

OST

Ostschweizer
Fachhochschule

Smart Factory Lecture

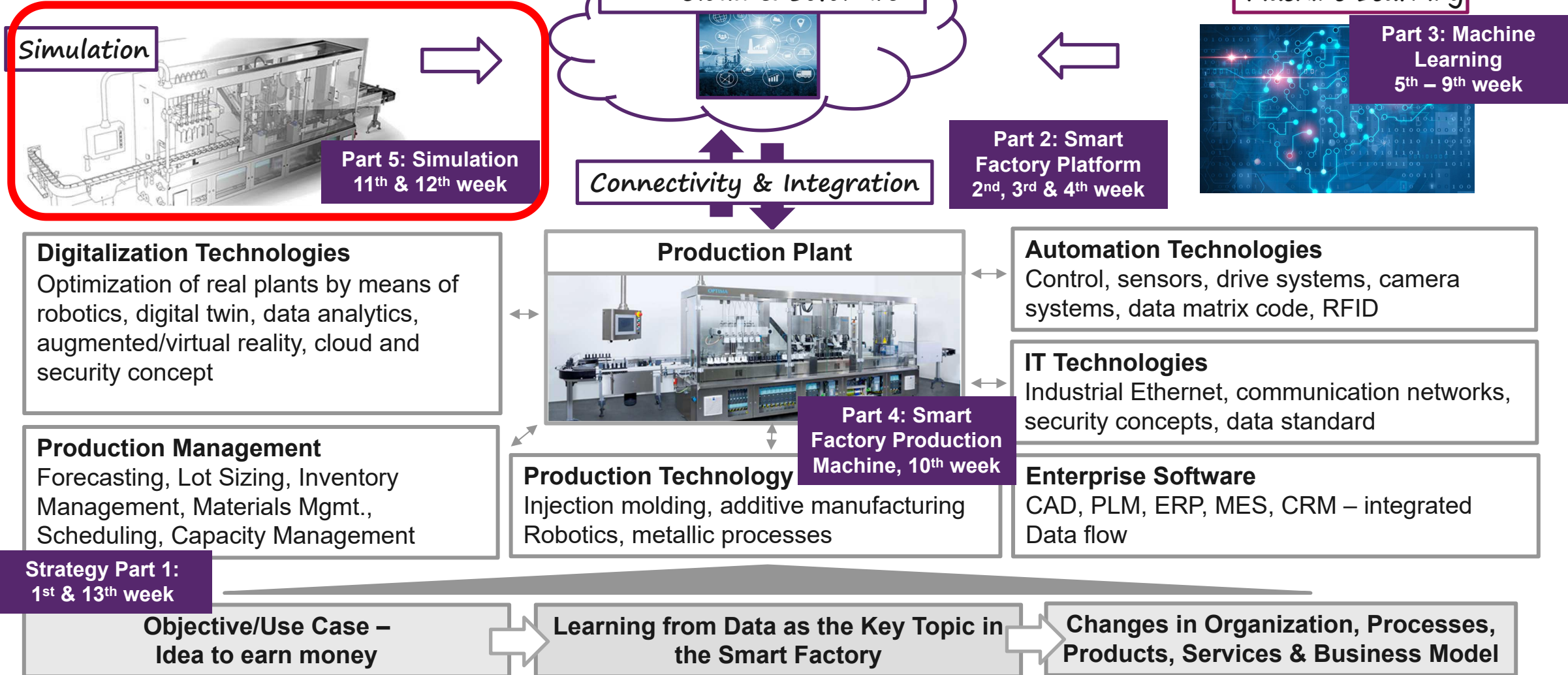
Rapperswil HS23

Dr. Shuangqing Liao

8. December 2023

Industrial Engineering (OST-RJ)

Overview



Course at-a-Glance

	Week	Content	Date
Part I) a	1	Strategy Development for Smart Factory	22.09.2023
Part II)	2	Device & Data	29.09.2023
	3	Cloud & Data Modeling	06.10.2023
Part III)	4	Data Visualization	13.10.2023
	5	Machine Learning: Machine Learning	20.10.2023
	6	Machine Learning: Neural Networks	27.10.2023
	7	Machine Learning: Training of a Multi-Layer Neural Network	03.11.2023
	8	Machine Learning: Neural Network and Classification	10.11.2023
Part IV)	9	Machine Learning: Deep Learning	17.11.2023
	10	Smart Factory @ Techpark	24.11.2023
Part V)	11	Simulation: Application in Lot Size Optimization	01.12.2023
	12	Simulation: Application in Production Network Management	08.12.2023
Part I) b	13	Strategy Implementation	15.12.2023
	14	Summary	22.12.2023

Outline

Basics

DES for process improvement

Simulation
Industrie 4.0
Smart Factory

Applications in Smart factory

Traditional simulation applications

- Production planning:
 - Milkrun configuration
 - Lot sizing
- Product delivery management
 - Production network management

Digital twin

- Overview
- Application in Smart Factory

Perspective

Simulation for the Better:
The Future in Industry 4.0

Today's Objectives

- You understand how to use simulation to support decision-making in production network
- You understand the difference between digital twin and simulation
- You understand the relations between digital twin, CPS, and IoT
- You understand the benefits of simulation in Industrie 4.0

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Perspective

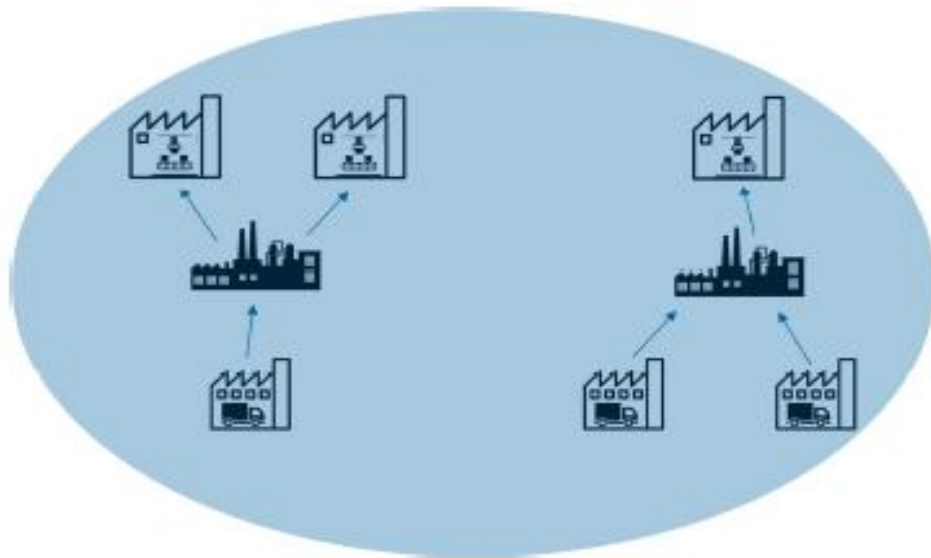
Simulation for the better:
the future in Industrie 4.0

Production Network

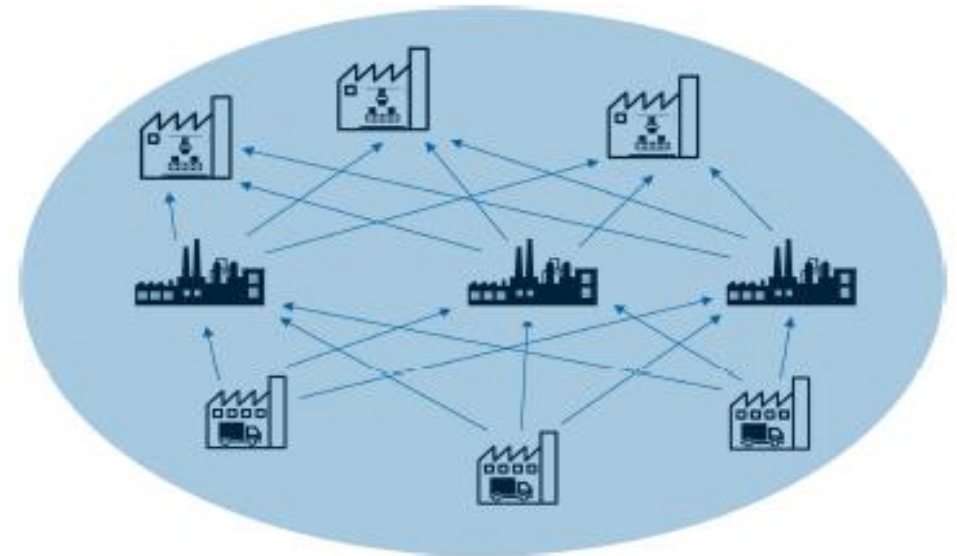


Production Network: Strategy level

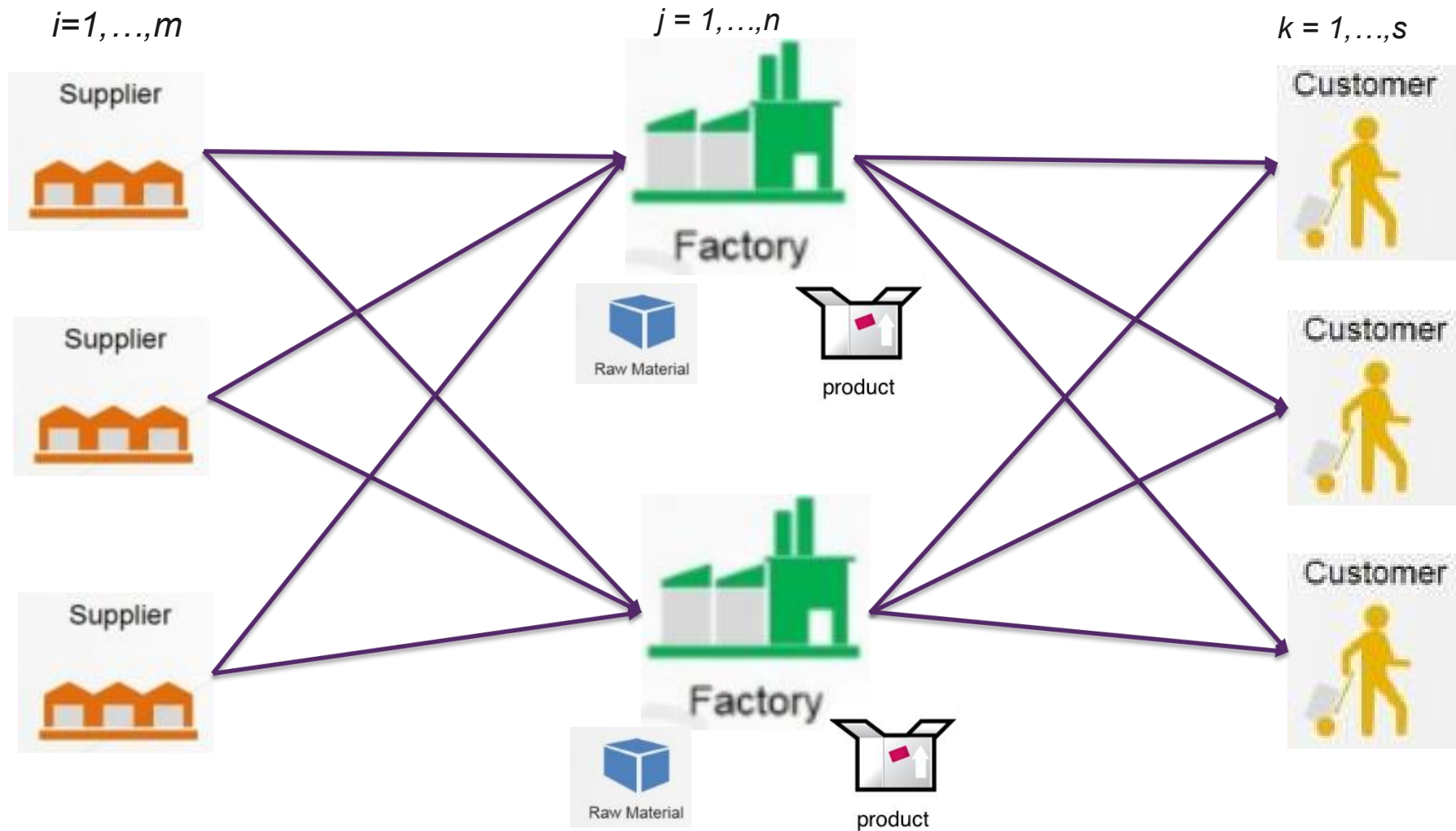
Local-to-local network






Global cross-shipping network






Production Network: Operations level



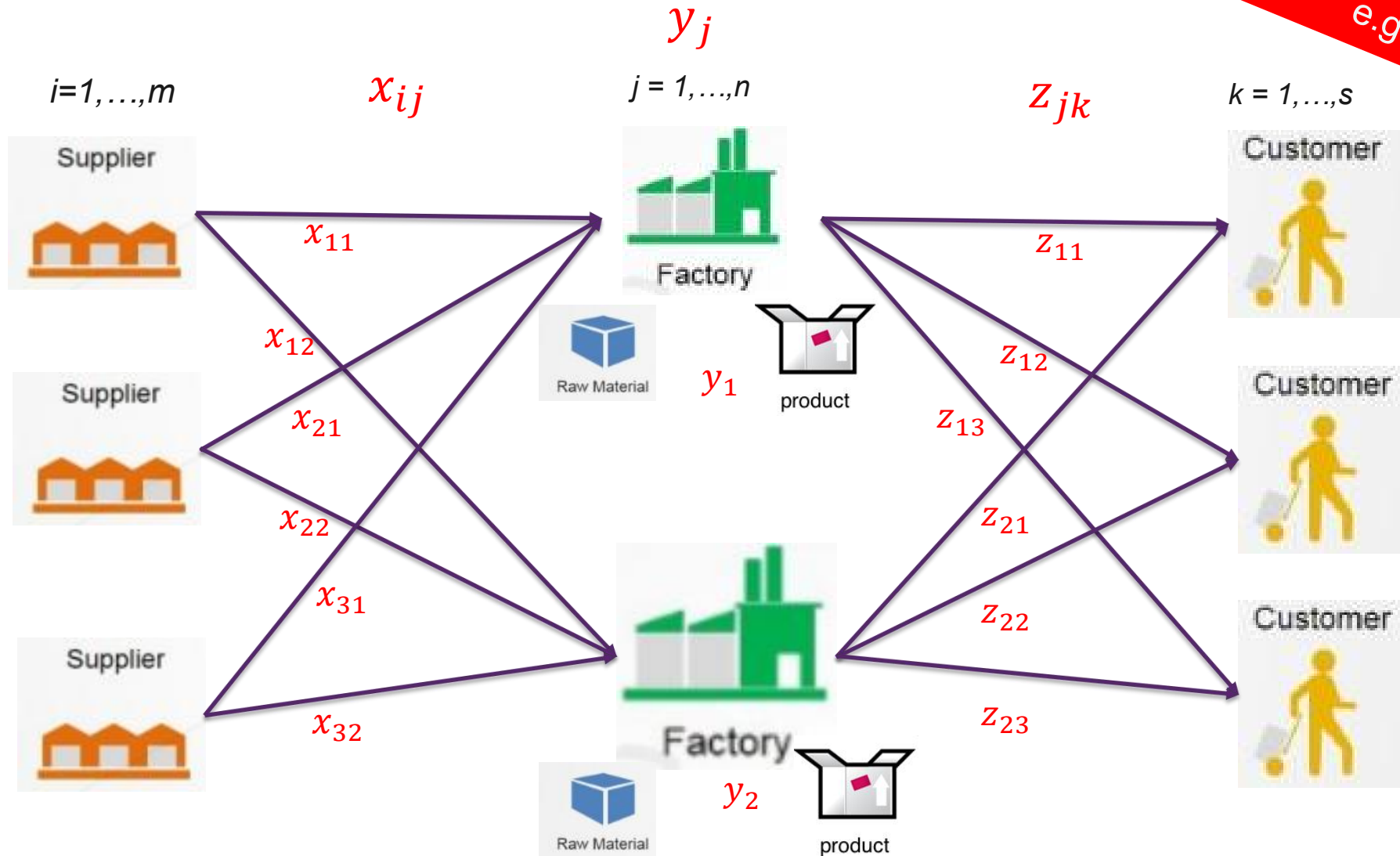
Input Elements to be considered

Topic	Elements
 <p>Supplier</p> <p>Purchasing: $i=1, \dots, m$ $j=1, \dots, n$</p>	<ol style="list-style-type: none"> 1. Material cost, material overhead 2. Transportation cost, import cost 3. Lead time, transportation time
 <p>Factory</p> <p>Production: $j=1, \dots, n$</p>	<ol style="list-style-type: none"> 1. For each process at each machine in each factory: machine speed in PCS/h, machine hourly rate, personal hourly rate, setup time, running time, fixed cost, variable cost 2. Work schedule (employee and equipment) 3. Production overhead, production development overhead, administration overhead, logistic overhead, sales overhead
 <p>Customer</p> <p>Delivery $j=1, \dots, n$ $k=1, \dots, s$</p>	<ol style="list-style-type: none"> 1. Sales prices 2. Transportation cost, export tax 3. Transportation time

KPIs and Constraints

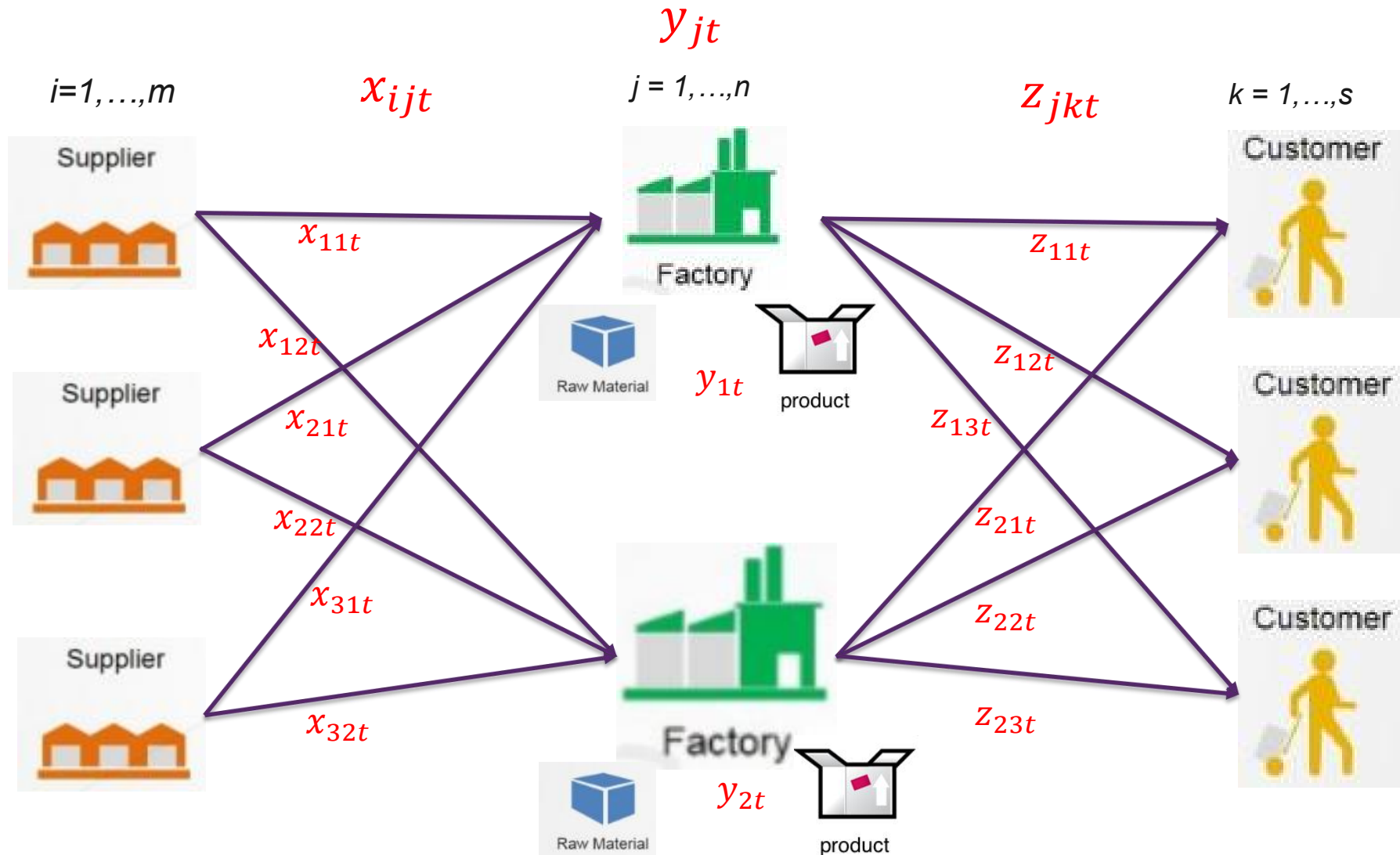
Topics	KPIs	Constraints
The whole network	Profit (revenue, costs)	
 Supplier Purchasing	Supplier volume	Supplier capacity limits, commercial limits
 Factory Production	<ol style="list-style-type: none"> 1. Inventory levels 2. Capacity utilization 	<ol style="list-style-type: none"> 1. Inventories (raw material inventory and finished good inventory) space, safety stock 2. Production factories capacity limits
 Customer Delivery	<ol style="list-style-type: none"> 1. Fill rate 2. On-time delivery rate (OTD) 	<ol style="list-style-type: none"> 1. Customer demands 2. Due date

Decisions to make



For each decision time period t ,
e.g. each week

Decisions to make



Mathematical Formulation (Deterministic)

$$\max_{x_{ijt}, y_{jt}, z_{jkt}} \sum_{j=1}^J \sum_{k=1}^K \sum_{t=1}^T c_k \times z_{jkt} - \sum_{j=1}^J \text{Cost}_j(x_{ijt}, y_{jt}, z_{jkt}) \quad (1)$$

$$\begin{aligned} \text{Cost}_j(x_{ijt}, y_{jt}, z_{jkt}) &= \sum_{i=1}^I \sum_{t=1}^T r_i \times x_{ijt} (1 + TC_{ij} + ImTax_{ij}) + \text{ProdCost}_j \\ &+ \sum_{k=1}^K \sum_{t=1}^T (ExTax_{jk} \times c_k \times z_{jkt} + DLC_{jk} \times \left\lfloor \frac{z_{jkt}}{\bar{V}max_{jk}} \right\rfloor), \forall j \end{aligned} \quad (2)$$

$$\sum_{j=1}^J \sum_{t=1}^T x_{ijt} \leq Cmax_i, \forall i \quad (3)$$

$$\sum_{j=1}^J \sum_{t=1}^T x_{ijt} \leq CL_i, \forall i \quad (4)$$

$$CL_i \leq \alpha_i \sum_{i=1}^I \sum_{j=1}^J \sum_{t=1}^T x_{ijt}, \forall i \quad (5)$$

$$IM_{jt} = IM_{j(t-1)} - BOM \times \frac{y_{jt}}{Quality_j} + \sum_{i=1}^I x_{ij(t-L_{ij})}, \forall j, t \quad (6)$$

$$MSS_j \leq IM_{jt} \leq MSpace_j, \forall j, t \quad (7)$$

$$IP_{jt} = IP_{j(t-1)} + y_{j(t-PLT_j)} - \sum_{k=1}^K z_{jkt}, \forall j, t \quad (8)$$

$$PLT_j = \frac{\max(VT_v)}{OEE_j}, \forall j \quad (9)$$

$$PSS_j \leq IP_{jt} \leq PSpace_j, \forall j, t \quad (10)$$

$$\frac{\sum_{t=1}^T y_{jt}}{\sum_{v=1}^V \frac{B_{vj} \times PT_j \times OEE_j}{VT_v}} \leq \beta_j, \forall j \quad (11)$$

$$\begin{aligned} \text{ProdCost}_j &= \left\{ p_{1j} \times \min \left(\sum_{t=1}^T y_{jt}, \frac{B_{1j} \times PT_j \times OEE_j}{VT_1} \right) \right. \\ &+ \sum_{v=2}^V p_{vj} \\ &\times \min \left(\max \left(\sum_{t=1}^T y_{jt} - \sum_{\bar{v}=1}^{v-1} \frac{B_{\bar{v}j} \times PT_j \times OEE_j}{VT_{\bar{v}}}, 0 \right), \frac{B_{vj} \times PT_j \times OEE_j}{VT_v} \right) \left. \right\} \\ &\times (1 + OPDALS_j), \forall j \end{aligned} \quad (12)$$

$$\hat{D}_{k1} = \min \left\{ D_{k1}, \sum_{j=1}^J z_{jk(1-L_{jk})} \right\}, \forall k \quad (13)$$

$$\hat{D}_{kt} = \min \left\{ D_{kt}, \max \left(\sum_{\bar{t}=1}^t \sum_{j=1}^J z_{jk(\bar{t}-L_{jk})} - \sum_{\bar{t}=1}^{t-1} D_{k\bar{t}}, 0 \right) \right\}, \forall k, t = 2, \dots, T \quad (14)$$

$$\frac{\sum_{t=1}^T \hat{D}_{kt}}{\sum_{t=1}^T D_{kt}} \geq \gamma_k, \forall k \quad (15)$$

$$y_{jt} = 0, z_{jkt} = 0, x_{ijt} = 0, \forall i, j, k, t \leq 0 \quad (16)$$

$$y_{jt}, z_{jkt} \in Z_0^+, x_{ijt} \geq 0, \forall i, j, k, t \in [1, T] \quad (17)$$

Variances/Risks to be considered

- Purchasing:
 - Supplier capacity limits, commercial limits
 - Material quality, rejection rate at incoming
 - Material availability due to Covid-19
 - Transport delay
- Production:
 - Scrap rate due to material quality
 - Equipment/ employee availability decreases due to Covid-19
- Delivery
 - Demand variation: 10%,20%,...,50%
 - Transport delay

Even more !!

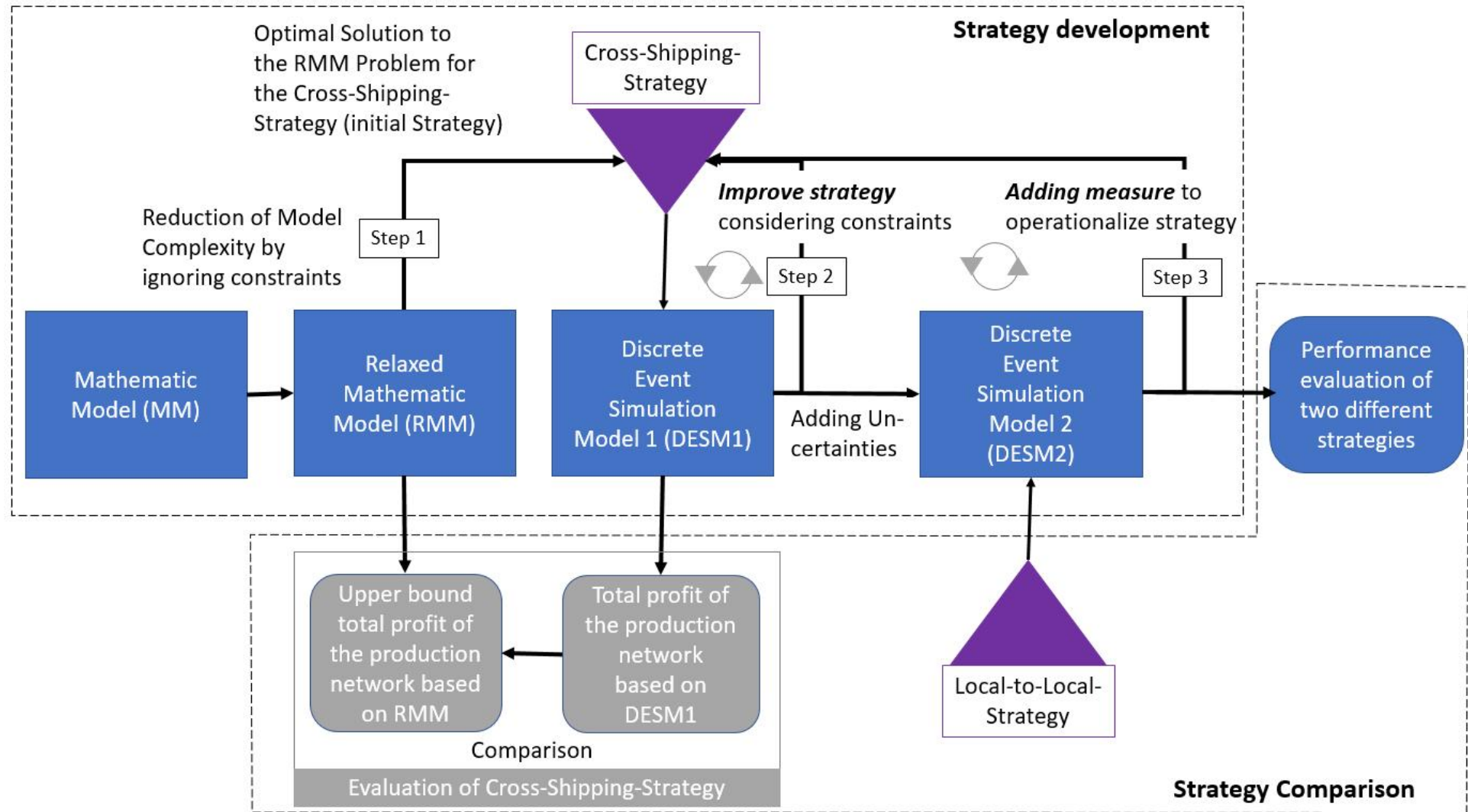


Problem Complexity

- **Dynamic** (multistage) production-inventory problem: The state of future stages depend on the decision variable values of previous stages.
- **Non-linear** problem (with $3 \times 52 + 3 \times 3 \times 52$ integer and $3 \times 3 \times 52$ real variables)
- **Uncertainties**
- **Multiple objectives** (KPIs) and constraints

You need to use dynamic programming to solve this problem,
Even with a very powerful computer, it takes ages to get the optimal solution

Approach



Input Data & Decisions

0_Excel variables_simulation - Excel

Shuangqing Liao

	A	B	C	D	E	F	G
1	Raw material demand in kg						
2		Total Demand	Supplier_1	Supplier_2	Supplier_3	Remark	
3	A	397885	318308		79577	Optimized according to volume price, transport costs, import c	
4	B	491505		491505		Optimized according to volume price, transport costs, import c	
5	C	70215	56172		14043	Optimized according to volume price, transport costs, import c	
6							
7	Supplier	Capacity in kg	Share	Commerical limitation	Utilization		
8	Supplier_1	500,000	80%	None	74.90%		
9	Supplier_2	600,000		None	81.92%		
10	Supplier_3	120,000	20%	191,921	78.02%		
11							
12		Material cost	Transport percentage	Transport cost	Import Taxes	Import costs	Total costs
13	A	1328683		167360			1496
14	Supplier_1	1062497	15%	159375	0%		1225
15	Supplier_2	0	30%	0	20%		0
16	Supplier_3	266186	3%	7986	0%		274
17		Material cost	Transport percentage	Transport cost	Import Taxes	Import costs	Total costs
18	B	2086480		271242			2355
19	Supplier_1	0	30%	0	20%		0
20	Supplier_2	2086480	13%	271242	0%		2355
21	Supplier_3	0	30%	0	20%		0
22		Material cost	Transport percentage	Transport cost	Import Taxes	Import costs	Total costs
23	C	234473		29534			264
24	Supplier_1	187499	15%	28125	0%		215
25	Supplier_2	0	30%	0	20%		0
26	Supplier_3	46974	3%	1409	0%		48
27							
28							
29							
30	Material price table (CHE/kg)						
	Overview	Sales price	Plant Capacity	Product data	Process data	Raw material	Production cost
							Overhead
							Transport
							Storaç ...

Ready Count: 3 100%

Data

When building a simulation model, how much detailed data should you include?

- A. All raw data that I received
- B. Only the data that I really need
- C. The data that I like



Solution with Excel

Step 1: Ignoring **all randomness/Risks**

Step 2: Simplifying the multi-stage problem to **single-stage problem**

- 52 decisions stages $(3*3*2+3)*52$ decision variables
- 1 decision stage per year $3*3*2+3$ decision variables

Step 3: Relaxing **integer** requirements

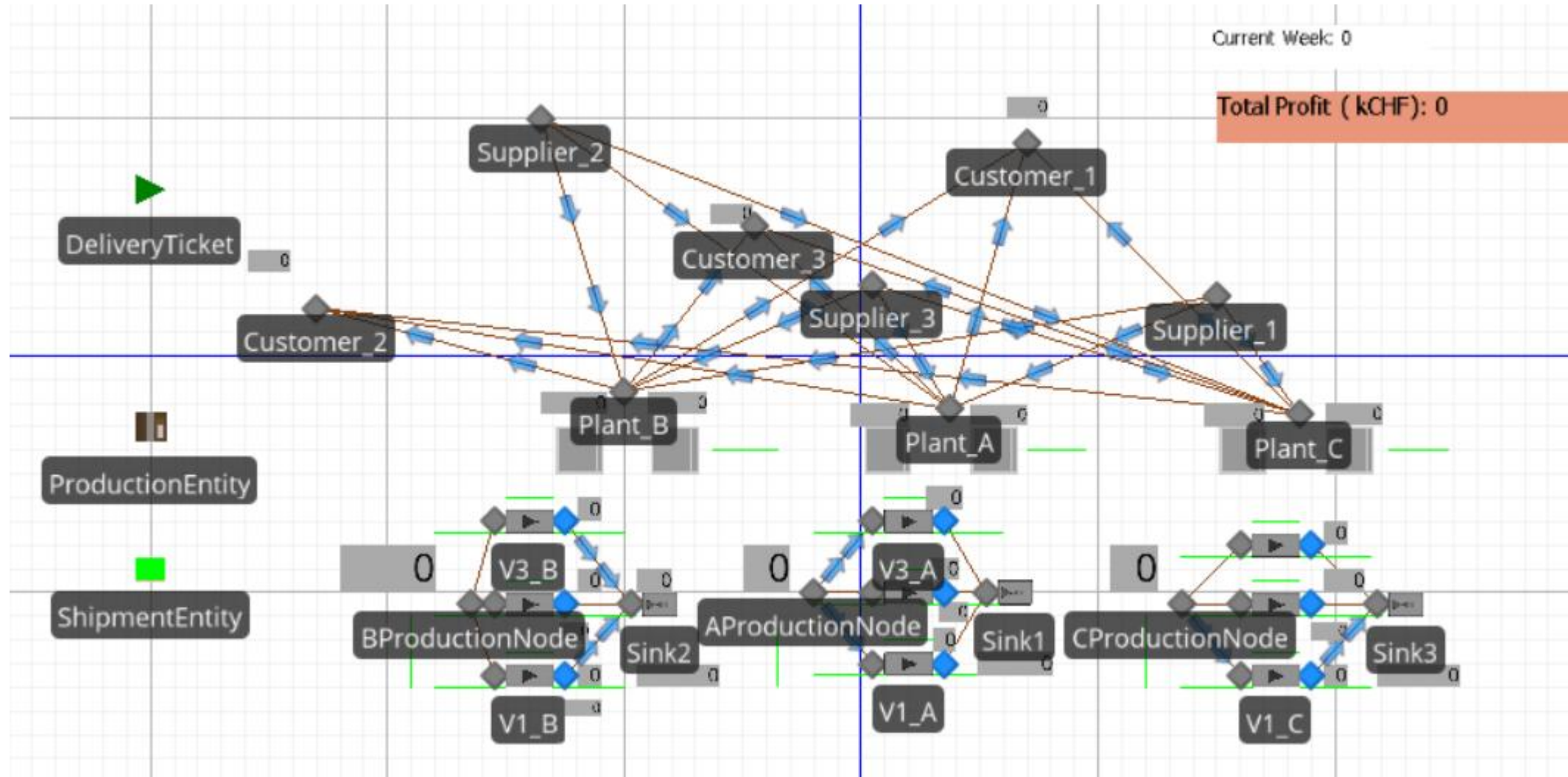
- Batches number
- Delivery times

Step 4: Ignoring several **constraints**

- Inventory constraints (space, safety stock)
- OTD
- Machines tasks assignments

Step 5: using Excel solver, Simplex LP, we can get an **upper bound** of the **total profit**

DES in Smart Factory Production Network

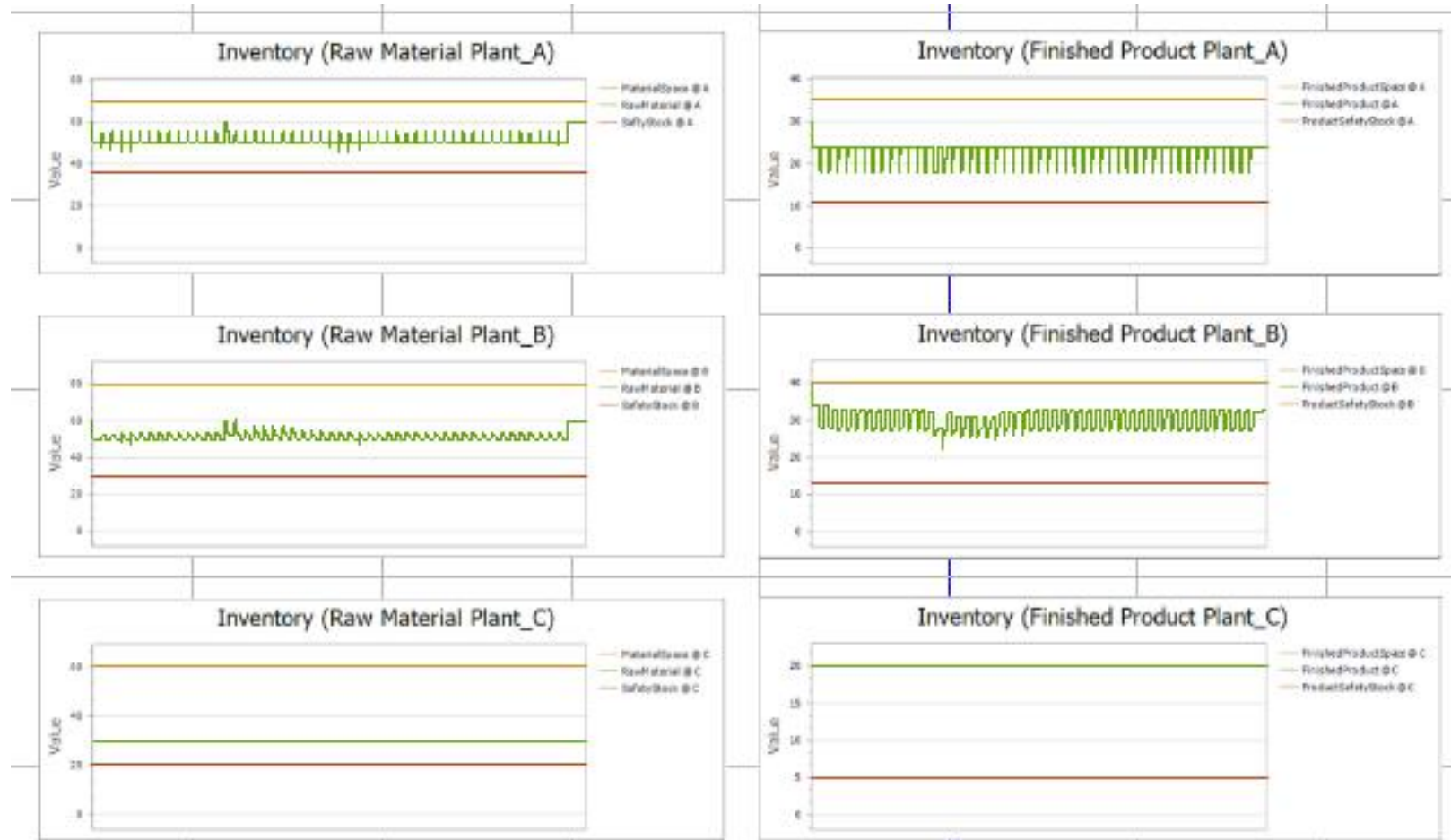


KPIs Status Display

Suppliers	Supplier_1	Supplier_2	Supplier_3
Total Capacity	500	600	120
Utilization Limit	450	540	108
Supplied Volume	378.84	497.25	94.71
Customers	Customer_1	Customer_2	Customer_3
Demand Qty.	306	51	255
Received Qty.	306	51	255
Fill Rate	1.00	1.00	1.00
OTD Rate	1.00	1.00	1.00

Plants	Plant_A	Plant_B	Plant_C
Profit (kCHF)	1980.70	2933.95	0.00
Revenue	7193.02	7705.02	0.00
Total Cost	5212.31	4771.07	0.00
Material Cost	1763.97	2216.46	0.00
Material OH	156.56	154.19	0.00
DALSOverhead	1236.69	750.76	0.00
Production Cost	1741.82	1365.02	0.00
Prod. OII	243.85	150.15	0.00
Shipment Cost	69.41	134.49	0.00
Utilization	73.92	87.45	0.00
Mat. In Stock	60.00	60.00	30.00
Avg. Mat. Qty	51.32	51.53	30.00
Mat. Space	70	80	60
Mat. Safetystock	36	30	20
Prod. In Stock	24.00	33.00	20.00
Avg. Prod. Qty	23.20	30.32	20.00
Prod. Space	35	40	20
Prod. Safetystock	11	13	5
Required	306.00	306.00	0.00
Delivered	306.00	306.00	0.00
OTD	306.00	306.00	0.00
Fill Rate	1.00	1.00	0.00
OTD Rate	1.00	1.00	0.00

Inventory Levels Graphical Display



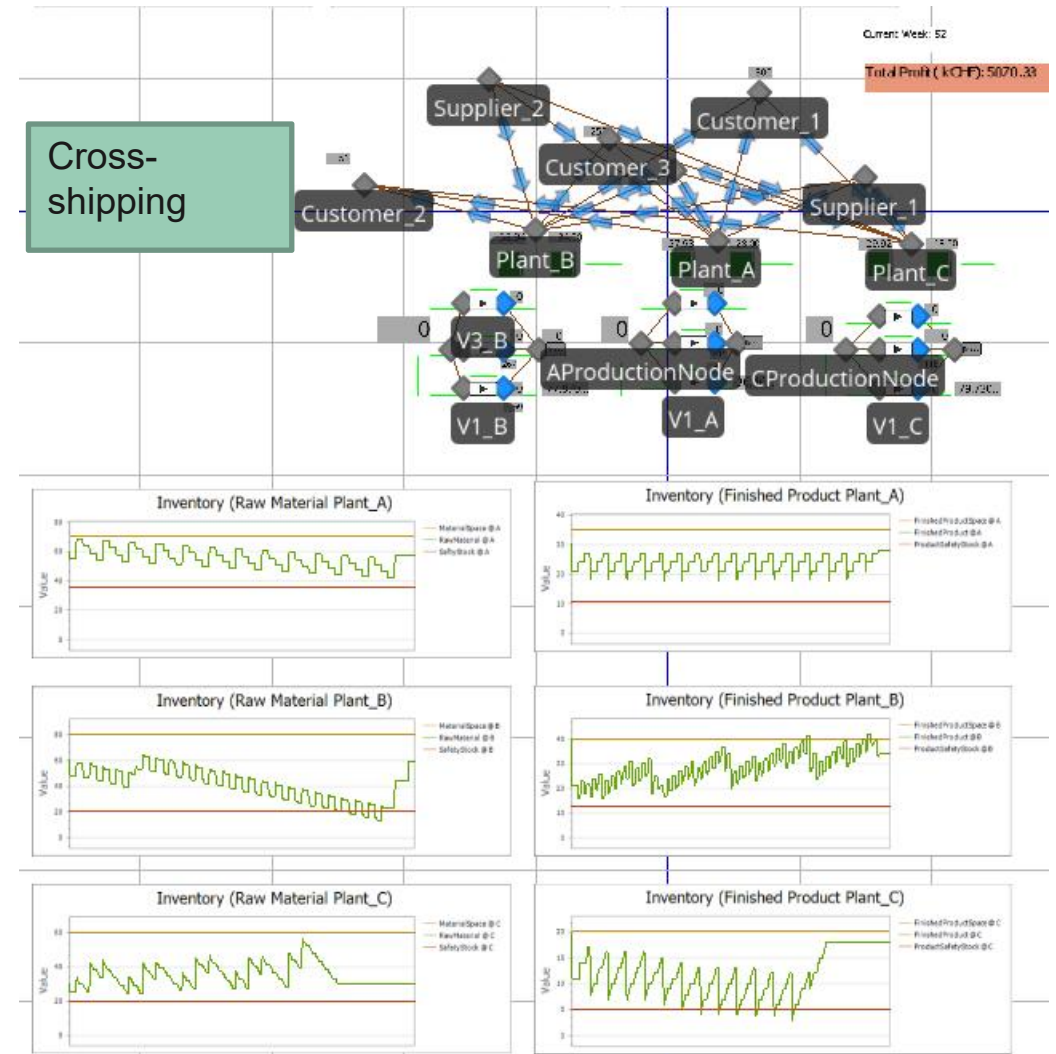
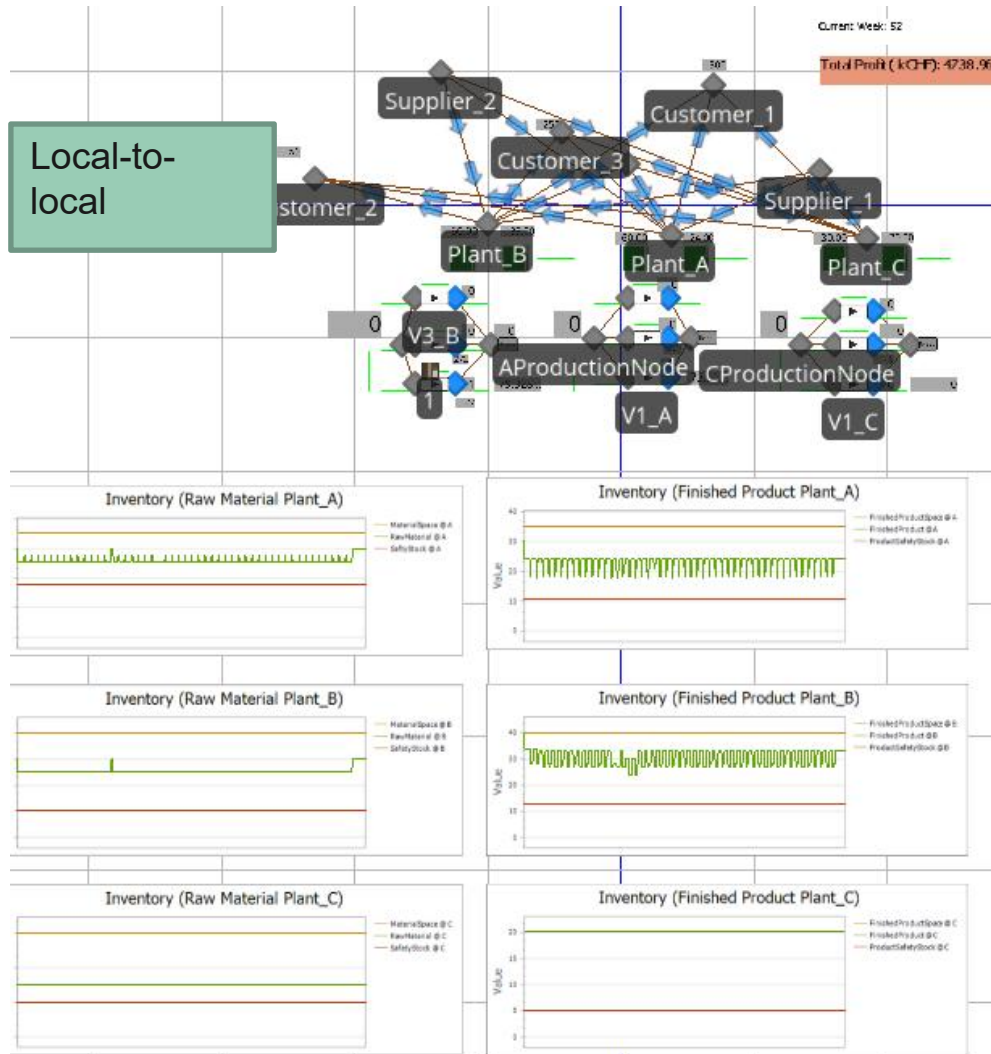
Production Strategies Evaluation

- Strategy 0: Local to local
- Strategy 2: Cross-shipping, based on the Excel solution

Compare the total profits, OTD, Inventory Levels
under various situations

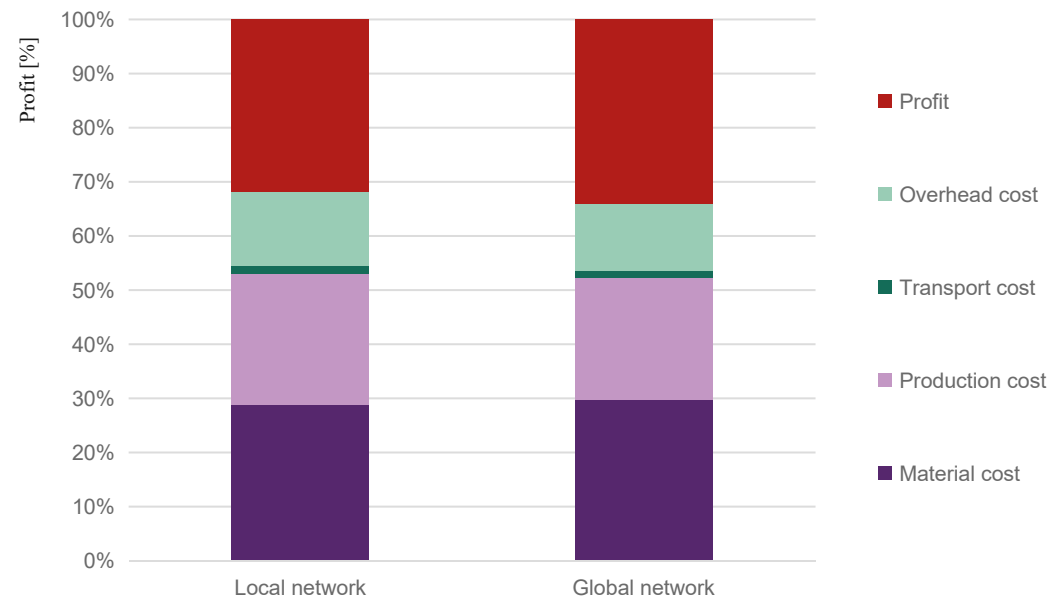
1. Deterministic demand
2. Demand variation (10%, 50%, 100%, 200%, etc.)
3. Plant failure (10%, 20%, 50%, etc.)
4. Supplier failure (10%, 20%, 50%, etc.)

Production Strategies Evaluation: Deterministic Demand

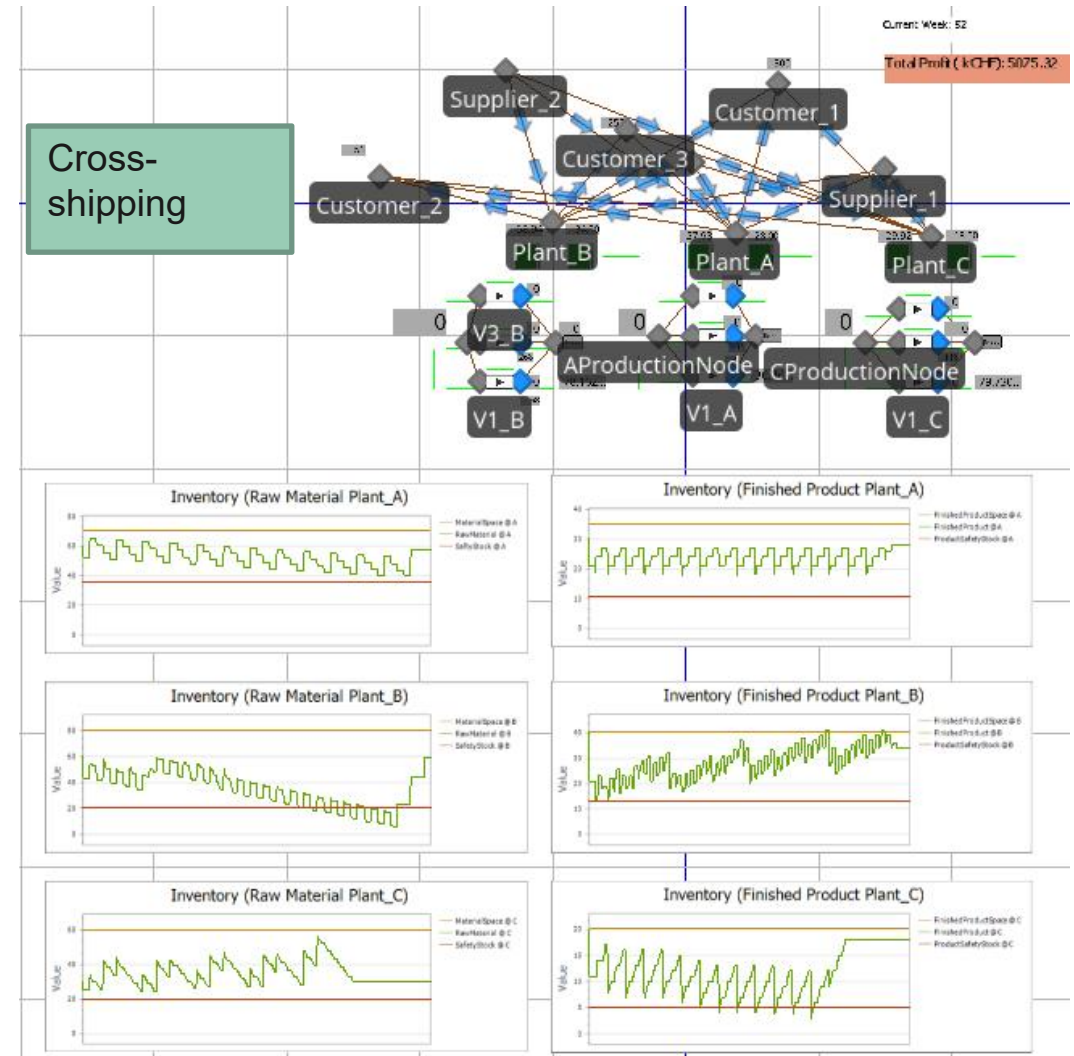
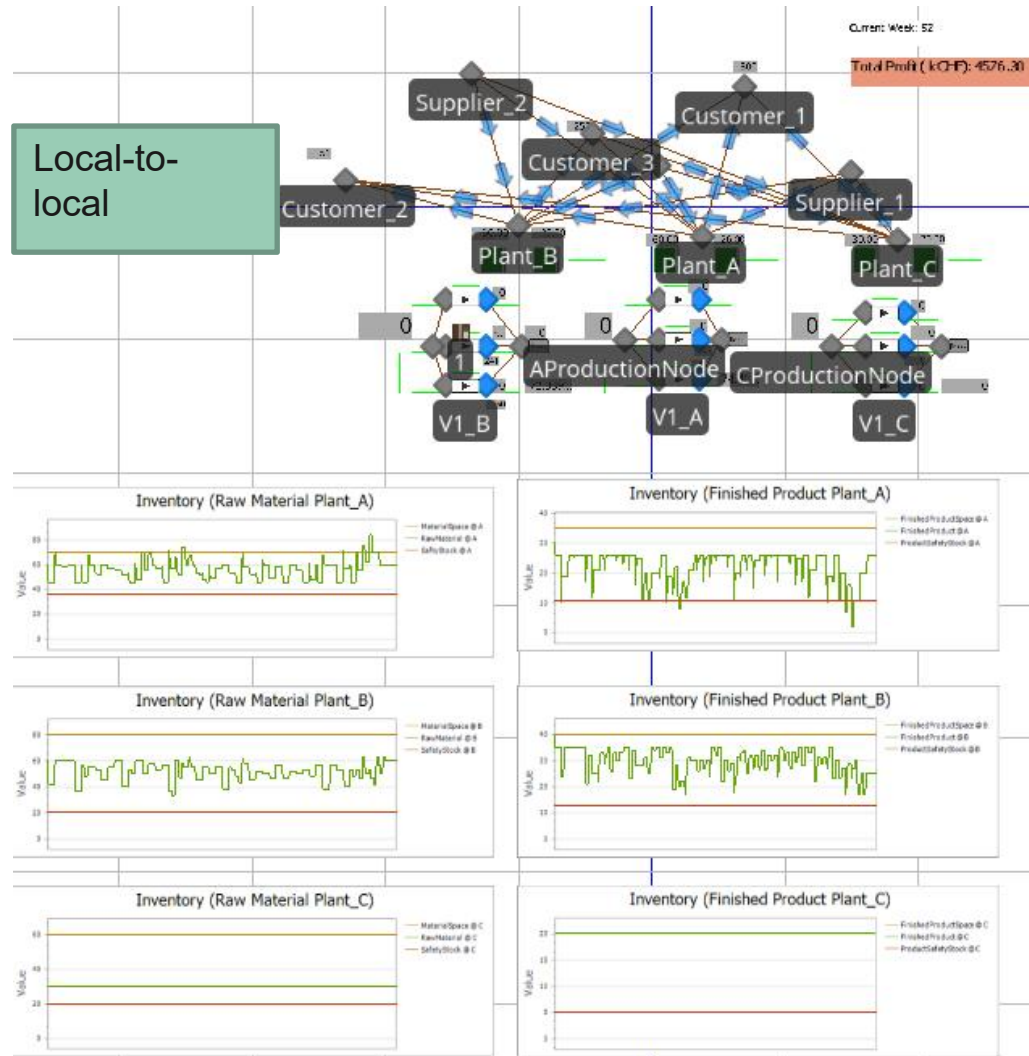


Production Strategies Evaluation: Deterministic Demand

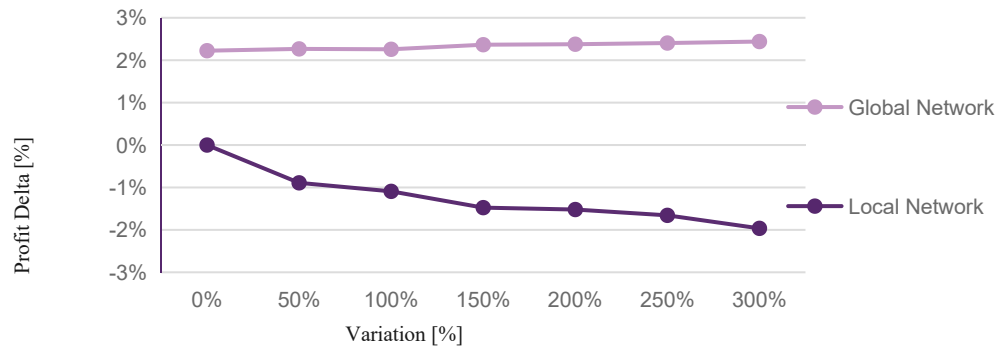
Costs and Profits local vs. global network



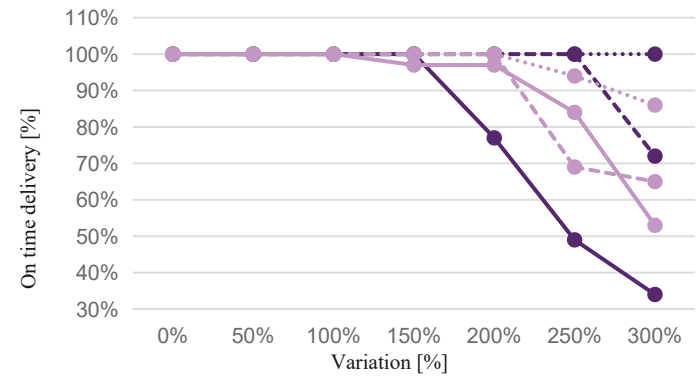
Production Strategies Evaluation: Demand varies 100%



Production Strategies Evaluation: Demand variation

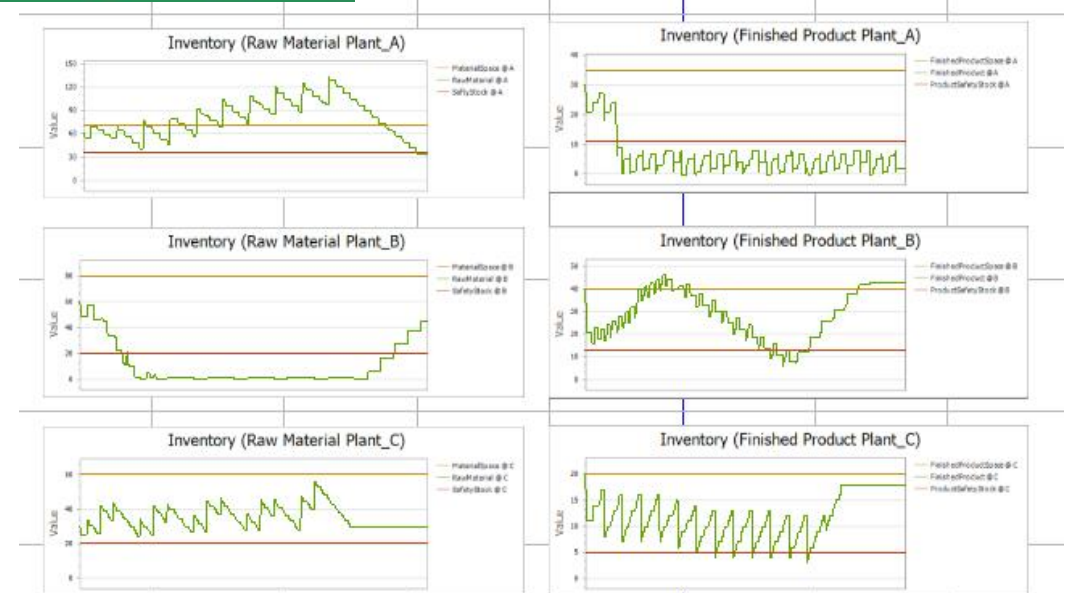
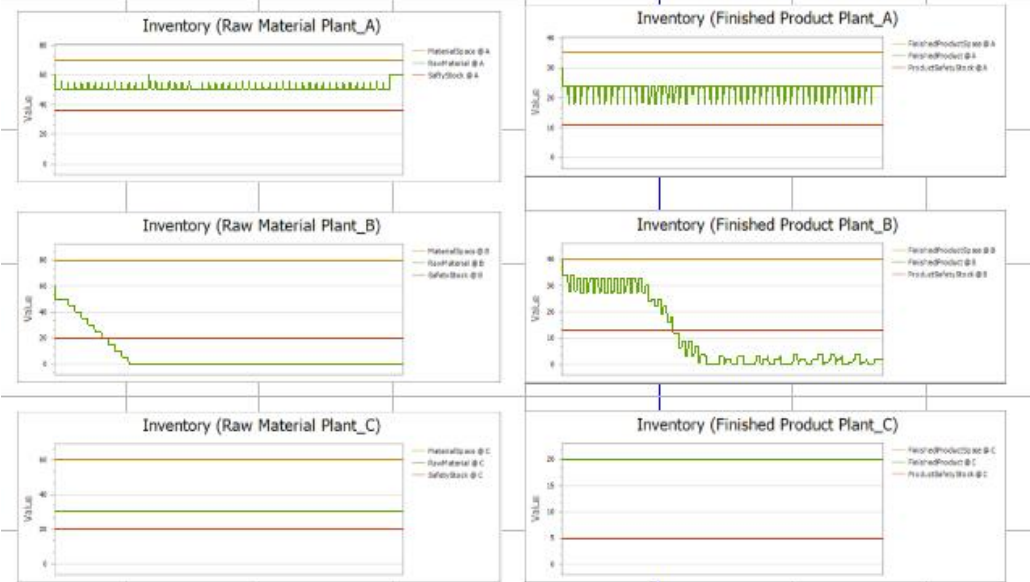
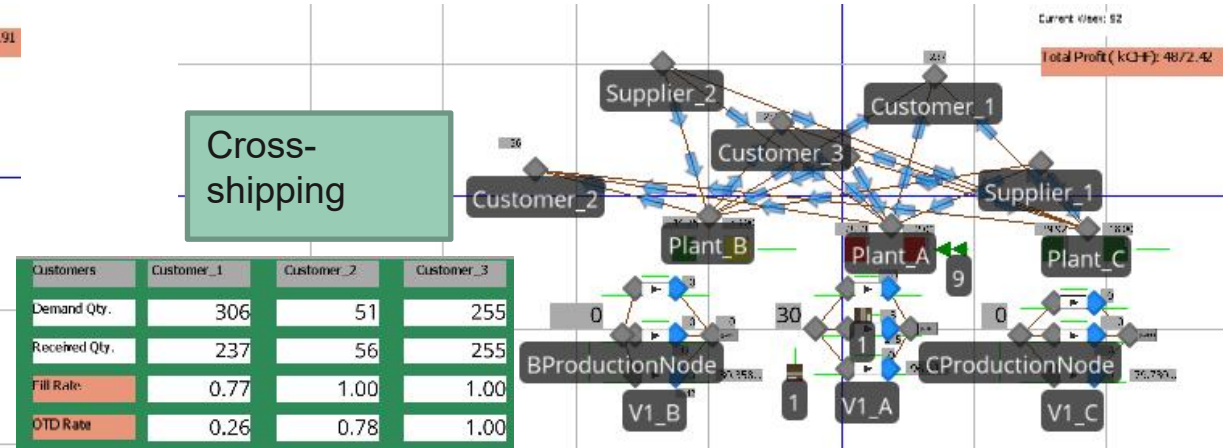
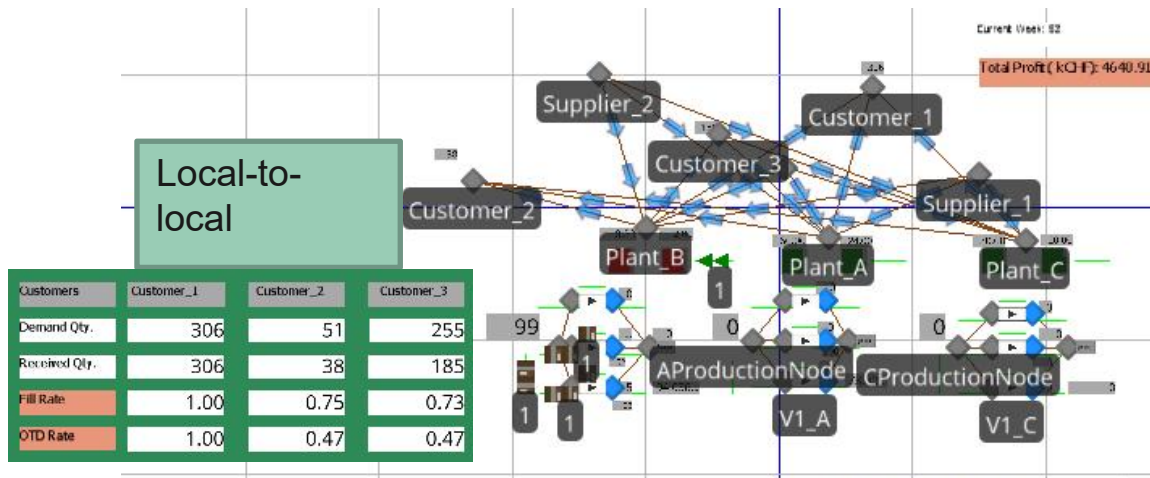


Profit vs. Demand Variation

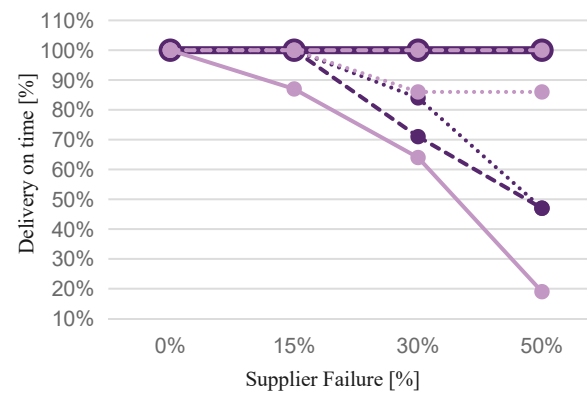
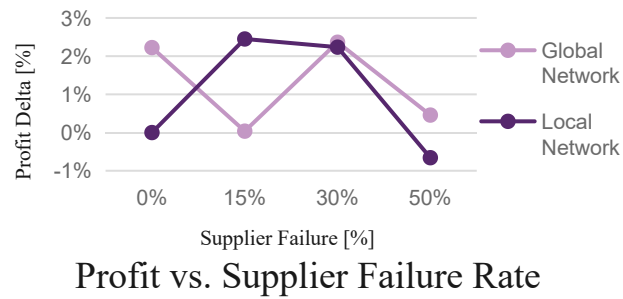


On Time Delivery vs. Demand Variation

Production Strategies Evaluation: Supplier Fails 50%

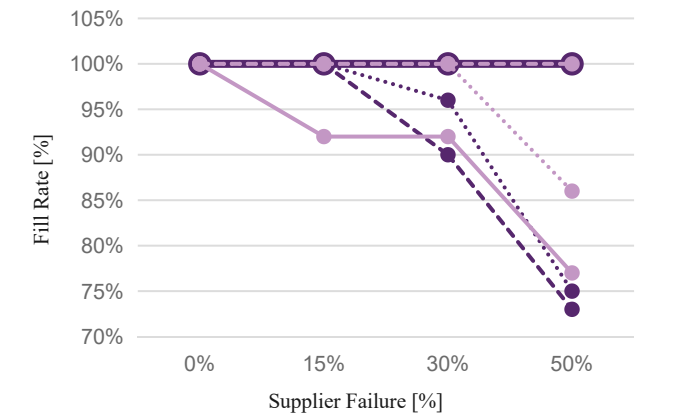


Production Strategies Evaluation: Supplier Failures



- Customer Europe 1 (local) ● Customer USA 1 (local)
- Customer USA 2 (local) ● Customer Europe 1 (global)
- Customer USA 1 (global) ● Customer USA 2 (global)

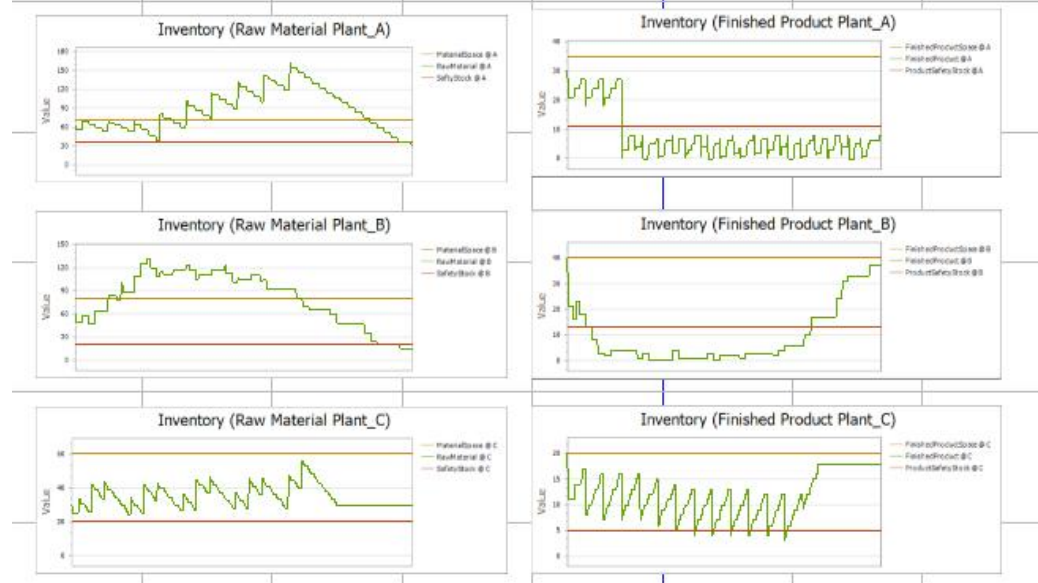
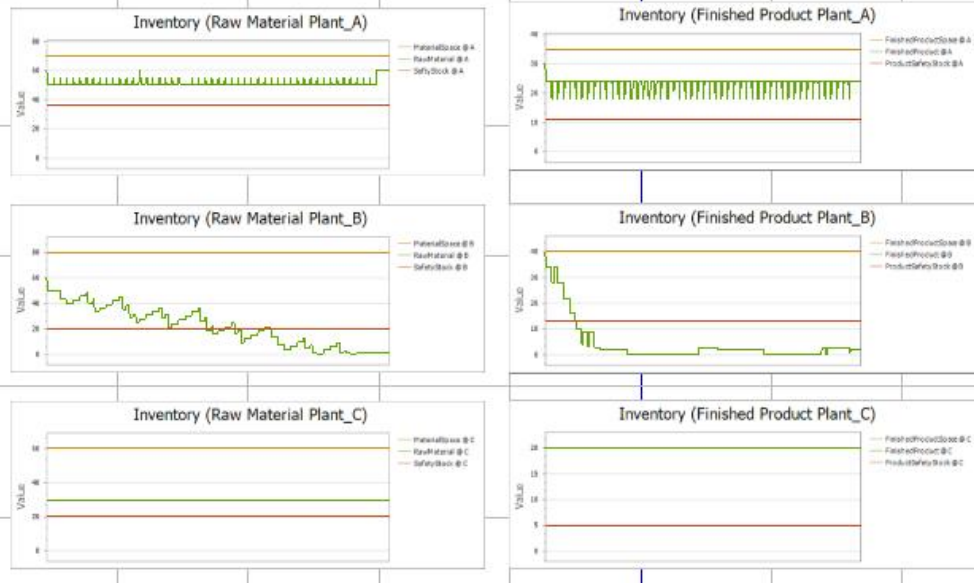
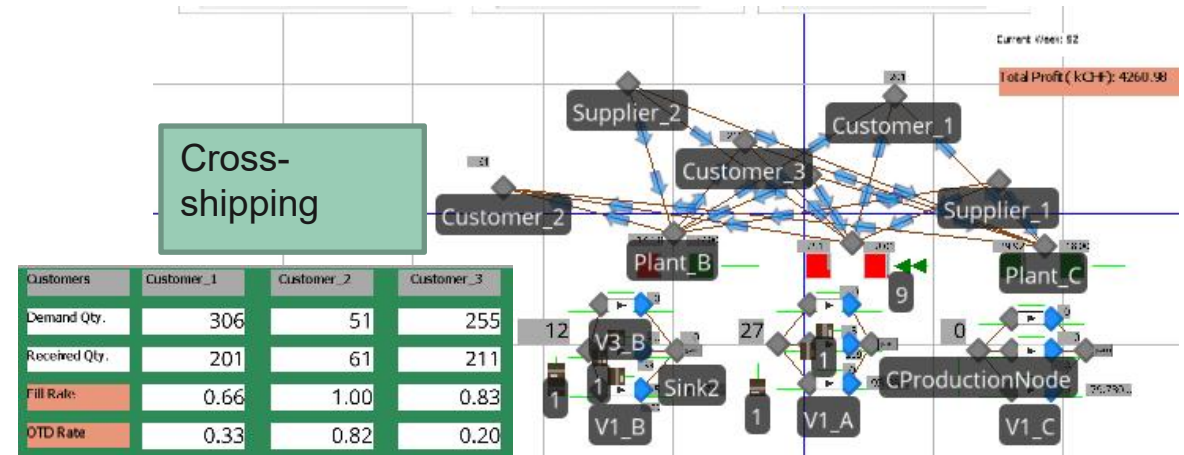
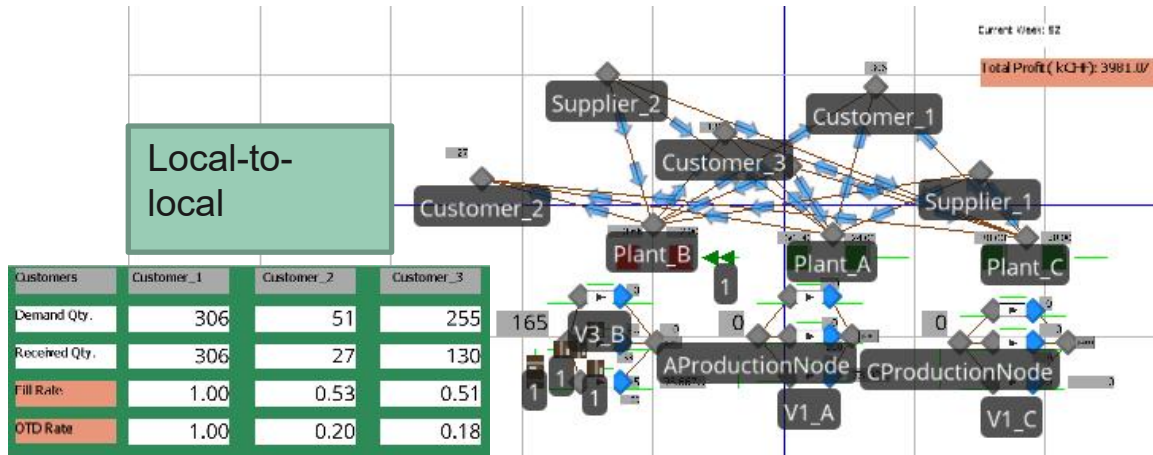
On Time Delivery vs. Supplier Failure Rate



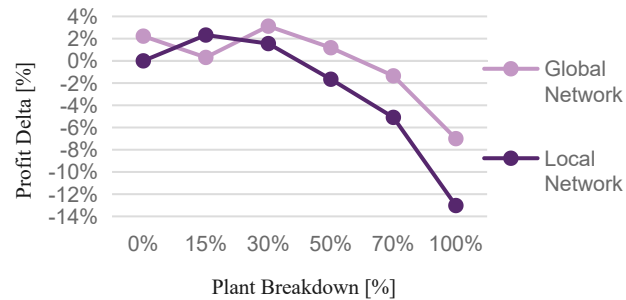
- Customer Europe 1 (local) ● Customer USA 1 (local)
- Customer USA 2 (local) ● Customer Europe 1 (global)
- Customer USA 1 (global) ● Customer USA 2 (global)

Fill Rate vs. Supplier Failure Rate

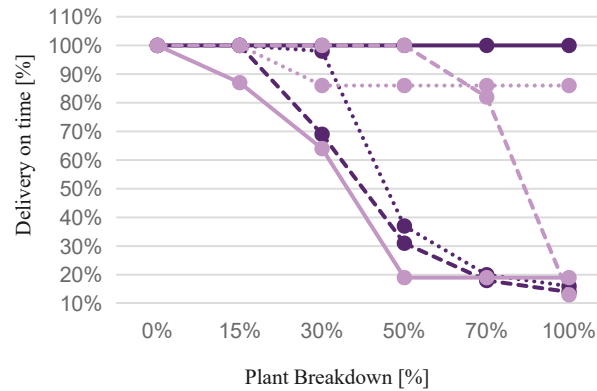
Production Strategies Evaluation: Plant Fails 70%



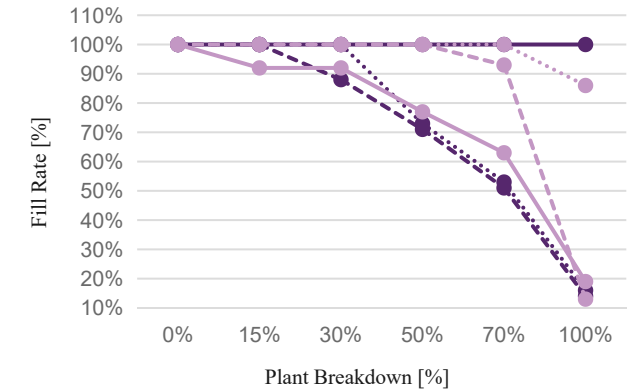
Production Strategies Evaluation: Plant Failures



Profit vs. Plant Breakdown



On Time Delivery vs. Plant Breakdown



Fill Rate vs. Plant Breakdown

- Customer Europe 1 (local) ● Customer USA 1 (local)
- Customer USA 2 (local) ● Customer Europe 1 (global)
- Customer USA 1 (global) ● Customer USA 2 (global)

- Customer Europe 1 (local) ● Customer USA 1 (local)
- Customer USA 2 (local) ● Customer Europe 1 (global)
- Customer USA 1 (global) ● Customer USA 2 (global)

Capacity Planning

Machine number for plant B:

9?

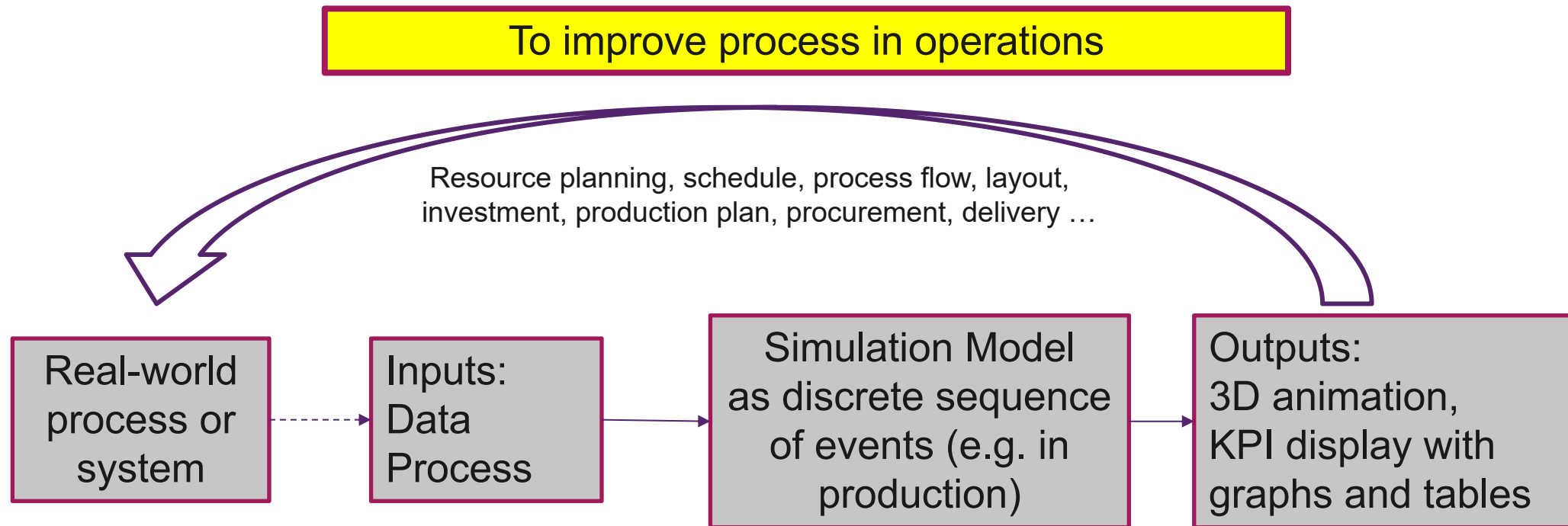
10?

11?

Target: Capacity utilization smaller than 80%, OTD 100%

Plants	Plant_A	Plant_B	Plant_C
Profit (kCHF)	916.75	2710.07	1443.52
Revenue	3525.99	8551.26	2820.79
TotalCost	2609.24	5841.19	1377.28
Material Cost	886.69	2486.23	675.98
Material OH	92.52	214.59	62.40
DALSOverhead	627.29	1020.10	205.30
Production Cost	859.30	1789.64	394.81
Prod. OH	120.30	196.86	19.74
Shipment Cost	23.14	133.77	19.05
Utilization	65.64	79.85	79.73

What Simulation can do in Smart Factory?



Outline

Basics

DES for process improvement

Simulation
Industrie 4.0
Smart Factory

Applications in Smart factory

Traditional simulation applications

- Production planning:
 - Milkrun configuration
 - Lot sizing
- Product delivery management
 - Production network management

Digital Twin

- Overview
- Applications

Perspective

Simulation for the Better:
The Future in Industry 4.0

Digital Twin Definition

Digital Twin was conceived in as a method to predict the structural behavior of an aircraft by analyzing and simulating the aircraft's behavior on its digital model in 2011. A year later, NASA defined Digital Twin as “an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, and so forth, to mirror the life of its flying twin.”

Digital Twin was seen as the next generation of simulation.

Digital Twin is a method of achieving the convergence between physical and virtual spaces.

Now, Digital Twin has evolved into a broader concept that refers to a **virtual representation** of **manufacturing elements** such as personnel, products, assets and processes, a living model that continuously updates and changes as the physical counterpart changes to **represent** status, working conditions, product geometries and resource states **in a synchronous manner**. The **digital representation** provides both **the elements and the dynamics** of how a physical ‘thing’ operates and lives throughout its life cycle.(ISO, ISO/AWI 23247)

Lu et al. 2020. Robotics and Computer Integrated Manufacturing.

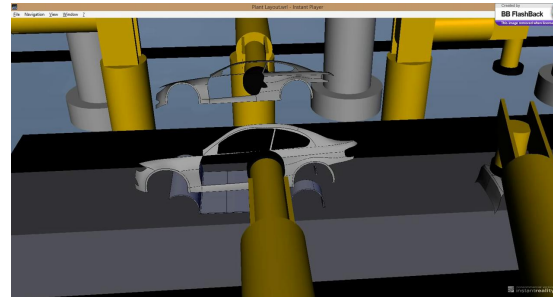
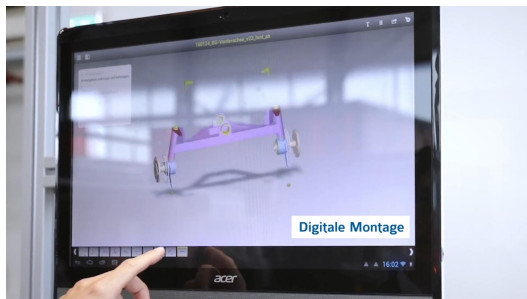
Digital twin: Recap Week 1



Physical



Virtual



Digital Twin and Simulation

A Digital Twin is a digital replica of a real-world 'thing.' While this looks close to simulation, Digital Twin is much more.

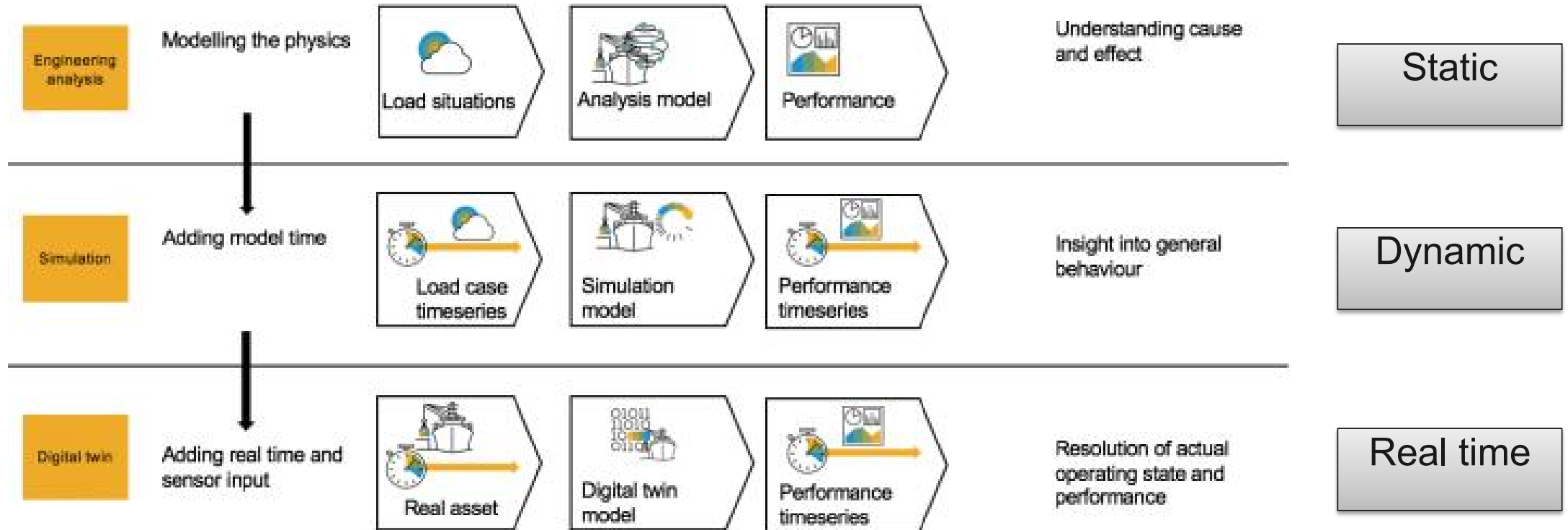
A Digital Twin is a **high-fidelity representation** of the operational dynamics of its physical counterpart, enabled by near real-time synchronization between the cyberspace and physical space.

The **operational dynamics** are critical elements of a Digital Twin because a twin's behavior is based on near real-time data coming from the actual physical counterpart.

Simulation focuses on **what could happen in the real world (what-if scenario)**, but not what is currently happening. In the manufacturing context, a Digital Twin can be used **for monitoring, control, diagnostics, and prediction, other than just simulation.**

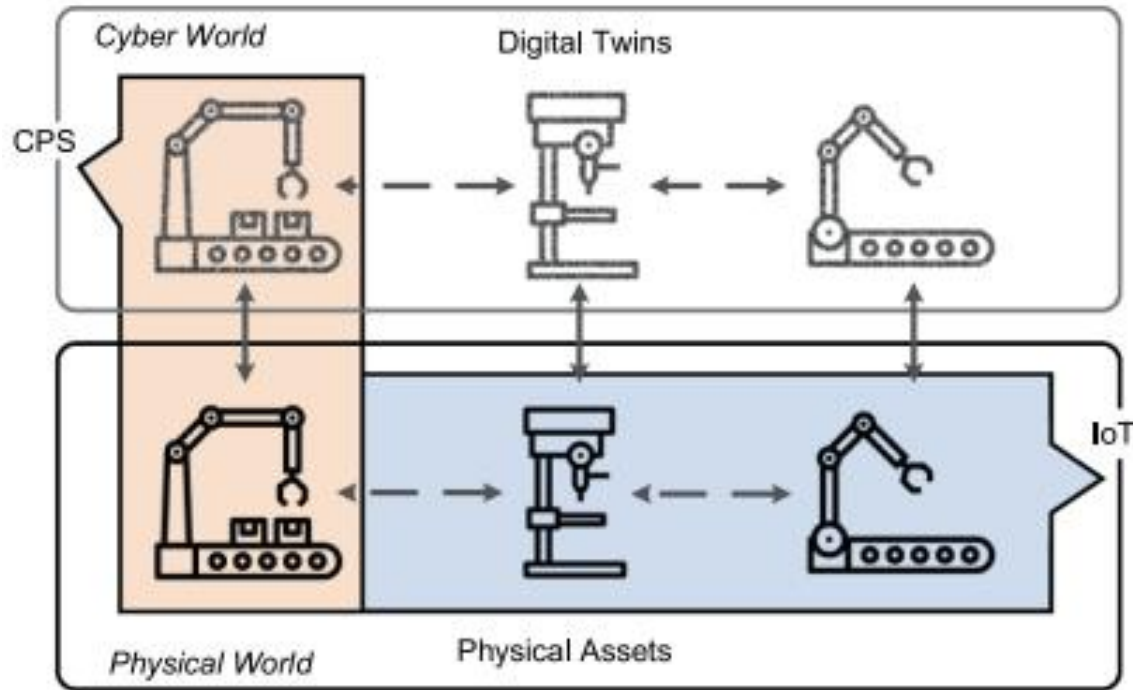
Lu et al. 2020. Robotics and Computer Integrated Manufacturing.

Engineering Analysis & Simulation & Digital Twin



Digital Twin, CPS, and IoT

Digital Twin, CPS (Cyber-Physical Systems), and IoT all use networking and sensors.



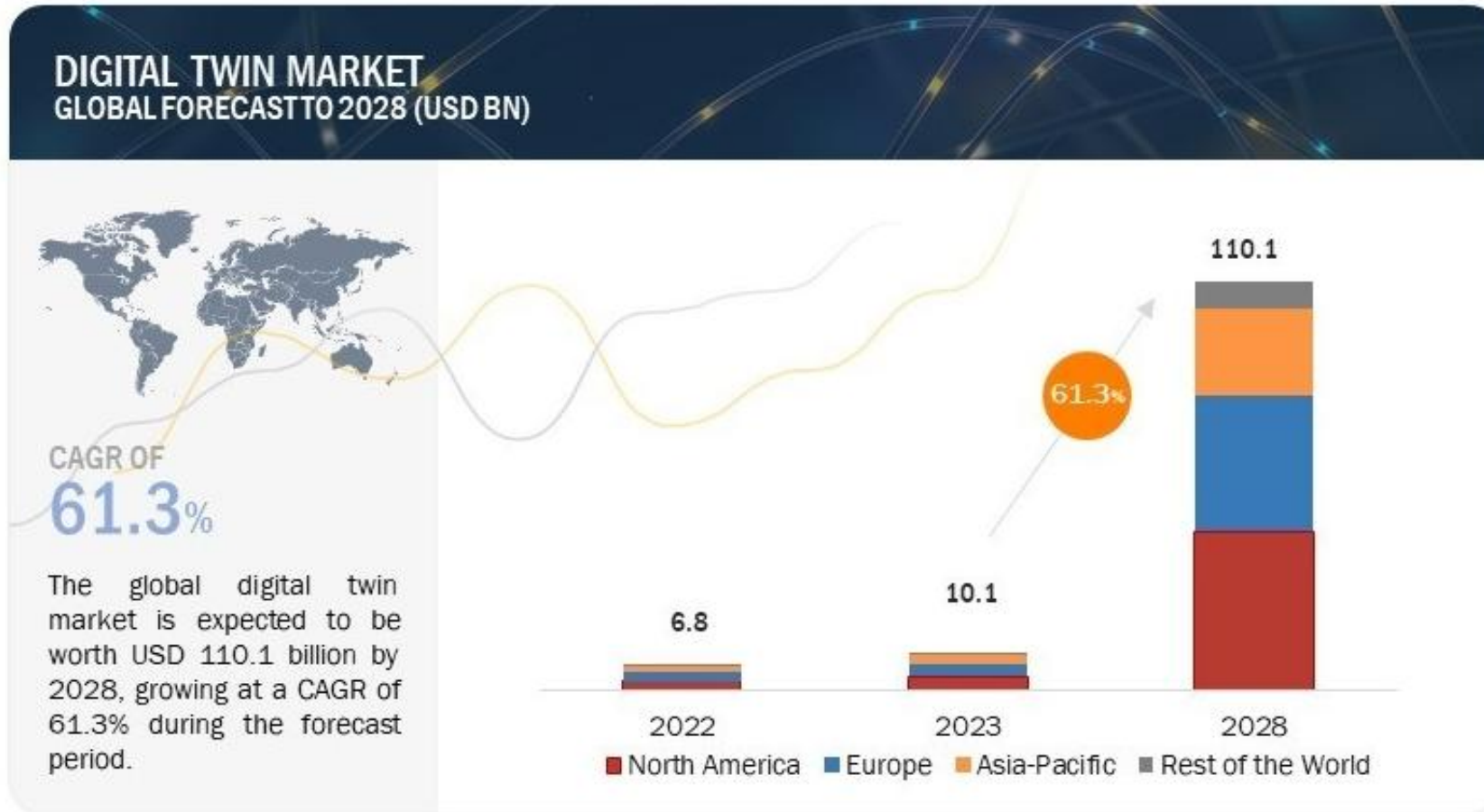
The relationship between Digital Twin, CPS and IoT

A CPS is characterized by a physical asset and its Digital Twin. Digital Twin represents the prerequisite for the development of a CPS.

IoT refers to connections between a network of physical assets through which data can flow between themselves. However, despite the connectivity, IoT does not include the idea of digital models in the cyberspace. The IoT is the infrastructure in the physical space for connecting physical assets.

Digital Twin Market

Digital twin market: Poised for growth



Main players:



<https://www.marketsandmarkets.com/Market-Reports/digital-twin-market-225269522.html>

Digital Twin Market

ATTRACTIVE OPPORTUNITIES IN THE DIGITAL TWIN MARKET

North America is estimated to account for the largest share of the digital twin market during the forecast period.



Rising emphasis on digital twin in manufacturing industries to reduce cost and improve supply chain operations and growing focus on predictive maintenance are acting as major drivers for digital twin market.



Predictive Maintenance application is expected to hold the largest market share in 2023.



Healthcare is anticipated to exhibit the highest CAGR during the forecast period.



The market in North America is projected to record the highest CAGR owing to adoption of advanced technologies, robust infrastructure, advanced data analytics capabilities, and a skilled workforce contribute to the growth of digital twin.

Outline

Basics

DES for process improvement

Simulation
Industrie 4.0
Smart Factory

Applications in Smart factory

Traditional simulation applications

- Production planning:
 - Milkrun configuration
 - Lot sizing
- Product delivery management
 - Production network management

Digital Twin

- Overview
- Application in Smart Factory

Perspective

Simulation for the Better:
The Future in Industry 4.0

Digital Twin Examples

Siemens: Digital Twin

Azure: https://www.youtube.com/watch?v=ScmK-bKJ4MI&ab_channel=MicrosoftAzure

Digital Twin of Smart Factory

https://www.youtube.com/watch?v=RcY7dBBkx8g&ab_channel=twinz0

Digital Twin Concept

Management layer: This applies the required changes to objects or processes, also includes an admin control panel, user interface, and dashboards for displaying data

Decision-making layer: a set of tools to identify possible scenarios manually or automatically

Analytics and Simulation layer: An object or process-based virtual presentation layer, allowing you to replicate its behavior with all relevant features and then analyze it

Data integration and storage layer: Data collection and preparation for future usage

IOT/ connectivity layer: data acquisition and transfer

<https://www.dataart.com/digital-twins-development>

IOT/ connectivity layer:

- Protocols
- Scalability
- Suggested traffic and message size
- Internet connection methods
- Security
- Equipment integration
- Device certifications

Activities

- ✓ Requirements collection
- ✓ Priorities evaluation
- ✓ Technical documentation investigation
- ✓ Sensor and device installation
- ✓ IoT network setup

Data Integration and Storage Layer

- Data collection and storage
- Data preparation (Cleaning, aggregation, etc.)

Activities

- ✓ Evaluating data collection options
- ✓ Long-term data storage
- ✓ Development activities

Management layer:

Activities

- ✓ Facility integration
- ✓ Digital twin control system development
- ✓ Solution deployment

<https://www.dataart.com/digital-twins-development>

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Benefits of Simulation in Industry 4.0

Reduced Waste in Time and Resources, Increased Efficiency

- Simulation will enable optimum configurations in processes and “optimum” decisions in CPS.
- Simulation tunes the **synchronization parameters** for machines, this reduces in work-in-progress (WIP) inventory through better information exchange in value-chain.

Increased Revenue and Productivity

- Development and testing robotics, which have significant role in increasing revenue and productivity.
- Information linkage between machines and between suppliers are critical for optimum use of resources. Factory simulations, digital twins, and supply chain simulations can help increase revenue and productivity.

Simulation for Industry 4.0, Gunal, Murat (Ed. 2019)

Benefits of Simulation in Industry 4.0

Individualization in Demand for Products

- Simulation exists in custom production and additive manufacturing in two ways: in the design of products, and in the 3D printing process.

Increase in Skilled Workers

- Augmented Reality (AR) and Virtual Reality (VR) help humans increase their knowledge about systems, and hence, reduce human related errors.
- AR help simplify the complexity in manufacturing, increases understandability

Simulation for Industry 4.0, Gunal, Murat (Ed. 2019)

Benefits of Simulation in Industry 4.0

Increased Work-Safety

- With AR and VR, workers can be trained before they work on shop floors in factories. The training can be for general safety rules or for specific machine usage.

E.g., forklift simulators can train drivers to make them aware of possible dangers.

New Opportunities with Data

The IoT

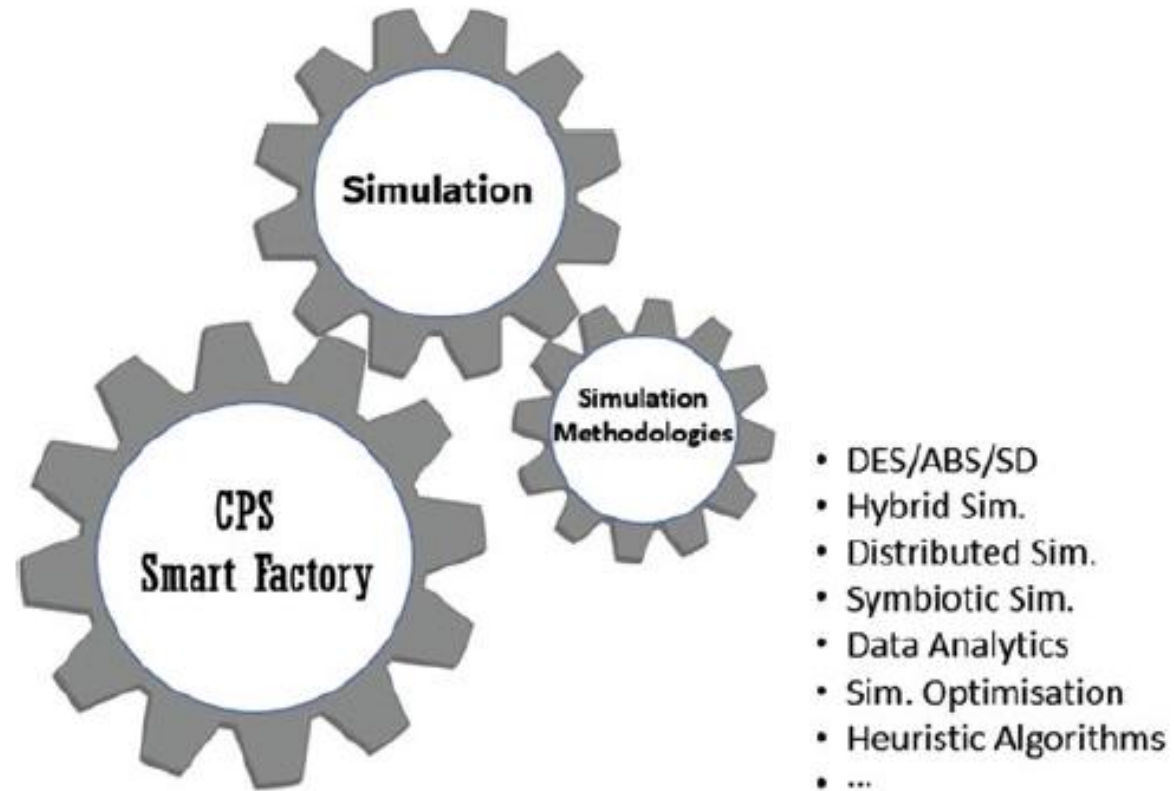
will provide the data and smart algorithms

will make inferences from the data and simulation models

will predict or inform about the future.

Simulation for Industry 4.0, Gunal, Murat (Ed. 2019)

The Role of Simulation in Industry 4.0



Simulation as a driver of CPS and smart factory

Smart Factory is driven by Simulation

Summary

1. Digital Twin definition



Digital representation of elements and dynamics
in a synchronous manner

2. Digital Twin vs. Simulation



"What if" vs. "What is happening now"

3. Digital twin, CPS, and IoT



Not the same

4. Benefits of Simulation in Industry 4.0



Tool to understand complex systems/
see effects of changes

DES can help making a factory smart