Centre for
Process
Systems
Engineering

Supply Chains of the Future

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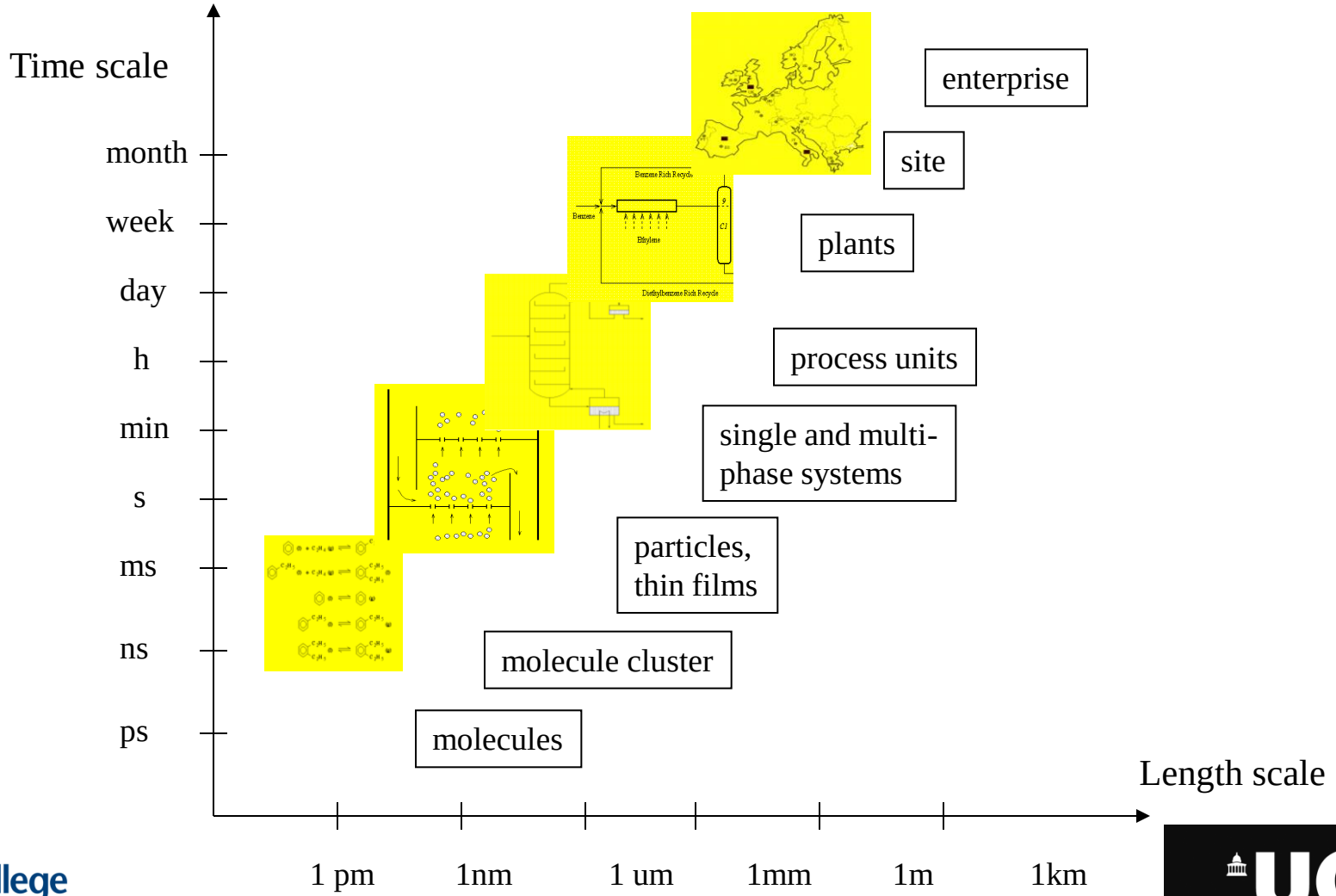
CPSE: Chemical/Energy supply/value chain



Supply Chain

- Procurement, processing and distribution of materials
- Optimisation opportunities:
  - Infrastructure
  - Planning
  - Short-term operation

Infrastructure

- How many plants and where ?
  - in-house or outsource ?
- What resources in each plant ?
- What distribution/warehousing resources
  - own or third party
  - share with competitors ?
- What are sensible goals to set ?
- Which long-term suppliers ?
- What strategic parameters to set for business to run smoothly ?

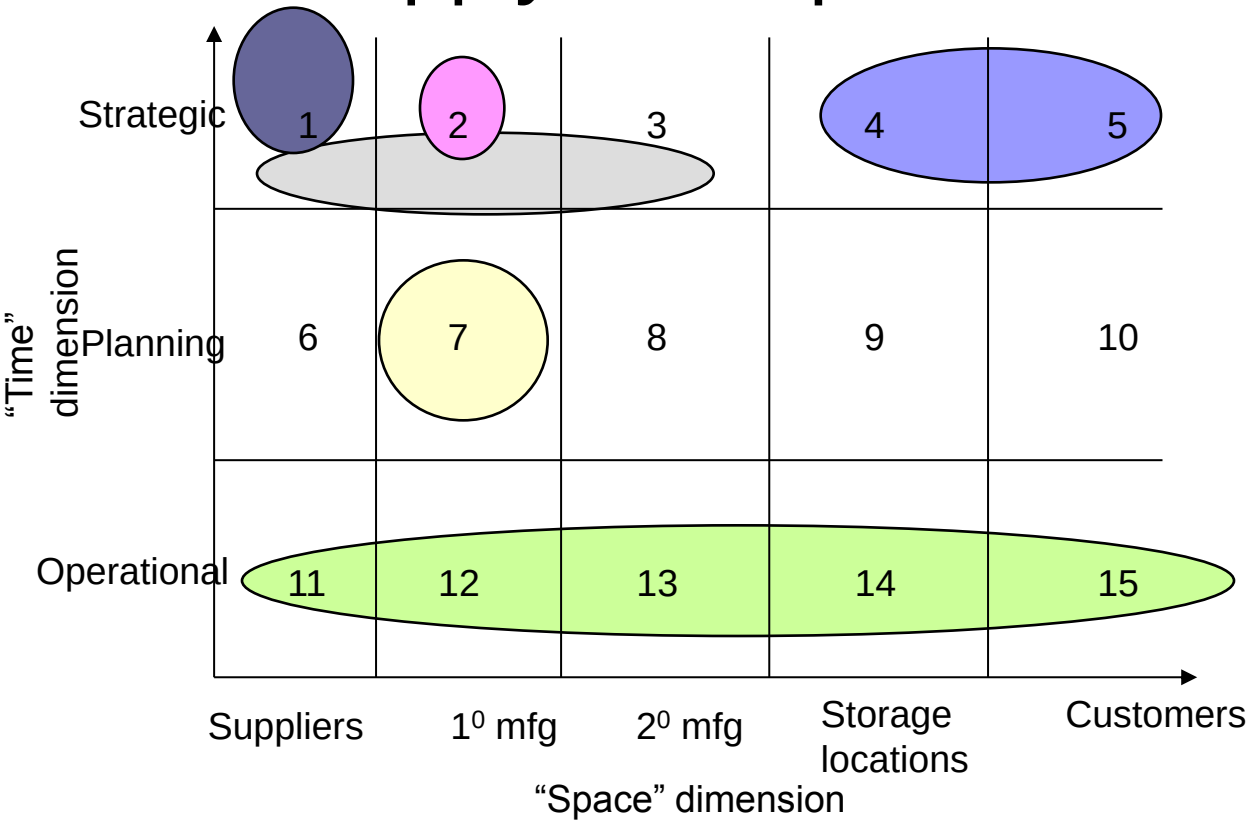
Planning

- Forecasting and demand management
  - What are we likely to sell ?
  - What stocks will we need ?
- Production
  - What should be made where & how ?
    - e.g. over the next month
    - exploit regional differences to maximise return
    - identify improvements with supply chain impact
- Distribution
  - How best to distribute material
  - consider concurrently with production planning

Short-term operation

- Daily production scheduling at each site
  - minimise cost/waste/changeovers
  - meet targets set by higher level planning
- Daily vehicle routing
  - minimise distance
  - maximise capacity utilisation
  - explore backhauling opportunities
- Short-term supply chain management
- How do we get the right product in the right place at the right time at the right price ?

Supply chain problems

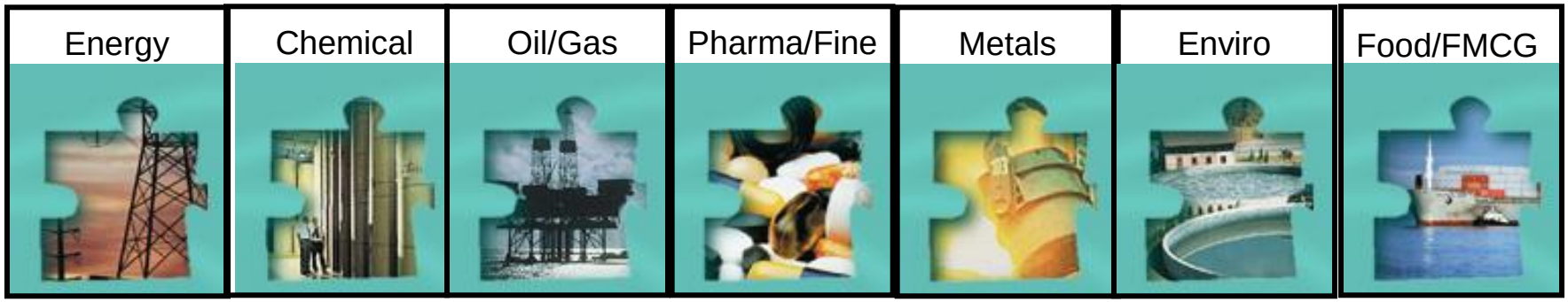


Examples

- Redesign logistics network
- Campaign planning at a primary manufacturing site
- Real-time supply chain management and control
- Negotiation of long term supply contracts
- Improved design of primary manufacturing processes and plants
- Long-term manufacturing capacity planning and value-chain management

Process industries

- Very broad
- Many companies do not operate at "customer-facing" end of chain, mainly B2B
  - Affects supply chain performance significantly



Opportunities of digitalisation

- Integration across scales; seamless use of data and models
- Integration across lifecycle (discovery -> operations)
- Integration between real-time, planning and strategy
- “Real-time optimisation” at supply chain level
- Adaptive operation and customisation
- Incorporation of advanced process analytics to reduce testing and improve quality and responsiveness
- …

Integration across modelling scales: European feedstock selection and flexible cracker operation problem

What feedstocks to buy?

How to operate plants?

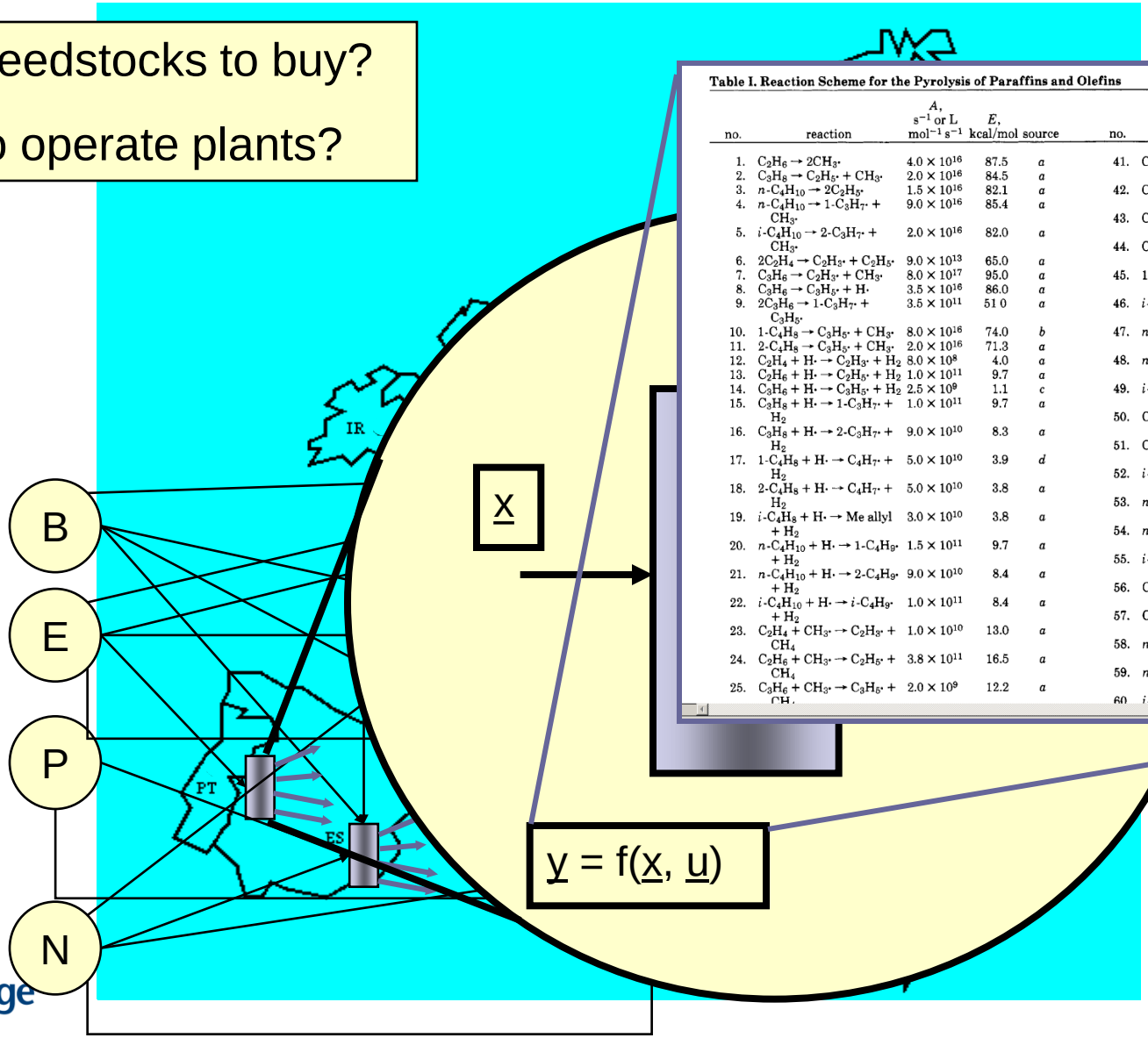


Table I. Reaction Scheme for the Pyrolysis of Paraffins and Olefins

no.	reaction	A, s^{-1} or L mol^{-1} s^{-1}	E, kcal/mol	source
1.	$C_2H_6 \rightarrow 2CH_3\cdot$	4.0×10^{16}	87.5	*a*
2.	$C_3H_8 \rightarrow C_2H_5\cdot + CH_3\cdot$	2.0×10^{16}	84.5	*a*
3.	$n\text{-}C_4H_{10} \rightarrow 2C_2H_5\cdot$	1.5×10^{16}	82.1	*a*
4.	$n\text{-}C_4H_{10} \rightarrow 1\text{-}C_3H_7\cdot + CH_3\cdot$	9.0×10^{16}	85.4	*a*
5.	$i\text{-}C_4H_{10} \rightarrow 2\text{-}C_3H_7\cdot + CH_3\cdot$	2.0×10^{16}	82.0	*a*
6.	$2C_2H_4 \rightarrow C_2H_3\cdot + C_2H_5\cdot$	9.0×10^{13}	65.0	*a*
7.	$C_3H_6 \rightarrow C_2H_3\cdot + CH_3\cdot$	8.0×10^{17}	95.0	*a*
8.	$C_3H_6 \rightarrow C_3H_5\cdot + H\cdot$	3.5×10^{16}	86.0	*a*
9.	$2C_3H_6 \rightarrow 1\text{-}C_3H_7\cdot + C_3H_5\cdot$	3.5×10^{11}	51 0	*a*
10.	$1\text{-}C_4H_8 \rightarrow C_3H_5\cdot + CH_3\cdot$	8.0×10^{16}	74.0	*b*
11.	$2\text{-}C_4H_8 \rightarrow C_3H_5\cdot + CH_3\cdot$	2.0×10^{16}	71.3	*a*
12.	$C_2H_4 + H\cdot \rightarrow C_2H_3\cdot + H_2$	8.0×10^{8}	4.0	*a*
13.	$C_2H_6 + H\cdot \rightarrow C_2H_5\cdot + H_2$	1.0×10^{11}	9.7	*a*
14.	$C_3H_6 + H\cdot \rightarrow C_3H_5\cdot + H_2$	2.5×10^{9}	1.1	*c*
15.	$C_3H_8 + H\cdot \rightarrow 1\text{-}C_3H_7\cdot + H_2$	1.0×10^{11}	9.7	*a*
16.	$C_3H_8 + H\cdot \rightarrow 2\text{-}C_3H_7\cdot + H_2$	9.0×10^{10}	8.3	*a*
17.	$1\text{-}C_4H_8 + H\cdot \rightarrow C_4H_7\cdot + H_2$	5.0×10^{10}	3.9	*d*
18.	$2\text{-}C_4H_8 + H\cdot \rightarrow C_4H_7\cdot + H_2$	5.0×10^{10}	3.8	*a*
19.	$i\text{-}C_4H_8 + H\cdot \rightarrow$ Me allyl $+ H_2$	3.0×10^{10}	3.8	*a*
20.	$n\text{-}C_4H_{10} + H\cdot \rightarrow 1\text{-}C_4H_9\cdot + H_2$	1.5×10^{11}	9.7	*a*
21.	$n\text{-}C_4H_{10} + H\cdot \rightarrow 2\text{-}C_4H_9\cdot + H_2$	9.0×10^{10}	8.4	*a*
22.	$i\text{-}C_4H_{10} + H\cdot \rightarrow i\text{-}C_4H_9\cdot + H_2$	1.0×10^{11}	8.4	*a*
23.	$C_2H_4 + CH_3\cdot \rightarrow C_2H_3\cdot + CH_4$	1.0×10^{10}	13.0	*a*
24.	$C_2H_6 + CH_3\cdot \rightarrow C_2H_5\cdot + CH_4$	3.8×10^{11}	16.5	*a*
25.	$C_3H_6 + CH_3\cdot \rightarrow C_3H_5\cdot +$ CH_4	2.0×10^{9}	12.2	*a*
41.	$C_2H_4 + C_2H_5\cdot \rightarrow CH_3\cdot + C_3H_6$	3.0×10^{9}	19.0	*e*
42.	$C_3H_6 + C_2H_5\cdot \rightarrow C_3H_5\cdot + C_2H_6$	1.0×10^{8}	9.2	*d*
43.	$C_3H_8 + C_2H_5\cdot \rightarrow 1\text{-}C_3H_7\cdot + C_2H_6$	1.2×10^{9}	12.6	*a*
44.	$C_3H_8 + C_2H_5\cdot \rightarrow 2\text{-}C_3H_7\cdot + C_2H_6$	8.0×10^{8}	10.4	*a*
45.	$1\text{-}C_4H_8 + C_2H_5\cdot \rightarrow C_4H_7\cdot + C_2H_6$	2.0×10^{8}	8.3	*a*
46.	$i\text{-}C_4H_8 + C_2H_5\cdot \rightarrow$ Me allyl $+ C_2H_6$	6.0×10^{7}	8.3	*a*
47.	$n\text{-}C_4H_{10} + C_2H_5\cdot \rightarrow 1\text{-}C_4H_9\cdot + C_2H_6$	2.0×10^{9}	12.6	*a*
48.	$n\text{-}C_4H_{10} + C_2H_5\cdot \rightarrow 2\text{-}C_4H_9\cdot + C_2H_6$	4.5×10^{8}	10.4	*a*
49.	$i\text{-}C_4H_{10} + C_2H_5\cdot \rightarrow i\text{-}C_4H_9\cdot + C_2H_6$	1.5×10^{9}	10.4	*a*
50.	$C_3H_8 + C_3H_5\cdot \rightarrow 1\text{-}C_3H_7\cdot + C_3H_6$	1.0×10^{9}	18.8	*d*
51.	$C_3H_8 + C_3H_5\cdot \rightarrow 2\text{-}C_3H_7\cdot + C_3H_6$	8.0×10^{8}	16.2	*d*
52.	$i\text{-}C_4H_8 + C_3H_5\cdot \rightarrow$ Me allyl $+ C_3H_6$	2.0×10^{8}	13.5	*a*
53.	$n\text{-}C_4H_{10} + C_3H_5\cdot \rightarrow 1\text{-}C_4H_9\cdot + C_3H_6$	4.0×10^{8}	18.8	*d*
54.	$n\text{-}C_4H_{10} + C_3H_5\cdot \rightarrow 2\text{-}C_4H_9\cdot + C_3H_6$	8.0×10^{8}	16.8	*d*
55.	$i\text{-}C_4H_{10} + C_3H_5\cdot \rightarrow i\text{-}C_4H_9\cdot + C_3H_6$	1.0×10^{9}	19.0	*a*
56.	$C_3H_6 + 1\text{-}C_3H_7\cdot \rightarrow C_3H_5\cdot + C_3H_8$	1.0×10^{8}	9.2	*d*
57.	$C_3H_6 + 2\text{-}C_3H_7\cdot \rightarrow C_3H_5\cdot + C_3H_8$	1.0×10^{8}	10.2	*d*
58.	$n\text{-}C_4H_{10} + 1\text{-}C_3H_7\cdot \rightarrow 2\text{-}C_4H_9\cdot + C_3H_8$	2.0×10^{8}	10.4	*a*
59.	$n\text{-}C_4H_{10} + 2\text{-}C_3H_7\cdot \rightarrow 2\text{-}C_4H_9\cdot + C_3H_8$	2.0×10^{8}	12.6	*a*
60.	$i\text{-}C_4H_{10} + 2\text{-}C_3H_7\cdot \rightarrow i\text{-}$	1.0×10^{8}	13.4	*a*

Pharmaceutical case studies

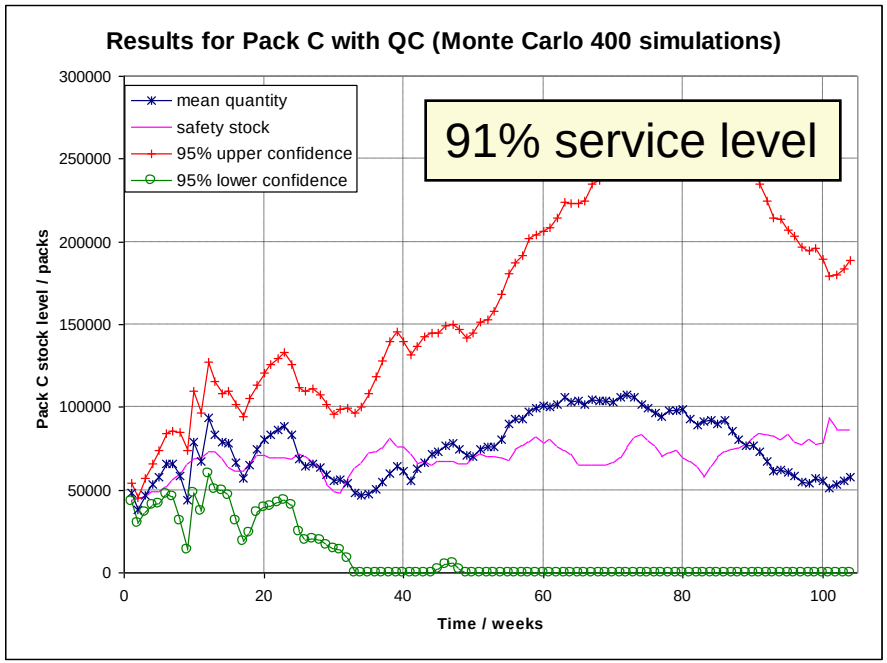
- Case study 1: supply chain advantages of advanced process analytics and digital release
- Case study 2: application of MPC at supply chain level

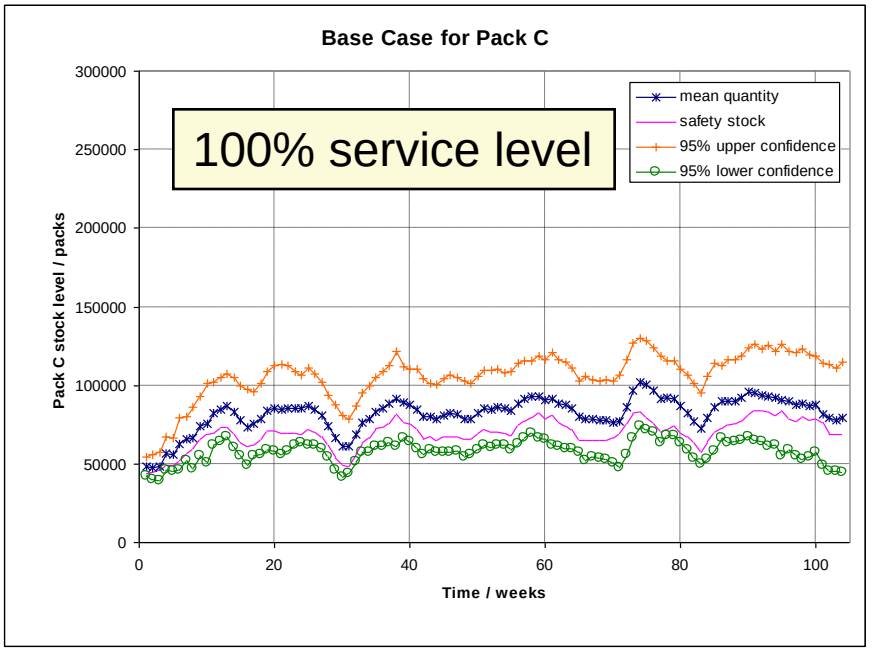
Interaction between process and supply chain levels: Comparison of two supply chain responses

- Pharmaceutical process
  - primary production has five synthesis stages
  - two secondary manufacturing sites

- Two different recipes
  - Case A: QbT: QC (analysis) at the end of each synthesis stage and the final products (6 QC checks)
  - Case B: QbD and PAT: QC only for the product of the primary process (AI), and the final product (2 QC checks)

Inventory variation for one SKU 6versus 2 QC points



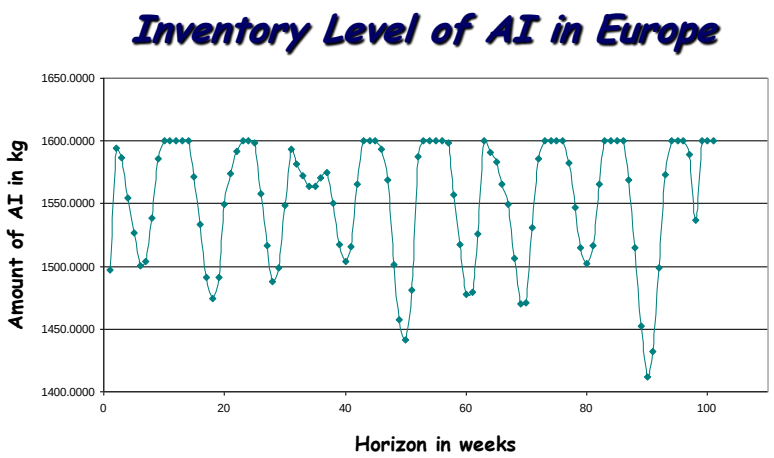


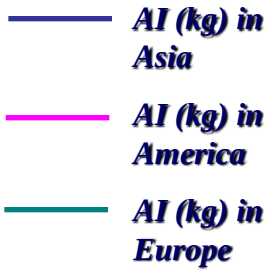
Case A – extra delays cause poor responsiveness

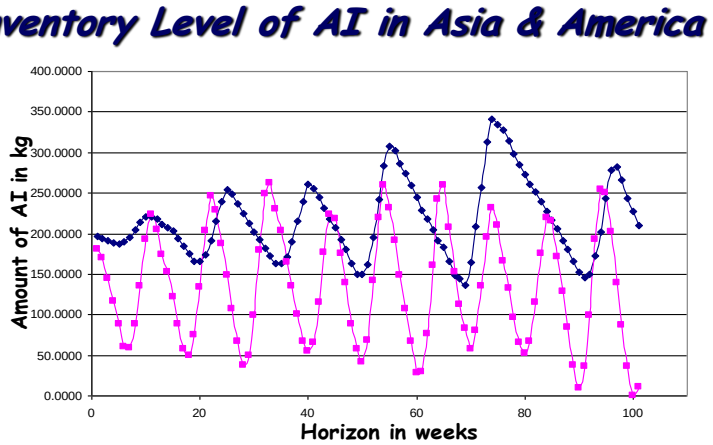
Case B

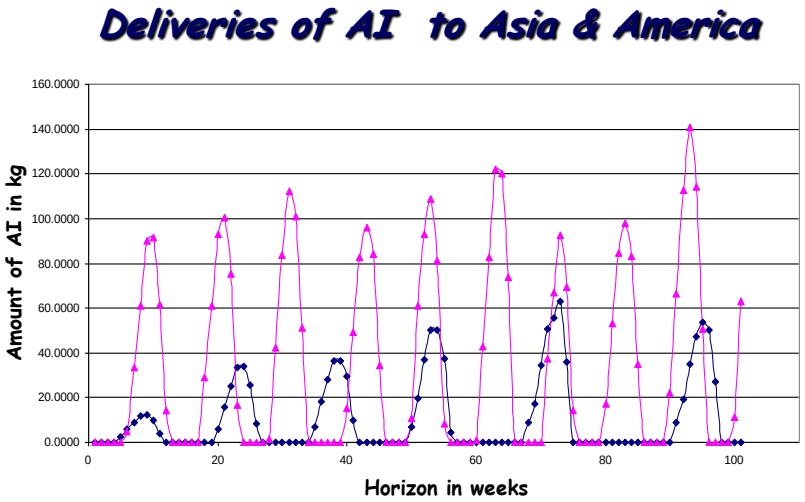
Important to consider supply chain performance when designing processes – use process analytics/digital release rather than lab-based analysis where possible

Control: Results of standard ("feedback") policy



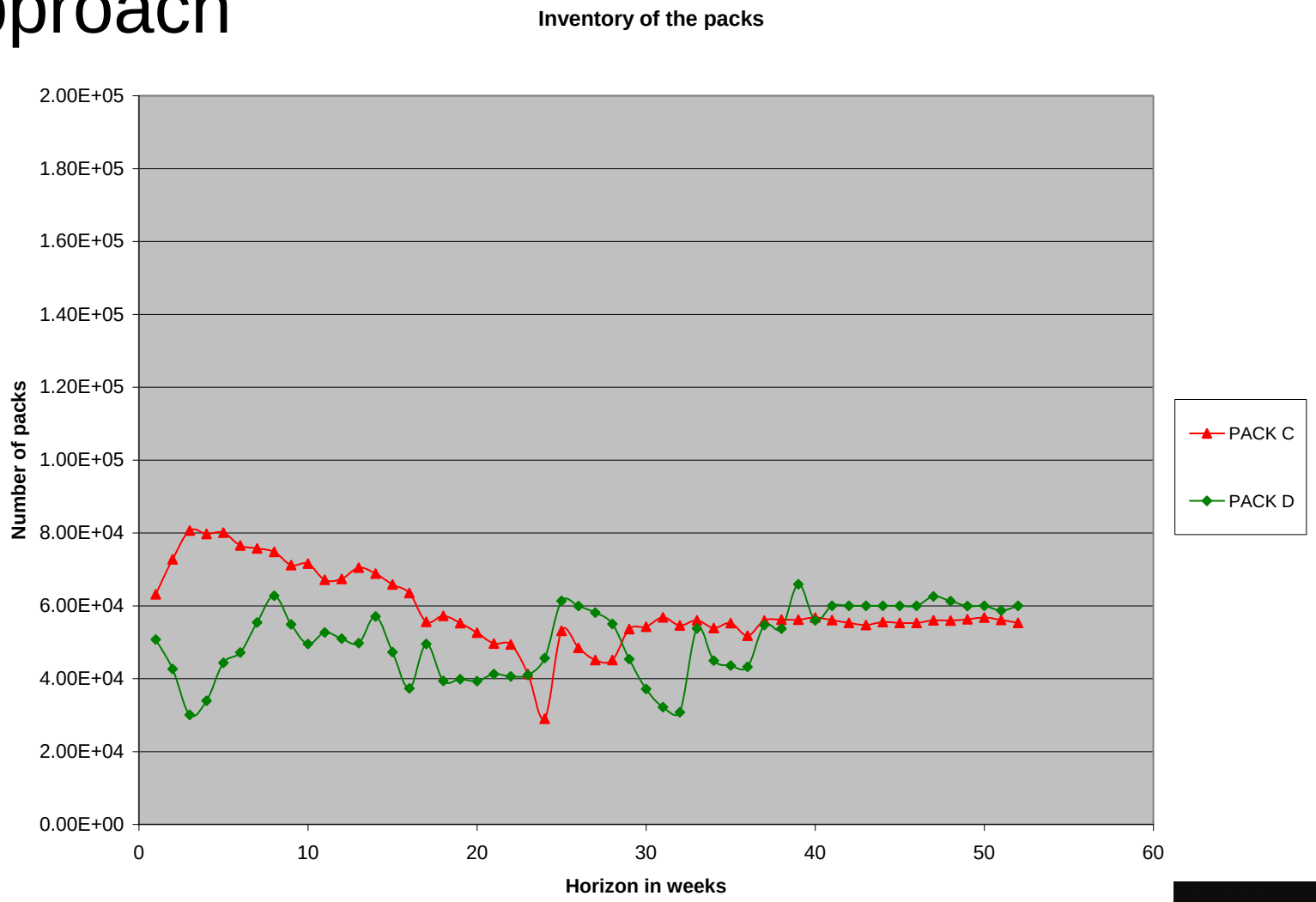






Standard policies introduce internal dynamics and large upstream fluctuations

Results of planning/model predictive control approach



Improved operation for existing chains

- Supply chain is not logistics
- Process industry supply chain strongly affected by flexibility and responsiveness of manufacturing process
- Manufacturing processes have not traditionally been designed with supply chain performance in mind
- Scope for “process design for supply chain responsiveness”
  - E.g. lean, worldscale manufacture of intermediates, mass customisation of final products
  - Process intensificiation and improved control:
    - Operation of processes at intrinsic rates to increase manufacturing velocities
    - Many processes much slower than they need to be
  - Flexible, multipurpose plant of the future…

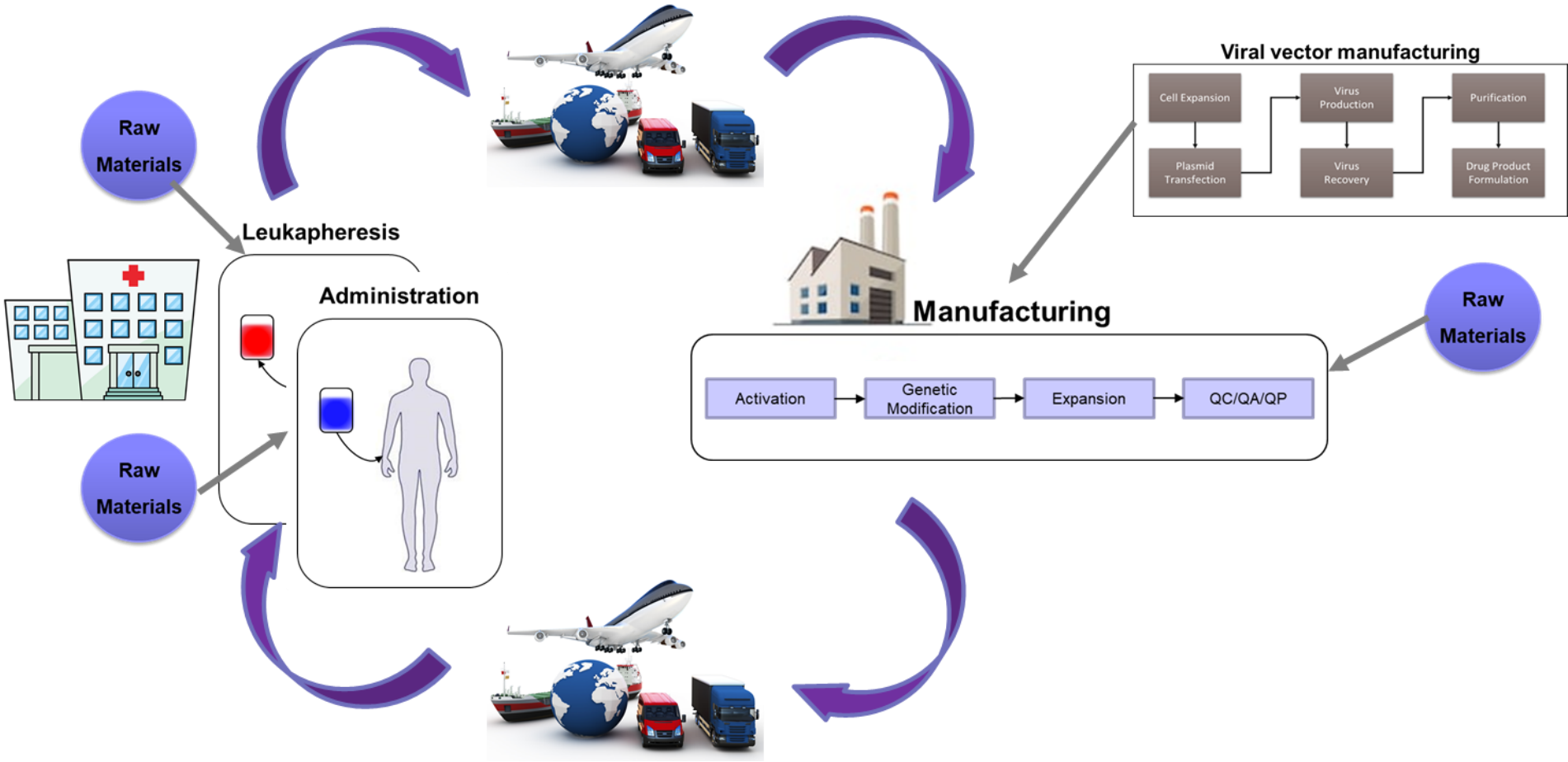
Improved operation for existing chains

- New pressures:
  - Desire to move from product-oriented business to service-oriented business
    - providing life-cycle solutions for customers
    - perception of higher margins and USPs
  - Need to respond ever more rapidly to changing market circumstances
    - shorter product life-cycles
  - Aim of mass customisation
    - E.g. designer drugs which are tailored to small populations
      - existing pharmaceutical supply chains are inappropriate
  - Need to evaluate, report and improve sustainability and environmental and social impacts throughout the supply chain
    - cf. “REACH”
  - Anticipate and respond to future regulation and compliance requirements
    - E.g. responsibility to recover and recycle consumer products at end-of-use

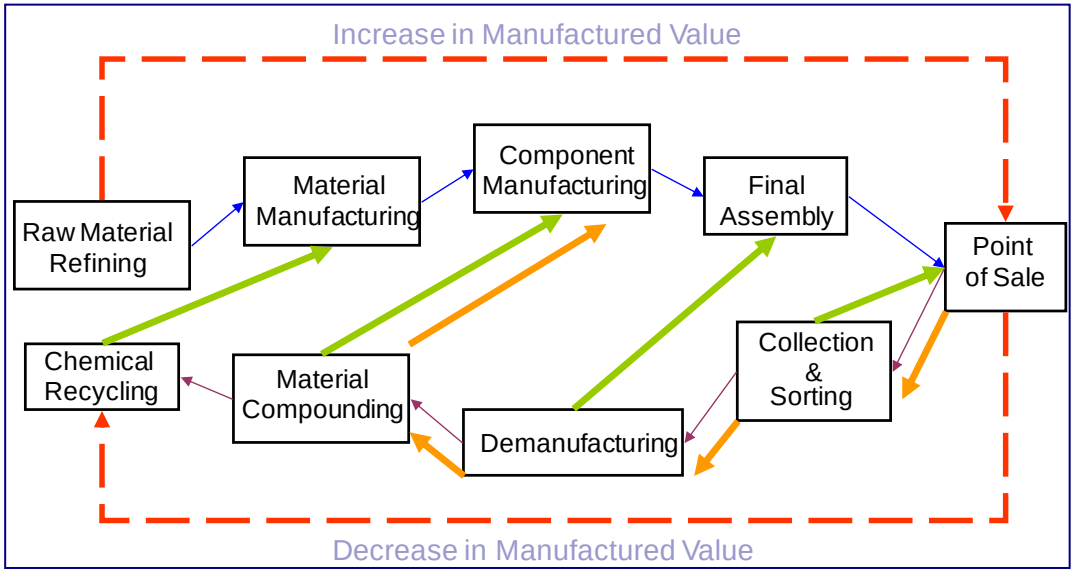
Design of new supply chains

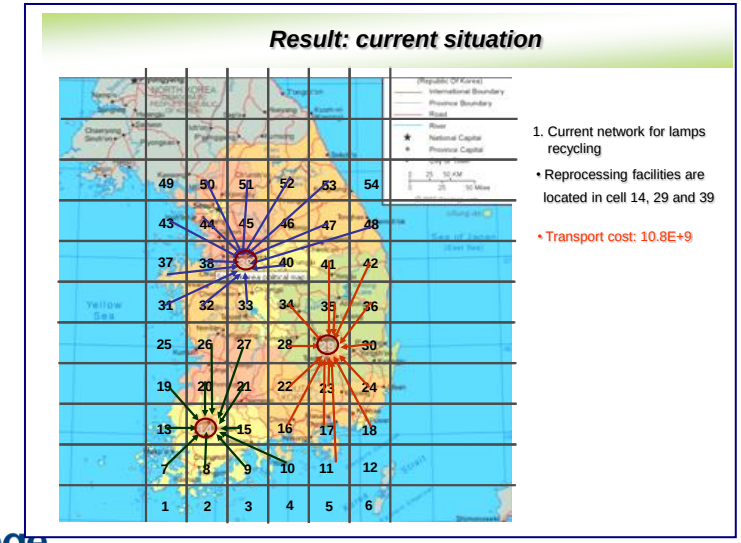
- Supply chains of the future:
  - Hydrogen, and more generally, supply chains to support fuel cells
  - Water
  - Fast response therapeutics (particularly vaccines)
  - Clean Energy: significant pressures for decarbonisation
  - Life science products; customised healthcare
  - Crops for non-food use and biorefineries
  - Waste-to-value and reverse production systems (closed loop supply chains)
- Generic issues
  - Dealing with complexity and scale
  - Consideration of both business processes and physical processes;
  - Dealing with extended enterprises with different information structures and cultures
  - Accounting for significant, often structural, future uncertainties related to strategic decisions

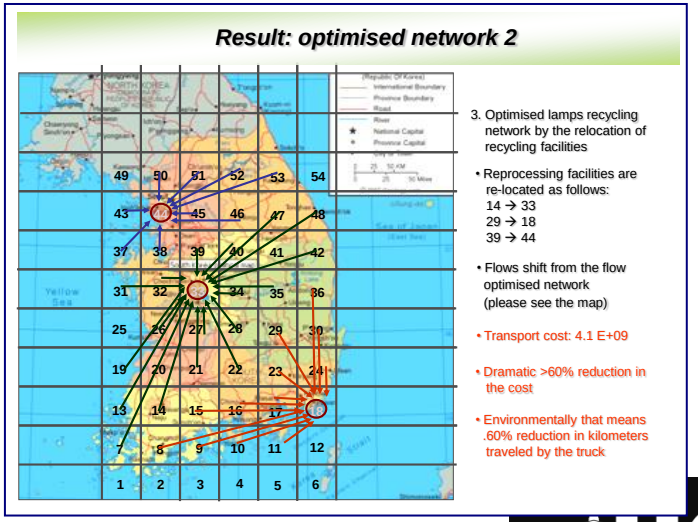
Example: Personalised healthcare



Example: closed loop supply chains







Some 21st century challenges

- Sustainability
  - New energy and material sources
  - Cleaner exploitation of existing sources
  - Increasing scarcity of other resources (H_2O, P, Cu,…)
  - Decarbonised supply chains
  - Waste
- Healthcare
  - Affordable
  - Customised
  - Safe
- Innovation
  - How can engineering and production respond to rapid advances in science?
  - How to mass customise innovative products?