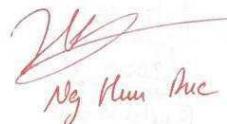


# Industrial Logistics

  
Ng Kuan Rue

## Log Introduction

- +> Origin: military - the necessity of troop supply & the provision of armament

Industrial logistics: the holistic approach to design the flow of materials and information towards an economic optimum

In-house

- Procurement
- Warehousing - picking
- Process Planning
- Production
- Sales department / customer

Inter-company

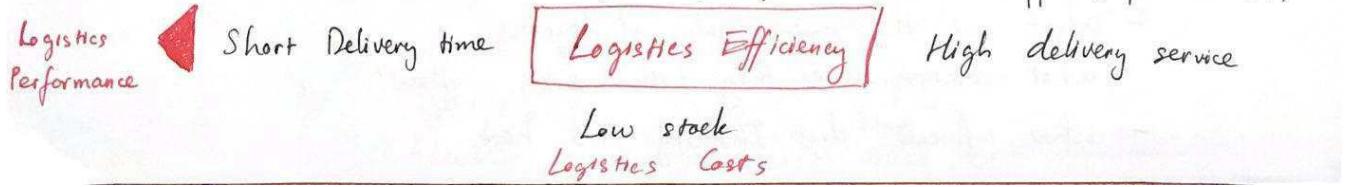
- Logistic networks
- Transport / Distribution
- Supply Chain Management
- Efficient customer response

## 6/7 R of Logistics - Plowman

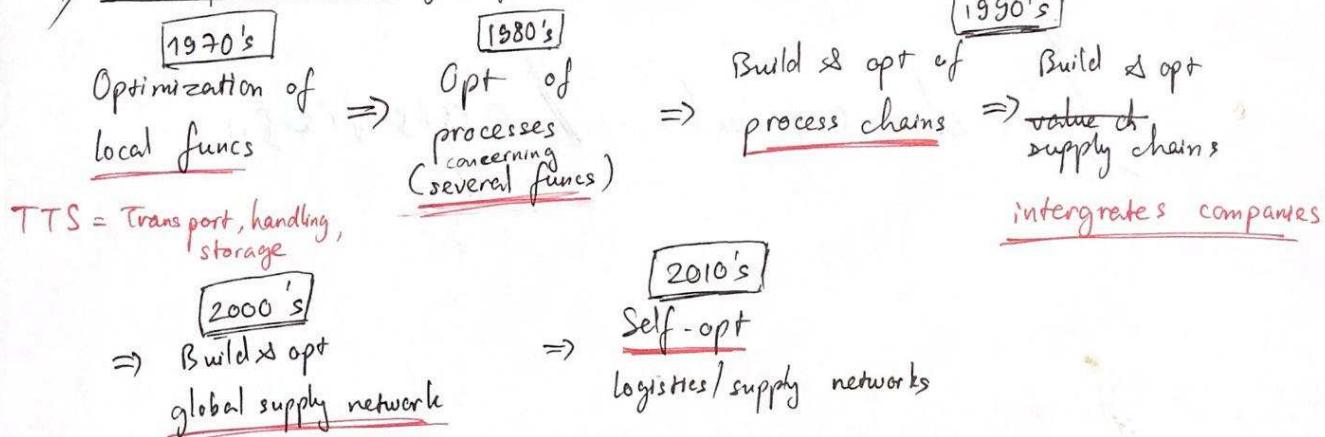
Right object	Right quantity	Right location	Resource efficiency
Right time	Right quality	Right costs	

+> Two goals of Logistics Management:  $\Rightarrow$  Conflict: of objectives

High through-put



+ Development history of logistics: starting research in 60s & 70s



+ Smart Logistics:

- Industry 4.0: information flow ↔ material flow  
autonomous driving - Transport logistics

- Questions:
- which periods did logistics go through since the 1970's?
  - what are the flow man's G/F R of logistics?
  - How is industrial logistics defined?
  - What are the main goals of logistics?  
what relation are they with each others?
  - What influence does Industry 4.0 have?

# Supply Chain Design

L02

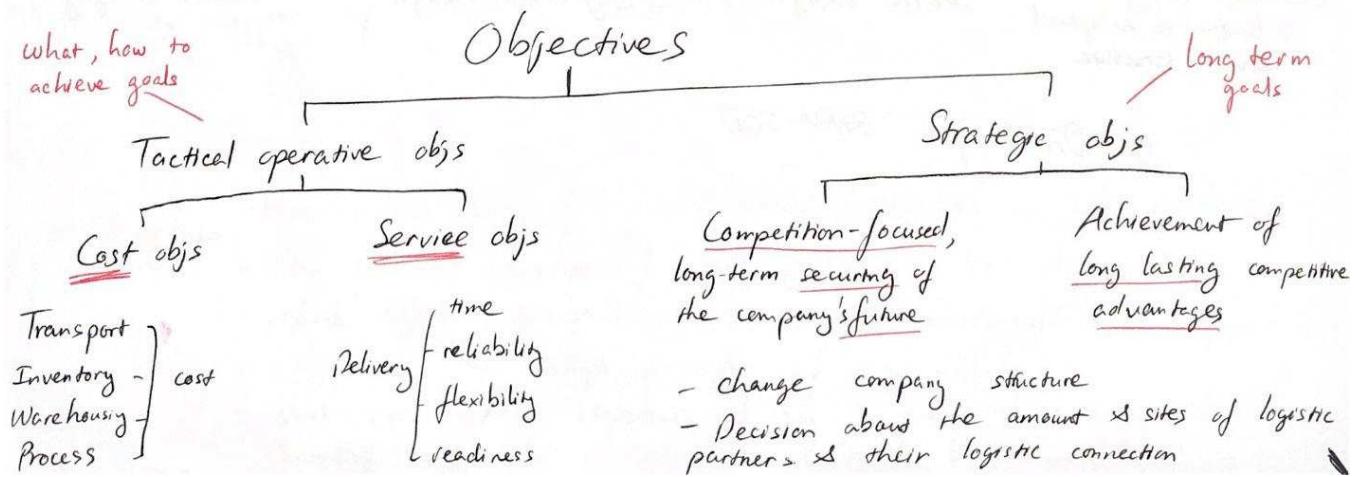
+)Definition: part of strategic logistic management  
 includes long-term decisions  
 ( location & capacitive configs  
 of production & logistic sites )  $\Rightarrow$  determine the structure  
 of logistic network

Logistic network: a mesh of source & sink relations  
 ( handling, transportation & inventory processes are handled )  
 related information

2 models for Supply Chain Management (<sup>generic</sup>  $\Rightarrow$  as reference)  
 Supply Chain Planning matrix / Aachen PPC Model  
 follow the timeline task-oriented

In which:  
Supply Chain Design  $\in$  Strategic Network Planning / Network tasks

+)Tasks and Objectives of SDM:



+ Trade-offs: company obj's  $\times$  logically dependent variables

+ Ex: - high revenues/profit  $\times$  high service level

- "Going East": outsourcing

- "Global Footprint": Strategic Analysis  
Site Analysis & Planning



### Approaches

- "Completely Knocked Down" - CKD: export partly dismantled products and assemble them at locations in the local markets  
Check quality at the production site

+ Challenges of SMART SCD

#### Perspectives of SMART SCD

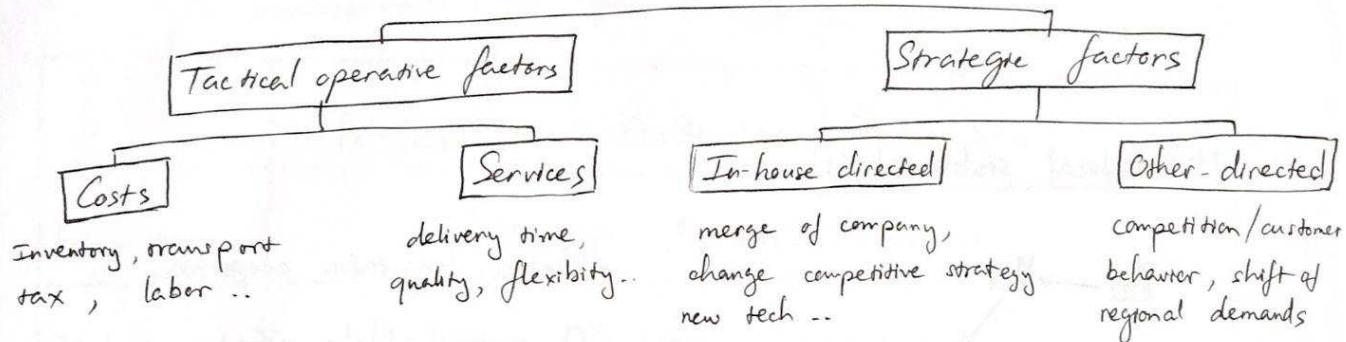
New design  $\times$  Redesign

Structure design  $\times$  Resource design

One-time config  
 $\Rightarrow$  leading to an optimal network structure: Static design  $\times$  Dynamic design : Several reconfig

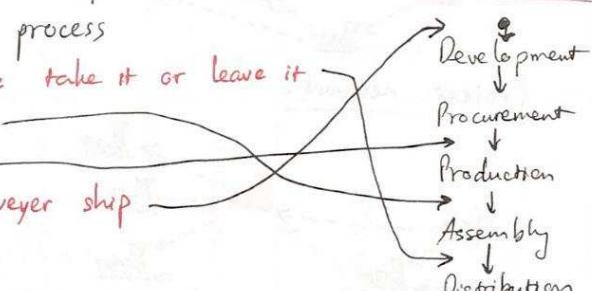
+ Driver for SMART SCD

## + ) Drivers for SCD:



## + ) Design principles:

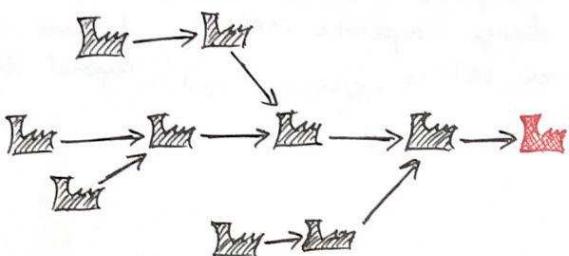
- Reactive ✗ Cost efficient  
(react quickly on demands variations)
- Central ✗ Decentralized  
(few big central warehouses) ↗ (includes several regional warehouses)
- Push ✗ Pull : different positions of the customer's decoupling point in the value creation process
  - Made-to-Stock : Ex: Iphone : take it or leave it
  - Assemble-to-Order : Ex: Laptop
  - Make-to-Order : Ex: Car
  - Engineer-to-Order : Ex: Big conveyor ship
- + Type of supply chain



- ② Questions:
- How is the config. of logistic's networks classified in ref. models?
  - How can the objectives of config. of log. net. be distinguished?
  - Which different perspectives have to be considered when config. lo. net.?
  - What are the design principles of log. net.?
  - What are specific structure of SC & their characteristics?
  - According to which criteria can a location be selected?

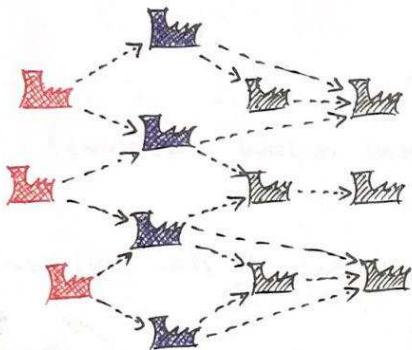
## +)Types of supply chain structure:

### Hierarchical stable chain:



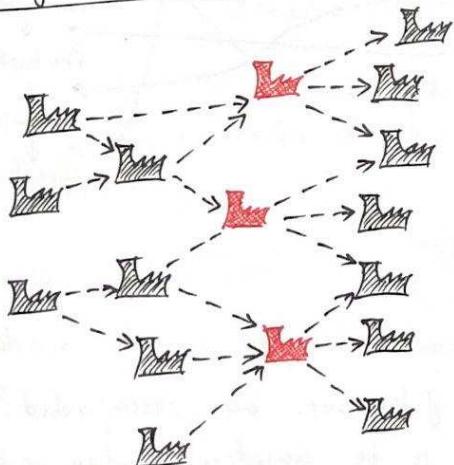
- Stable, long-term cooperation
- Dominance of the OEM (Original Equipment Manufacturer)
- Ex: BMW, Hilti

### Hybrid production network:



- Long-term, but loose cooperation
- Network dominated by the procurement
- Ex: Bayer, Shell

### Project network:



- Temporary cooperation
- Polycentric Network (having many centers)
- Ex: Claas, Heidelberg

## +)Site selection: 3 step:

{ Market region: politics, currency, culture ..  
sub region: tax, transport, labor ..  
local site: transport, environment ..

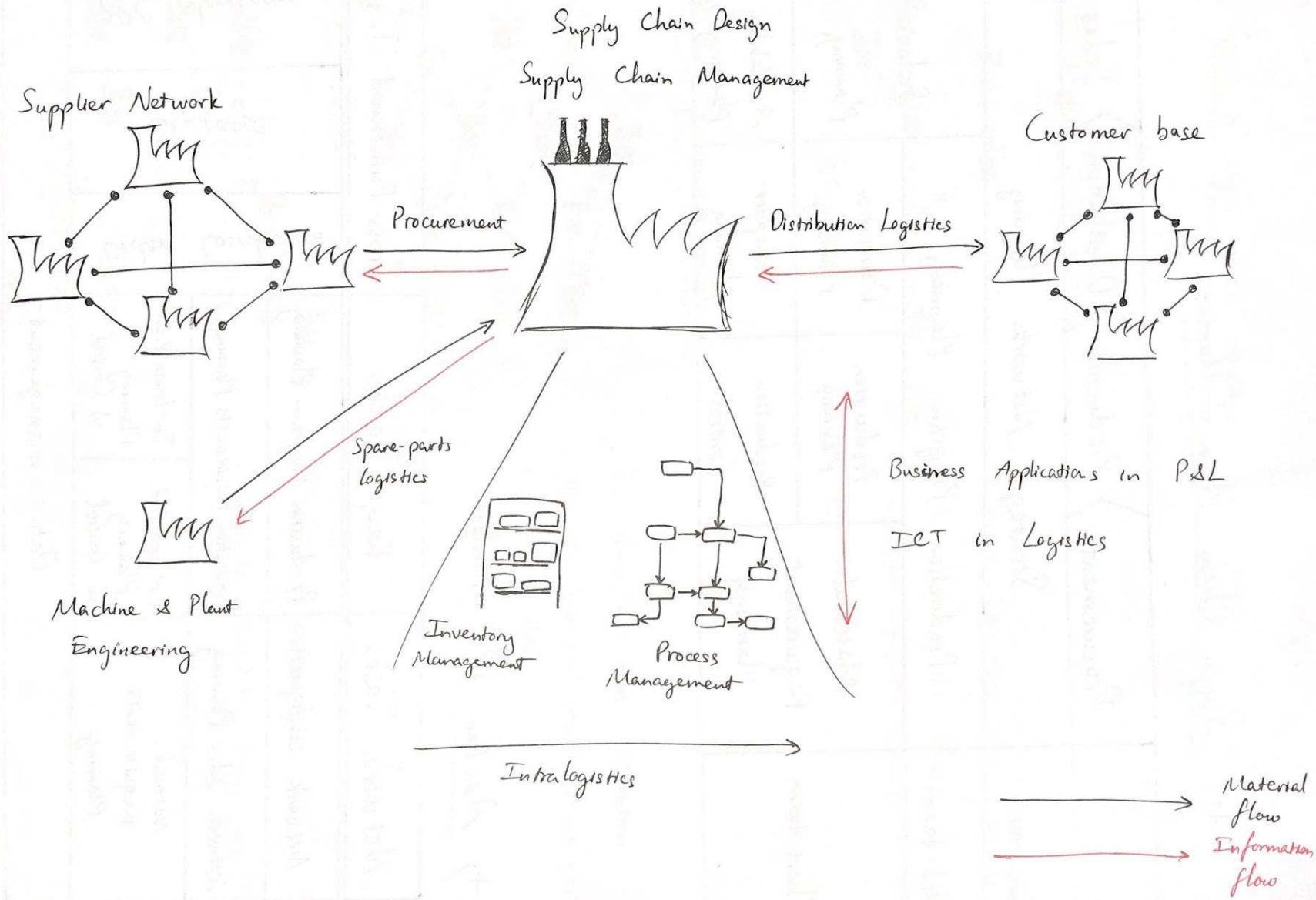
+ Supply Chain Planning Matrix:

	Procurement	Production	Distribution	Sales
Long-term	Strategic Network Planning			
Mid-term	Production Program Planning			Sales
Short-term	Material Requirement planning	Production Planning	Distribution Planning	Sales Planning
		Production Control	Transport planning	Availability planning

+ Aachen PPC Model:

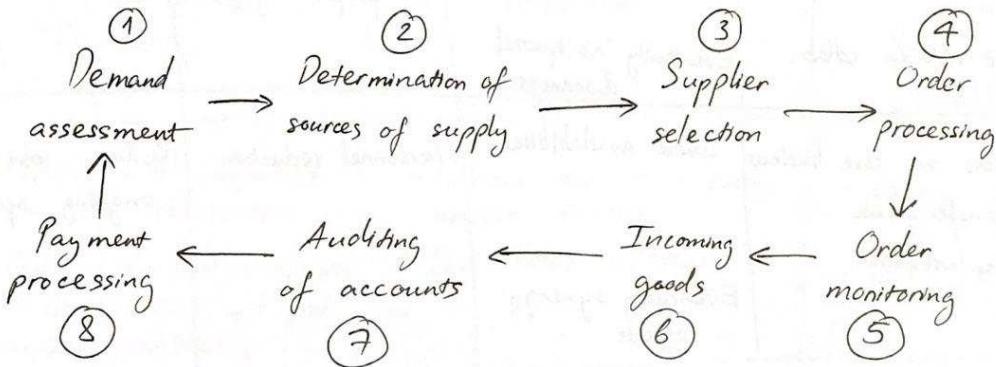
Network Tasks	Key Tasks		Cross-Functional Tasks		
Network configuration	Production Program Planning				
Network Sales Planning	Production Requirements Planning				
Network Requirements Planning	External Prod. Planning & Control	In-house Prod. Planning & Control	Order Coordination	Storage	PPC Monitoring
Data management					

# In production



# Procurement

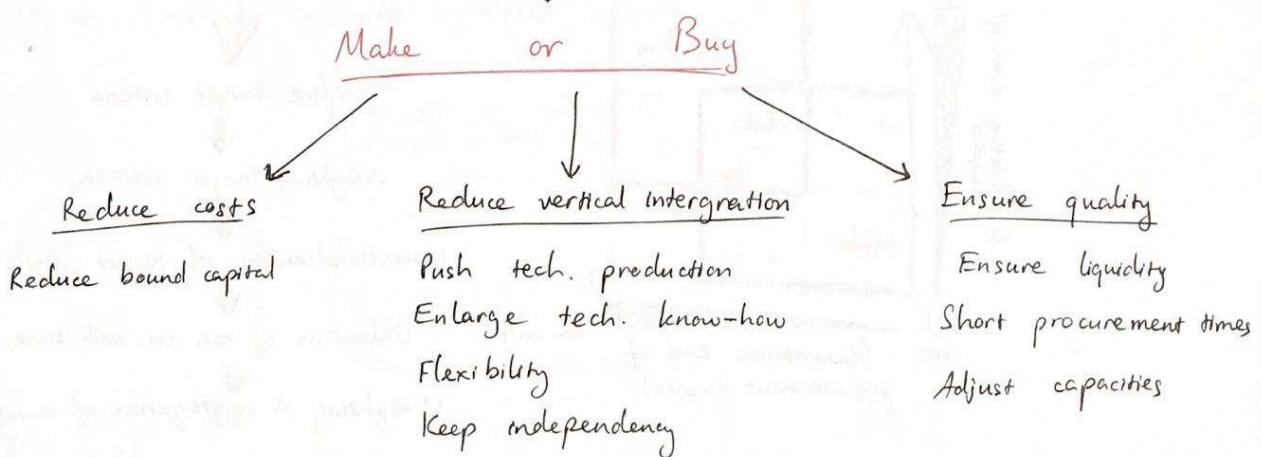
L3,



- Definition: General term for all measures that provides a company with the necessary production means.

SCHUH-STITCH 2013

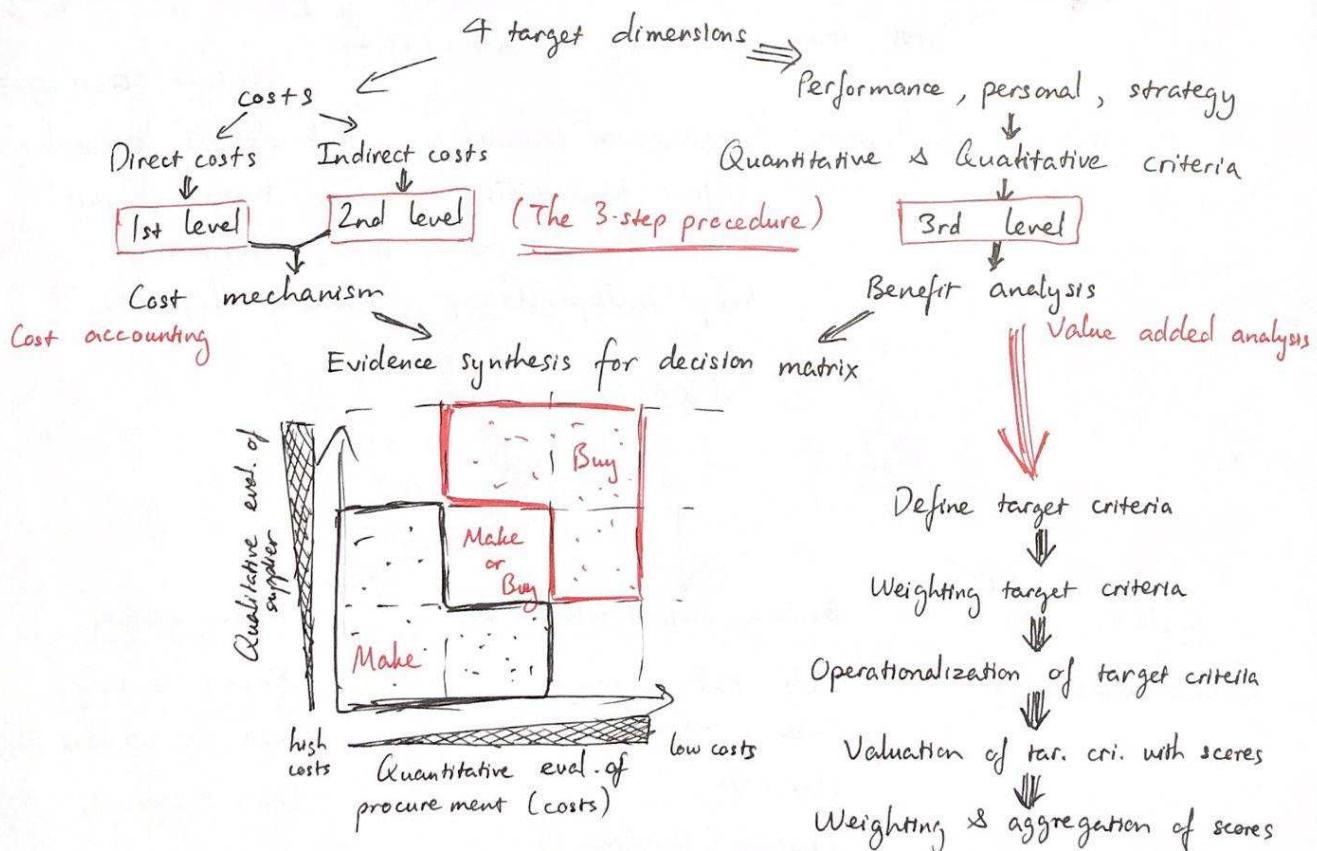
- Typical challenges: production technology, technological know-how adjust capacities, reduce bound capital short procurement times, flexibility keep independency, ensure liquidity



# Target Dimensions

	Strategy	Performance	Personal	Costs
MAKE	Technology Know-how  No risk in collab.	Know-how stays in company  Eventually no spatial distances	No prob with motivation  No prop. layoffs	No transaction cost  No switching cost
BUY	Focus on core business  Transfer of risk  Standardization	Quick availabilities  Eventually synergy effects	Personnel reduction	Reduce cost in ongoing operations

We need to measure/assess these targets



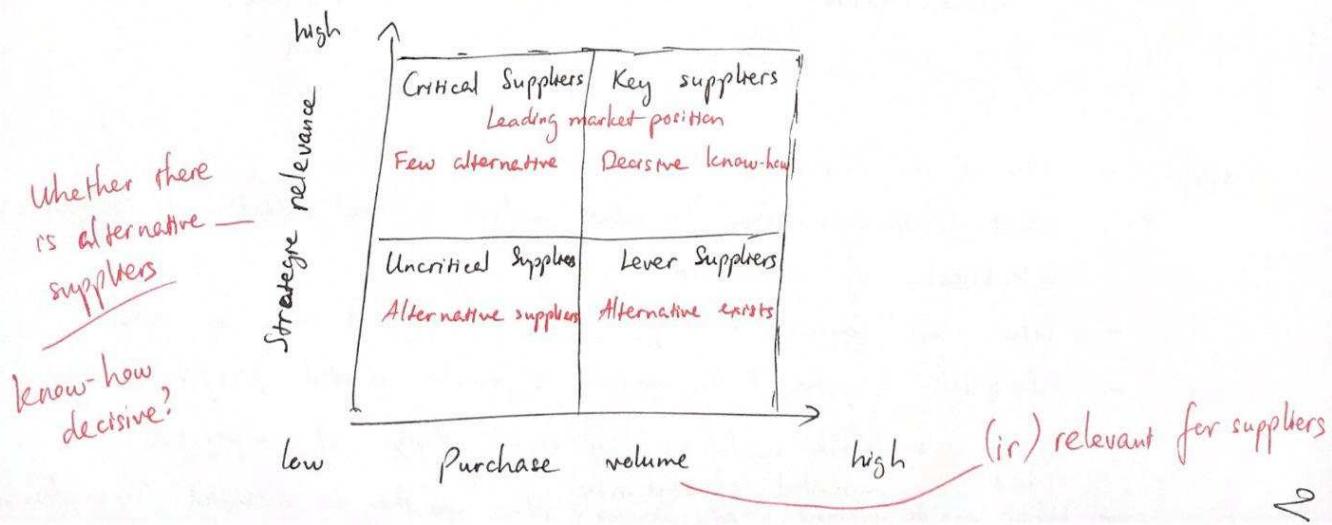
## ~~(1)~~ Strategies of sourcing:

↳ Concern factors: permitted delivery time, availability of suppliers, required delivery flexibility of suppliers, transport costs, political factors.

Multiple Sourcing (global)	Modular Sourcing (regional)	Single Sourcing (local)
<ul style="list-style-type: none"> <li>- Relation solely adjusted on the transaction</li> <li>- Good with low complexity &amp; specification, and good market availability</li> </ul>	<ul style="list-style-type: none"> <li>- Delivers pre- or completely mounted modules</li> <li>- Less direct relations</li> <li>- .</li> </ul>	<ul style="list-style-type: none"> <li>- Lasting partnership</li> <li>- Good with high specification</li> </ul>
<p>↑ stimulates competition between suppliers low switching costs</p> <p>↓ high-degree of info needed low purchase quantity</p>	<p>↑ more quality-support precise predictability</p> <p>↓ Increased info requirement Conflicts between standardization &amp; individual customer wishes</p>	<p>↑ reduce cost constant quality support high prediction accuracy less procurement interfaces</p> <p>↓ Higher dependency Eliminate competition Disregard tech. innovation High - switching costs</p>

## ~~(2)~~ How to select & evaluate supplier?

— Revenue oriented supplier matrix:



- Cooperation: between legally & commercially independent companies  
to support common & separate competitiveness

+ Cooperation as a reaction on changes in  
operational framework conditions:

- [Rising complexity of the products]
- [Changing requirements on production technologies  
information technologies]
- [Decreasing logistic challenges]

+ Classification of cooperation concepts:

Planning Concepts	Operational planning concepts	Operational Concepts
long term orientation	← hybrid of both →	short term stuff
Focus: Planning strategic stuff forecast, location..		Focus: operative process
Ex: CPFR 4PL	Collaborative planning Forecasting & replacement JiT, JiS 3PL	Kanban VMI

- Questions:
- How is the 3 step procedure structured?  
what contribution does procedure make to the selection of suppliers?  
weaknesses of procedure?
  - When are sourcing strategies applied? pros & cons of each
  - What info is provided by turnover & benefit oriented portfolio analysis?
  - How framework conditions influence design of cooperation?  
What are essential characteristics?
  - What are the different coop. concept? How can they be classified? Their characteristics?

# Distribution Logistics

14)

- Definition:

(\*) Planning, management, control, execution of material flow & the associated info. flow, from completion of production → customer

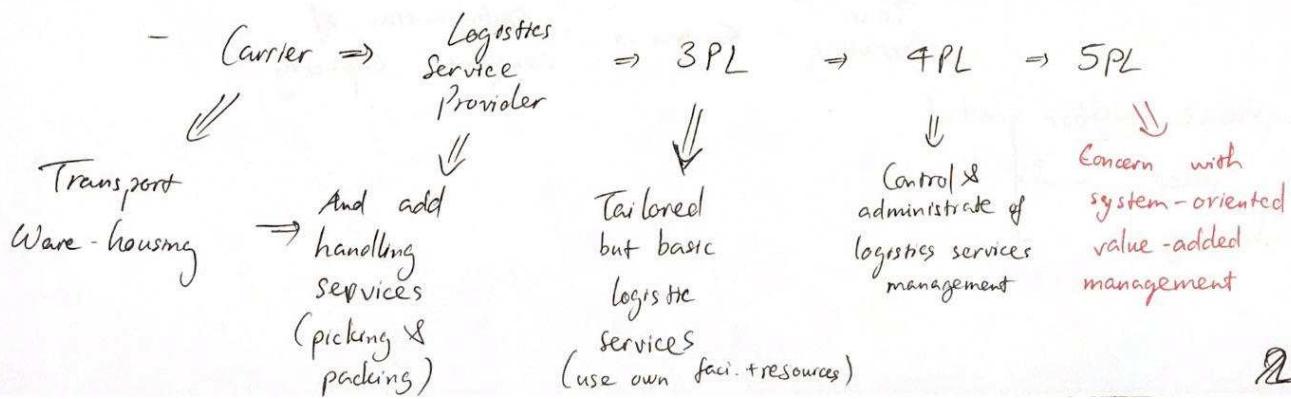
- Challenges: delivery quality, capability, time, flexibility  
transport, warehousing, order-processing costs  
information ability

- 4 Participants: Sender, Forwarding Agent, Common Carrier, Recipient  
(ship, container...) (small truck)

## 1) Distribution planning: 3 levels

+ Strategic planning: consider with sales channel & desired delivery time

	<u>Centralized</u>	vs	<u>Decentralized</u>	distribution systems
6 →	adequate ← delivery time ⇒		faster	
	1 source ← production facilities ⇒		many sources	
	few major or non homo. ← Customer structure ⇒		lots of small or homogeneous	
	wide range, expensive ← products ⇒		small range, cheap	
The No. of invent. sold	low stock turnover ← Stock turn-over ⇒		high stock turn over	
	a few ← Regional feature ⇒		a lots	



## - Distribution Concepts:

Direct Procurement

Production faci. → Customers

Central warehouse procurement

Production faci. → Central warehouse → Customers

Regional forwarding  
agent concept / Milk-run  
mixed products

1 truck from various supplier → for 1 customers

Cross docking  
1 - staged

Retail supermarket  
lots of type of products ..

Transshipment points  
suppliers ⇒ terminal ⇒ customers

change from long distance ⇒ short distance traffic

Cross docking  
2 - staged

Production faci. ⇒ Cross-docking point ⇒ stores

Good Receipt ⇒ Good Issue

Good Receipt ⇒ Temporary storage ⇒ Good Issue zone

⊕ Wait for decision / order

## Tactical distribution planning : distribution structure

- Factory warehouse, central warehouse, regional warehouse, distribution centre??

→ Warehouse location ?

↗ influencing factors

(similar to characteristics between centralized & decent.)

## Operational distribution planning :

Choice of containers  
means of transport

Optimization of carrying capacity

Tour scheduling

Nearest neighbor method

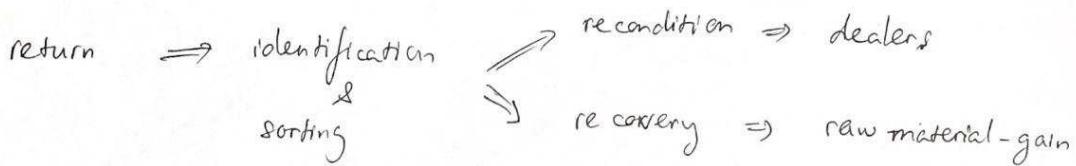
Sweep

Savings

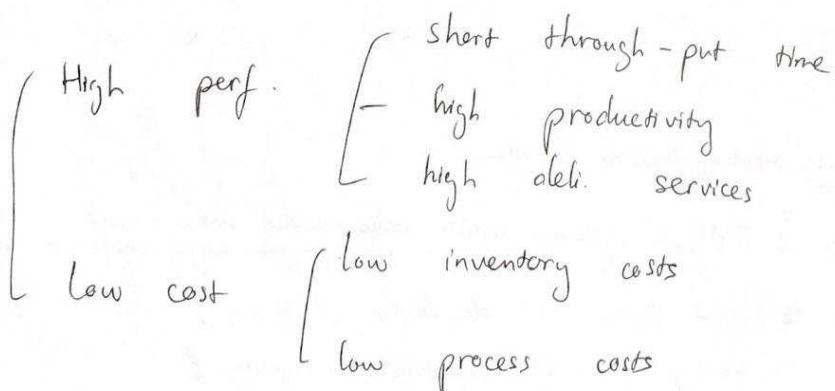
## 2, Distribution Control:

- In case of deviation: delay, change of order ..
- Information flow: anticipatory, accompanying, lagging
  - Ensure necessary planning
  - provide info (date & time) window variances
  - measure quality

## ④ Reverse supply chain:



## 3, Distribution Assessment:



## management of logistics service

- 4PL & SPL → system-oriented value-added management  
manage change from logistic supply chain → supply network
- Name different tasks of distribution Logistics!
- Name different players in distribution logistics!
- Which core func & additional services are increasingly to be found in the growing range of services offered by logistics company?
- Name various decision criteria of strategic distribution planning & characteristics that speak for a centralized or decentralized distri. system
- Which heuristic opening procedures for tour planning do you know?
- Name different aspects of distribution control

## Answers:

### Questions:

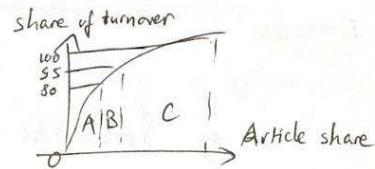
# Inventory Management

L5,

Target: maximize Service level  
 while minimize Inventory costs  $\times$  Capital commitment

## 1) Article structuring & classification:

+ ABC Analysis: rank based on turnover  
 A is more important than C

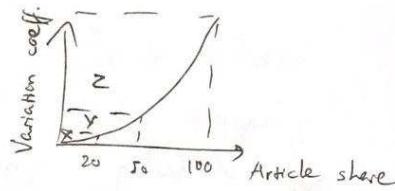


$$\bar{x} = \frac{\sum x_n}{N}$$

$$s = \sqrt{\frac{\sum (x_n - \bar{x})^2}{N-1}}$$

$$V = \frac{s}{\bar{x}}$$

XYZ Analysis: how sure we are about getting back turnover from an article  
 X is more predictable than Z



$\Rightarrow$  The ABC/XYZ matrix

	X	Y	Z
A			
B			
C			

Ex: New iPhone 2 from CZ  $\Rightarrow$  AX  
 when iPhone 4 is out, iPhone 2  $\Rightarrow$  CX

- We have to conduct these analysis over & over again.

$\Rightarrow$  Derivation of disposition strategies (of procurement)

Over time transition  
 from consumption-oriented  
 to deterministic procurement

Consumption-oriented procure.  
 (reorder point / reordering  
 cycle procurement)

	X	Y	Z
A	JIT External	JIT Internal	
B			
C			

Procurement when needed  
 (demand-oriented)

Minimum stock planning  
 (consumption-based procurement)

## 2, Demand Planning:

Record of time series  $\Rightarrow$  Determination of Consumption models  $\Rightarrow$  Selection of suitable Forecasting methods

### 5 Steps

Assessment of the Demand Forecast

Creation of the Demand Forecast

- The Bullwhip effect:

- 3 different methods for demand planning:  $\begin{cases} \text{deterministic} \\ \text{heuristic} \\ \text{stochastic} \end{cases}$   $\begin{cases} \text{demand} \\ \text{planning} \end{cases}$

Exercise

$\Rightarrow$  Stochastic demand planning:  $\begin{cases} \text{moving average} \\ \text{regression analysis} \\ \text{exponential smoothing} \end{cases}$   $V_m = \frac{1}{m} \sum_{i=n-m+1}^n T_i$   
 $V_{n+1} = \alpha V_n + \beta (T_n - V_n)$

⊗ Why: no / only little additional disposition effort

+ Potentials: increase forecast accuracy  
 $\Rightarrow$  reduce safety stocks

## 3) Inventory planning

- Classic stockholding model

- Determination of the optimal safety stock from demand planning

- Safety stocks  $\times$  time are compensation for uncertainties in planning



to be continue luh..

## 4) Procurement Planning:

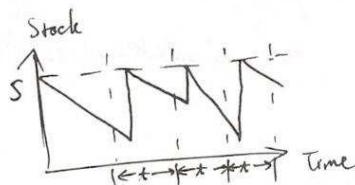
constantly optimize procurement volume  
 ⇒ reduce cost, maintain service

- to determine optimal procurement strategy (procurement date quantity)

take into account warehousing & procurement costs

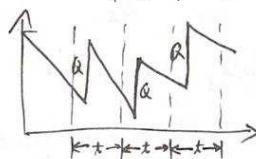
### - Procurement triggering:

(T, S) policy



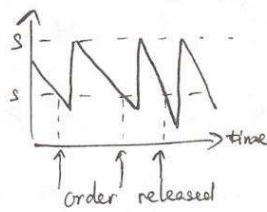
Schedule-related order triggering

(T, Q) policy



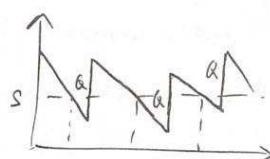
(ordering cycle procedure)

(s, S) policy



Stock-related order triggering

(s, Q) policy



(reorder point procedure)

Harris-Andler method:

$$\frac{dC_T}{dx} = 0 = \frac{D \times C_p}{x^2} = \frac{C_w \times T}{2}$$

$$\Leftrightarrow x_{opt} = \sqrt{\frac{2 \times D \times C_p}{C_w \times T}}$$

### - Procurement quantity calculation:

Method	Procurement quantity on demand		Calculation effort	Application sustainability
	Constant	Fluctuating		
Harris-Andler	.	not useful	extremely low	BC-parts
Wagner-Whitin	Optimum value	optimal	high	A-parts
Silver-Meal	approximation	medium		ABC-parts

Questions: - 3 targets of Inventory Management?

- 4 main steps to approach the Inventory management?  
Describe each step and the main purpose of each.
- What are the steps in Demand Planning?
- What are the forecast methods available?
- What is the purpose of having safety stocks?
- What are the choices for procurement triggering?
- How to calculate / conduct procurement quantity calculation?

L8, Questions: - why do we need spare parts?

Is it bring us much financial benefit?

- Definition of spare parts? Categorization of its.  
Differentiate it with add-ons.
- Characteristics of spare-parts ? 5
- Name the type of wear-behavior and its influencing factors.
- Definition of maintenance.  
Name 4 basic measures of maintenance.

L9, Questions: - Name 4 steps of the approach to process analysis and process design

- Name 4 different types of order processing in the PPC model.
- Name & explain measures for process improvement

# Supply Chain Management

26,

## 1) Fundamentals:

- Definition: coordination of logistics activities  
includes all materials, infor., financial flow from supplier  $\Rightarrow$  till end customers
- Must consider: time, cost, quality, flexibility

## 2) Planning Tasks:

- + Characterization:
  - Temporal: long, mid, short-term
  - Hierarchical: strategic, tactical, oper.-planning

- + 3 Planning levels: Supply Chain
  - Configuration
  - Planning
  - Execution

## + 3 Groups of Planning Tasks:

- Targeted Design of SC: product program planning  
 technology  
 capacity  
 site
- Integrated Service program planning: workforce planning  
 production  
 distribution  
 transportation
- Short-term adjustment & realization of defined service programs:  
 customer production transport | order processing

## 7) Designs of SC:

	Lean	Linked	Agile	Rapid
Example:	Automotive	Chemical Pharmaceutical	Electronic	Customer good
Characteristics	Integral <i>Efficient</i>	Concentrated <i>S</i>	Modular <i>S</i>	Reactive <i>S</i> Fast
Type of production	Serial prod.	Mass prod.	Serial or Mass prod.	Batch prod.
Objective	Lean mat. flow low invent. cost	linked, concentrated SC	Flexible, agile SC for dynamic, modular products	Fast, reactive SC for simple products with short innov. cycle
Strategic challenge	↓ invent. cost ↑ stock turnover <i>↑ workload</i>	↓ costs	↑ delivery service <i>↑ flexibility</i> <i>↓ cycle times</i>	

## 5) Digital Evolution:

- Innovative technology concepts: sensor tech, mobile, robotics
- Changes in value chain: platforms & portals, ..
- Changing competence requirements: IT skills, staff shortage, ..
- New & adapted business models: digital services, ..

- Questions:
- what are the key planning tasks? Describe them!
  - Describe the 3 reference models
  - Describe different supply chain designs

# Intra logistics

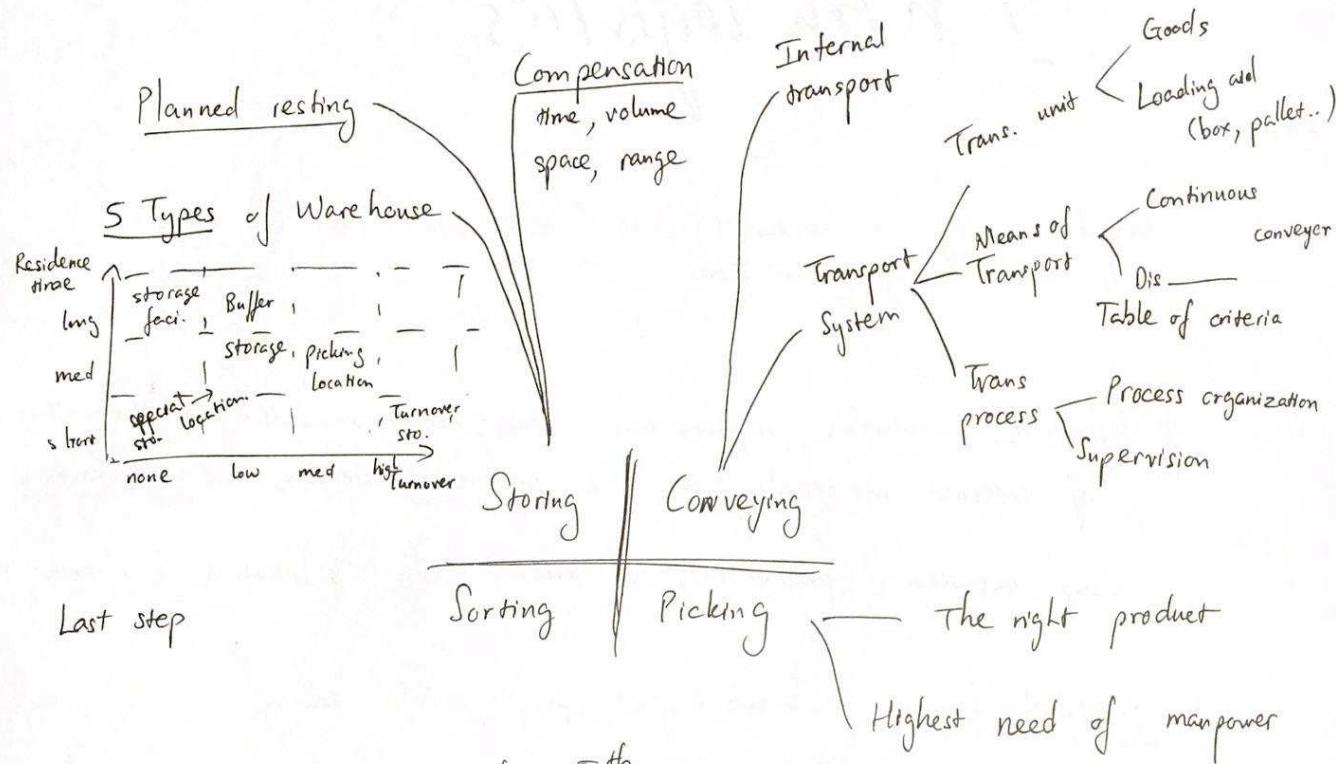
L7,

- Bounds mostly to material flow, but with loss of support from the information flow
- + Definition: includes organization, management, execution & optimization of internal material flow, the information streams & cargo handling  
Coop between: production companies with distribution companies
- + Material flow:
  - { Objects (goods, people, info, energy)
  - work equipment
- + Flexibility

<	system		management
	cost		
	service		

core-competency  
of Intra logistics
- ⊗ Material flow definition:
  - { the linking of all operations - of goods
  - all form of throughput of work items through a system

## ④ 4 Core Tasks of Intra-logistics:



## ⑤ IT solutions as the 5<sup>th</sup> piece.

⇒ better plan, less underestimated cost factor, smoother operation

Intelligent networking ⇒ information transparency

## ⑥ Independent combination of modules ⇒ decentralization

Milk run?

Supermarket as buffer/warehouse stage

- Questions:
- How is Intra-logistics defined & what isolates it from pure logistics?
  - Core competency of Intra-logistics & how to achieve it?
  - What is the definition & core components of the material flow?
  - What are the core tasks in Intra-logistics & how are they defined?
  - Influence of Industry 4.0 to the material flow

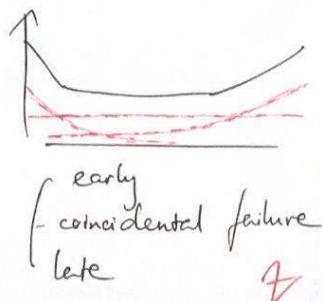
# Spare Parts Logistics

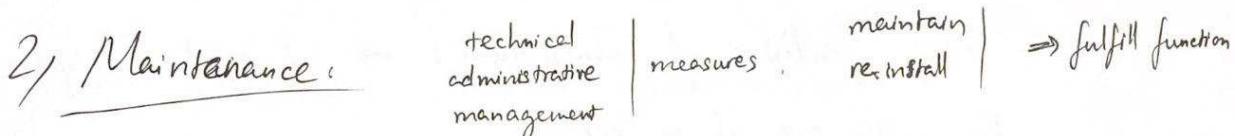
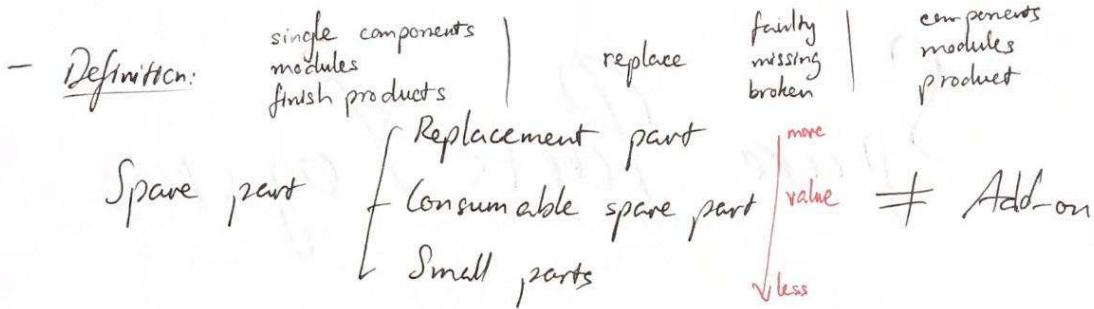
18,

- The failure of components  $\Rightarrow$  a need for spare parts
  - Ex: The tire of a car ..
  - The screen of an iPhone ..
- As part of After - Sales service.
  - Steady income, expected value accumulate up to 9 times initial sales of primary product
- Industrial 4.0: accelerates .. everything
  - data - analysis - decision - realisation latency making
  - reduce the time needed to complete the measure

## 1) Characteristics of spare parts:

- Urgency, wear-behavior, installed-base, life-cycle origin,
- Wear-behavior:
  - influencing factor.
  - 2 type:
    - successive
    - unprompted
    - unpredictable
  - component properties
  - technological conditions
  - framework conditions





- 4 basic measures:
  - General maintenance
  - Inspection
  - Repair
  - Improvement
- Different strategies:

Unplanned Reactive	Planned Preventive	Condition-based	Condition - prognosis based
hóng ròi mồi tinh	thay theo kí điều kiện cần thay	đto đtac tán calo	phân mềm dự báo tín nắn

$$OEE = \frac{\text{Running time}}{\text{Operating time}} \times \frac{\text{Actual amount}}{\text{planned amount}} \times \frac{\text{Good amount}}{\text{Actual amount}}$$

Overall equipment effectiveness = availability factor  $\times$  performance factor  $\times$  quality factor

# Process Management

with focus in order processing

6,

## 1) Introduction:

- Project       $\neq$       Process
- Uniqueness, problem-solving      repetition, optimization
- of process management** - Definition: planning, control, supervision of internal, inter-comp. processes
- Goal: efficient execution

## 2) Process management in order processing:

- Order processing: from the arrival of customer order  $\rightarrow$  dispatch of goods
- Aachen PPC Model (Production Planung & -Steuerung): reference models as generic support for existed process.  
(same type of production  $\Rightarrow$  will have similar processes  $\Rightarrow$  take reference for faster implementation)

## ④ 4 types of order processing:

Contract manufacturer	Blanket order manu.	Variant manu.	Stock manu.
<u>Individual orders</u>	<u>Longterm agreements (contract)</u>	<u>Pre-production without customer relation ..</u>	<u>Produce on basis of anonymous sale forecasts</u>
Ex: machinery, plant engineering	Ex: screws, washer, nut..	Ex: Car	Ex: Consumer goods (tooth paste..)

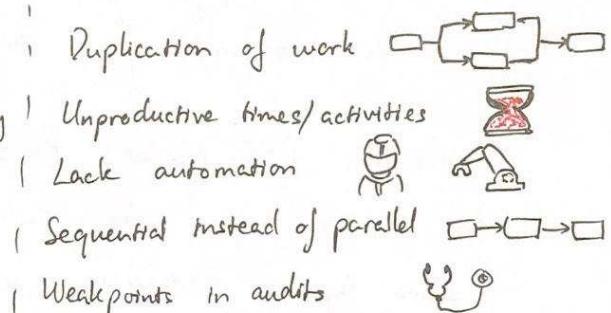
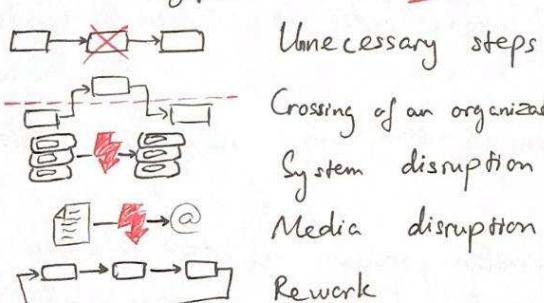
## + 4 steps approaches to process analysis & process design:

### ① Assessing current processes:

- A model: representation of the reality under certain aspects
- Process modeling at the right level of detail, not too broad or fine
- Languages & notations: each process.. will have 1 suitable..
- Tools : visualize , model , simulate , automate  
Ppt , Office Visio , Ans , SyCat ..

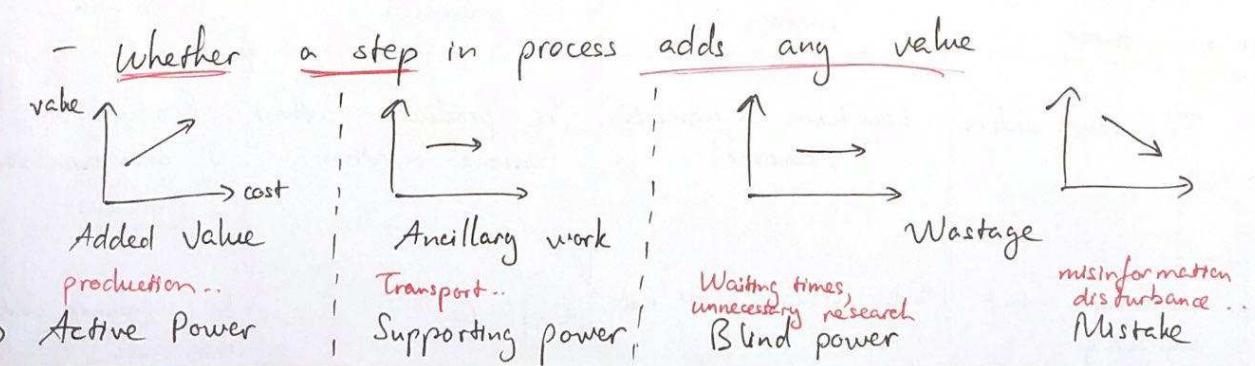
### ② Weak point Analysis:

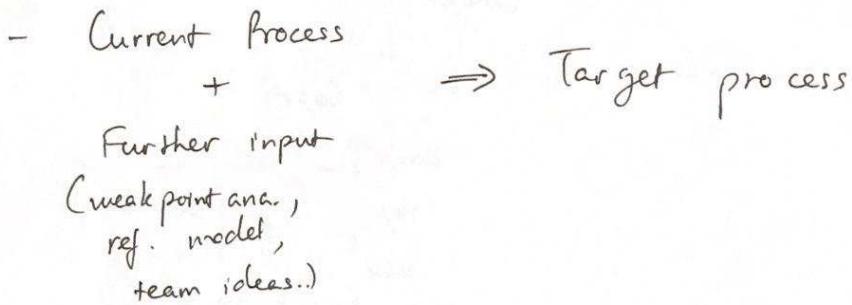
- Typical ones: **10**



### ③ Develop target processes:

- Good ?  $\Rightarrow$  speed , reliability , efficiency





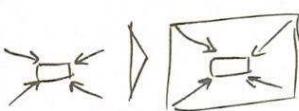
#### ④ Implementation of improvement measures:

- Typical measures: 12

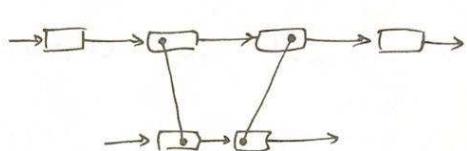
##### Elimination



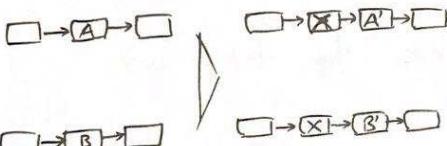
##### Shape Autonomously



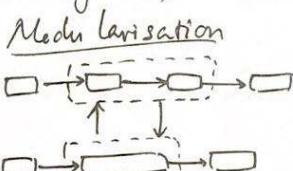
##### Cooperation



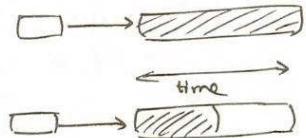
##### Standardization



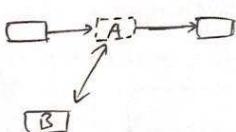
##### Integration



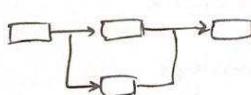
##### Time reduction



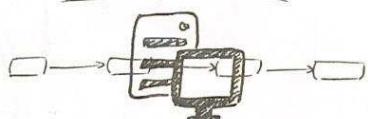
##### Substitution



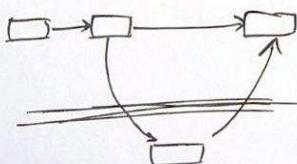
##### Parallelization



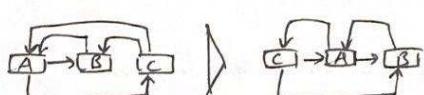
##### Integration of IT-systems



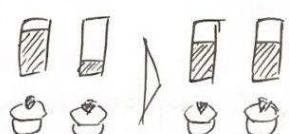
##### Outsourcing



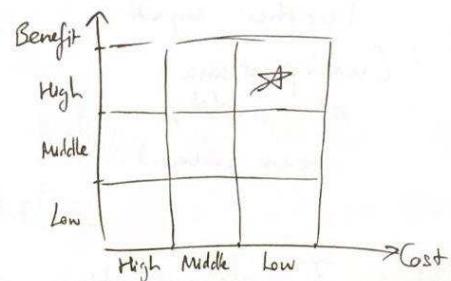
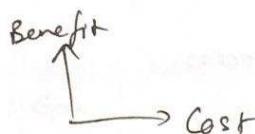
##### Avoiding of iterations



##### Adapting workload distribution



- Prioritize the measure:



### 3) IT-Systems:

- + ERP systems are the core system for order processing.  
(Enterprise Resource Planning)

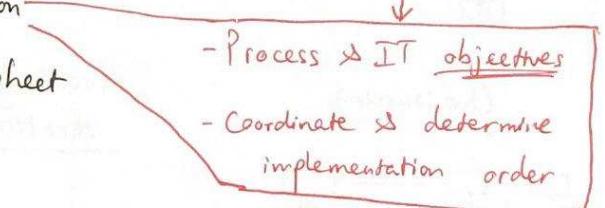
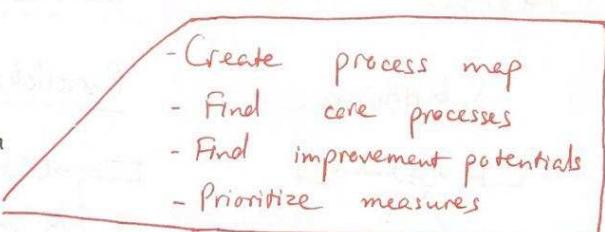
- Consisting several modules: order processing, production planning ..., which are connected with a central database

- A systematic selection of IT system.

- + Too early: not much cost incurrence of the project has been made
- + Too late: low possibilities to influence the total costs

### 3 phase concept:

- Analysis:
  - Project implementation
  - Process & IT analysis
  - Process & IT conception
- Selection
  - Compile specification sheet
  - Tendering
  - System presentation
- Implementation
  - Compile technical specification
  - Contract negotiations
  - Mentored Implementation



# Business Applications in PSL

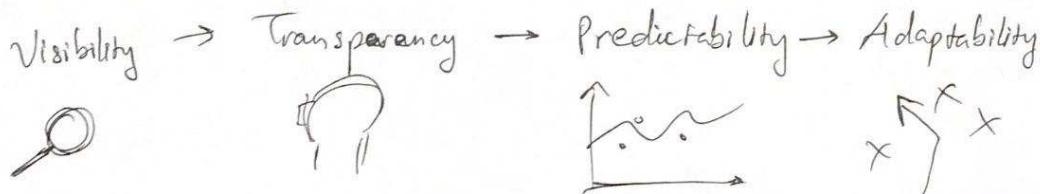
40)

## 1) Information Systems:

### + Definition:

- ~~Information~~ Information Systems: Socio-technical systems |  $\Rightarrow$  provide info  
human & mechanical comp. communicate  
optimal way

- A large number of Business Applications exist and are used in different fields of application.
- Business applications: are software applications to support information storage, processing, transfer, rating .
- 4 Steps to reach Industrial 4.0:



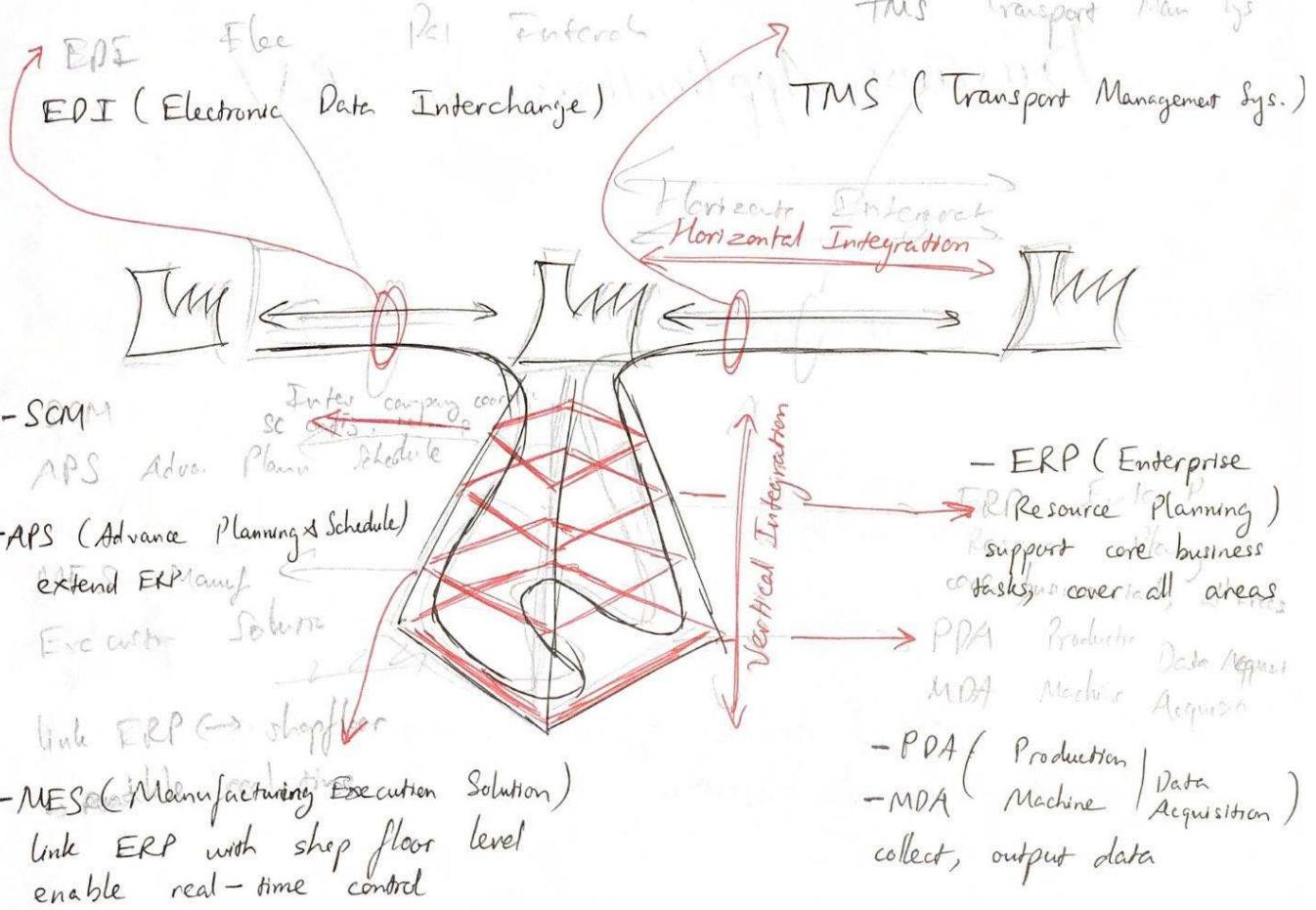
- Requirements of Industry 4.0 need to be realized by Business Applications:

- decentralization
- unified shopfloor connection
- flexibility
- intergrative data management
- interoperability

7

SRM (Supplier Rel. Man.) Manage

CRM (Customer Rel. Man.)

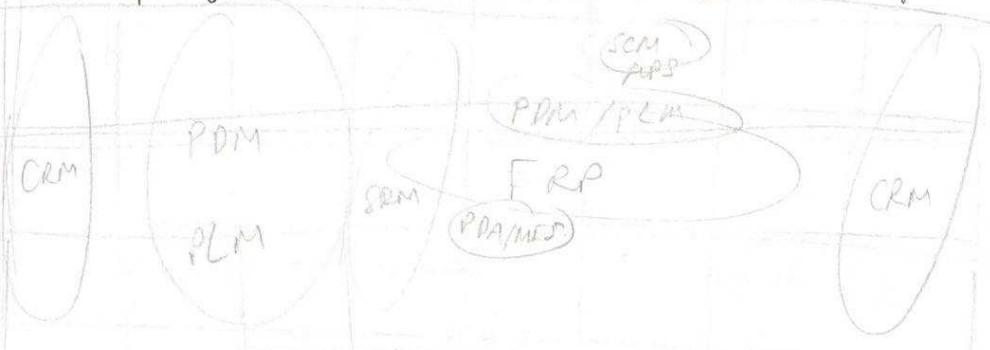


Supply project planning Construction Purchase Production Assembly Shipping After Sales

Designing of jobs

Planning of jobs

Execution of jobs



# Information & Communication Technology

## in Logistics

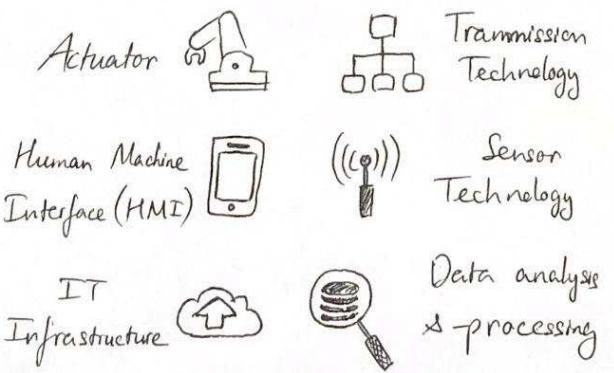
LII

1) CPS as Connector: between Process & System Operator

- How to get information from the use of my products?
  - How to connect with my clients?
  - CPS: Cyber-Physical Systems.

2) Tasks & Benefits of CPS: in Production & Logistics

- 4 Industrial Revolution:
    - End of 18<sup>th</sup> cent. → Beginning of 20<sup>th</sup> → Early 1970s → Today
    - Mechanical      Electrical      Automatically      Autonomous
  - CPSs : { are the KEY to a data-driven optimisation
    - enable real-time improvement (autonomous, adaptive control)
  - There are a lot of things need to be set up, before we can achieve a smart factory : 6 technology clusters



- ) The content tasks of a CPS in P&L can be described on the basis of ~~the~~ economic operational target triangle



- ) The tasks of the CPS are reflected in 5 ~~case~~ use case classes

- Tracking / Tracing
- Commissioning Support
- Test support
- Maintenance Forecasting
- Automatic Material Supply

# Exercise:

## L5, Inventory Management:

- XYZ analysis: mean:  $\bar{x} = \frac{\sum x_n}{N}$   
standard deviation  $s = \sqrt{\frac{\sum (x - \bar{x})^2}{N-1}}$   
coefficient of variation:  $V = \frac{\text{standard deviation}}{\text{average value}} = \frac{s}{\bar{x}}$

- Harris - Andler:

$$\frac{dC_T}{dx} = 0 = \frac{D \cdot c_p}{x^2} = \frac{c_w \cdot T}{2}$$

$$\Rightarrow x_{opt} = \sqrt{\frac{2 \cdot D \cdot c_p}{c_w \cdot T}}$$

- Moving average:  $V_{n+1} = \frac{1}{m} \sum_{i=n-m+1}^n T_i$
- Exponential smoothing:  $V_{n+1} = V_n + \alpha (T_n - V_n)$

- Vehicle fleet composition:

$$C(v) = N \cdot c_f \cdot v + c_v \cdot \sum_t \min\{v_t, v\} + c_h \sum_{t: v_t > v} (v_t - v)$$

$$m(v) = |\{t : v_t > v\}|$$

$$m(v)_{\text{optimal}} = N \cdot \frac{c_f}{c_h - c_v}$$