Product development and design methodology Research and application in industry

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Machine Design KTH

Design and Production Engineering

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Industrial revolutions

18th to 19th century: Steam Engines

19th to 20th century: Internal combustion engines, electric motors

Fossil fuel and nuclear based energy

→ Development & changes in many stages, long growth periods

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Today: chips, fiber optics, computer software, IT networks, ……

Transition to various forms of solar energy

solar inflow 1 Bill TWh/y
global consumption 0.15 Mill TWh/y

→ Much faster development and changes

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The fourth industrial revolution:

- Decentralized ”smart” factories
- Automation, robotization
- Data exchange, cooperation and service monitoring in networks

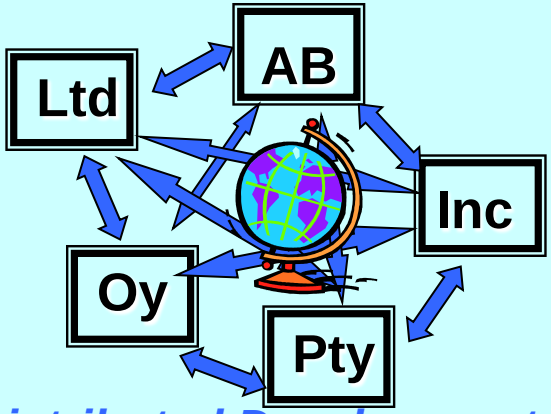
Changes → Opportunities

Risks

Current trends in Product Development



Service systems
Function sales
producer ownership



Distributed Development

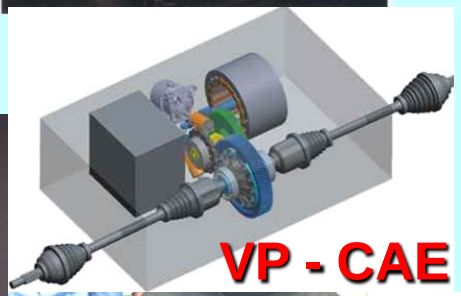
Industrial Design Engineering







Modular Design
Product Platforms

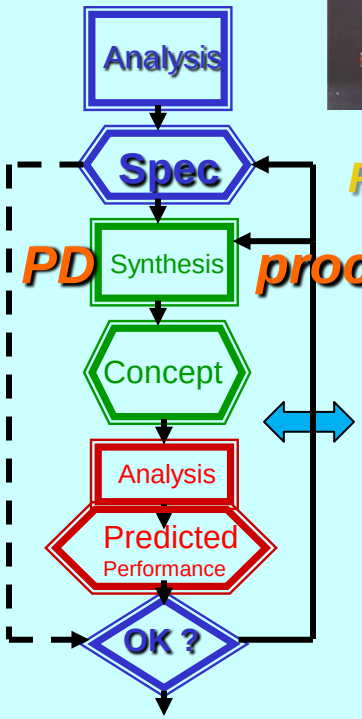


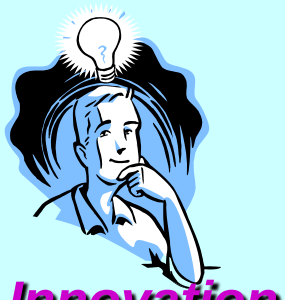
VP - CAE



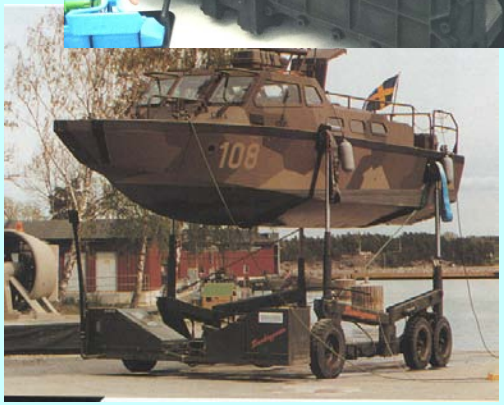


Mechatronics & robotics





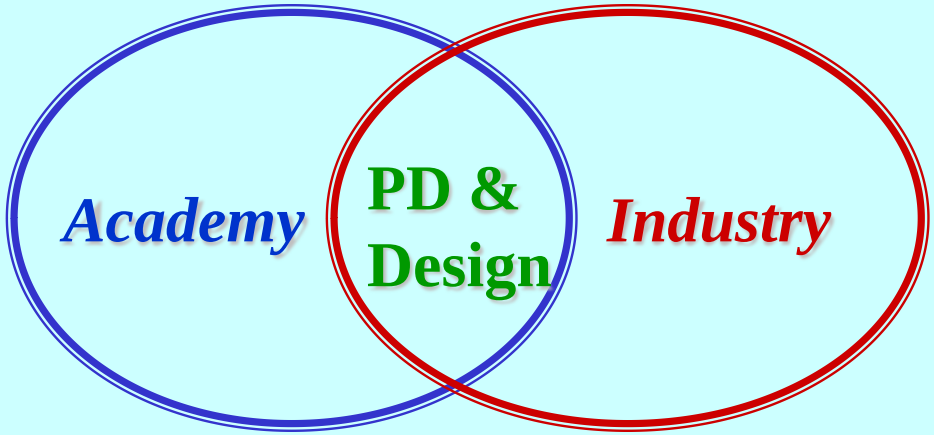
Innovation



Mechanics - hydraulics

Prodcuct Development & Design

Characteristics:



- ***A young research field***
- ***Holism***
- ***Synthesis***
- ***Sustainability***
- ***Integration - Innovation - Iteration***

PD Driving forces

- **Technology** — laser, integrated circuits, cellular phones, GPS-navigation, fiber optics, ……
- **Market** — product modifications, ”annual face-lift”
- **Society** — environmental performance, sustainability, health & safety, life style

Product Design - current situation

Complex Multi-Domain System Design

Engineering Design

"Hard" product properties = Nescessary Requirements

Industrial Design

"Soft" product properties = Basis for buing decision & competitiveness!

Product Development

Improve Performance/Cost ratio!

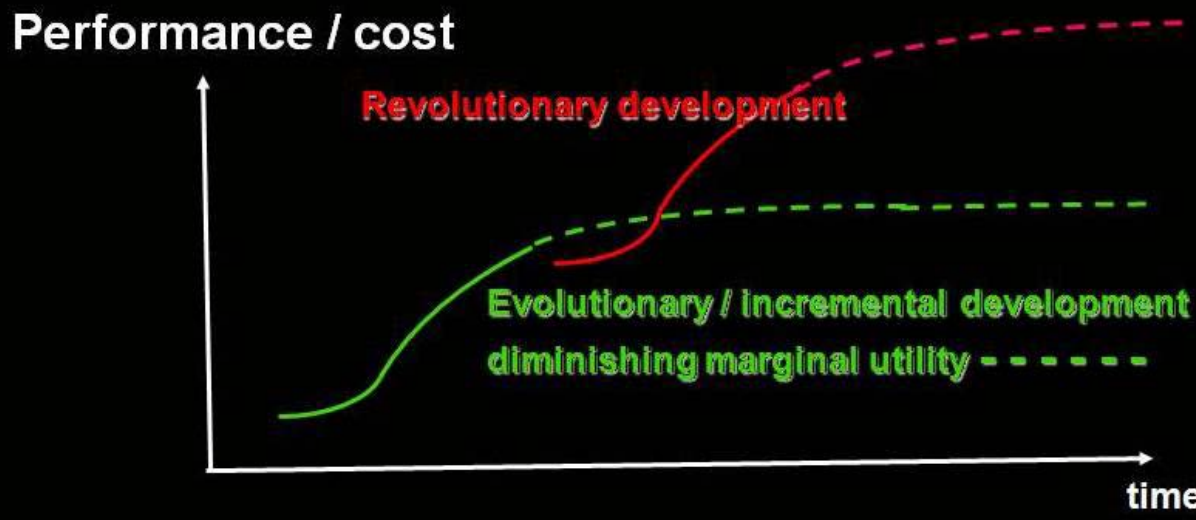
Hard & Soft Requirements

"Performance" = { *Technical performance, "**hard**" requirements*

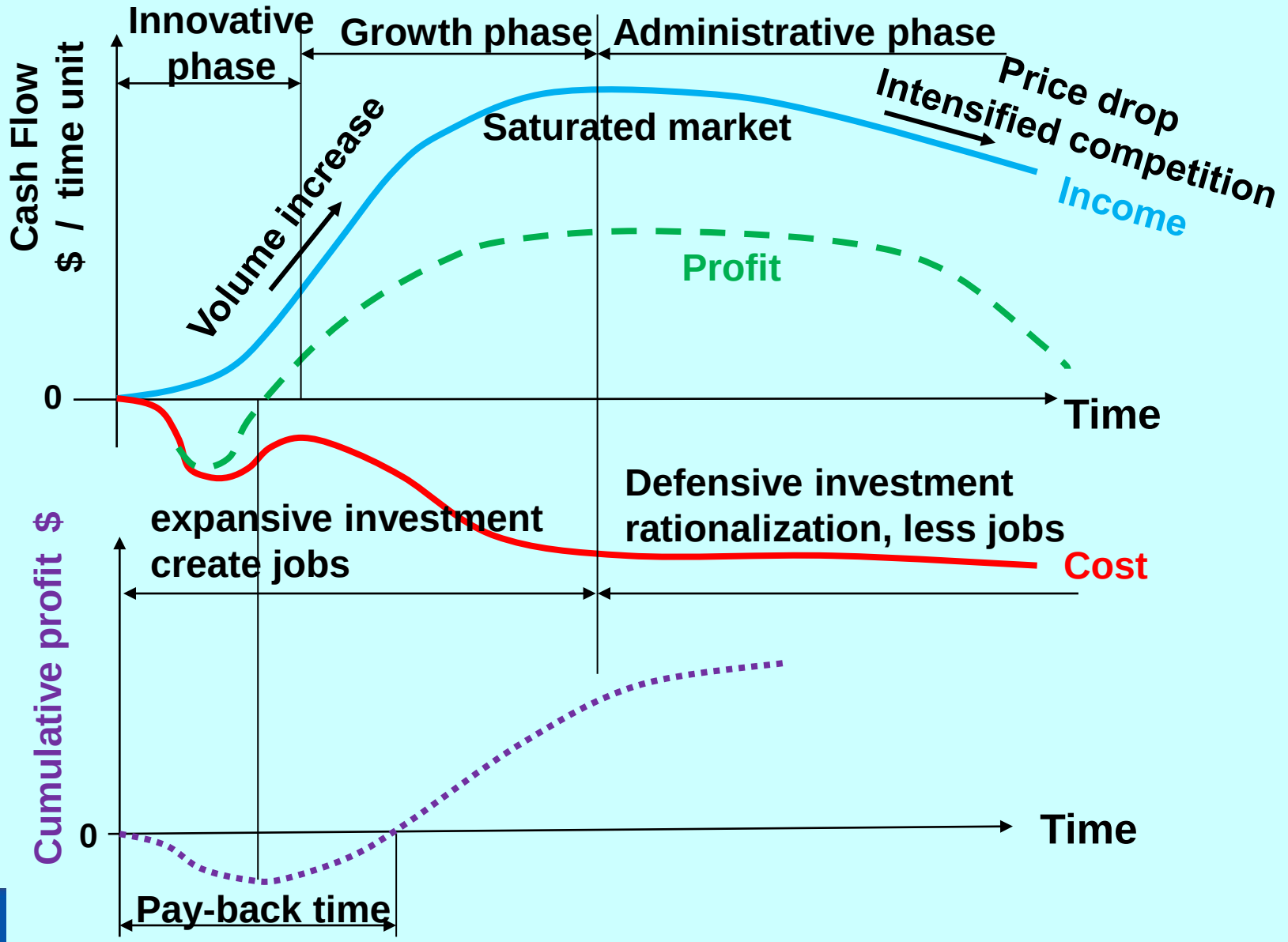
*Aestetics, ergonomics, user interface; "**soft**" req*

"Cost" = { *Economy for customer and manufacturer*

Environmental impact over Product Life Cycle

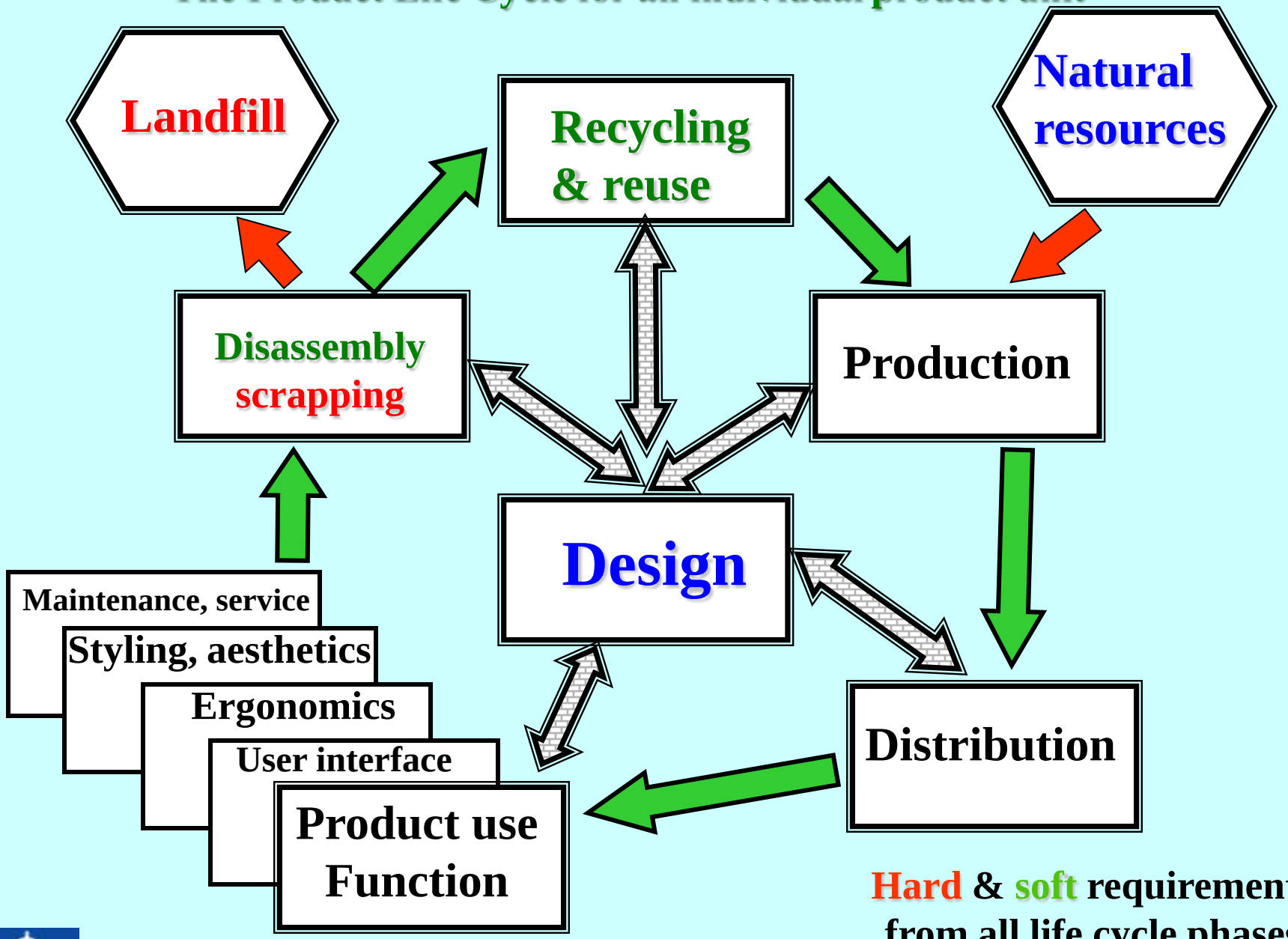


A product generation´s life cycle on the market - ”S-curve”



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The Product Life Cycle for an individual product unit



Hard & soft requirements from all life cycle phases

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Products´ environmental load

Active products: **Energy consumption and emissions in user phase dominating**

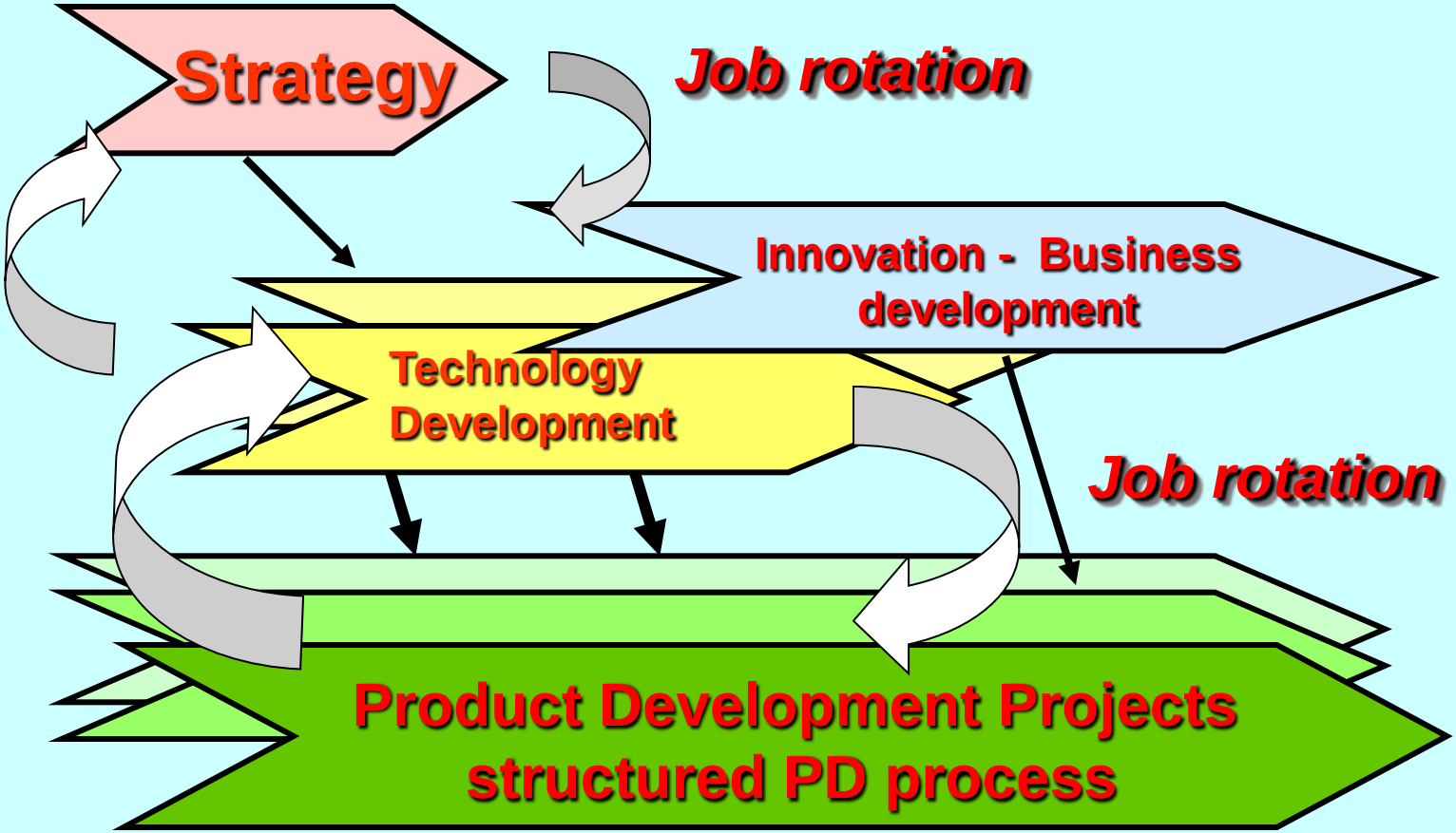
E.g. vehicles, refrigerators, stoves,…..

Passive products: **Virtually no energy consumption in user phase, energy & materials consumption in production and disposal phases dominating**

E.g. Building structures, storage vessels, ……..

3-stage Development Process

Industry and academic research



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Product Development (PD) Characteristics

Iteration: Speed up by simulation: CAE, Rapid Prototyping, VR-Virtual Reality

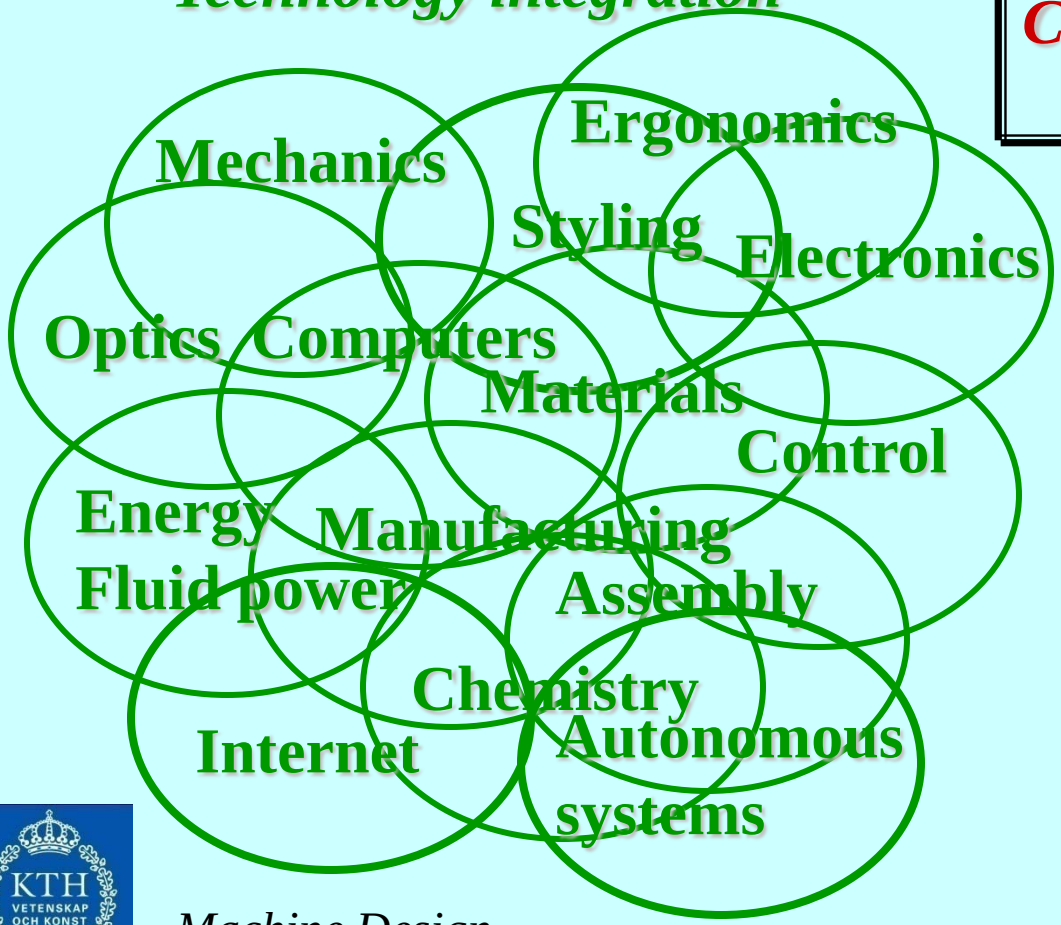
Integration:
- Engineering Design & Industrial Design
- Different technologies, multi-domain
- Organisational, Concurrent Engineering, IPD
- Distributed PD

Innovation: Free innovation vs´ controlled PD process

Prodcuct Development

Integration

Technology integration



Organizational integration
Concurrent engineering

- Marketing
- Engineering Design
- Industrial Design
- Production

Product Development – changing conditions

External pressures on companies

- increased customer req., performance/price
- customer preferences, “soft” properties
- customized products
- increasing society demands
- tougher competition
- shorter product life cycles

Impact on companies

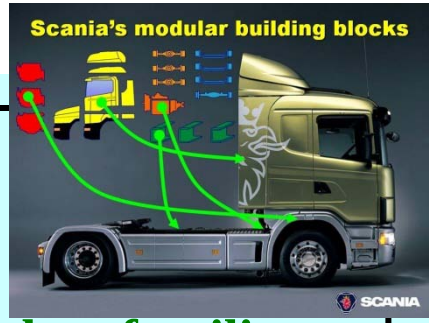
- higher development cost
- many product variants
- project time (“time-to-market”) critical

Companies´ response

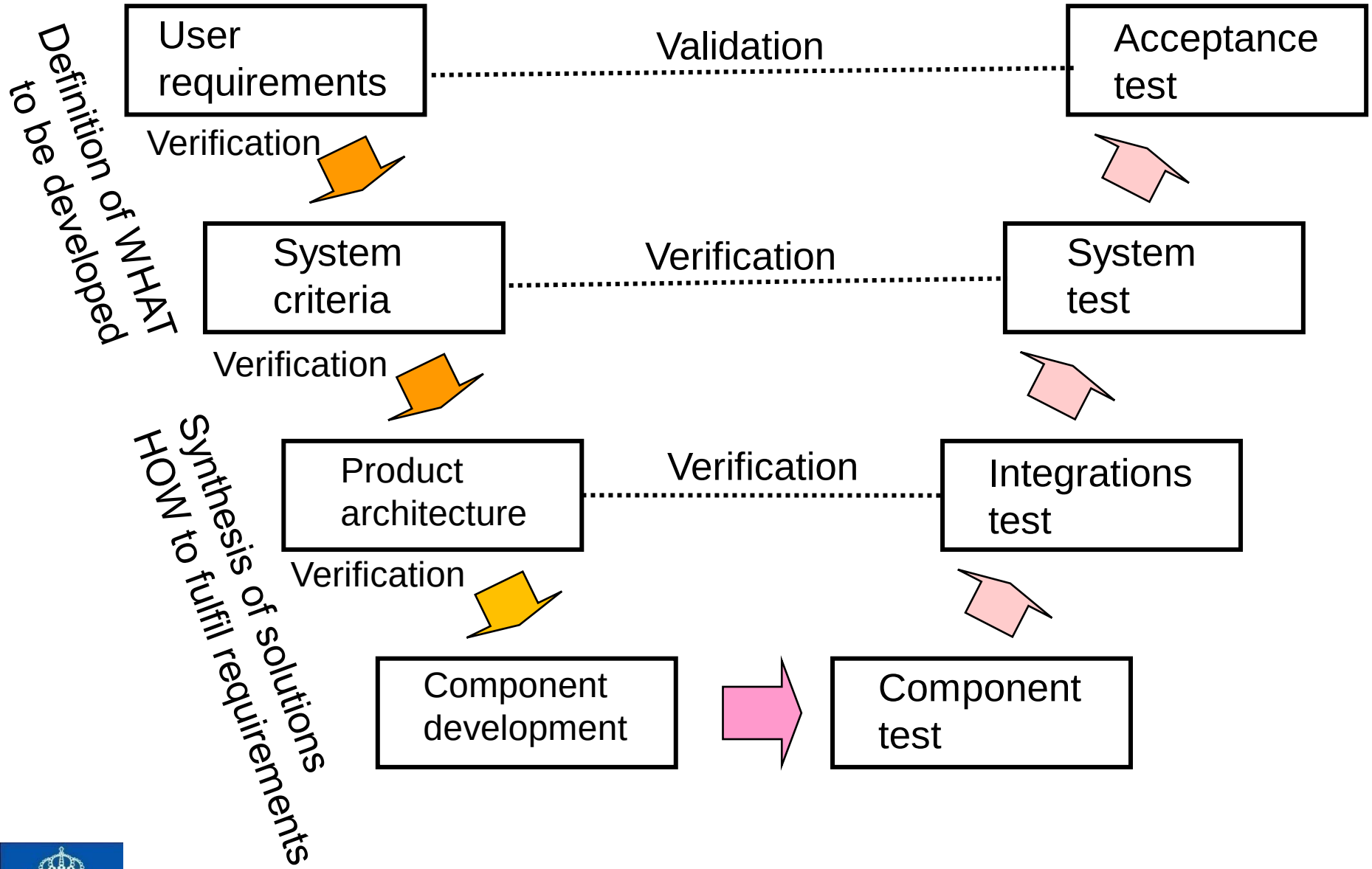
- design systematics, PD-process
- integration
- standardizing ***and*** flexibility => modularized product families

Atlas Copco Modular design
Rock drilling rig Boomer





The well established ”V-model” for PD



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Design support methods

often used for support in design teams

QFD - Qality Function Deployment

Customer requirements ⟹ design solutions

FMEA - Failure Mode and Effect Analysis

bottom-up approach

FTA - Fault Tree Analysis

top-down approach

} Safety

DFA - Design for Assembly

DOE - Design of experiments

LCC - Life Cycle Cost

LCA - Life Cycle Assessment

Estimation of environmental load over all life phases

Complex method – for specialists

Analysis of couplings and interdependencies

Seek to minimize couplings!

DSM – Design Structure Matrix:

A, B, C,… can represent components, sub-systems, or project activities

	A	B	C	D	E	F
A	■					
B	x	■				
C	x	x	■			
D	x	x	x	■		
E				X	■	
F		X		x	x	■

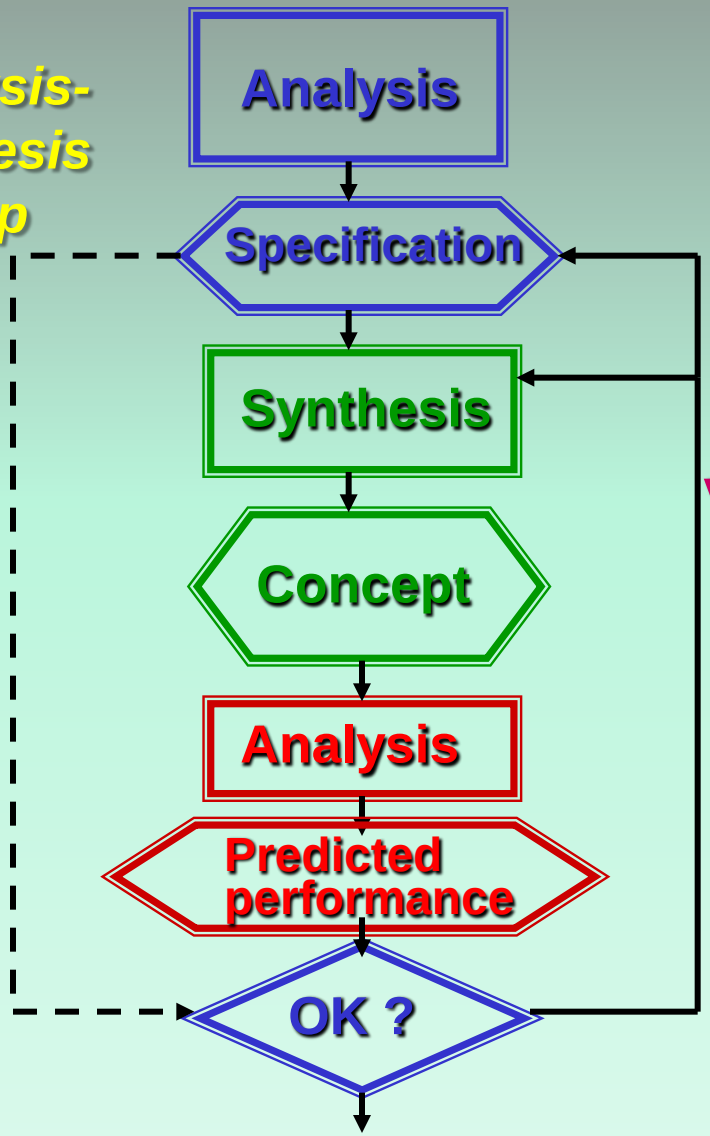
Decoupling possible if sequential execution:
All activities (or subsystems) dependent on the previous activities

	A	B	C	D	E	F
A	■		x			
B	x	■		X		
C	x	x	■	x	x	
D	x	x	x	■		
E				X	■	
F		X		x	x	■

Strongly coupled, decoupling not possible:
Activities (or subsystems) dependent on both previous and following activities

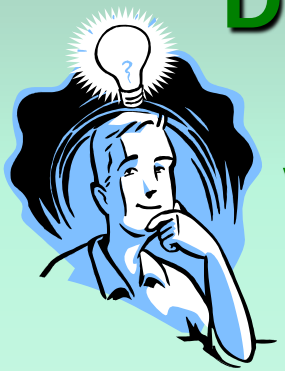
Structured PD process
Lean design

Analysis-Synthesis loop



VS´

Free innovative Design



Visionary

Slack resources

”Skunk Works”

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Innovation support – Industry sucess factors

- Investigate real needs – don´t ask customers!
- In-house R&D and development of key components
- Co-operate with major system integrators (globally)
- Visionary management persons, management support
- Freedom and responsibility
- Alternative solutions for critical subsystems

Both needed! { **structured PD process** **and** **free innovation**

Standards to be used in product development

ISO 9001 Quality management

ISO/TS 16949 (QS 9000) Automotive quality standard
AQAP 2110 NATO quality assurance
MIL-Q-9858A US military quality assurance

ISO 10303 STEP – Exchange of product model data

ISO 14001 Environmental management

ISO 50001 Energy management

ISO 27000 Information security

ISO 26000 Social responsibility (guidance)

……



Mechatronics Robotics

Robot & human co-operation

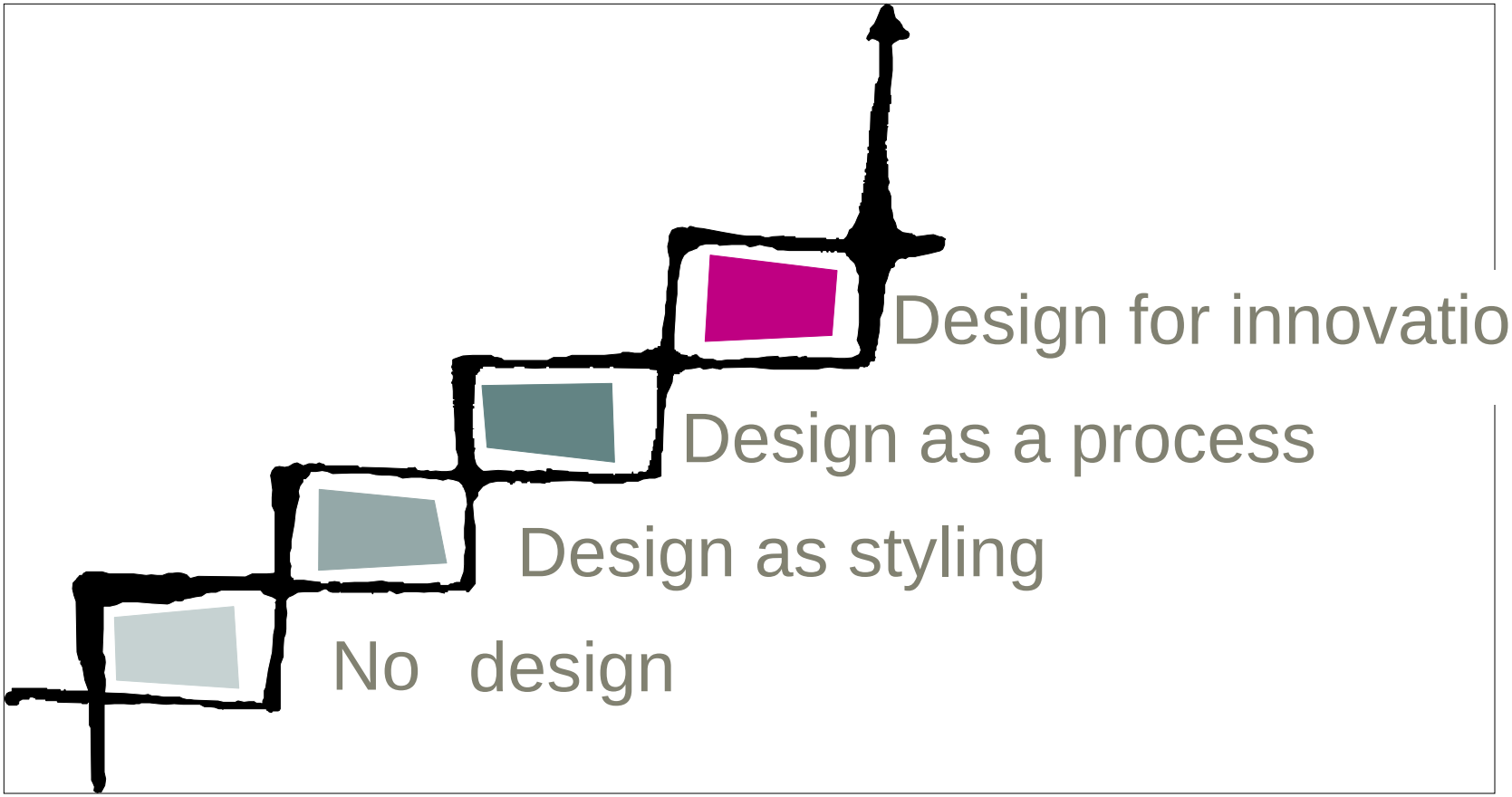
Artificial senses robot haptics





Industrial Design – more than just styling!

The design ladder – the company's design maturity



(September 2003, Danish Design Centre, "The economic effects of Design" - the design ladder model)

Current trends in Product Development

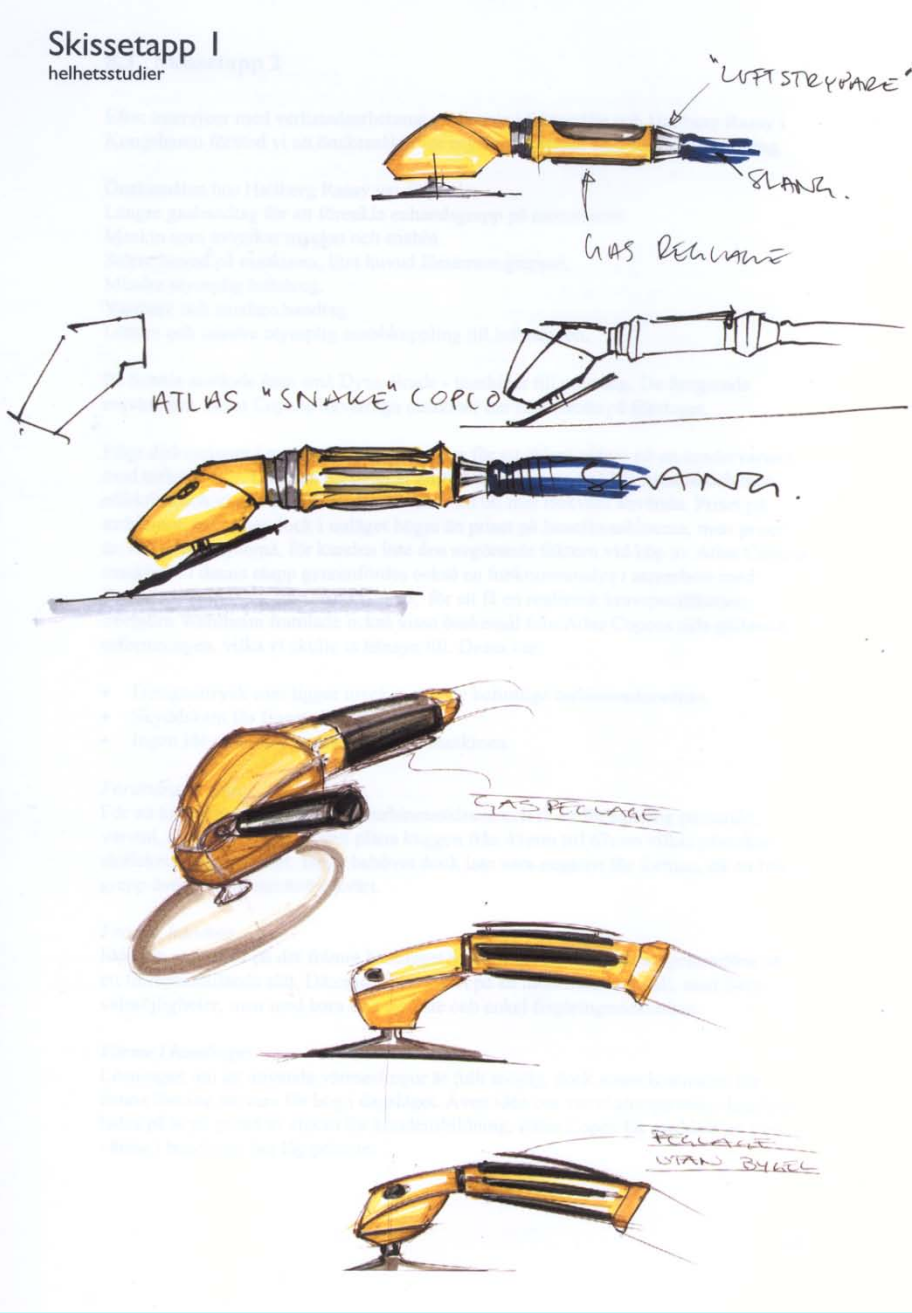
Industrial Design Engineering - synergy between Engineering and Industrial Design



- Ergonomics
- User friendliness
- Technology
- Performance
- Innovation

”Soft” Product properties:

- **Industrial Design**
  - Form
  - Colour
  - Surface structure (tactile, haptic perception)
  - Semiotics (product´s expression)
  - Sound, smell, …, all senses
- **Ergonomics**
  - Biomechanics (human force, power)
  - Anthropometrics (human geometry)
  - Perception (interpretation of signals)
- **Envirionmental Impact**



Industrial Design of investment goods – B2B

Atlas Copco



Mine Truck



Drill rig Control panel



Drill rig Operators cabin

Volvo Construction Equipment



Industrial Design of investment goods – B2B

SVID



SSRS

The Swedish Sea Rescue Society
Rescuerunner

Industrial Design

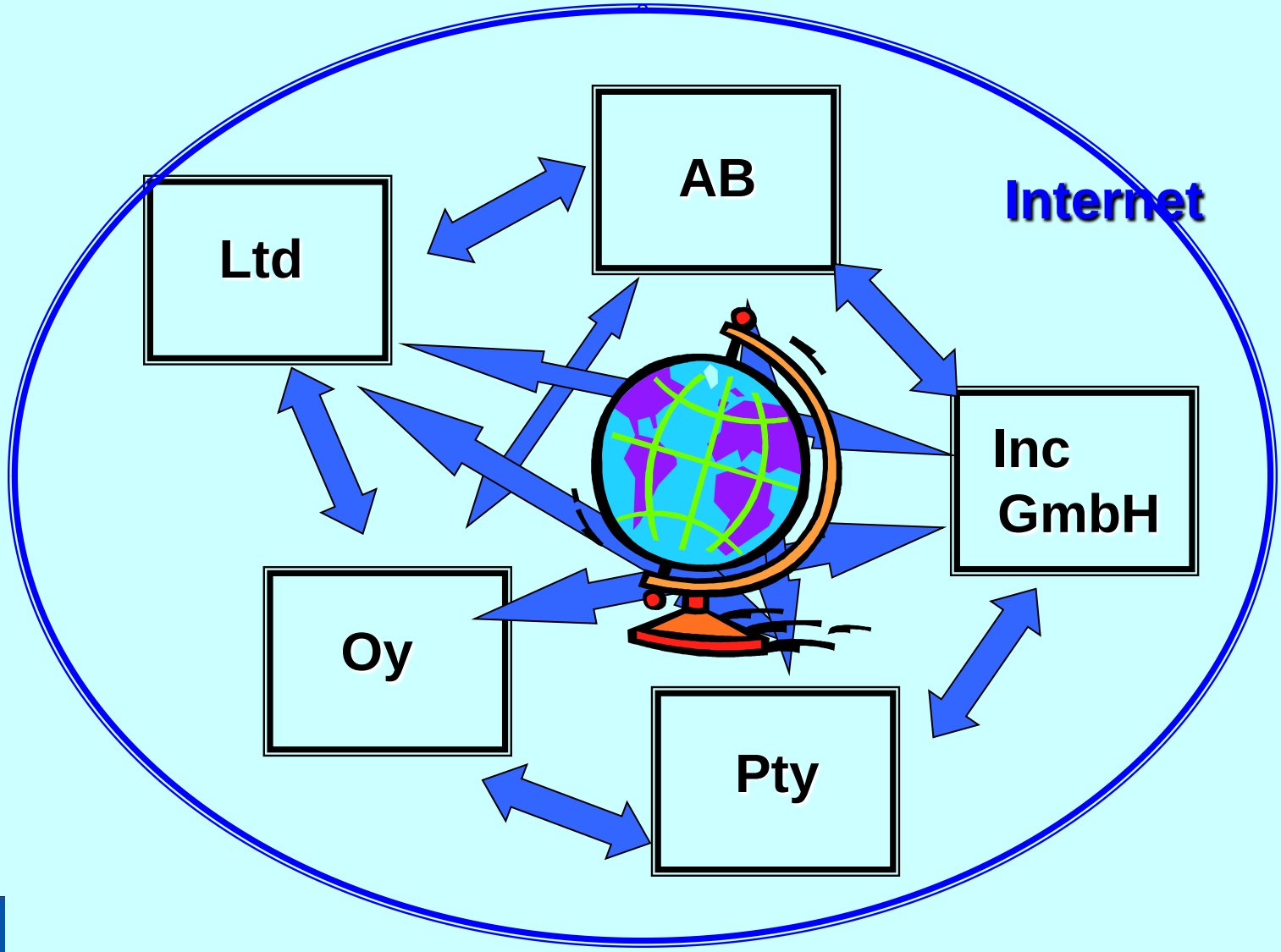






Current trends in Product Development

Distributed Development



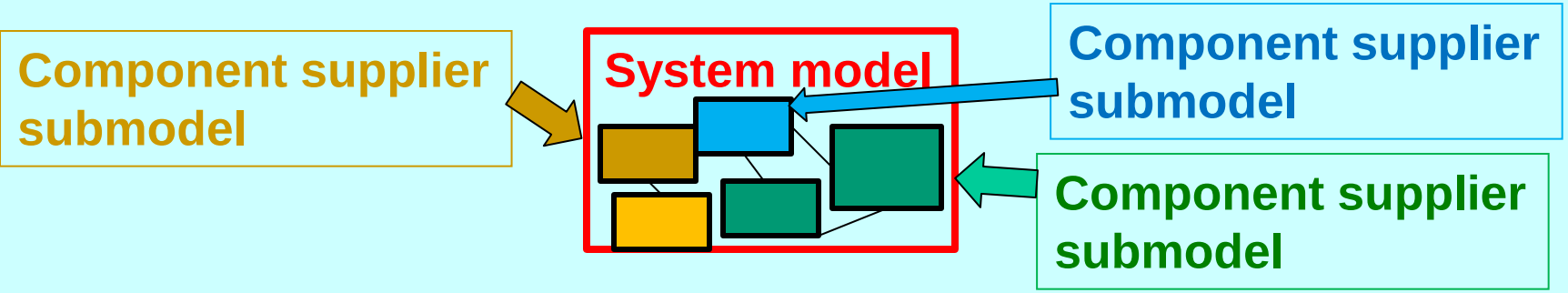
Distributed Product Development

Some examples:

EC 5th FP project: NFCCPP

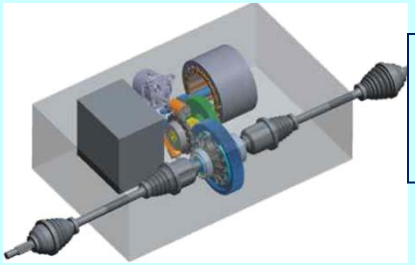
– Numerical Fuel Cell Component Performance Prediction

Fuel Cell modular system simulation



EC 7th FP project: ODIN

– Optimized electric Drivtrain by Integration



PD - VP Model based development

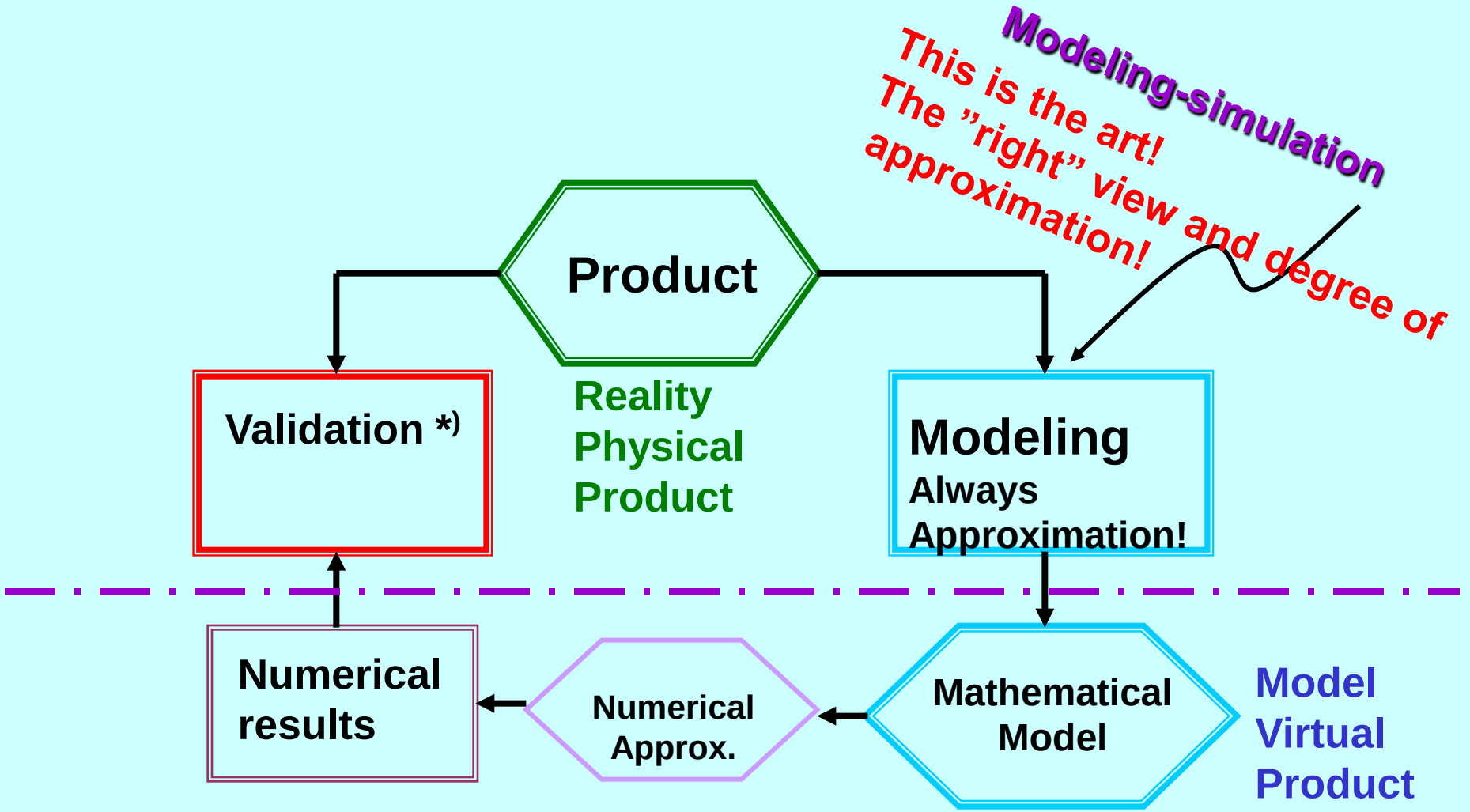
Virtual prototyping – VP

- Extensive use of CAE (simulation, optimization) to minimize physical testing
- Simulation means much faster iterations, many more parameter sets evaluated
- Simulation results to define most relevant test cases



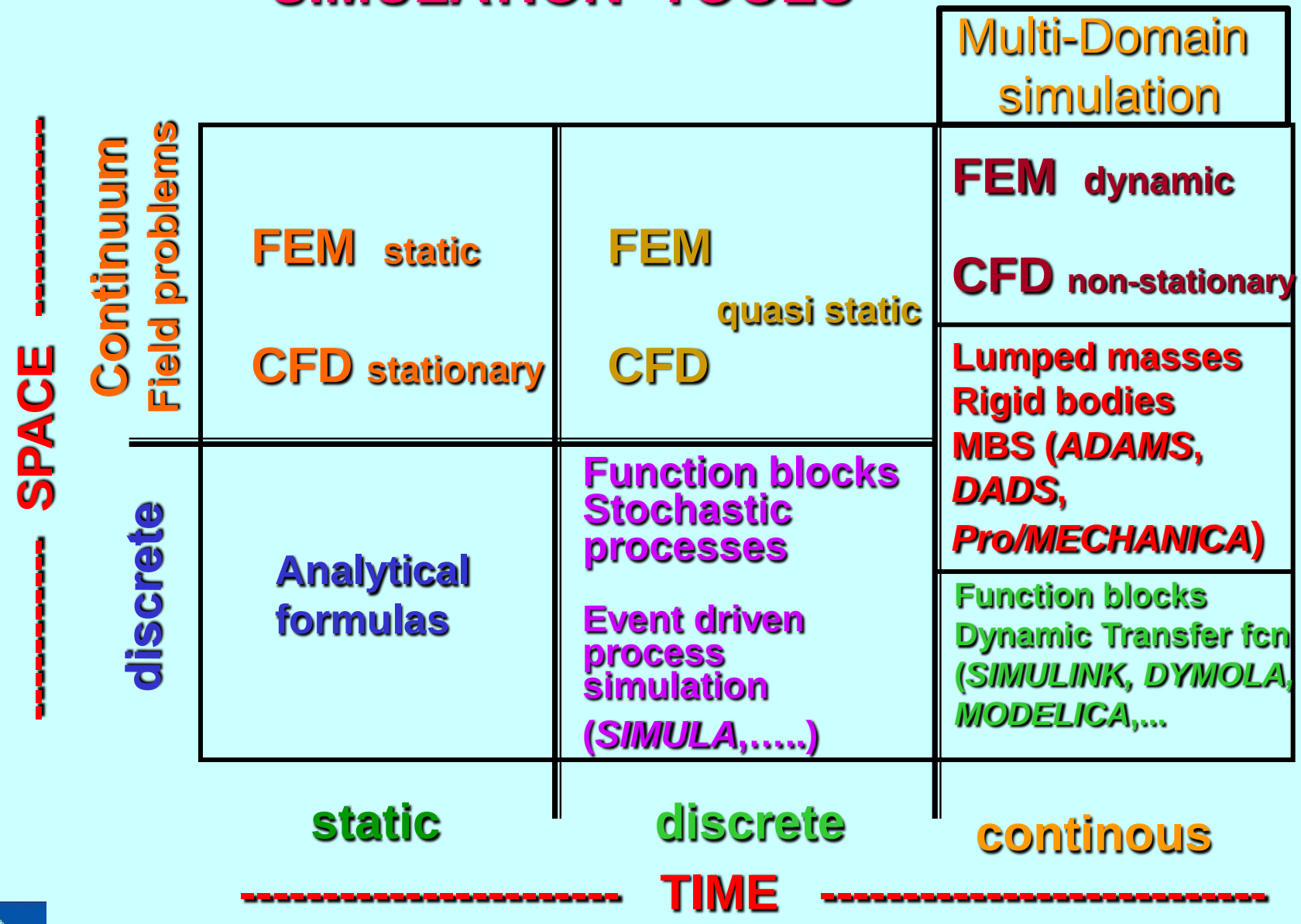
Interaction simulation – physical testing

- Test results to improve simulation models
  - anticipate the unexpected
- Integration of engineering analysis and design, replacing specialized analyst groups
- Modular model architecture



*) **Validation – verification & check for model relevance,**
e.g. vs´ measured data from real prototype tests
The validity cannot be strictly proven!

SIMULATION TOOLS

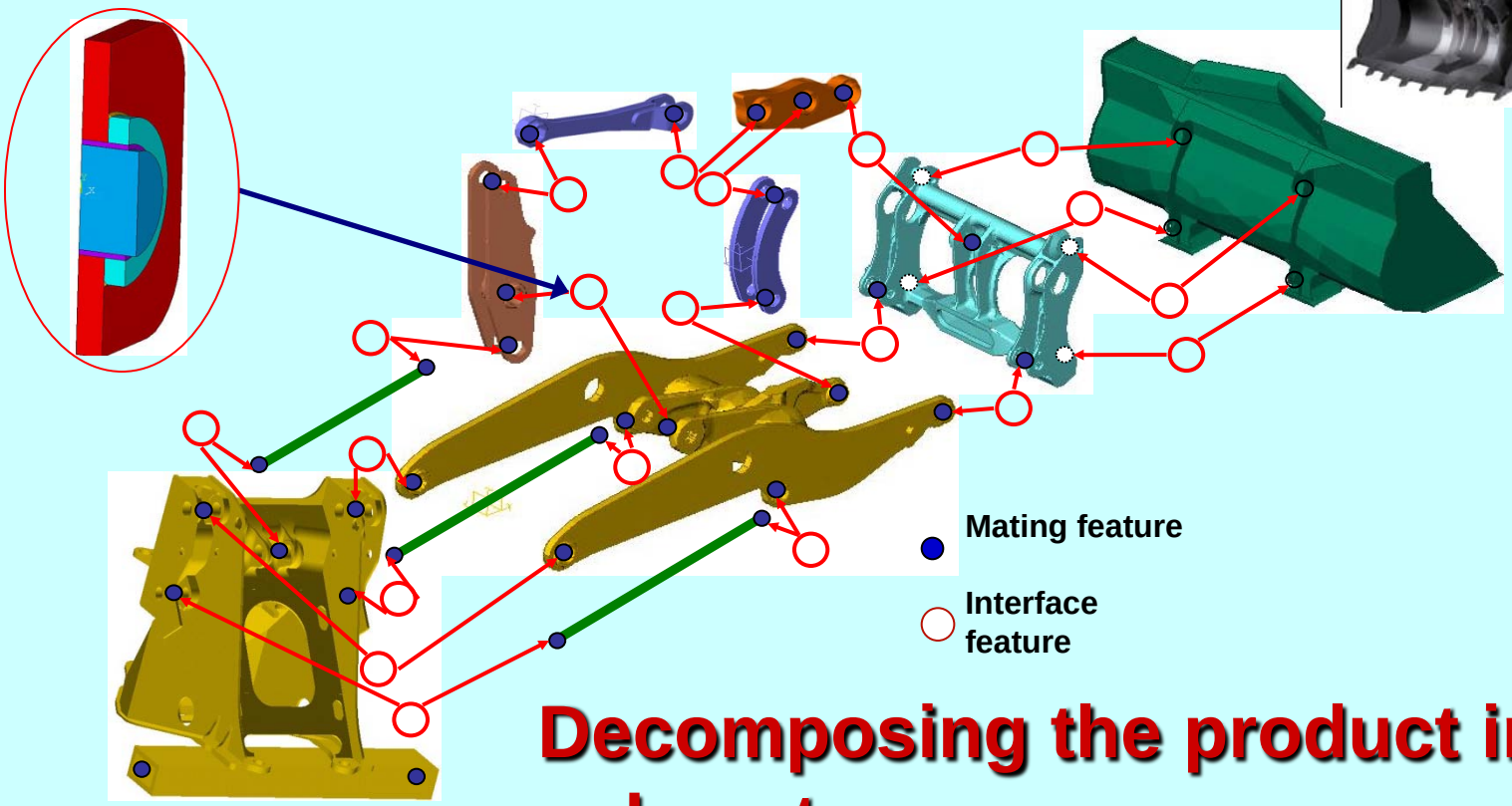


Modular model architecture

case Volvo VCE wheel loader







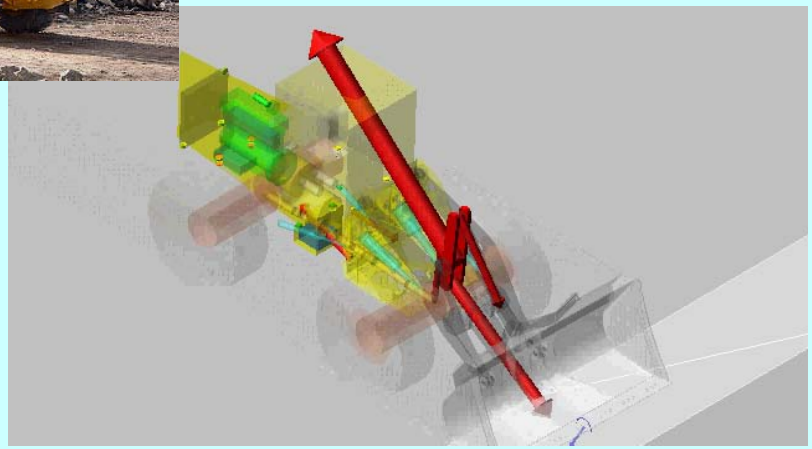
Decomposing the product into subsystems

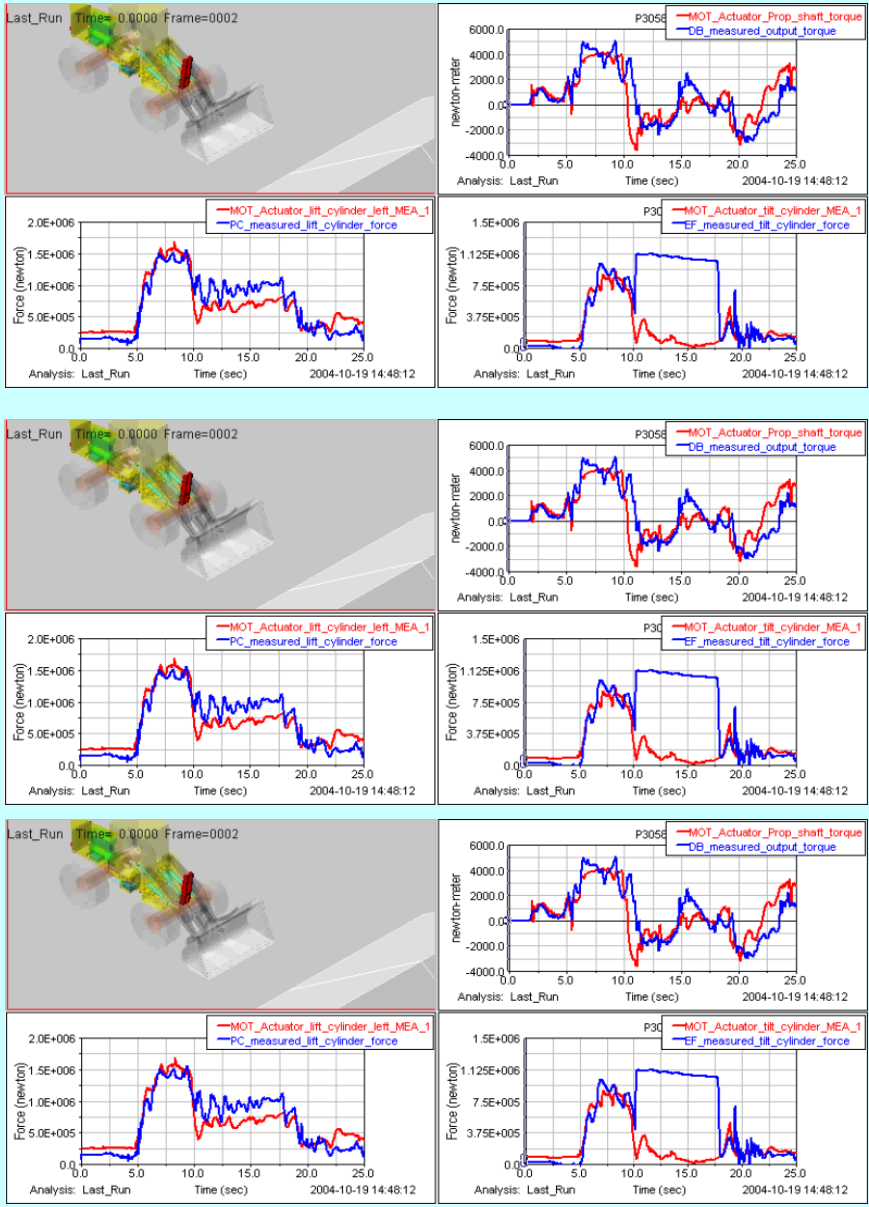
MBS – rigid body software for analysis of motion and forces

Wheel loader example

Bearing loads, bucket frame

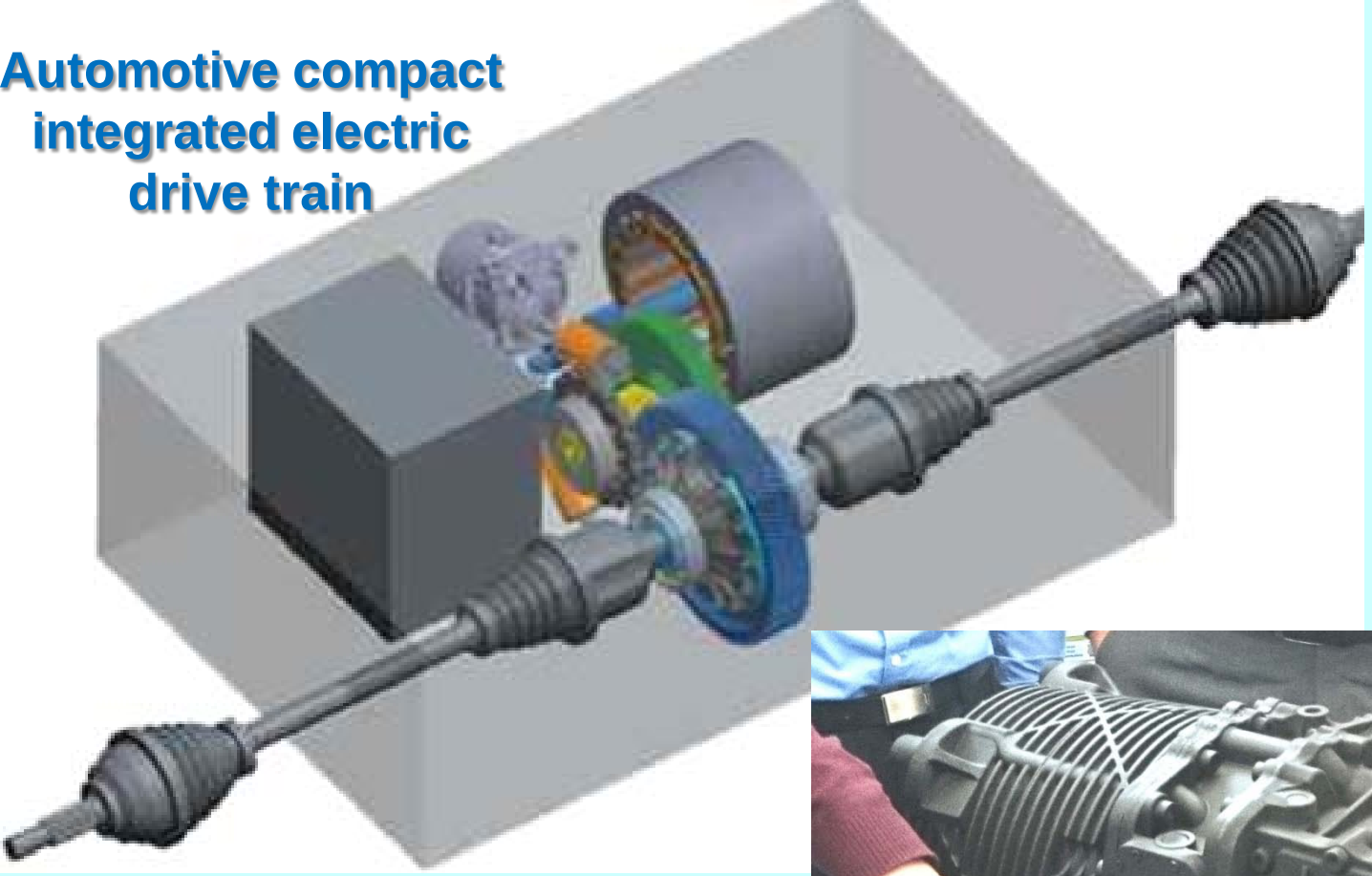






- Comparing measured and simulated values
- Good correspondance except for the tilt cylinder (as hydraulics not modelled)

Automotive compact integrated electric drive train



Model based design

VP - CAE



Rapid prototyping electric drive train mock-up

S T E P Express

S T E P = Standard for the Exchange of Product Model Data
ISO 10303

Effective information exchange between different IT systems

Neutral file data storage and communication between CAD, CAM, CAE, PDM, PLM
E.g. geometry, dimensions, tolerances, manufacturing data, maintenance data,…..
Data for all life pháses of a product

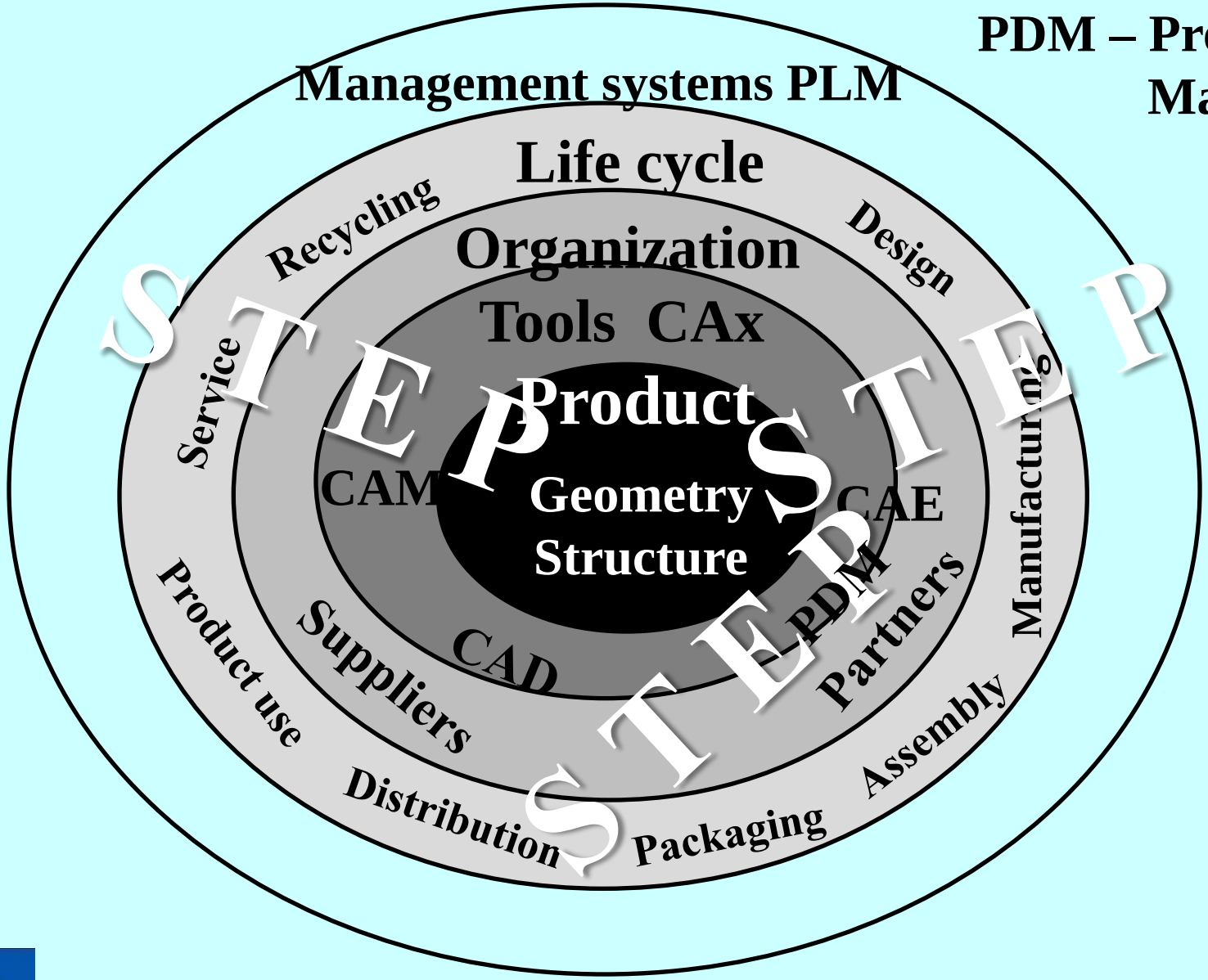
STEP comprises several industry specific areas of application AP = *Application Protocol*
E.g. AP 214 *for automotive mechanical design*

Express = information modelling language
to unambiguously define concepts and logical relations

AP 203 ***Configuration controlled 3D designs of mechanical parts and assemblies***

PLM – Product Life Management

PDM – Product Data Management



Reverse Enginering - RE

Physical product ⟶ CAD Model
for spare parts, redesign, copying, …

”2D” designs: Measurement of critical dimensions

Complex curved ”3D” designs:

- **3D scanning by:**
  - **coordinate measuring machine**
  - **optical methods (e.g. laser scanning)**
  - **X-ray – computed tomography**
- **Data reduction of measured ”point cloud”**
- **CAD modeling from reduced point cloud**

Info on tolerances, material properties etc not directly obtained

Market analysis

Products used in industrial processes

Potential max utilization of the product, total ”fleet” of products
Global volume expressed e.g. in value, capacity, power

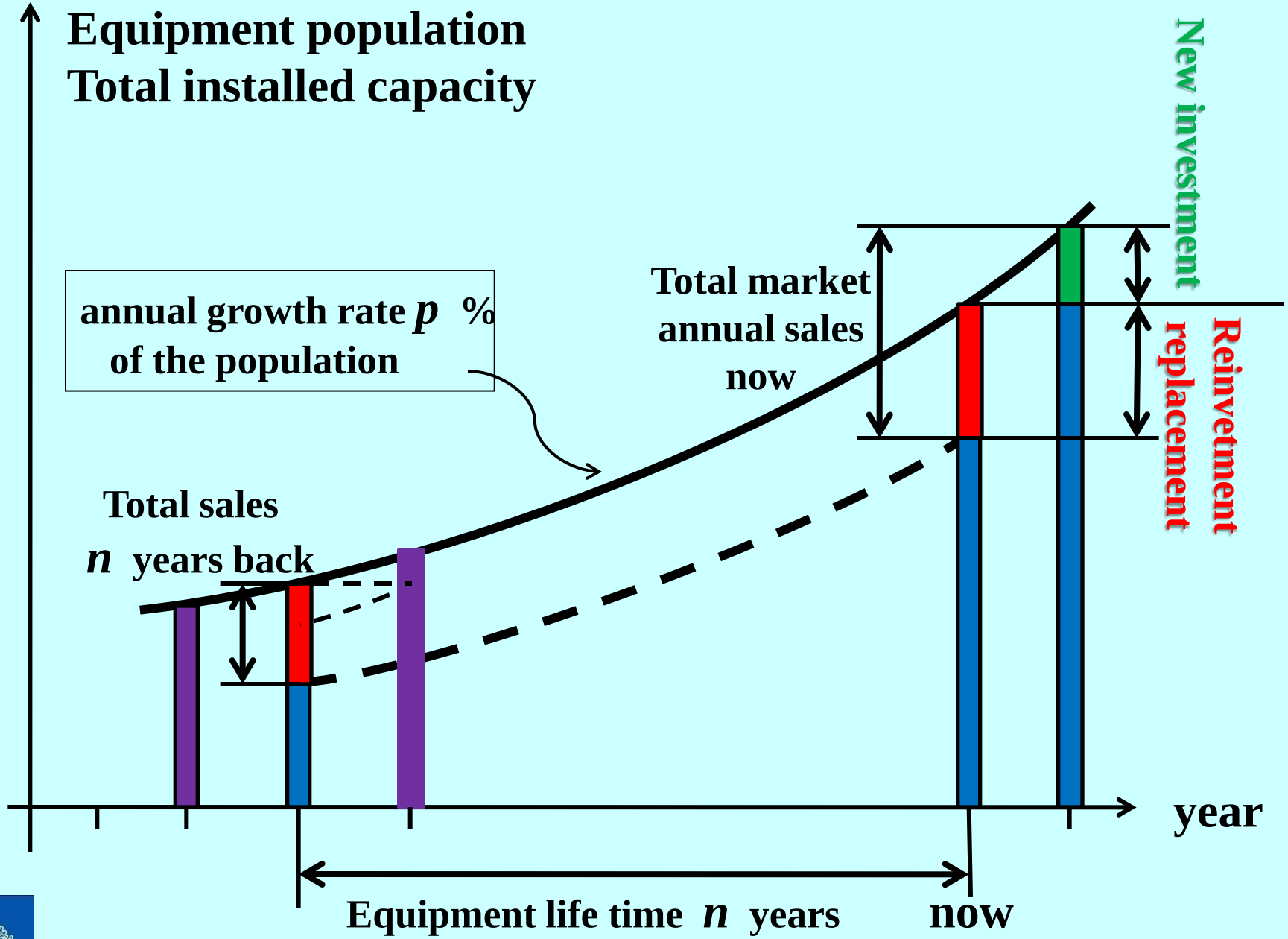
Based on:

- **business statistics, extent of the relevant industry processes**
- **the products´ share of the relevant industry processes**
- **process technology changes affecting the products´ use**

Potential annual market χ for the product , in % of total ”fleet”
Based on:

- **growth rate p % for the relevant industry processes**
- **life time n [years] for the equipment**

Annual market χ % of total fleet: $$\chi = \frac{p}{1-(1+p/100)^{-n}}$$


Equipment population
Total installed capacity
New investment
Reinvetment
replacement
annual growth rate p %
of the population
Total market
annual sales
now
Total sales
n years back
year
Equipment life time n years
now

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Annual market χ in percent of the total population of products

Business growth rate *p* % per year

Equipment life time *n* years

$$\chi = \frac{p}{1-(1+p/100)^{-n}}$$

Growth rate *p* %	0	2	5	10
χ for life time *n* = 3 years	33	35	37	40
χ for life time *n* = 10 years	10	11	13	16
χ for life time *n* = 20 years	5	6	8	12

Environmentally driven design

Eco-efficiency

product improvements to reduce products´ environmental impact

- materials selection and design (e.g. weight reduction)
- energy efficiency
- disassemblability
- ……

Eco-effectiveness

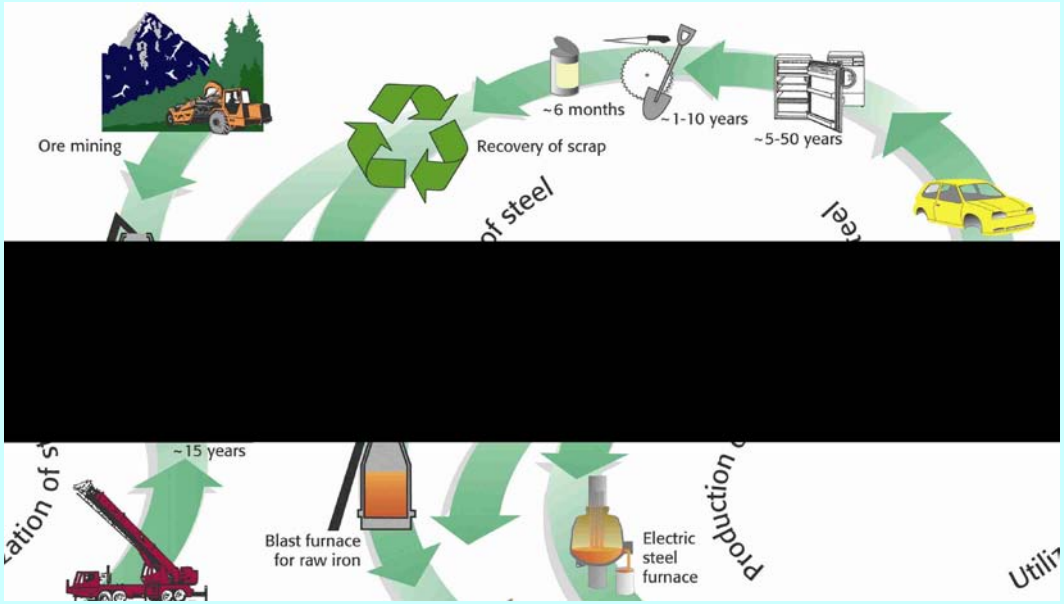
Alternative technical solutions to

- meet society´s functional requirements
- significantly reduce system environmental impact over life time

E.g. Various forms of solar energy, replacing fossil and nuclear

- Zero energy buildings
- New transport technology
- ……

EcoDesign – example: Swedish Research program the Steel Eco Cycle

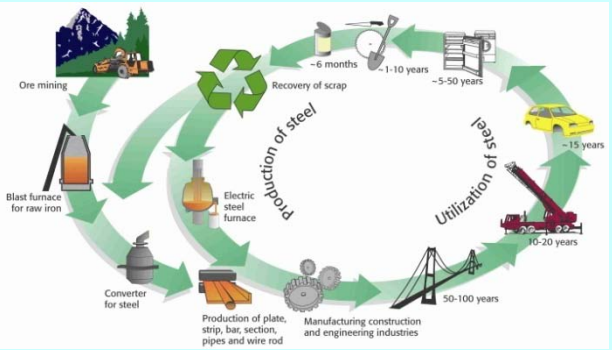


The Steel Eco Cycle

Eco Effective Design
of steel products

- ***Weight optimisation - reduction of all resurces used in production upstream***
- ***Weight optimisation of ”active” products reduction of energy consumption during use phase direct***
- ***Material hygiene – cleaner fractions in disassembly for improved quality in recycling downstream & upstream***

EcoDesign – example: Swedish Research program the Steel Eco Cycle



Eco Effective Design of steel products for

- ***reduced amount of material***
- ***improved disassembly and cleaner recycling***

State-of-the-art

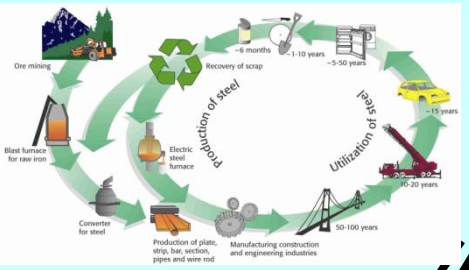
Existing theory base: solid mechanics, physical metallurgy, welding, optimisation…, disassembly, scrapping & separation processes

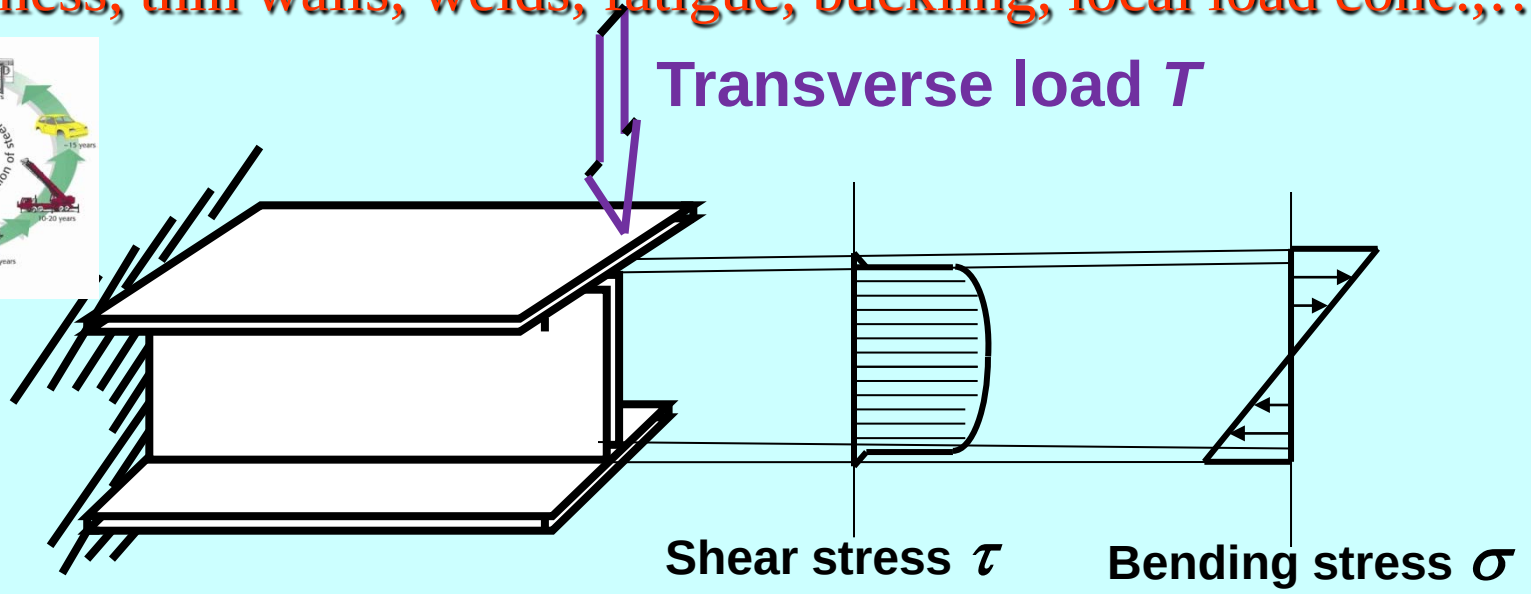
Existing detailed design rules

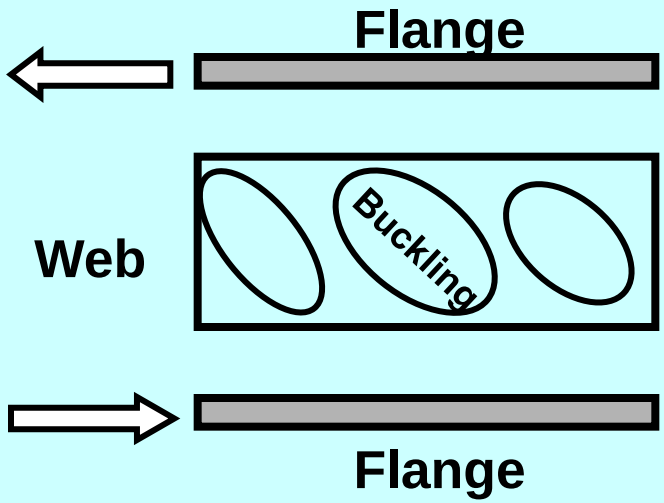
but lacking overview – risk of sub-optimisation

How to utilise high strength steel properties?

Strength-stiffness, thin walls, welds, fatigue, buckling, local load conc.,…

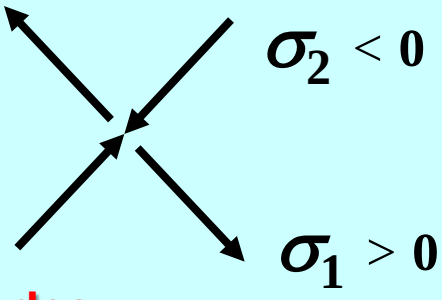






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Principal stresses for pure shear loading (in web)



Modulus of elasticity E same for all steel grades

=> use stiffernes to prevent buckling of thin walled structures

Some Design & Assembly rules to support disassembly, reuse and recycling

- Product structure adapted for easy disassembly
- No toxic or scarce materials
- Upgradable design ➡ longer product life
- Fasternes eliminated by geometrical locking
- Easy access to fasternes
- Standardized fasterners and screws just one tool needed
- No embedded metal parts in plastics moulds
- Design for ease of cleaning, avoid dirt traps
- Glue bonding: OK for metal, avoid for plastics
- Surface coating: OK for metal, avoid for plastics
- Disassembly info: manuals, integrated ”smart labels”
- ”Resting loadcases” – parts designed for prepared rupture
- ……..

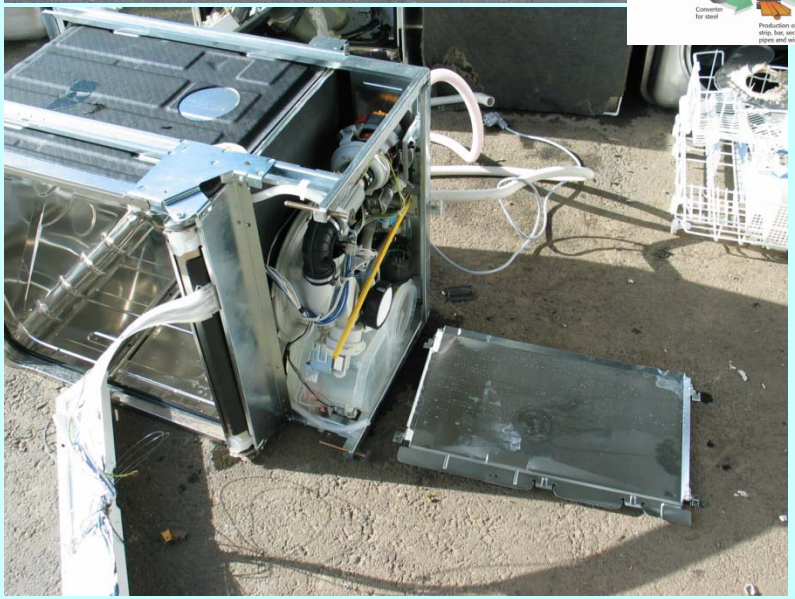
The Steel Eco Cycle

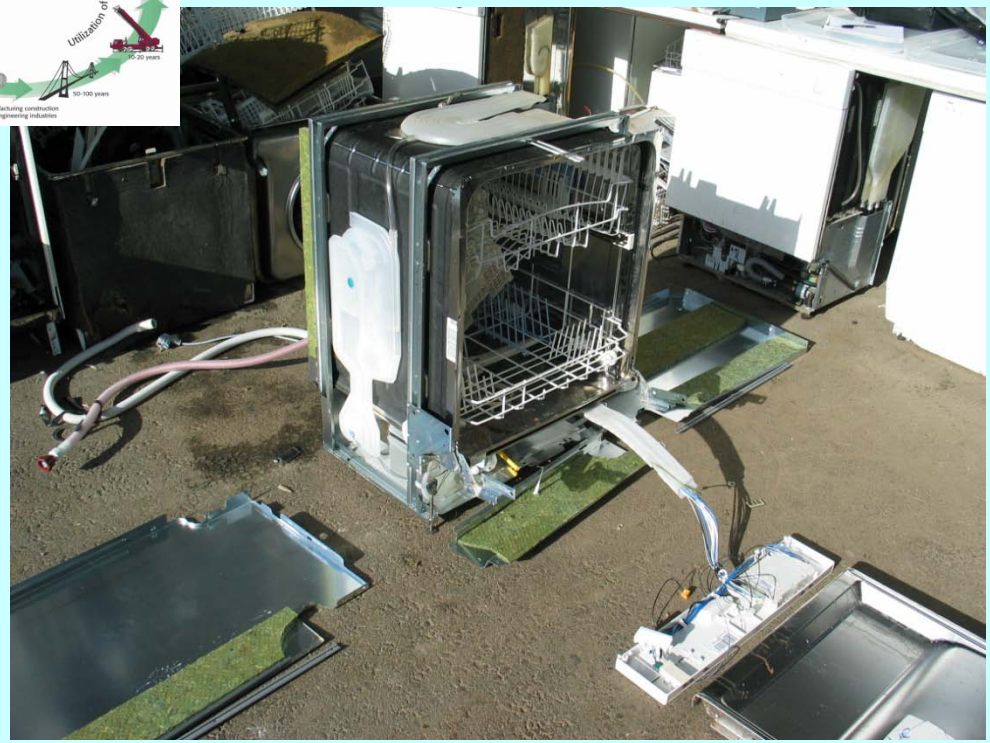
Eco Effective Design
of steel products

Disassembly tests – Dishwashers
Product structure



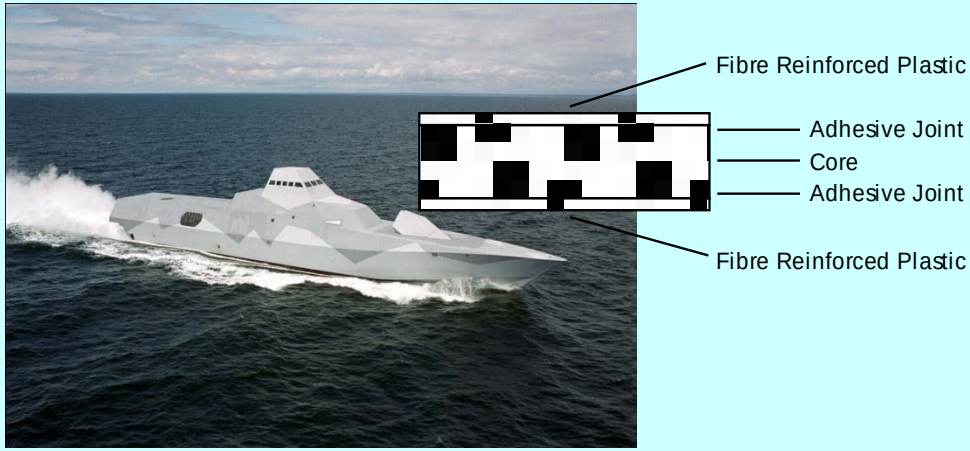




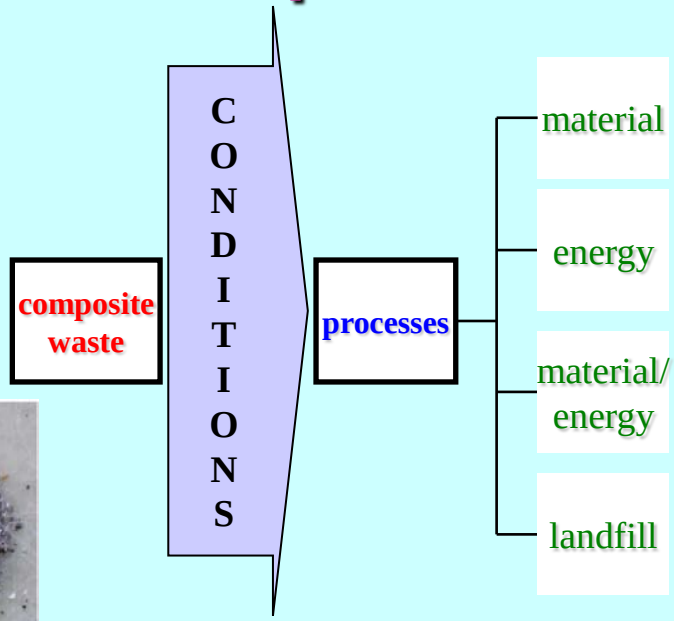


Recycling and recovery of polymer composite materials

Corvette HMS Visby



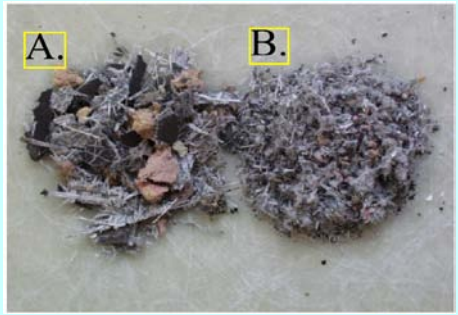
Model for assessment of disposal



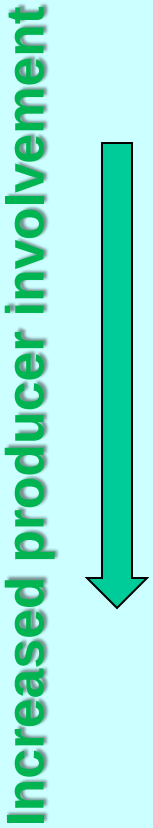
Dismantling



Grinding



Service systems – function sales



- *Scheduled preventive maintenance*
- *Extended producer responsibility*
- *Producer ownership*
- *New business concepts*
- *Integrated product-service - life cycle optimized*



- **Increased/efficient utilization of resources**
- **Reduced environmental load**

Current trends in Product Development

- **Integration**
  - * Complex Multi Technology Systems
  - * Industrial Design Engineering - ”Hard” & ”Soft”
  - * IPD – organisation, process
  - * Distributed PD over networks
- **Innovation**
- **Iteration - VP, model driven PD**

Future technology and PD challenges

- **Flexibility to meet changing conditions**
- **Sustainability** – { **environmental**, **economic**, **social** }
- **Service systems – function sales, producer ownership**
- **Long term development to meet major global needs**
  Energy supply, sustainable transportation, production,…..

CURRENT TRENDS IN INDUSTRY:

- *Fewer and larger suppliers*
- *Complex organisations*
- *Outsourcing – insourcing*
- *Distributed development, networks*
- *Industrial Design Engineering*
- *Integration of engineering analysis – engineering design*
- *Modular product architecture, platforms*
- *Virtual prototyping*
- *Service systems – new business concepts*
- *Sustainable technology development*