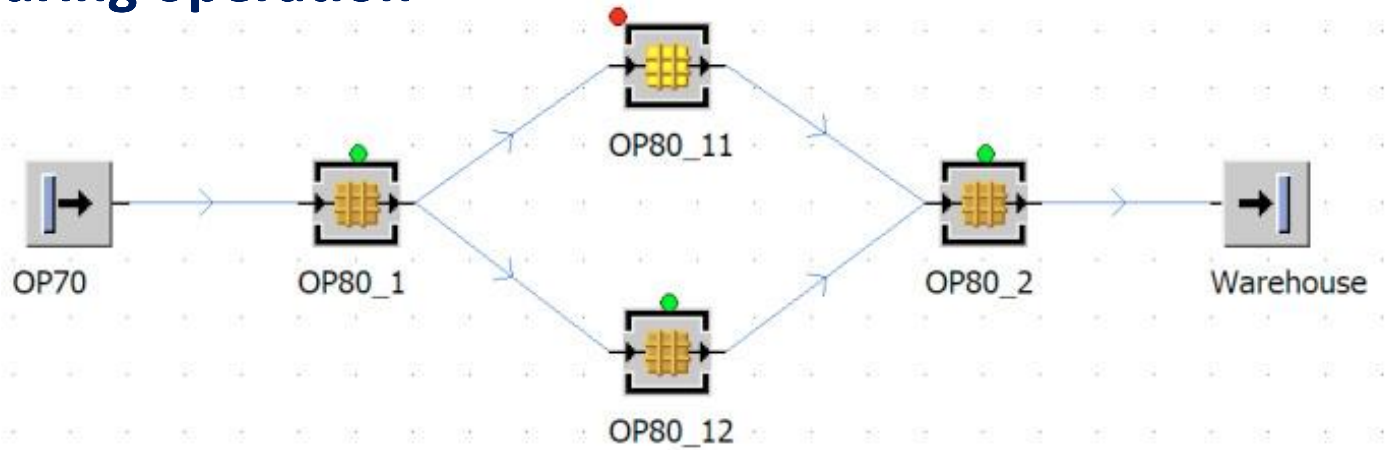
Tire Automotive

The proposed typology includes three types of models: **black-box model**, **operation model** and **integrated operating model**.

Black-box Model for a manufacturing operation



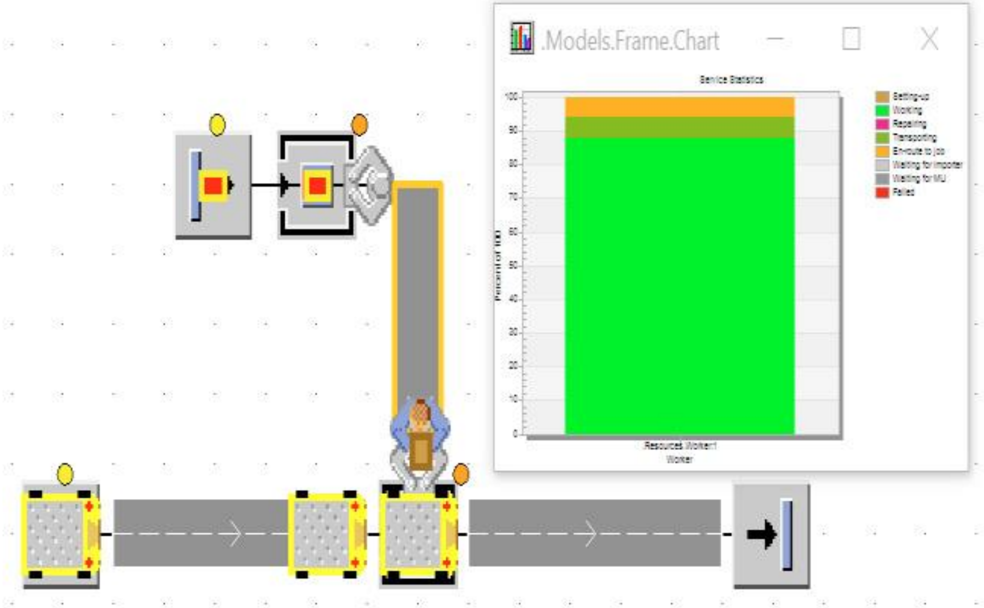
Identify and to represent the main activities of a process and the interaction between them. Several activities can be grouped within a single operation, to maintain a simplified process model. A black box is created for each activity that is involved in a process.

Chavarria , 2018

Co-funded by the Erasmus+ Programme of the European Union

Tire Automotive

Operation Model for an automotive assembly line



- An Operation Model, is a building block for creating an integrated model of operations.
- This level of detail is suitable for modelling a specific activity, a workstation or a small process.
- The maximum productive capacity of the activity or small process is analyzed.
- This model considers that the input of the material is always available and the output material of the system can be processed at any time.

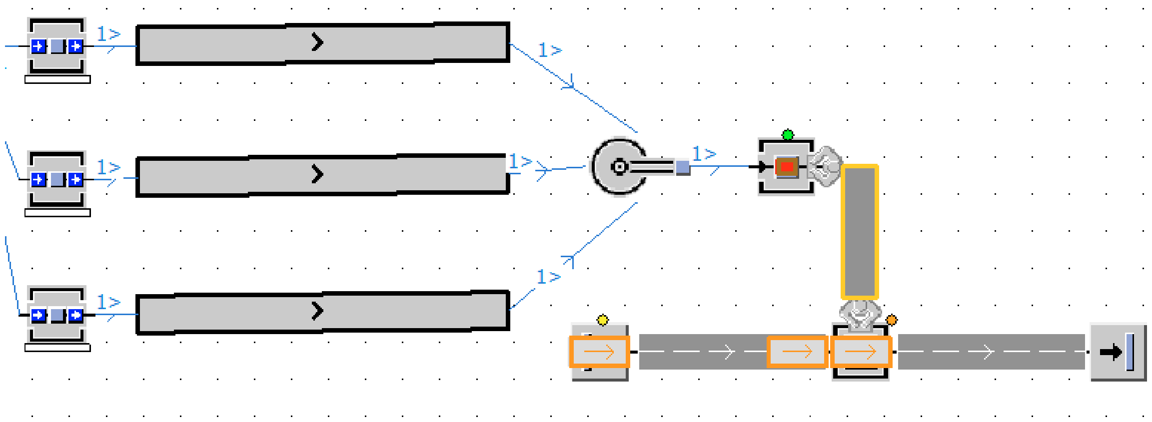
Chavarria , 2018

Co-funded by the Erasmus+ Programme of the European Union

Tire Automotive

The proposed typology includes three types of models: **black-box model**, **operation model** and **integrated operating model**.

Interconnected Operation Models to produce an Integrated Operation Model



- The Integrated Operation Model is useful for modelling the whole manufacturing system.
- An integrated operation model consists of interconnected operation models.
- This model is based on the material exchanges and operation connectivity information that were defined in the black box model.

Chavarria , 2018

Co-funded by the Erasmus+ Programme of the European Union

Tire Automotive

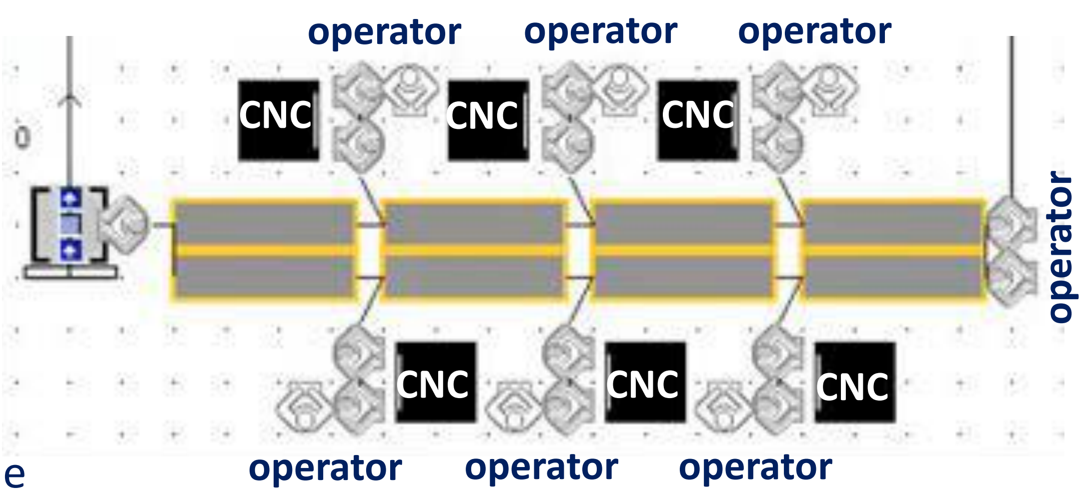
AUTOMOTIVE SUPPLIER CASE STUDY

The manufacturing system is being designed to achieve the capacity of up to 500,000 parts per year.

Example 1: worker strategy

- Determine the best operator loading and unloading strategies for a group of six CNC machines, where two operators load and unload parts.
- One operator is responsible for loading and unloading material of three machines.

Operation Model for loading and unloading materials in numeric control machines.



The distance travelled by the operators in the corridors and the distance between machines were obtained from the layout.

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Chavarria , 2018

Tire Automotive

AUTOMOTIVE SUPPLIER CASE STUDY

Result example 1: worker strategy

Strategy	Productivity (parts per week)	Productivity (percentage)	Downtime (percentage)
Company Strategy	10738	60	12
Strategy 1	10390	62	12
Strategy 2	6634	58	12
Strategy 3	13767	72	12

Maximize

Results of using different worker strategies for loading and unloading of material

From the results obtained in the observe step, the best strategy is strategy 3.

A new three additional operator strategies :

1) The operator follows a pre-established order to load and unload the machines,
2) Machines are synchronized to finish an operation at the same time. The operator unloads the parts after all the machines finished their jobs,
3) The operator is presented with an estimation of the time to completion for each machine and unloads the machine with shorter time to completion.

Chavarria , 2018

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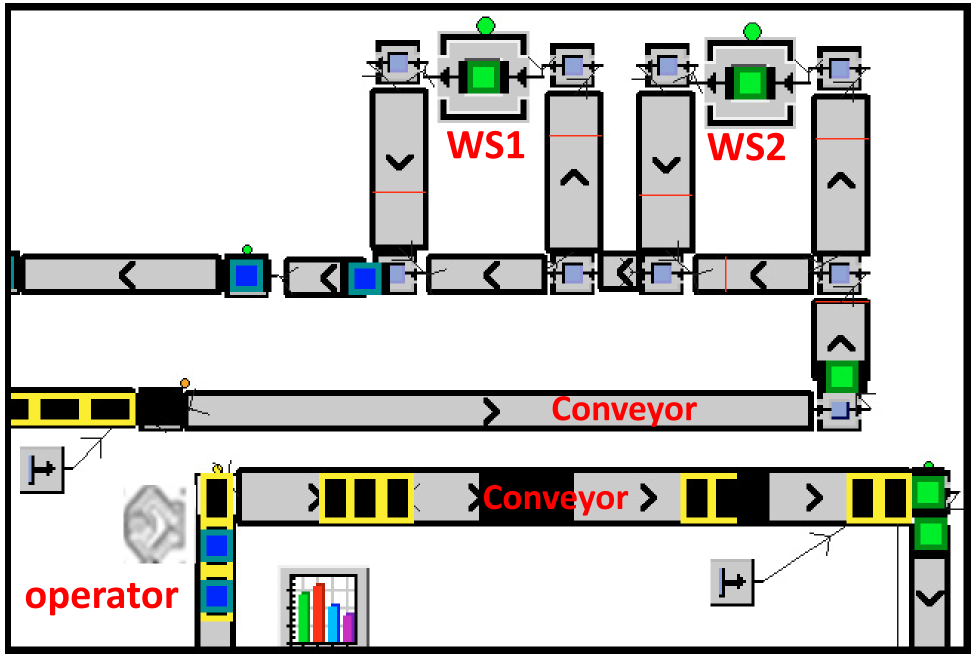
Tire Automotive

AUTOMOTIVE SUPPLIER CASE STUDY

Example 2: Optimal number of pallets



Integrated Model for two automated operations.

- Material handling in the new plant will be carried out by operators and through an automatic conveyor system.
- The system is composed of two workstations each having an automatic conveyor.
- An operator transfers each pallet from workstation WS1 to workstation WS2.

- The objective is to calculate **a number of pallets in each workstation**.
- The objective measure is to maximize the productivity in terms of number of parts produced per week.

Chavarria , 2018

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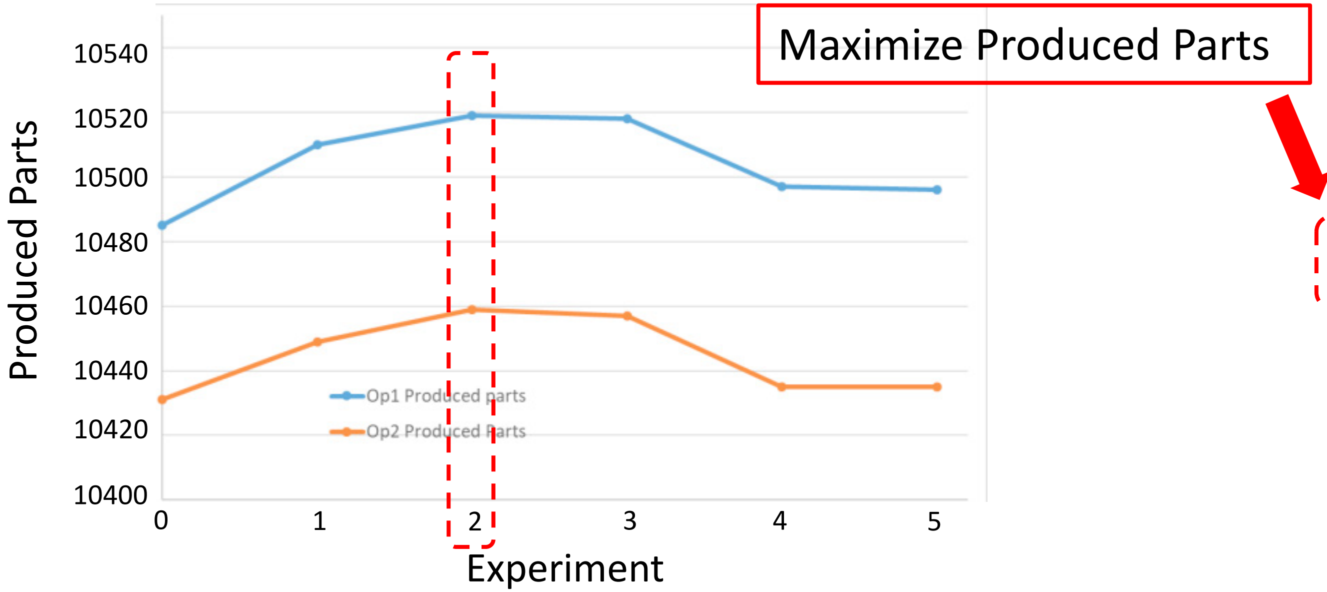
Tire Automotive

AUTOMOTIVE SUPPLIER CASE STUDY

Result example 2: Optimal number of pallets



Shows the relationship between the number of pallets (experiments) and the number of parts produced.

EXP	Pallets	WS1 Produced parts	WS2 Produced Parts
0	WS1 Pallets: 25 WS2 Pallets: 30	10485	10431
1	WS1 Pallets: 20 WS2 Pallets: 40	10510	10449
2	WS1 Pallets: 25 WS2 Pallets: 40	10519	10459
3	WS1 Pallets: 27 WS2 Pallets: 40	10518	10457
4	WS1 Pallets: 30 WS2 Pallets: 40	10497	10435
5	WS1 Pallets: 32 WS2 Pallets: 40	10496	10435

The number of parts produced for each experiment

Chavarria , 2018

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Tire Automotive

Critical points identification	Generate the technology viewpoint from the Sensing, Smart and Sustainable Enterprise Reference Model (S3E-RM) which allows the integrated manufacturing enterprise design. Enhance the plant design process by generating accurate predictions allowing the evaluation of different alternatives.
Indicator	Productivity, Optimal number of pallets.
Improvement	Worker strategy and optimal number of pallets.
Result	*Worker strategy* The best strategy is strategy 3. The data obtained from the actual plant will be used as to adjust the model and make improvements if necessary. *Number of pallet* Compared to the initial estimate, the optimal number of pallets represents an increment of 40 additional parts per week.

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Chavarria , 2018

Automated guided vehicles

- **Introduces the method of the determination of number of automated guided vehicles and choosing of optimal internal company logistics track.**

  - The internal logistics in the factory, which aims into production volume growth. Such changes will require a new internal logistics routes.

Static calculation of vehicles number and data collection

- The calculation has to be done before the data collection.
- The company was operated in a three-shift operation mode, where expected disposable working time of vehicle per shift is 7,5 hour. Vehicles will recharge at fast charging station during worker´s half hour break.
- Another data that need to be calculated are **speed parameters of vehicles** and **loading and unloading time**.

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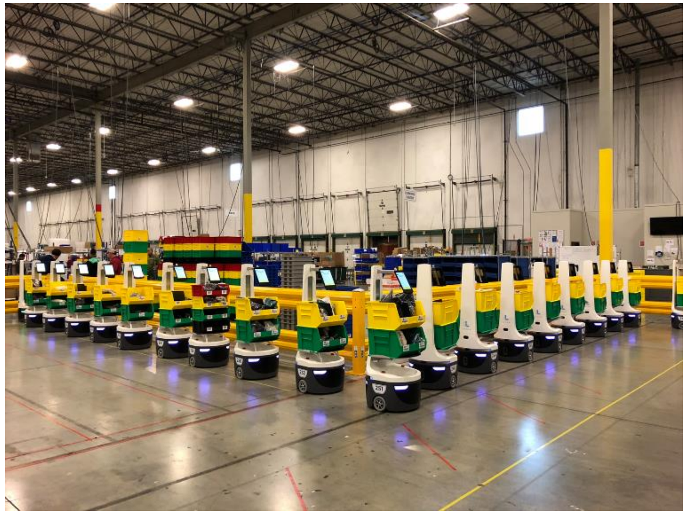
Vavrík, 2017

Automated guided vehicles

Simulation model design

- Creation of tracks for vehicle move.
- Creation of loading and unloading station.
- Creation of vehicle for transport of semi-finished product.
- Creation of logical rules for model.
- Verification and validation of created model.



2D and 3D visualization simulation model in Plant Simulation

Vavrík, 2017

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Automated guided vehicles

Simulation experiments

The result of simulation of proposed logistics tracks should be simultaneously evaluated and compared with the proposed variant tracks. The expected status of manufacturing because of logistics transport is supposed to **increase up to 66 pieces.**

A set of experiments was carried out depending on the change of model factors.

- Experiments defining necessary number of vehicles
- Experiments evaluating proposed tracks
- Experiments simulating changes in system

In the model, the original speed of vehicle was set on value
1,2 m/ per second on straight and **0,8 m/ per second in the curve**.

Vavrík, 2017

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Automated guided vehicles

Simulation of Automated Guided Vehicles in the Factory

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Vavrík, 2017

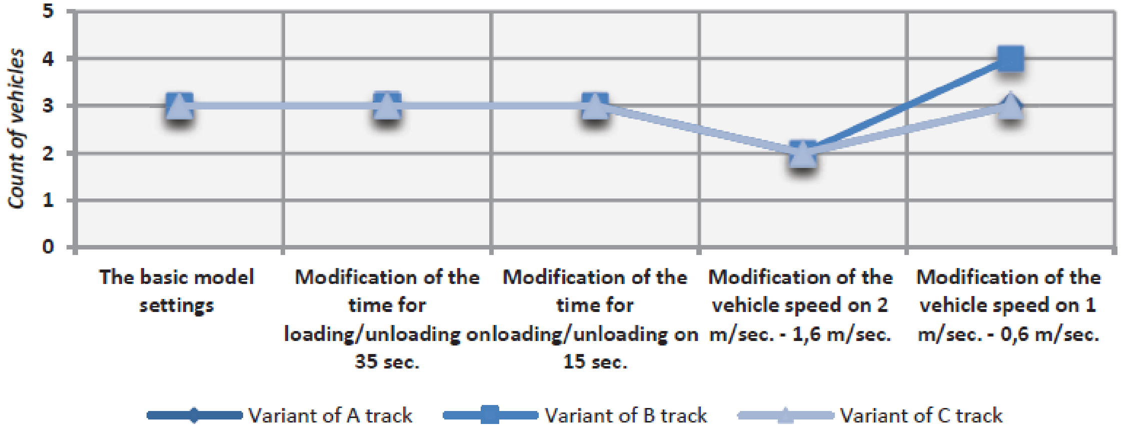
Automated guided vehicles

Two adjustments of **speed parameters** were carried out as follows:

- The vehicle's speed was ***decreased*** on 1 m/ per second on straight and 0,6 meter/ per second on the curve
- The vehicle's speed was ***increased*** on 2 m/ per second on straight and 1,6 meter/ per second on the curve

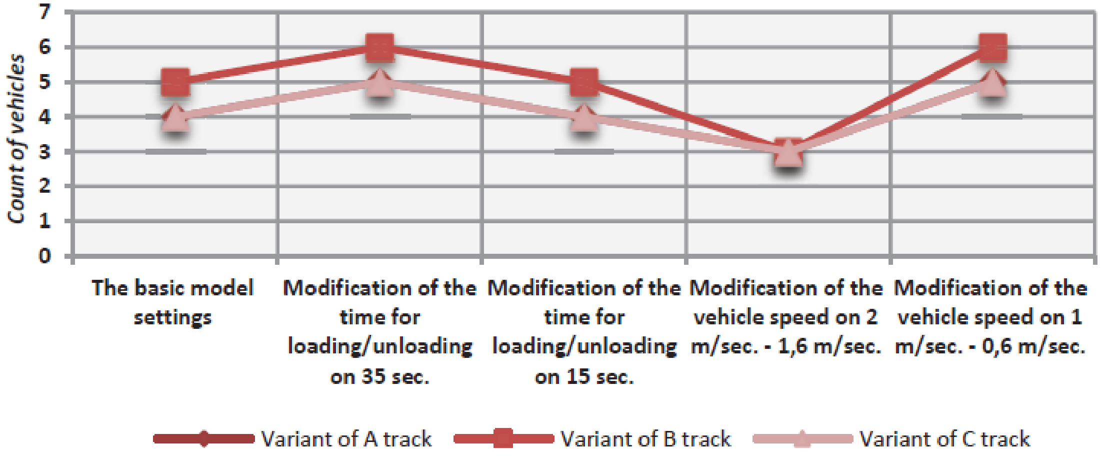
Development count of vehicles on specific system settings

for **actual state** of production



simulation experiments

for **future state** of production (increase up to 66 pieces.)



basic model

Vavrík, 2017

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Automated guided vehicles

Critical points identification	Production volume growth.
Indicator	Performance parameters and waiting time of vehicles.
Improvement	Introduces the method of the determination of number of automated guided vehicles and choosing of optimal internal company logistics track. A new internal logistics routes.
Result	The simulation results of the logistics system were variants for increasing the use of the operation areas, optimized material supply and created layout that would be able to flexibly response to the future company requirements.

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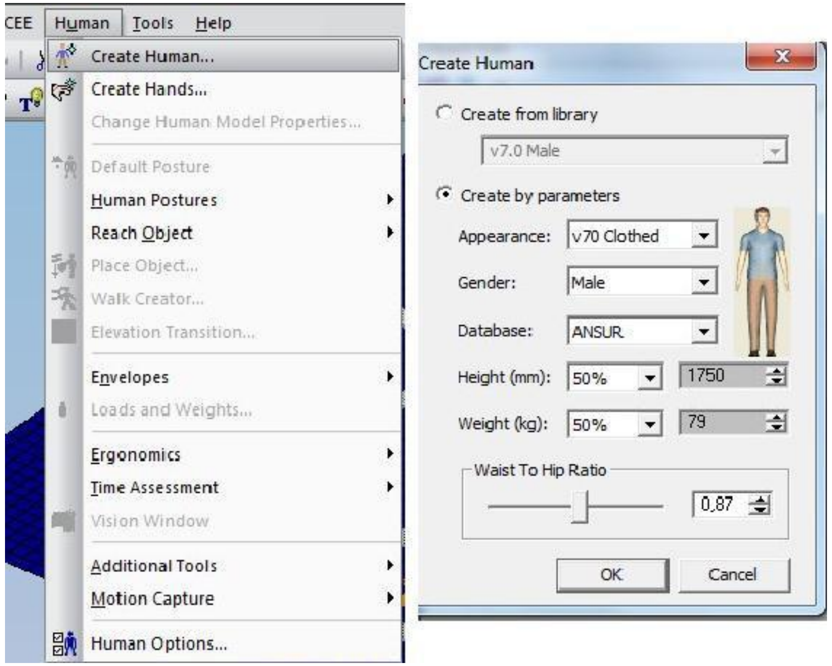
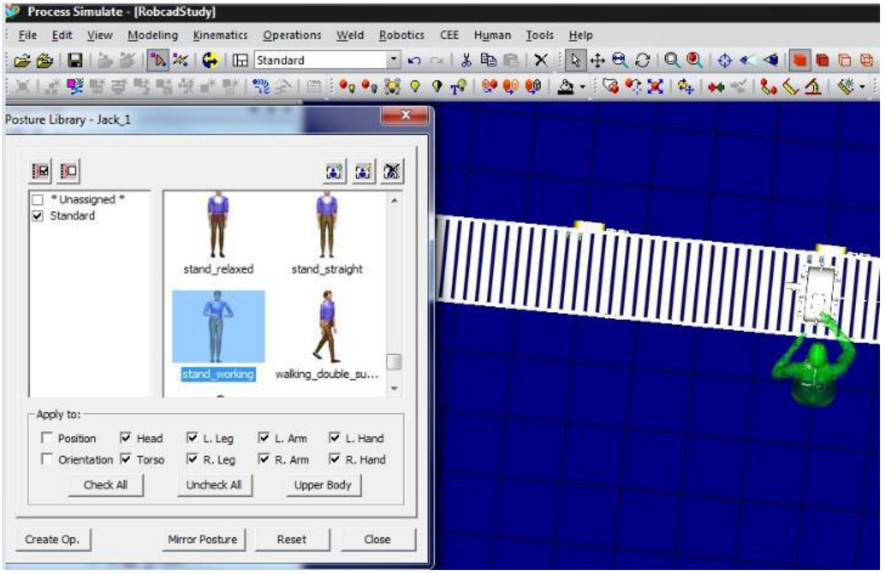
Vavrík, 2017

Human and Robot operation

- This article is showing some basic processes of the simulation, which are human operation and robot operation.
- Create a 3D model of a human and place it to the workplace.



Human creation in Process Simulate



The new human pose will be created and saved with the selected positions of human model.

Trebuna, 2014

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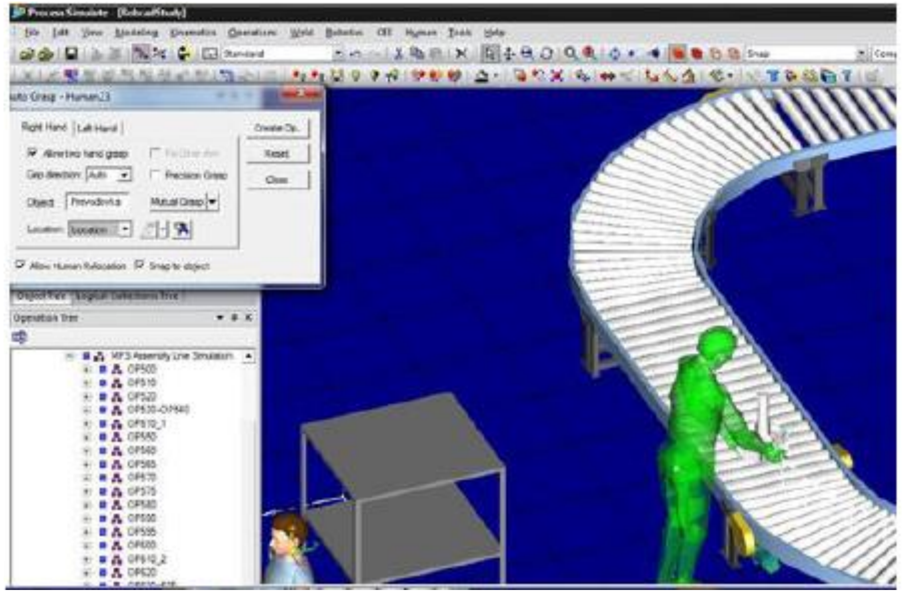
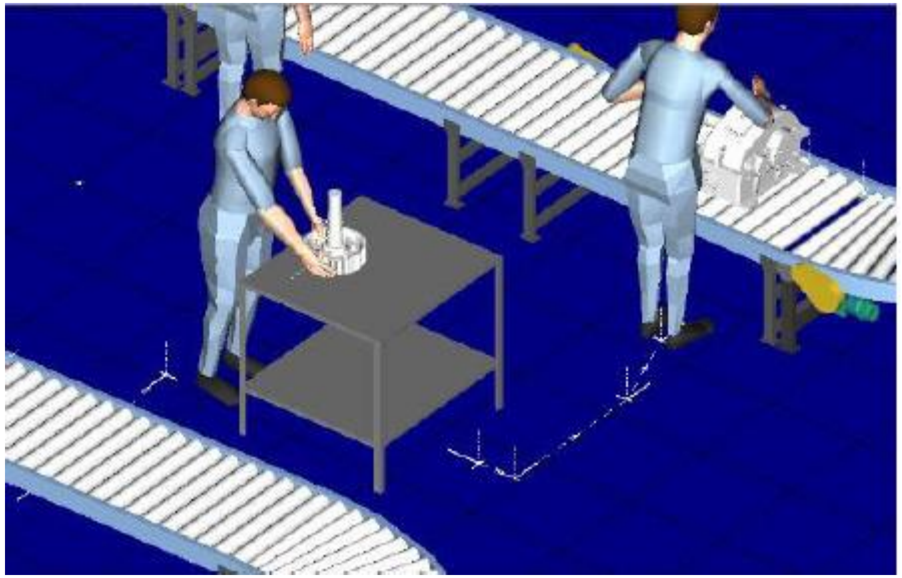
Human and Robot operation

Next necessary human operation should be grasping the object. Also there can be more ways how to catch an object, for example using both hands, clutching automatic mode, grasping of selected objects from the workplace and permissions to change locations for a grasping an object.





Reaching the object

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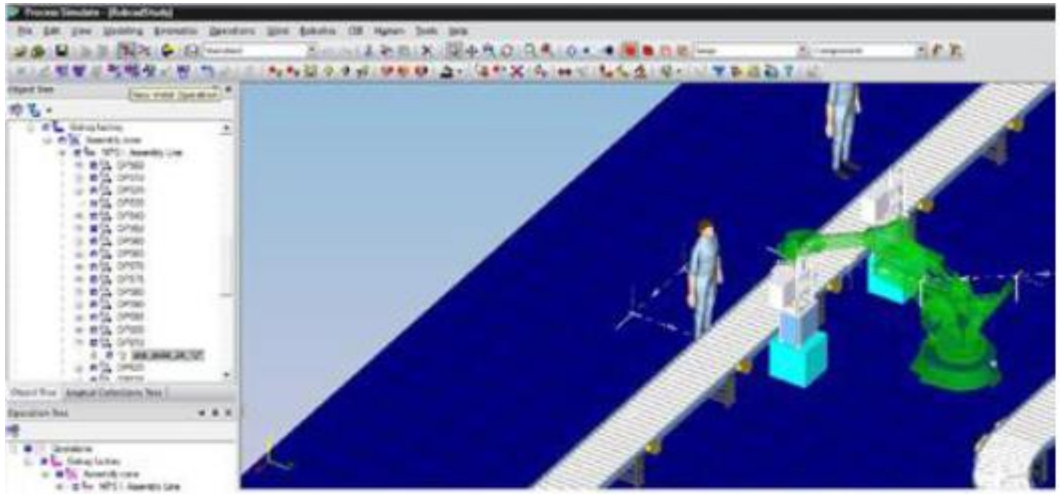
Trebuna, 2014

Human and Robot operation

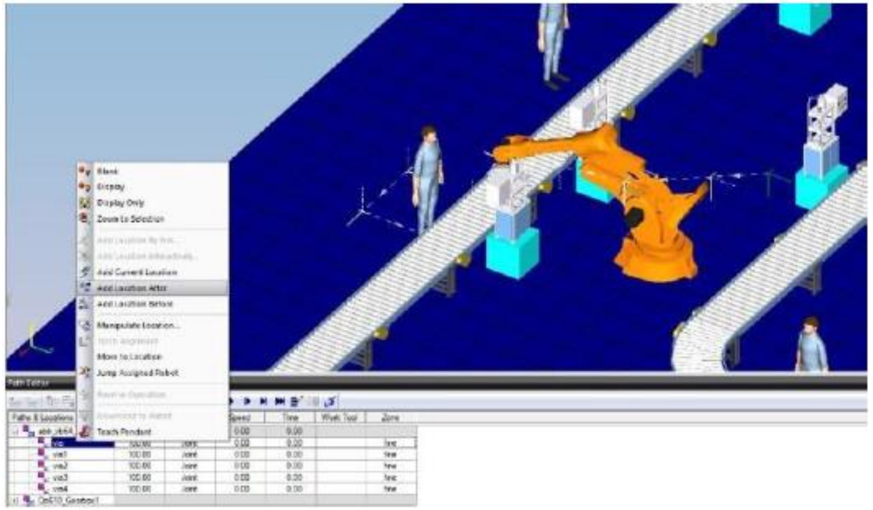
- **Creation of the robot operation**

The new robot operation begins selecting the desired robot model.



Creation of robot operation

Then we need to create requested movements of the robot using Path Editor to adjust the partial positions of the robot and the time which is needed to reach these locations.



Path Editor

Trebuna, 2014

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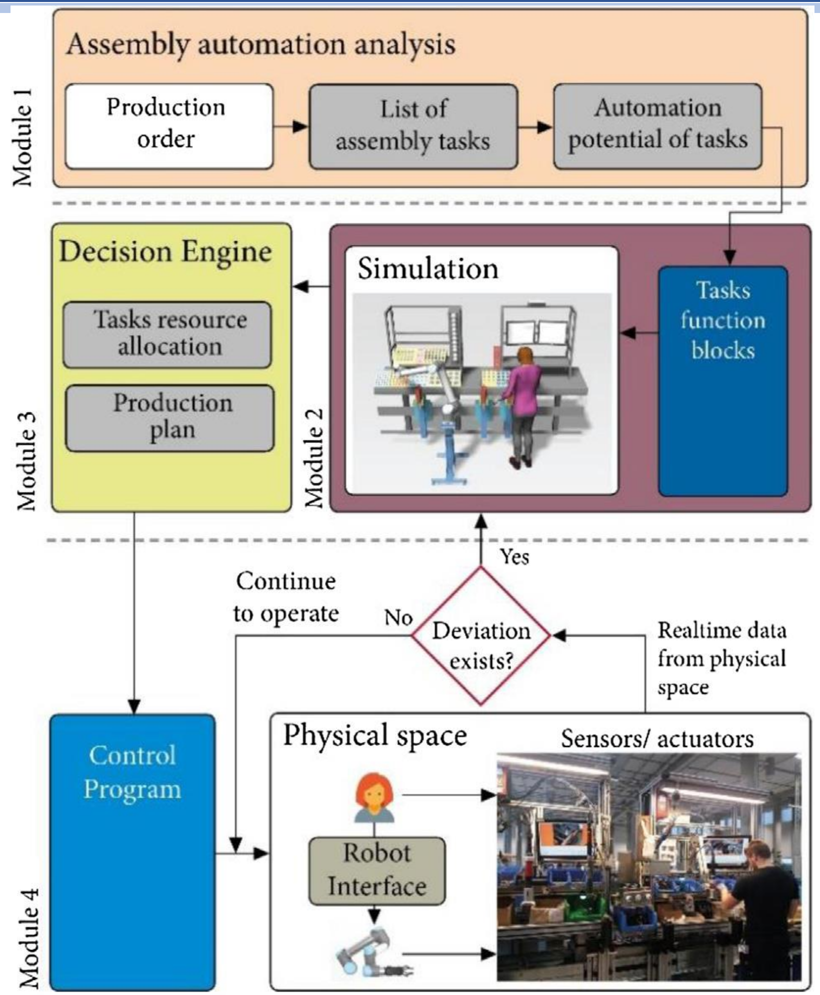
Human–robot collaboration (HRC): Assembly systems

- **Besides the significance of assembly work in manufacturing, the application of collaborative robots in variety-oriented assembly systems is very limited.**

- The issues solved by presented digital twins for HRC assembly are:

  - Rapid skills-based workload balancing between human and robot for product variety;
  - Dynamic workload balancing during operation to account for human factors;
  - Trajectory planning and generating robot control program.



Digital twins in HRC assembly

Bilberg, 2019

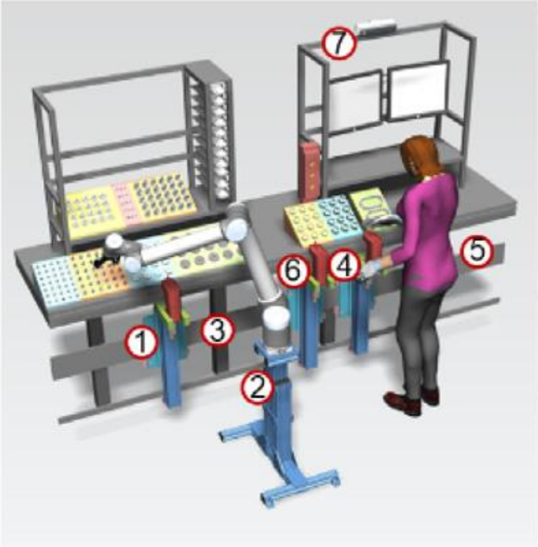
Co-funded by the Erasmus+ Programme of the European Union

Human–robot collaboration (HRC): Assembly systems

Human factors continue to play their role in man-machine systems.

If an operator at a workstation is getting delayed, a bulb lights-up alerting the fellow operator to help the colleague in completing the task. Once the delayed tasks are completed the whole production system will resume.

shows the points where different sensors are used to signal the control system for critical events happening at the assembly cell.



Proximity sensors	1. Product reaches robot location 3. Conveyer leaves robot location 4. Product reaches operator location 5. Product leaves operator location 6. Blocking by work in process
Robot feedback	2. Robot tasks completed
Kinect sensor	7. Operator leaves or enters the workspace

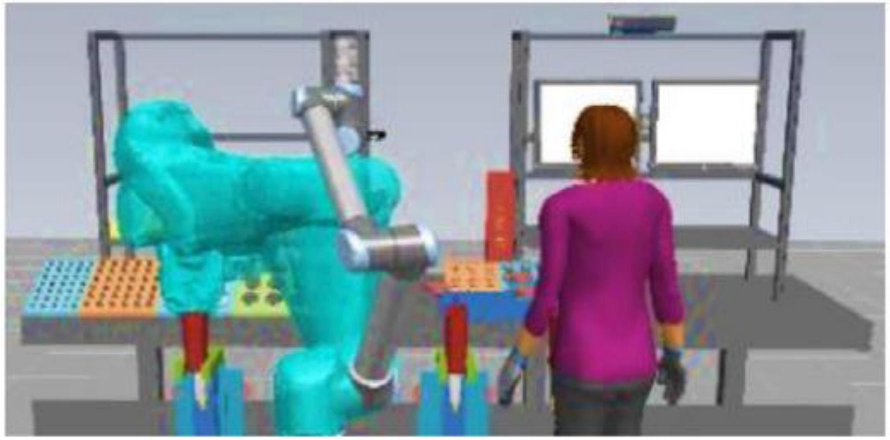
Feedback in HRC assembly cell for signalling of critical events.

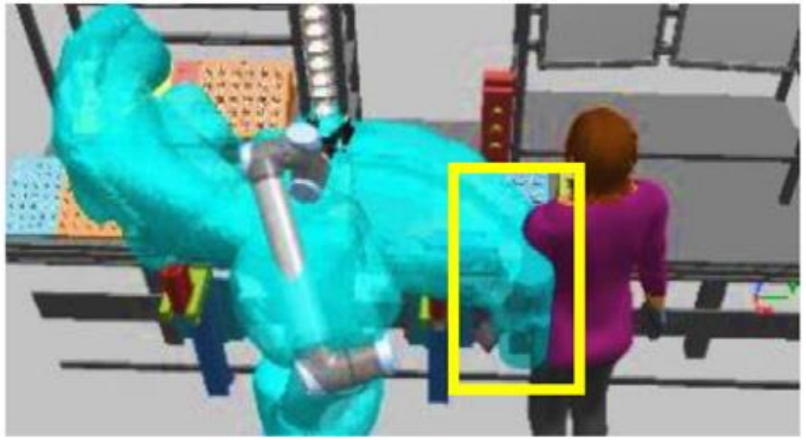
Bilberg, 2019

Co-funded by the Erasmus+ Programme of the European Union

Human–robot collaboration (HRC): Assembly systems

It is important that the HRC system is made safe for fellow human.
In some situations, a complete halt would require if the operator gets too close to the robot.



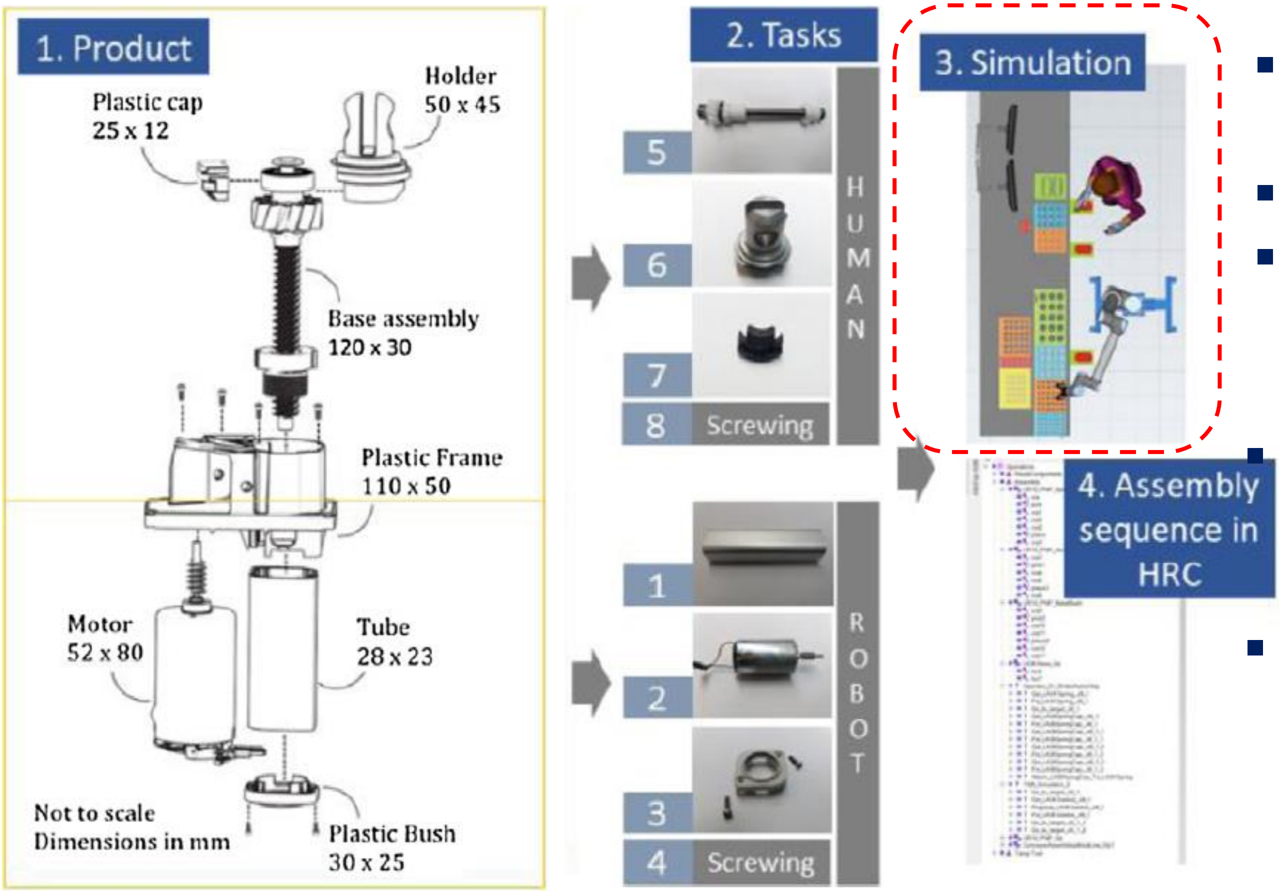


Volume of robot trajectories and possible human collision

Bilberg, 2019

Human–robot collaboration (HRC): Assembly systems

The product is currently **assembled as a manual process** and is **investigated for HRC production.**



Use case and experimentation

- Assembly of tasks 1, 2, 3 and 4 are pick & place and screwing tasks and are assigned to robot.
- The tasks 5, 6, 7 and 8 are kept manual.
- The sequence is sent to the simulation. Based on pre-defined key-locations a simulation is developed generating a control program.
- The work in-process monitoring is validated with the task 8 where the robot can perform the screwing task.
- Frequent occurring human-positions are integrated with the simulation model to form an obstacle-envelope to optimize the robot trajectories.

Bilberg, 2019

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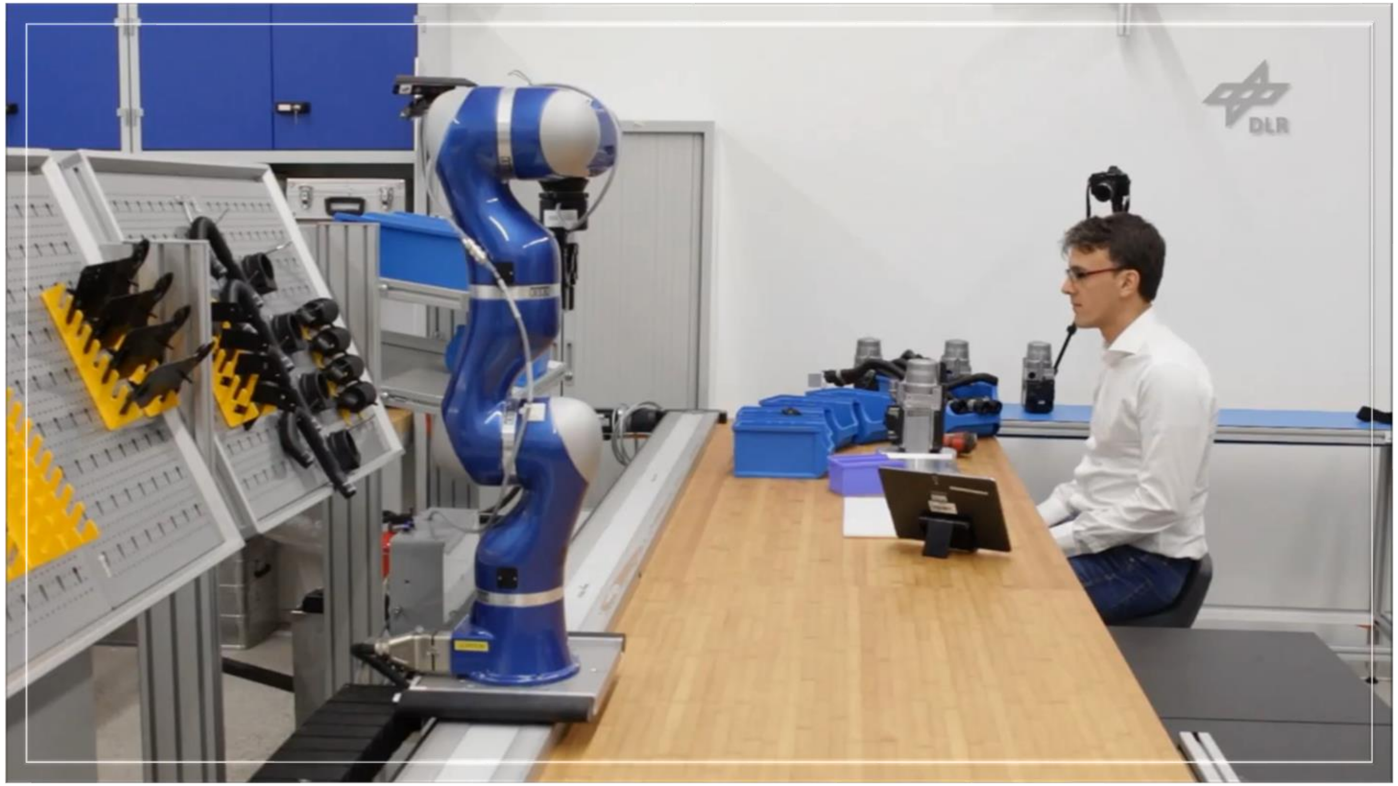
Human–robot collaboration (HRC): Assembly systems

Human-Robot Collaboration: Efficient Collaborative Assembly in an Industrial Scenario



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Human–robot collaboration (HRC): Assembly systems

Critical points identification	Safety of humans and frequent reconfigurations in the assembly work.
Indicator	Sufficient synchronization possibilities between physical and digital spaces and high-fidelity simulation models.
Improvement	A 3-dimensional virtual simulation model of human–robot cooperation.
Result	The ease of automation and availability of the resource, the tasks are assigned to the appropriate resource. Frequent occurring human-positions are integrated with the simulation model to form an obstacle-envelope to optimize the robot trajectories. The approach supports the notion of automation while maintaining assembly flexibility.

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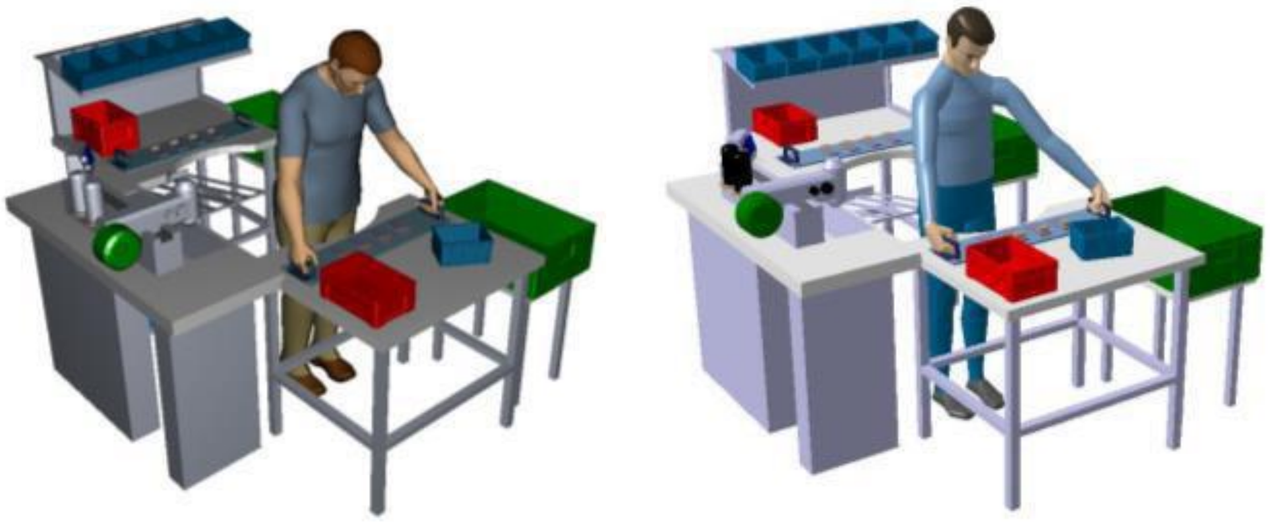
Bilberg, 2019

Ergonomics in Practice

- **Evaluated with the help of digital human models by means of two software (Tecnomatix Jack and Delmia) packages and theirs ergonomic analysis.**
  - **Evaluation of existing workplaces at a specific workplace – sewing seat belts**

These conditions are:
a) Software is able to represent investigated workplaces completely identically.
b) Same size and proportions of digital human models.
c) Analyses must work on same principle, same calculation or same standards.
d) Analyses have the same options.



Tecnomatix Jack and Delmia V5 Human workplace models

Polášek, 2014

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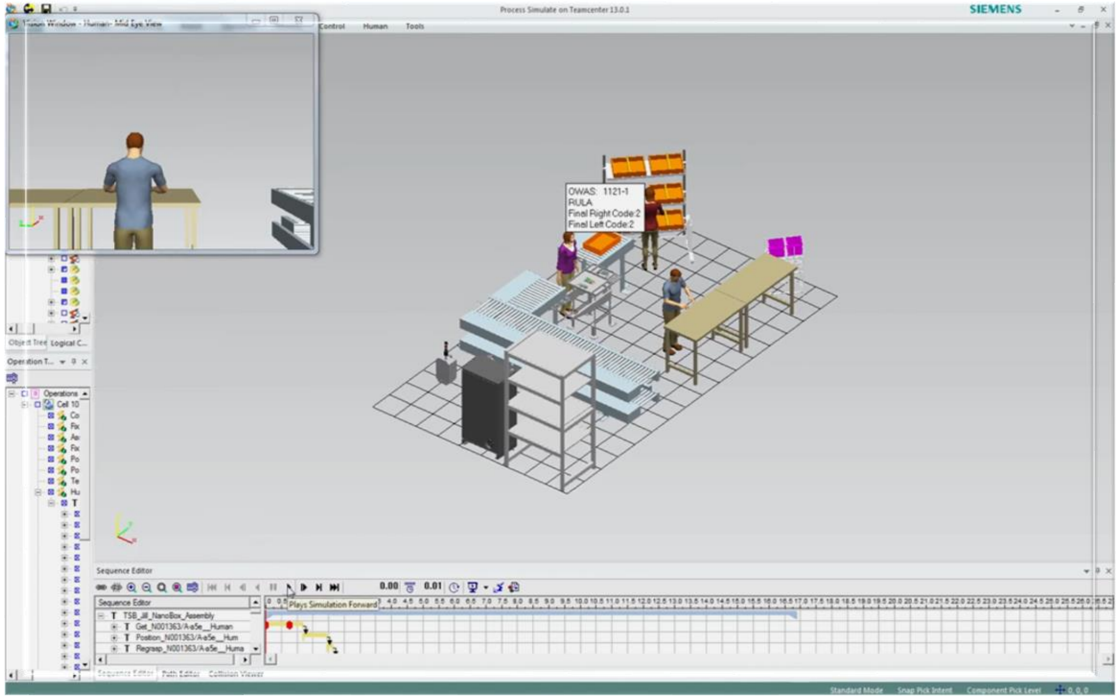
Ergonomics in Practice

For the activities that took place repeatedly on the workplace and therefore it was necessary to pay attention to the size of employee stress. These analyses were:

- Carry (Manual Handling Limit) analysis
- Lift-Lower (NIOSH) analysis
- Biomechanical (Lower Back) analysis



Tecnomatix - Human Simulation

Polášek, 2014

Ergonomics in Practice

Transferring the clamping jig to the sewing workplace

Shows the results value of MAW – Maximum Acceptable Weight, which is the weight that a chosen population can carry without risk.

The results for carry loads.

	Maximum Acceptable Weight [kg]			
	1 carry every 16s		1 carry every 60s	
	Jack	**Delmia**	**Jack**	**Delmia**
Man	11 kg	10,34 kg	15 kg	14,96 kg
Woman	10 kg	9,21 kg	13 kg	13,15 kg

Polášek, 2014

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Ergonomics in Practice

Lift-Lower (NIOSH)analysis

Result values of RWL and LI are for a worker after lifting the clamping jig from the table. RWL – Recommended Weight Limit is the load weight that healthy workers can lift without risk.

The results for lifting loads.

	Recommended Weight Limit [kg]	
	Jack	**Delmia**
Man	21,5 kg	18,7 kg
Woman	19,8 kg	17,2 kg

Polášek, 2014

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Ergonomics in Practice

Biomechanical analysis

The results from Biomechanical and Lower Back analysis.

	Compression limit L4-L5[N]	
	Jack	**Delmia**
Man	1429 N	1513 N
Woman	987 N	1175 N

Position the human model in both experiments in the same posture, slight differences in single joints may cause great differences in compression forces.

Polášek, 2014

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Ergonomics in Practice

- The outputs from analyses show that the results are not of an exact match.
- This fact is caused by different possibility of setting in both compared software.
- It can’t be said that Delmia either Tecnomatix is more precise because it depends on the concrete analysis.
- Our experiments confirm that the analyses in both software works on the same principles with nearly the same results.
- Both software are there for every suitable for ergonomic optimization of workplaces however close attention is needed when explaining the results.
- Results of individual ergonomic analysis between man and woman are naturally different.
- This difference is caused by different anthropometry of the sexes.

Polášek, 2014

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Ergonomics in Practice

Critical points identification	Prevent increased absence at work due to health problems, excessive employee turnover and related costs of retraining and also paying any compensation for injured employees.
Indicator	Acceptable Weight, Recommended Weight Limit, Compression limit.
Improvement	Simulation of work process (Carry (Manual Handling Limit) analysis, Lift-Lower (NIOSH) analysis, Biomechanical (Lower Back) analysis)
Result	Reflects the abilities and needs of the worker and leads to more efficient, more productive and safer production or assembly with less work.

Polášek, 2014

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Digital Mock-Up for Mechanical products

❑ **Aspects of composition of digital mock-up and the requirements of a digital mock-up model.**

This makes possible a number of advantages such a:

- Reduce time to market by identifying problems at the design.
- reduce production costs by minimizing the number of prototypes to be made.
- improving product quality by allocating alternative project to be verified before the final one to be elected.
- division of responsibilities regarding product functions within the enterprise.

The DMU of mechanical products, as important engineering data in a company, is supposed to be able to support all the activities in the whole life-cycle of the product including design, manufacture.

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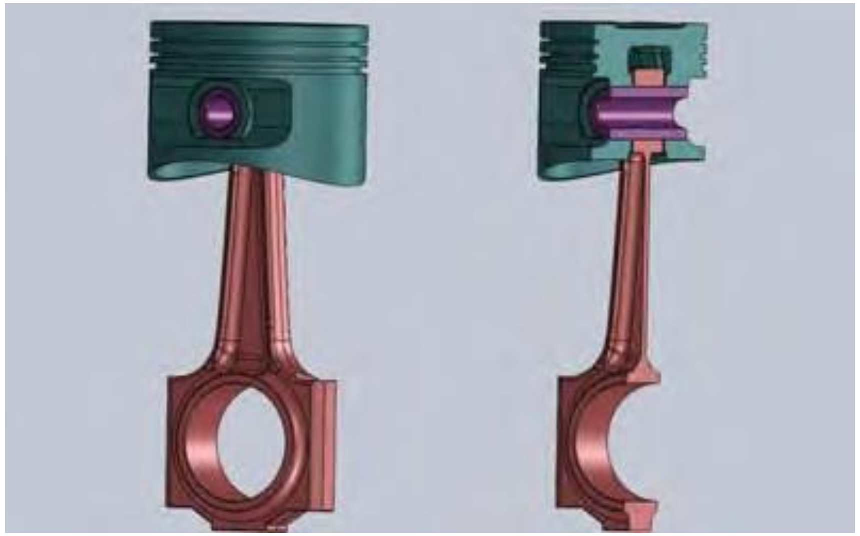
Digital Mock-Up for Mechanical products

- This focuses on developing and analyzing the importance and impact of the CAD strategy on Product Lifecycle Management (PLM) systems, on knowledge management and on parametric modeling methodologies [5].
- **CASE STUDY ANALYSES OF CONNECTING ROD**

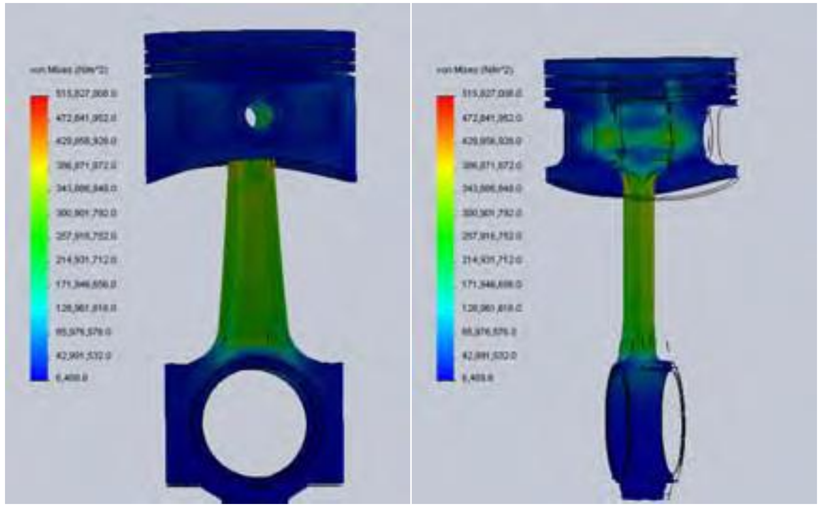


SolidWorks model of piston-connecting rod assembly

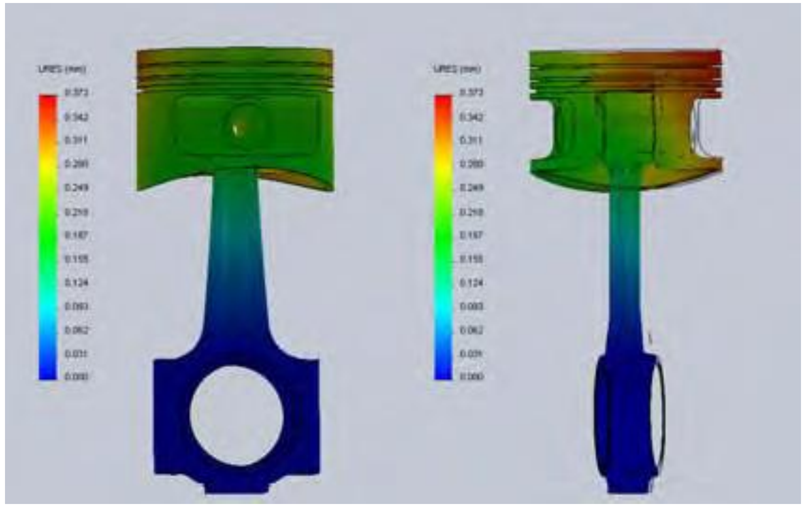
Co-funded by the Erasmus+ Programme of the European Union

Digital Mock-Up for Mechanical products

The structural analyses allow stresses and strains to be calculated in FEA, by using the structural model.



Stress distribution in connecting rod, resulted from maximum pressure considering Von Misses for compressive loading

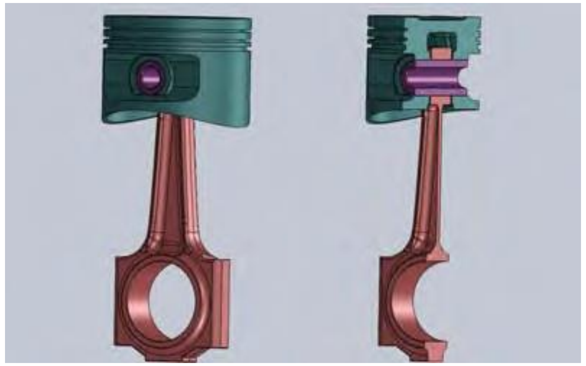


Displacement (URES) in connecting rod, resulted from maximum pressure of compressive loading

Co-funded by the Erasmus+ Programme of the European Union

Digital Mock-Up for Mechanical products

Critical points identification	The rapidly increasing product complexity requires the use of functional virtual prototyping.
Indicator	Stresses and strains.
Improvement	Created functional virtual prototyping with simulation.
Result	Digital mock-up design allows engineers to design, to model complex structures and verify the design of a product without ever needing the achieved physically real construction.



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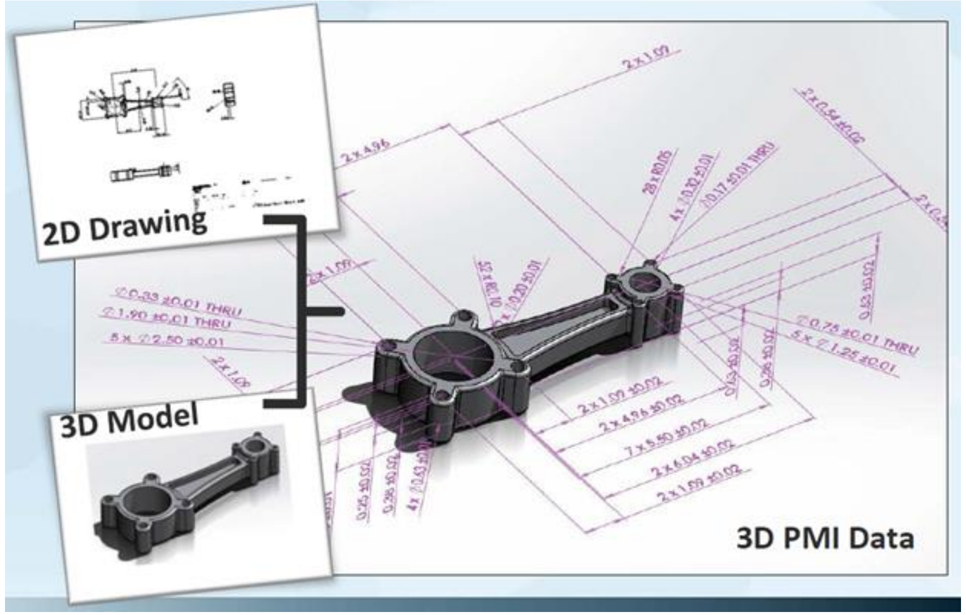
Spacecraft Collaborative Design Technology

❑ **A digital mock-up Support collaborative design of spacecraft typical subsystems.**

- A digital mock-up of the spacecraft is the assembling of Model-Based Design(MBD) model of all structural components, system equipment and accessories.
- MBD technology is a method to fully express product definition information with integrated three-dimensional entity model.
- In order to meet the requirements of spacecraft design, manufacture, assembly integration and collaborative design of different subsystems.



JING, 2019

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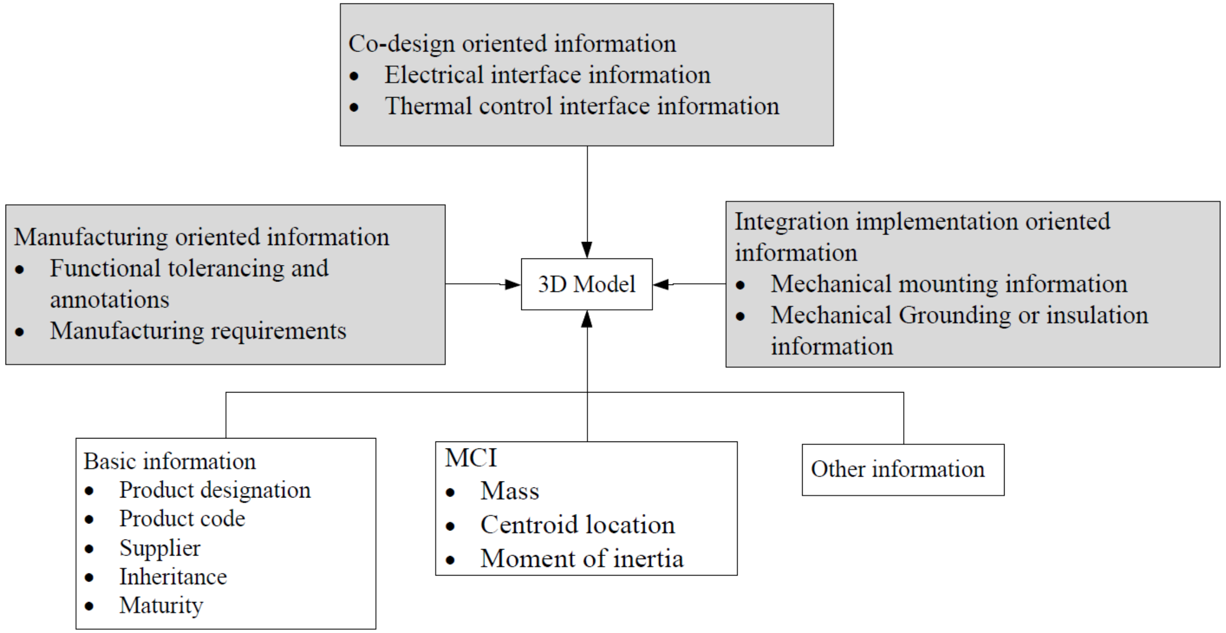
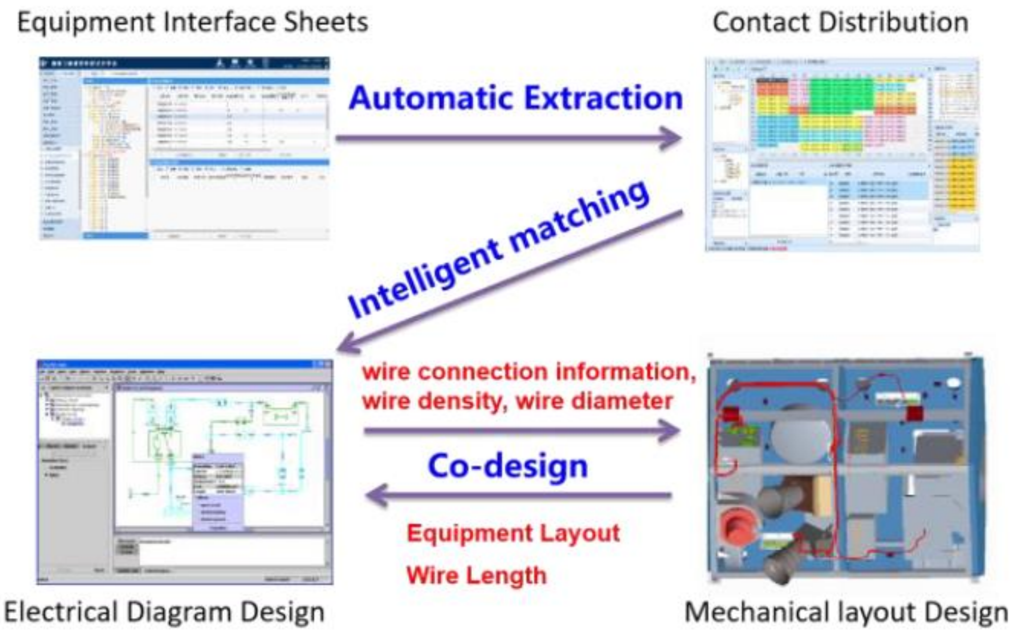
Spacecraft Collaborative Design Technology



MBD Structure based on spacecraft integration design



Lectrical diagram and mechanical layout Co-Design.

JING, 2019

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Spacecraft Collaborative Design Technology

Design-manufacturing Integration

Several typical applications are as follows:

Design-manufacturing Integration	Result
Using MBD model, combined with advanced manufacturing methods such as 3D printing.	The processing efficiency of typical structural parts is increased more than three times, and the production efficiency is greatly improved;
By extracting the installation information in the product MBD model.	The automatic processing of structural plate holes is realized, and the production preparation time is reduced by 30%
The MBD model of spacecraft pipeline is constructed, and the NC bending manufacturing of pipeline is realized in an all-round way.	The manufacturing cycle of pipeline is shortened by 40%.

JING, 2019

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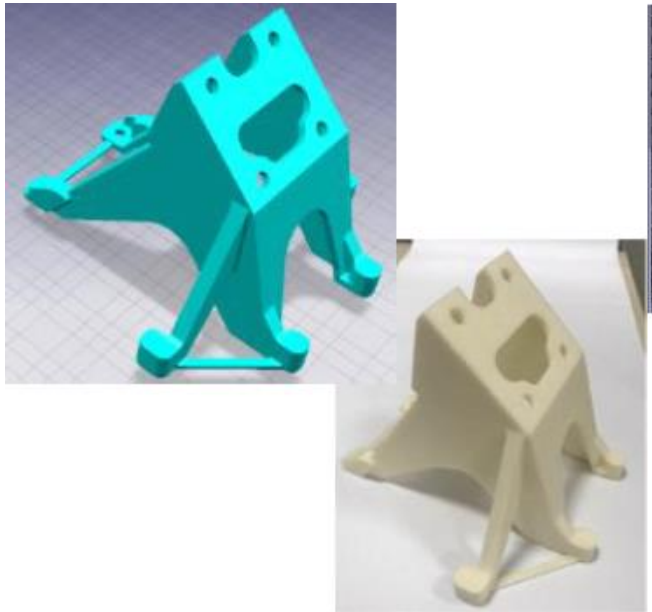
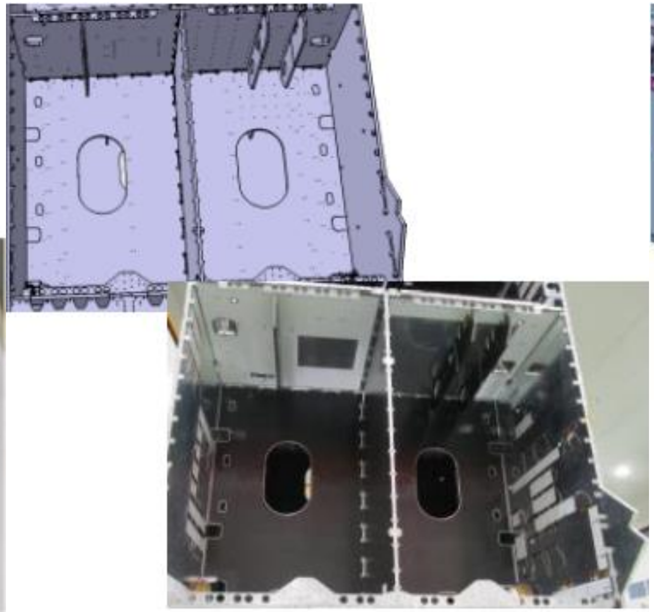
Spacecraft Collaborative Design Technology

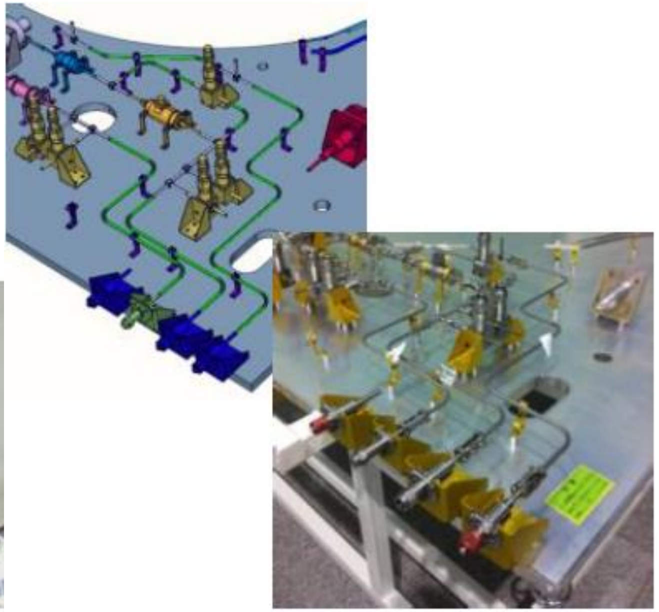
Typical applications of Design-manufacturing integration.



3D Printing Structures



structural plate



pipeline

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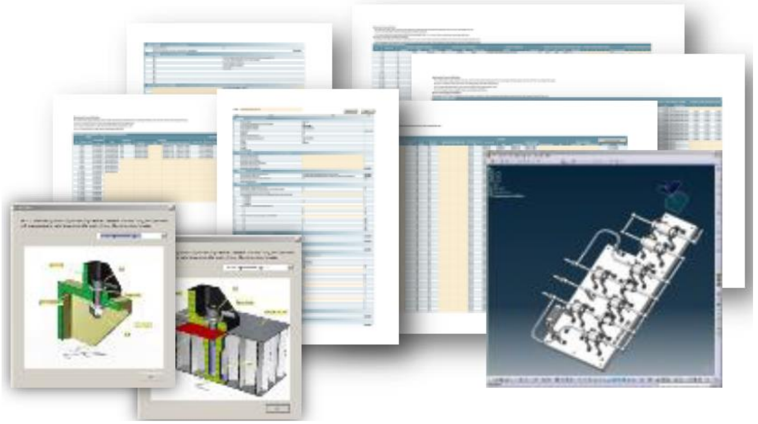
Spacecraft Collaborative Design Technology

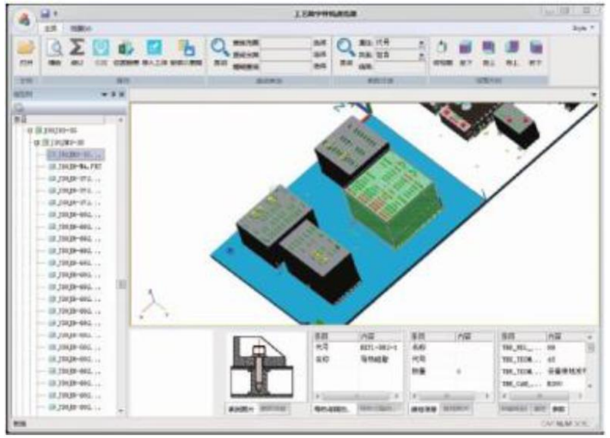
Digital Assembly

assembly occupies 30% to 50% of the total working hours, and each procedure is directly related to the success or failure of the product

EBOM is constructed by extracting product structure, and attributes of spacecraft digital mock-up. METRICS_AIT software has been developed to extract assembly information from digital mock-up and transfer it to assembly process digitally.



EBOM built by METRICS_AIT.



Digital Assembly based on Digital mock-up.

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Spacecraft Collaborative Design Technology

Critical points identification	The information transmission of spacecraft development depends on unstructured information such as documents and drawings, the information of design, manufacturing and assembly are relatively isolated and it is difficult to carry out collaborative design between subsystems
Indicator	Efficiency of collaborative design, assembly efficiency of the spacecraft.
Improvement	Using MBD model as a single data source, building a digital mock-up of spacecraft products.
Result	Compared with traditional serial design, the efficiency of collaborative design is improved by more than 50%. The assembly efficiency of the spacecraft is increased by 30% and shortening the development period of spacecraft .

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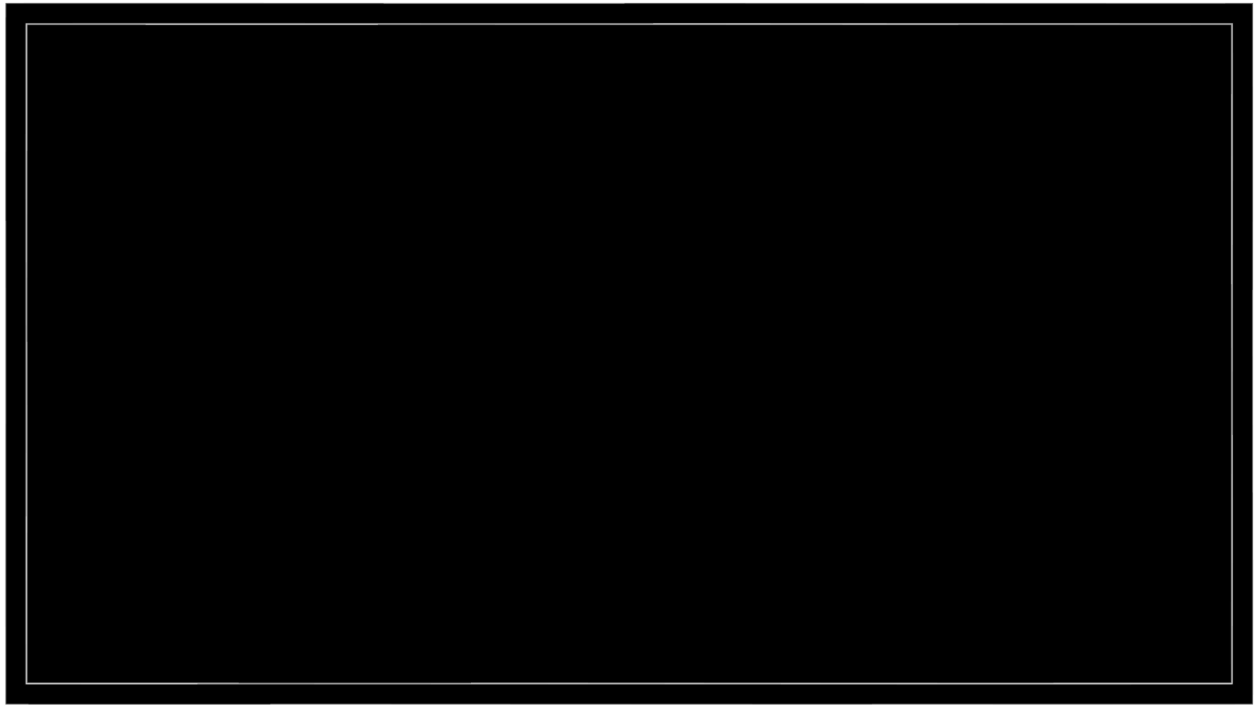
Digital Mock-Up

Process Simulate Human Solution



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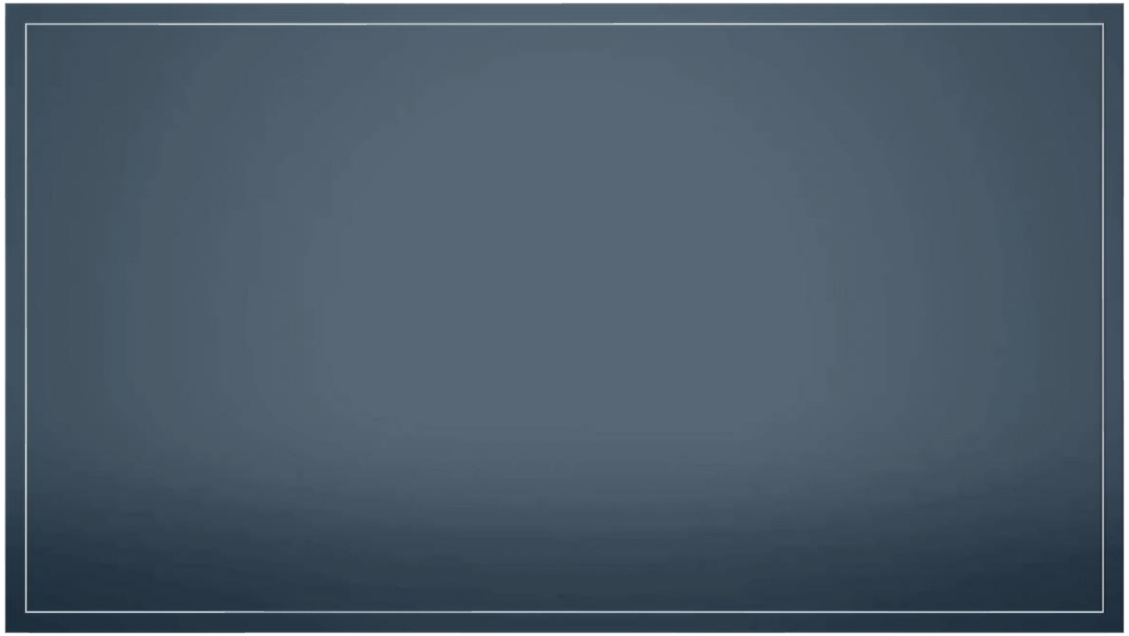
Digital Mock-Up

Robotic Assembly Planning and Programming



Human Simulation to perform Ergonomics Analysis in a PLM Enviornment

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Thank You

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