Roadmap Machinery / Equipment / Mechatronics

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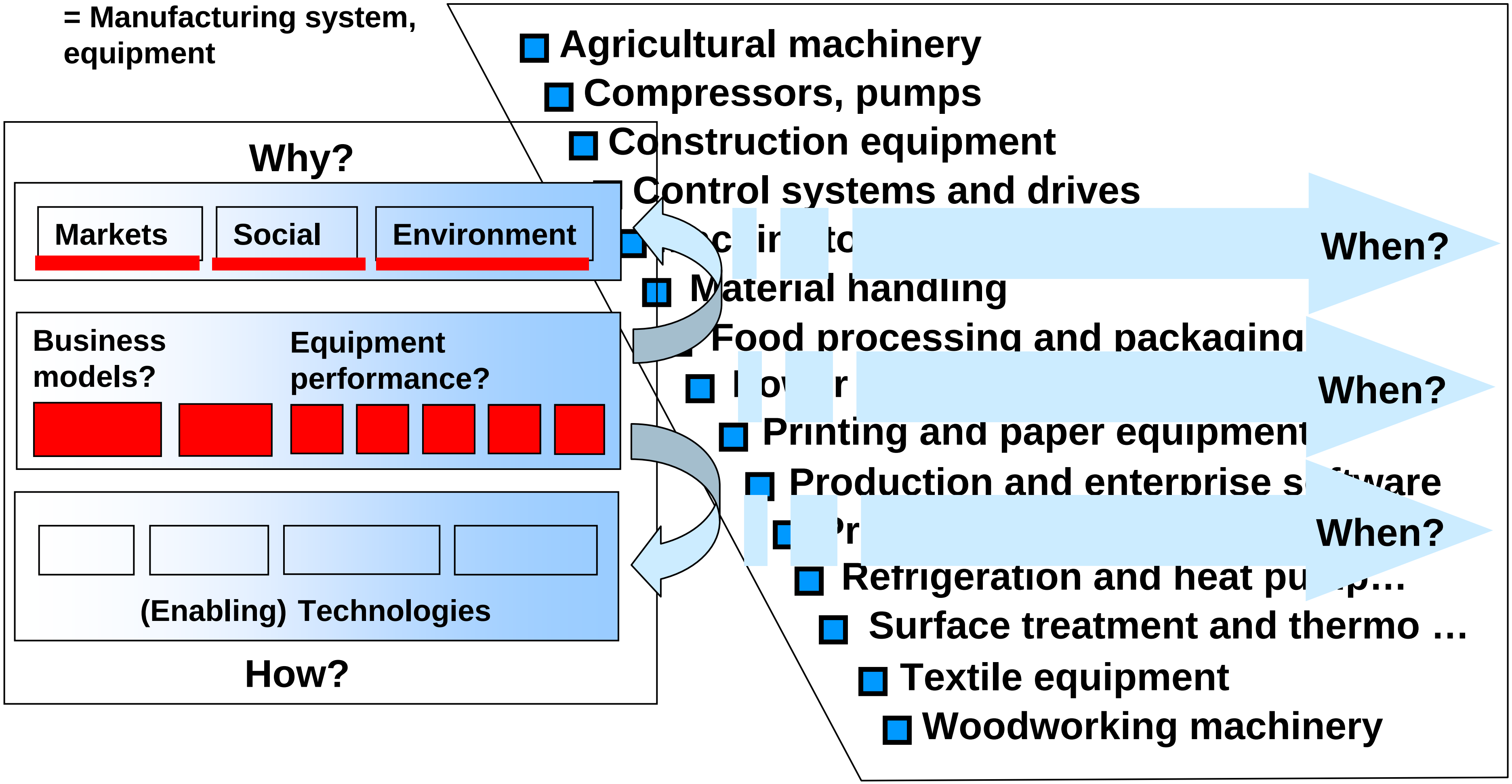
AGORIA

MANUFUTURE-BE

Manufacturing equipment roadmaps

Focus of roadmap
= Manufacturing system, equipment

Manufacturing equipment and components



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Equipment sectors and their targets or drivers

Manufacturing equipment and components

- Autonomy
- Customised machine
- Ergonomic machinery
- Flexible production …
- Healthy and safe …
- Higher precision
- Higher speed
- Miniaturisation of products …
- New business models …
- Productive material processing
- Reliable production systems
- Short time to market
- Total lifecycle cost …

- Agricultural machinery
- Compressors, pumps
- Construction equipment
- Control systems and drives
- Machine tools
- Material handling
- Food processing and packaging
- Power transmission engineering
- Printing and paper equipment
- Production and enterprise software
- Productronics equipment
- Refrigeration and heat pump…
- Surface treatment and thermo …
- Textile equipment
- Woodworking machinery

Equipment/service Performance = high level targets

Equipment sectors and their targets or drivers

- **Autonomy**
- **Customised machine**
- **Ergonomic machinery**
- **Flexible production systems**
- **Healthy and safe human machine (co)operation**
- **Higher precision**
- **Higher speed**
- **Miniaturisation of products and production…**
- **New business models – total solution delivery**
- **Productive material processing**
- **Reliable production systems**
- **Short time to market**
- **Total lifecycle cost (incl… environm. cost)**

Equipment/service Performance = high level targets

Equipment sectors and their targets or drivers

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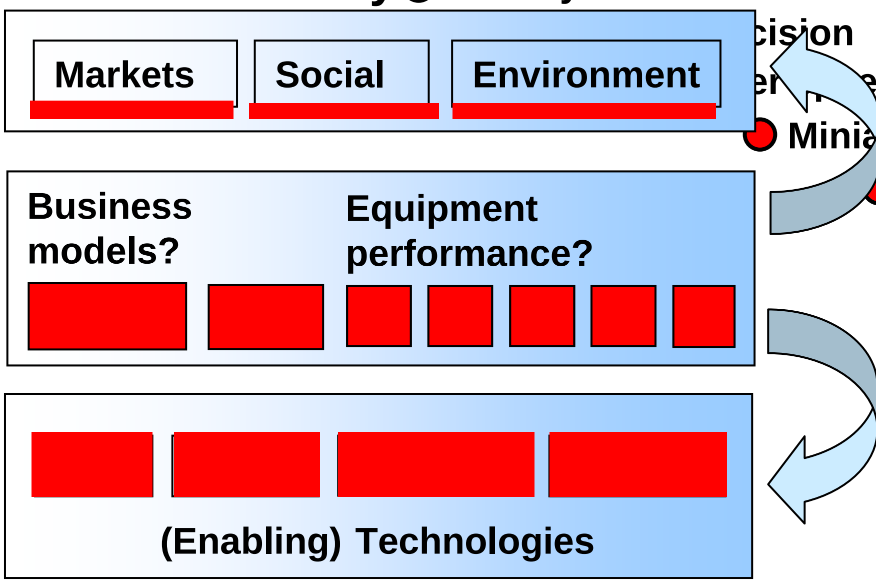
- Short time to market
- Total lifecycle cost

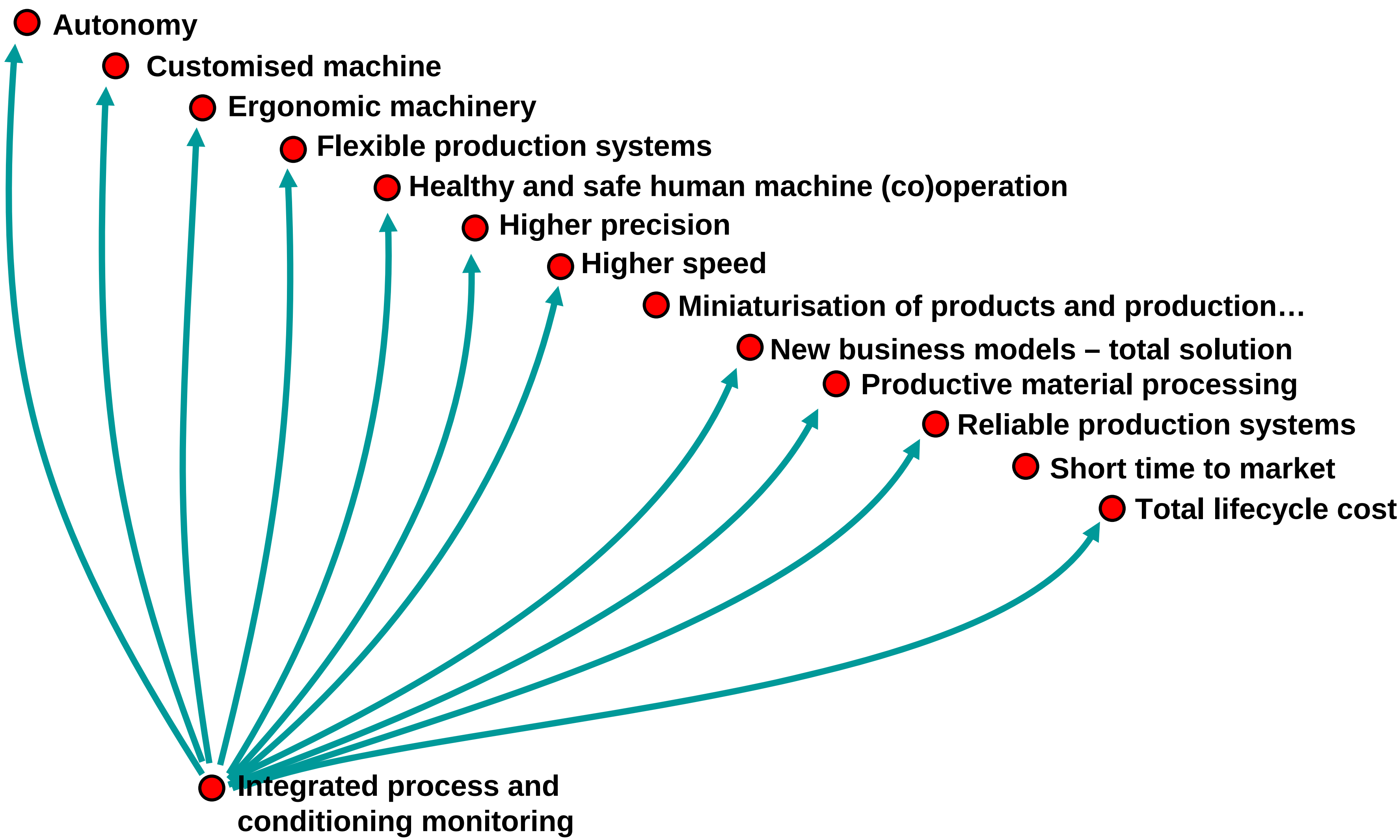
Why?



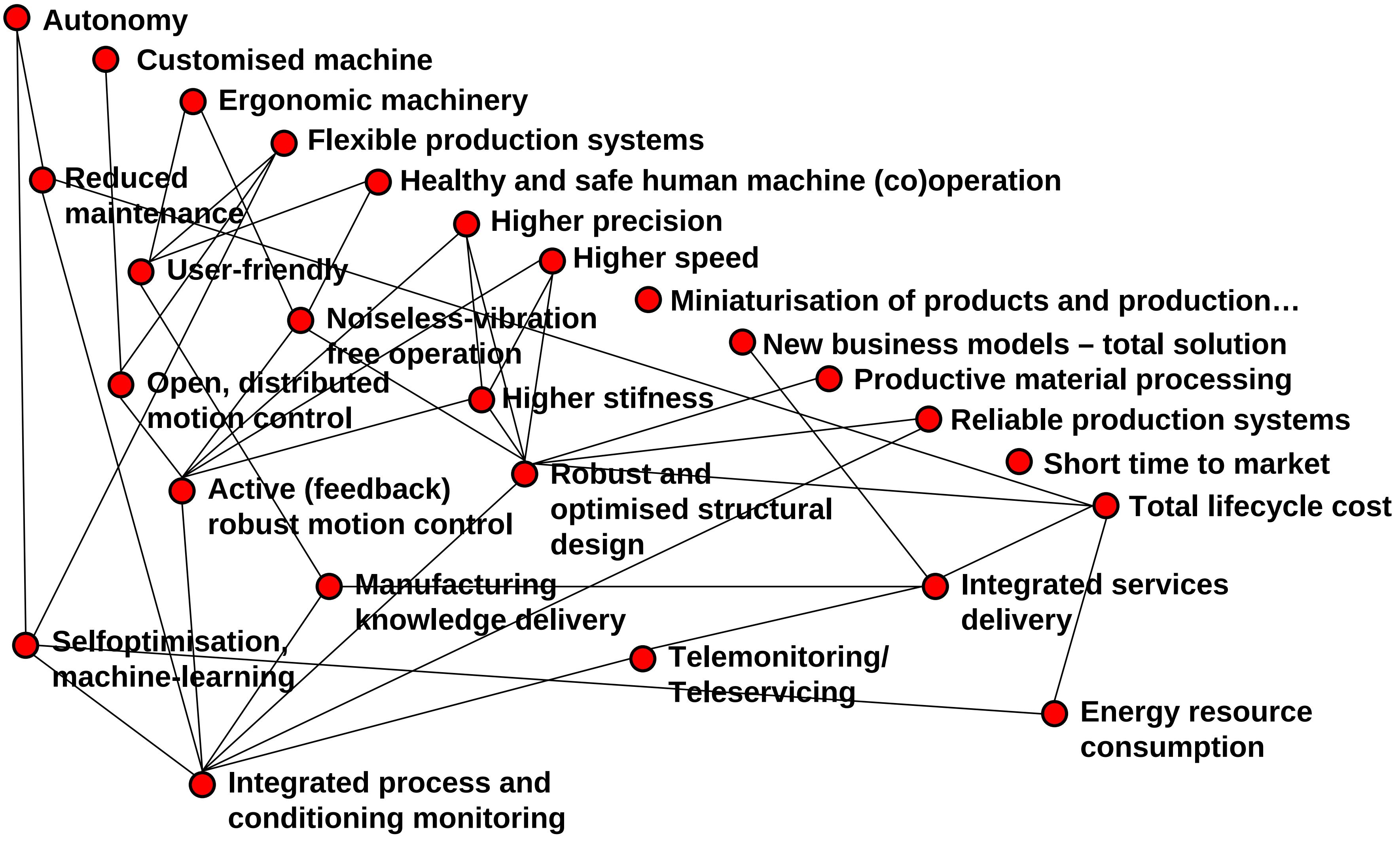
How?

Equipment/service Performance Requirements

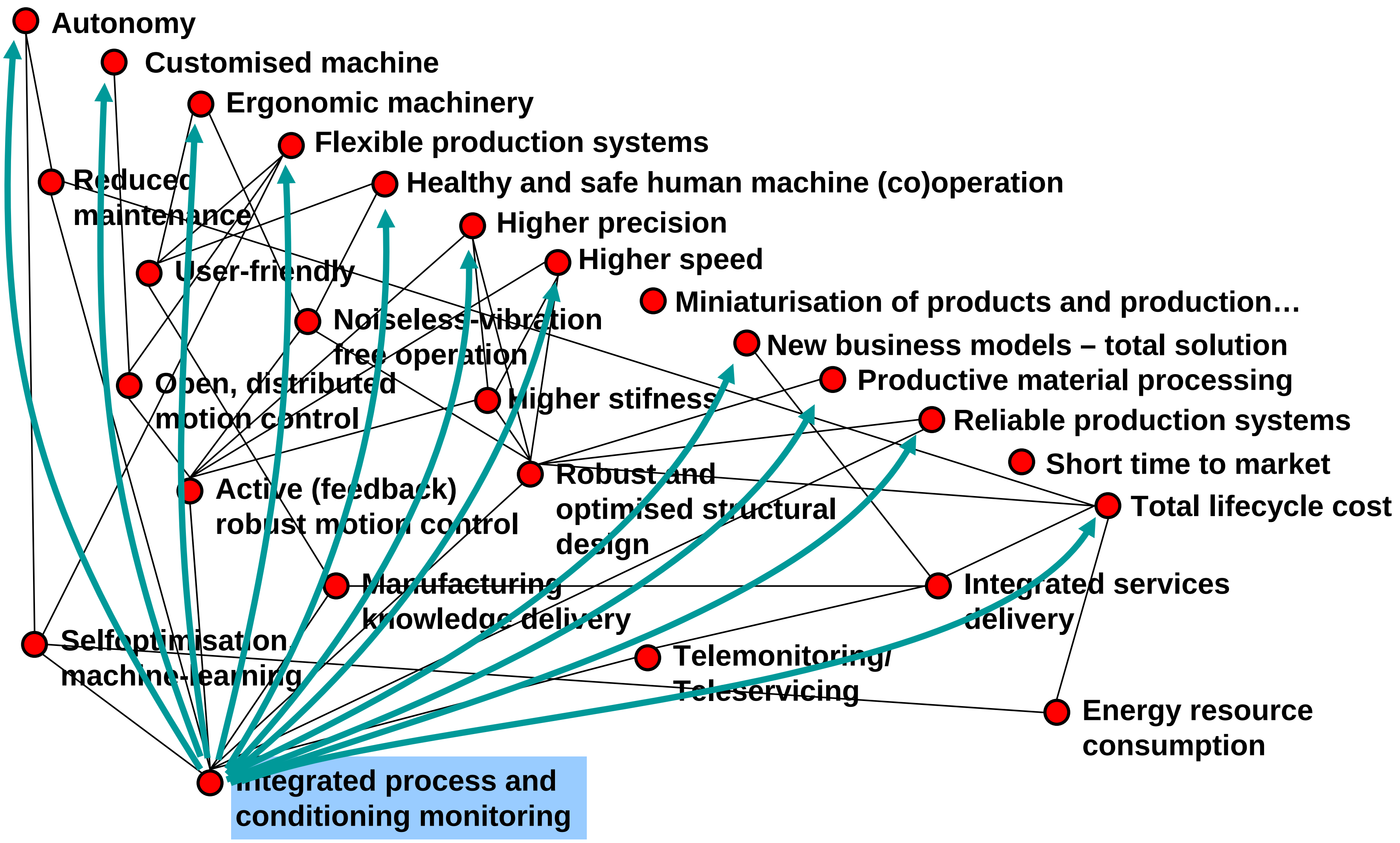
Equipment sectors and their targets or drivers

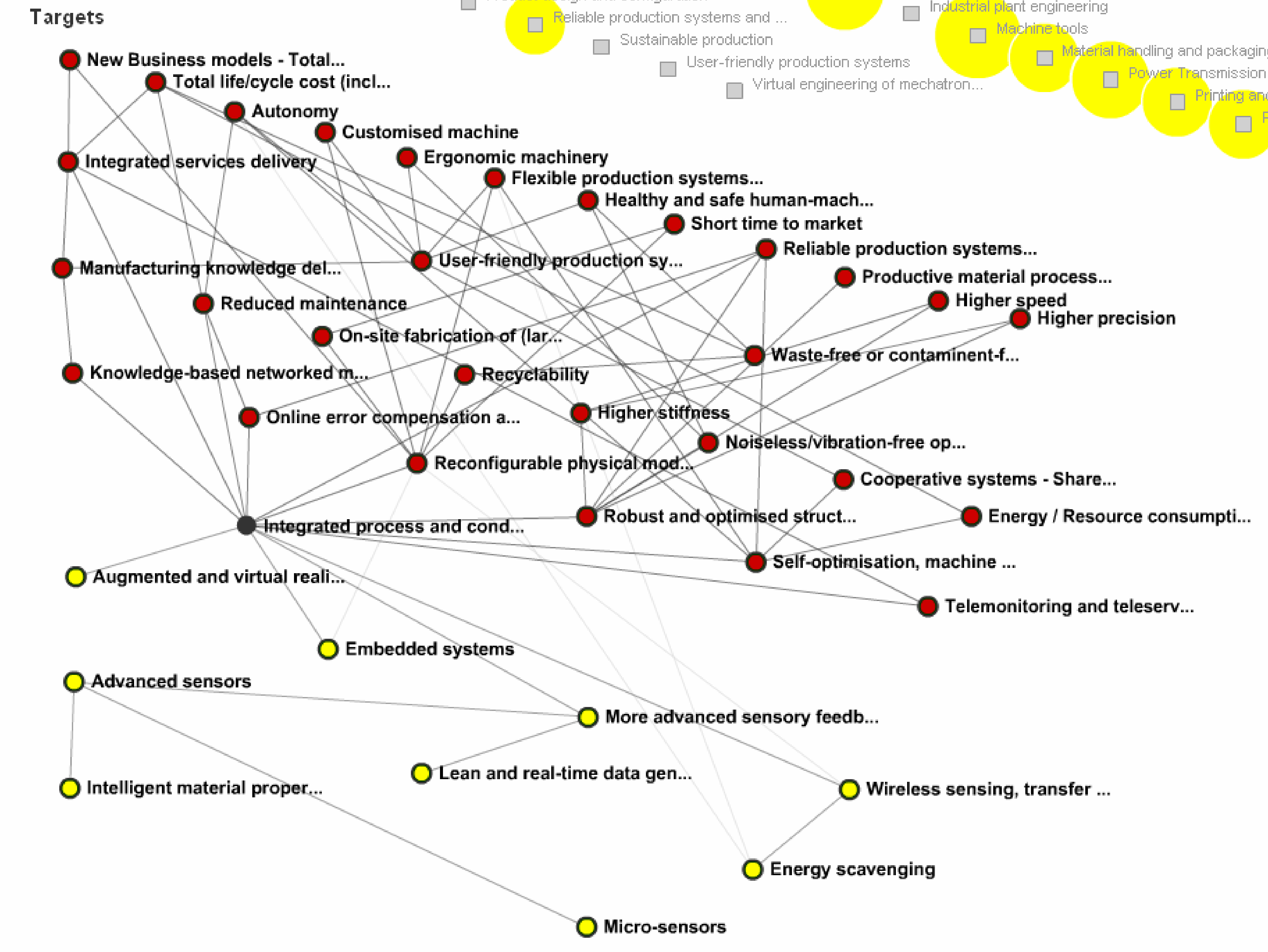


Equipment sectors and their targets or drivers



Equipment sectors and their targets or drivers





Targets
Reliable production systems and ...
Sustainable production
User-friendly production systems
Virtual engineering of mechatron...
Industrial plant engineering
Machine tools
Material handling and packaging
Power Transmission
New Business models - Total...
Total life/cycle cost (incl...
Autonomy
Customised machine
Integrated services delivery
Ergonomic machinery
Flexible production systems...
Healthy and safe human-mach...
Short time to market
Reliable production systems...
Manufacturing knowledge del...
User-friendly production sy...
Productive material process...
Reduced maintenance
Higher speed
Higher precision
On-site fabrication of (lar...
Waste-free or contaminent-f...
Knowledge-based networked m...
Recyclability
Online error compensation a...
Higher stiffness
Noiseless/vibration-free op...
Reconfigurable physical mod...
Cooperative systems - Share...
Integrated process and cond...
Robust and optimised struct...
Energy / Resource consumpti...
Self-optimisation, machine ...
Augmented and virtual reali...
Telemonitoring and teleserv...
Embedded systems
Advanced sensors
More advanced sensory feedb...
Lean and real-time data gen...
Intelligent material proper...
Wireless sensing, transfer ...
Energy scavenging
Micro-sensors

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Equipment sectors and their targets or drivers

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Equipment/service Performance Requirements

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- Total lifecycle cost …

Equipment sectors and their targets or drivers

Integrated mechatronics design methods and tools

- Autonomy
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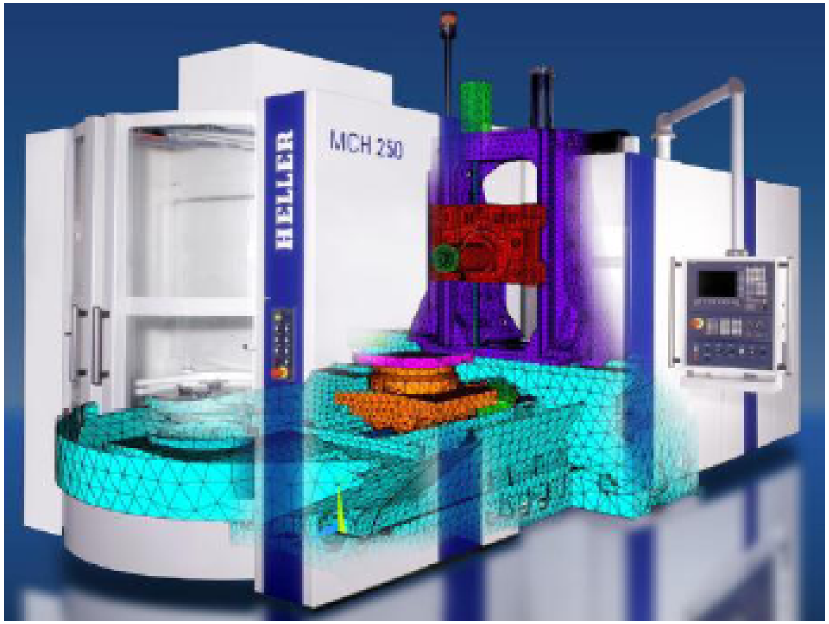
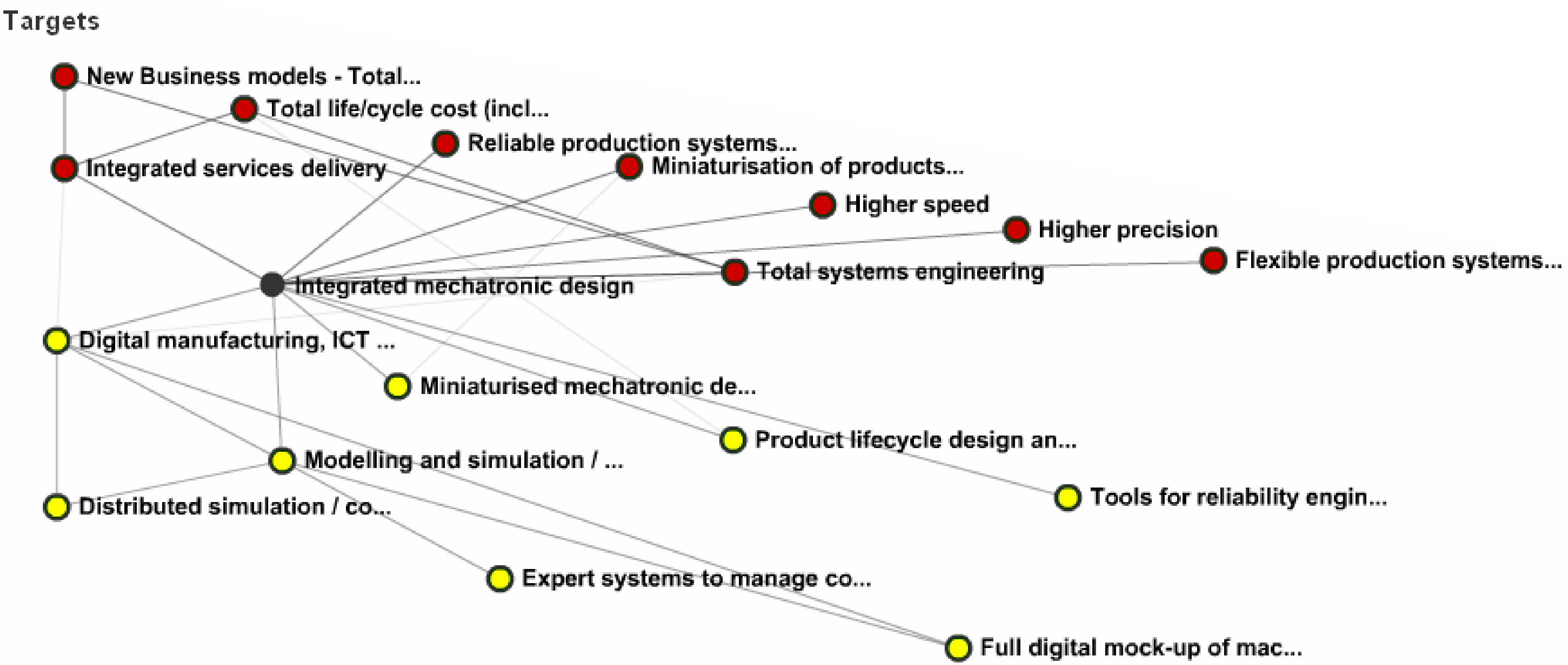
Virtual machine tool development and testing

Holistic assessment of machine and performance properties in early stages of machine tool development



Equipment/service Performance Requirements

Integrated mechatronic design – Modelling and simulation



Integrated mechatronic design – Modelling and simulation

As the mechatronic approach of the design of (production) systems heavily leans upon the ***systems approach*** to the design of controlled systems, all aspects of the mechatronic design process obviously need *software support*,

This need is addressed by ‘virtual engineering’ a terminology inspired by ‘virtual prototyping’, even though the final results are quite real and the distances to real systems and subsystems should be quite small (e.g. hardware-in-the-loop, model-based control, etc.).

Many software tools that support aspects of (mechatronic) design already exist.

They range from (process) planning tools, via MIS-Project Management tools, CAD, CAE and FEM tools to controller design tools and dynamic simulation tools, …

… but many are linked to a specific domain and jargon.

Integrated mechatronic design – Modelling and simulation

Shorter time-to-market, miniaturization, high-performance, total life-cycle design, user-friendly, reliable and flexible operation make structured, fast and synergistic conceptualization, innovation and diagnostics (‘learn from previous mistakes’) into key needs in production.

- *Therefore, first the initial requirements to achieve these targets are identified: insight, abstraction, cross-fertilization, domain-independence (multidisciplinarity), etc.*
- *At a secondary stage, this requires application of dynamics and control, (differential) geometry, network and graph theory, statistics and measurement, tribology, construction, etc.*
- *In turn, these enablers require good support of general areas like physics, mathematics, marketing, operations research, etc. All this is available, but in many cases only scattered, fragmented and isolated.*

Not only missing is a **truly integrated environment for the already existing tools**, combined with a proper common library environment that enables quick retrieval, reuse and tracking,

but also, and even more importantly, **an environment of tools that supports the decisions of the user, which can all be considered modelling and design decisions in a wide sense** and which should be taken to feed the above mentioned methods-skills-tools with information based on initial requirements as well as intermediate results of (other) tools.

Integrated mechatronic design – Modelling and simulation

In all cases the user of such tools should be supported by sufficient knowledge of what the tool is actually doing for him and the ability to decide when the support of an expert is required and, not in the last place, which expert should be consulted in such cases of doubt.

This means that the virtual engineering environment should not only support the mere process, but also contribute to the permanent education of the user.

Such a support strongly depends on the nature of the problem (conceptual design, detailed design, trouble-shooting, diagnosis, etc., but should not only support the user, **but also keep him from drifting away from his original goal**.

Furthermore, it should take the user out of his common context and jargon and thus facilitate communication with experts in other fields to stimulate synergy and cross-fertilization.

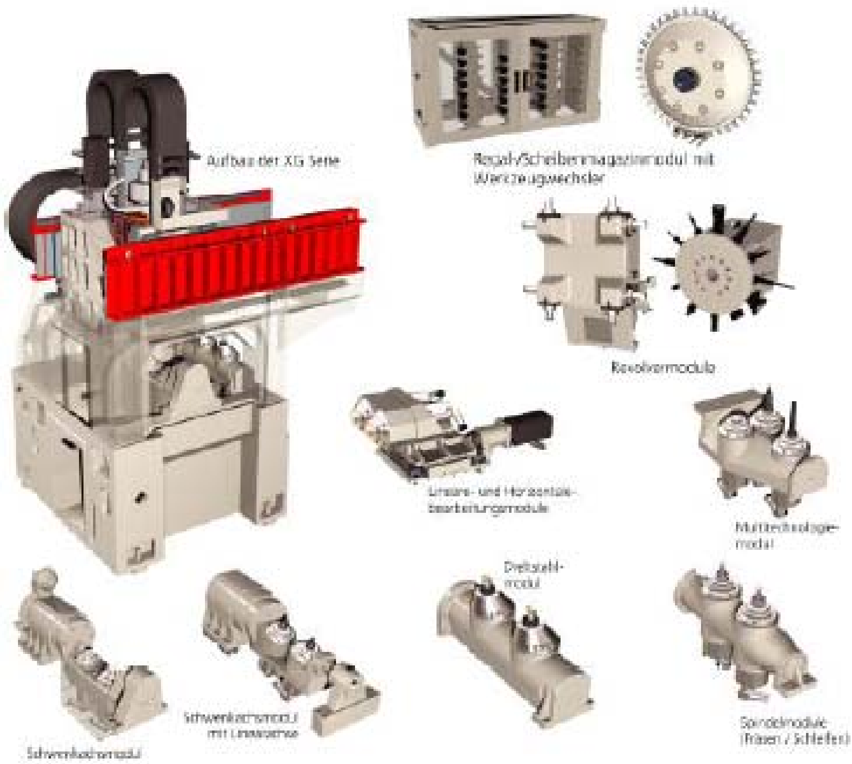
Reconfigurability - Flexibility

Reconfigurability - flexibility

- Autonomy
- Customised machine
- Ergonomic machinery
- Flexible production …
- Healthy and safe …
- Higher precision
- Higher speed
- Miniaturisation of products …
- New business models …
- Productive material processing
- Reliable production systems
- Short time to market
- Total lifecycle cost …

Multi technology, reconfigurable machines

Multi dimensional flexibility with with agile machine concepts



Equipment/service Performance Requirements

Reconfigurability – Flexibility – Modularity

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Modularity

- Autonomy
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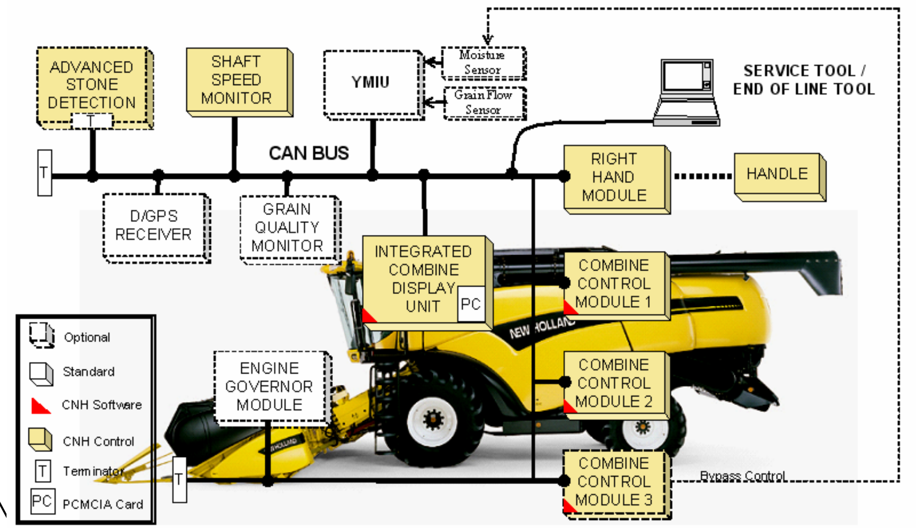
- Short time to market
- Total lifecycle cost …

Quality and product security - monitoring

Modular systems - configurations

Energy efficiency



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Equipment/service Performance Requirements

Reconfigurability – Flexibility – Modularity – Customised machines

Customisation

- Autonomy
- Customised machine
- Ergonomic machinery
- Flexible production …
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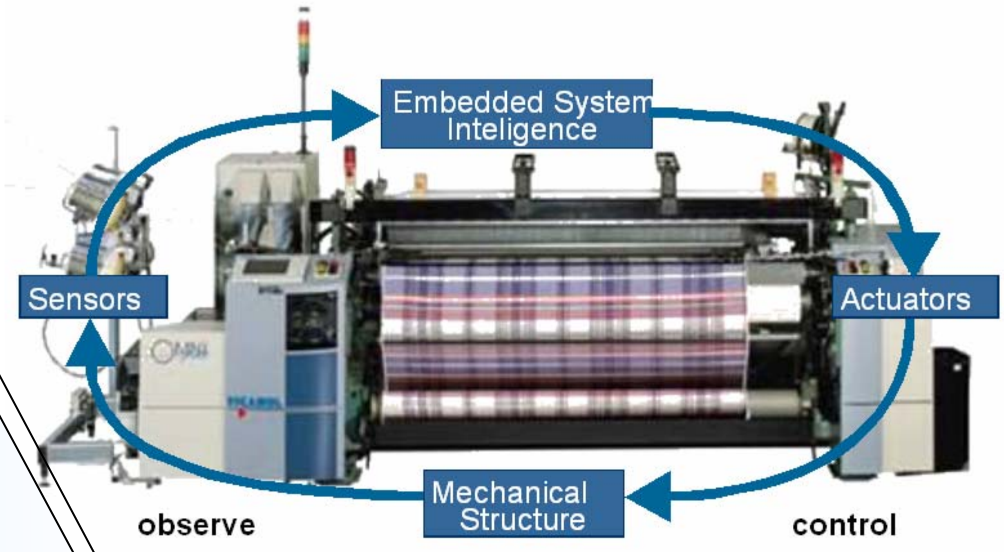
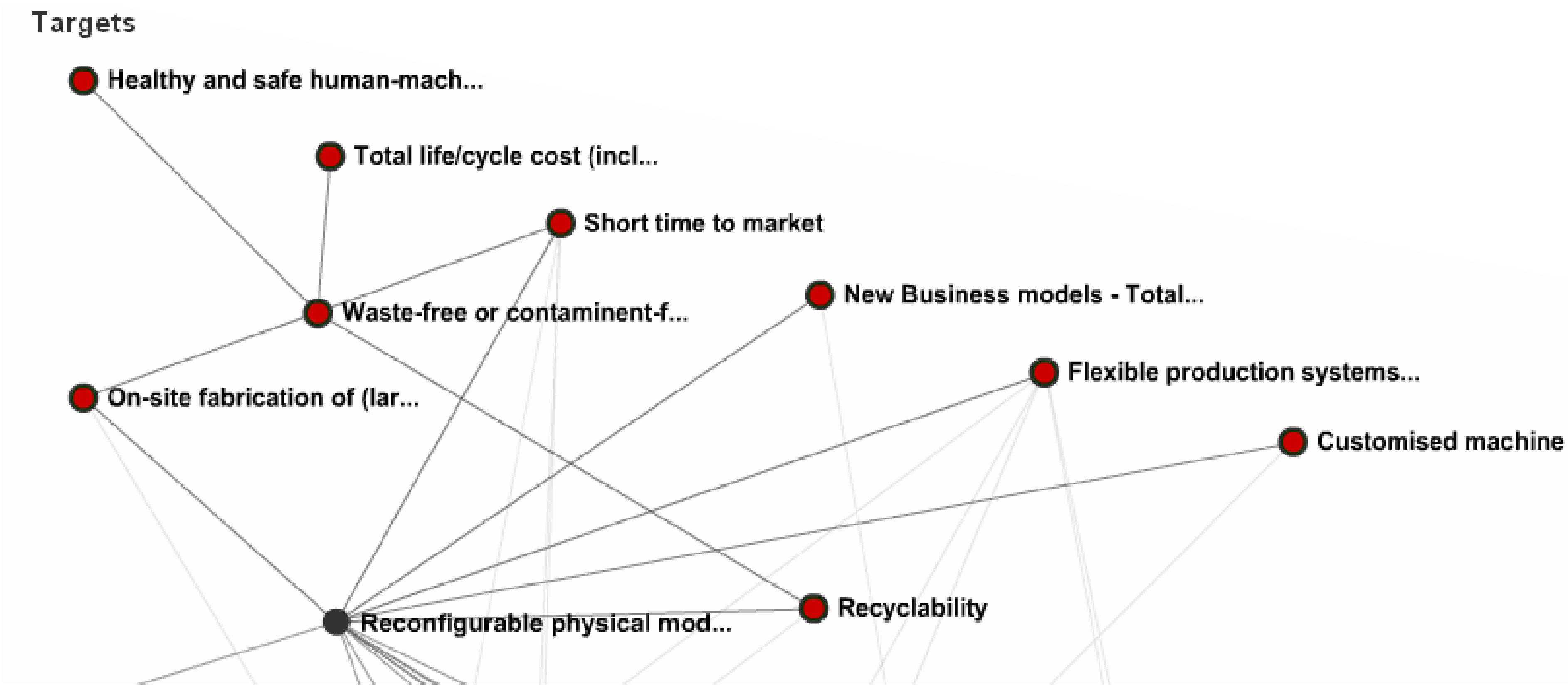


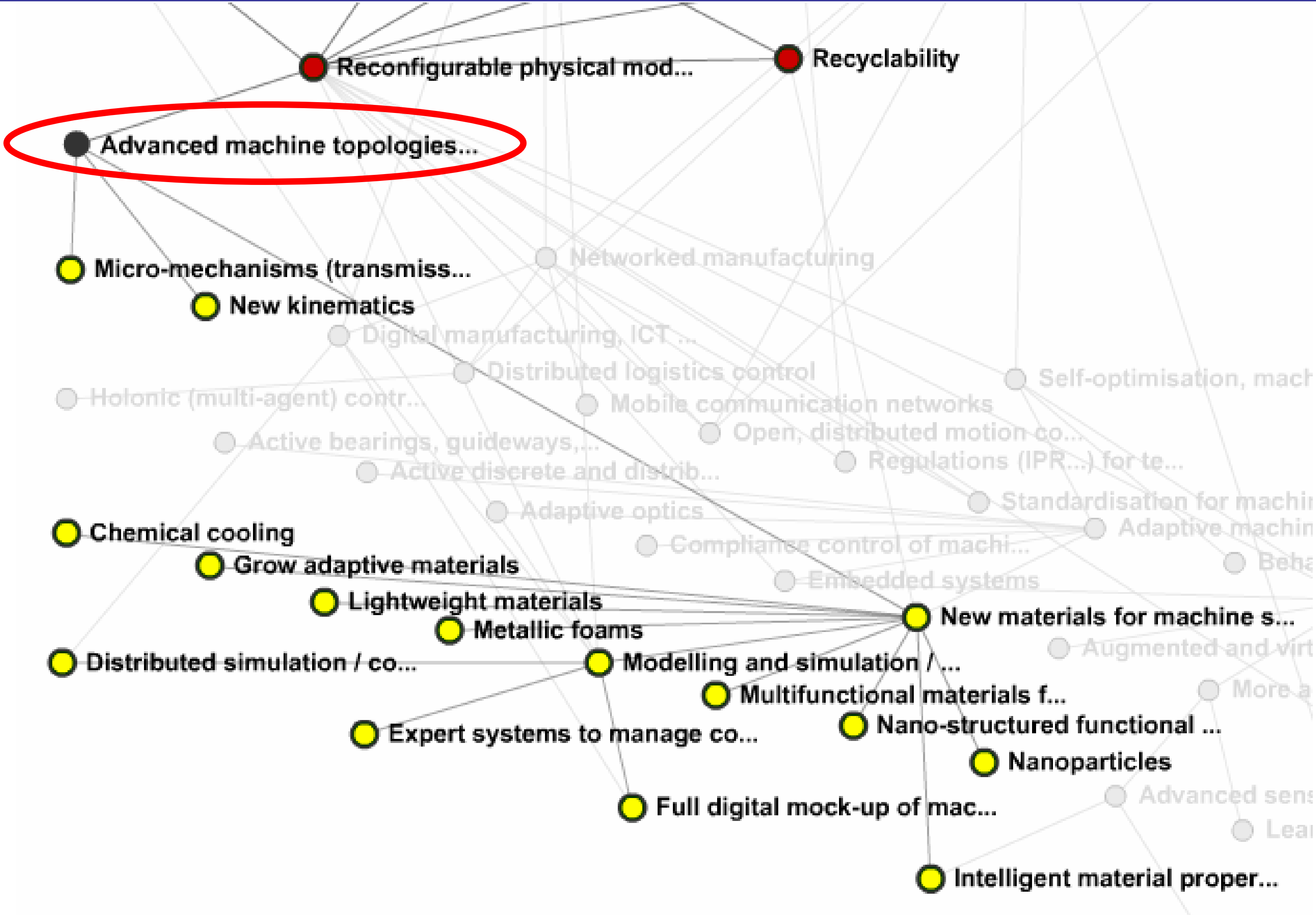
Costumised machines for technical textiles

Equipment/service Performance = high level targets

Reconfigurability - flexibility



Reconfigurability - Flexibility



Reconfigurability - Flexibility

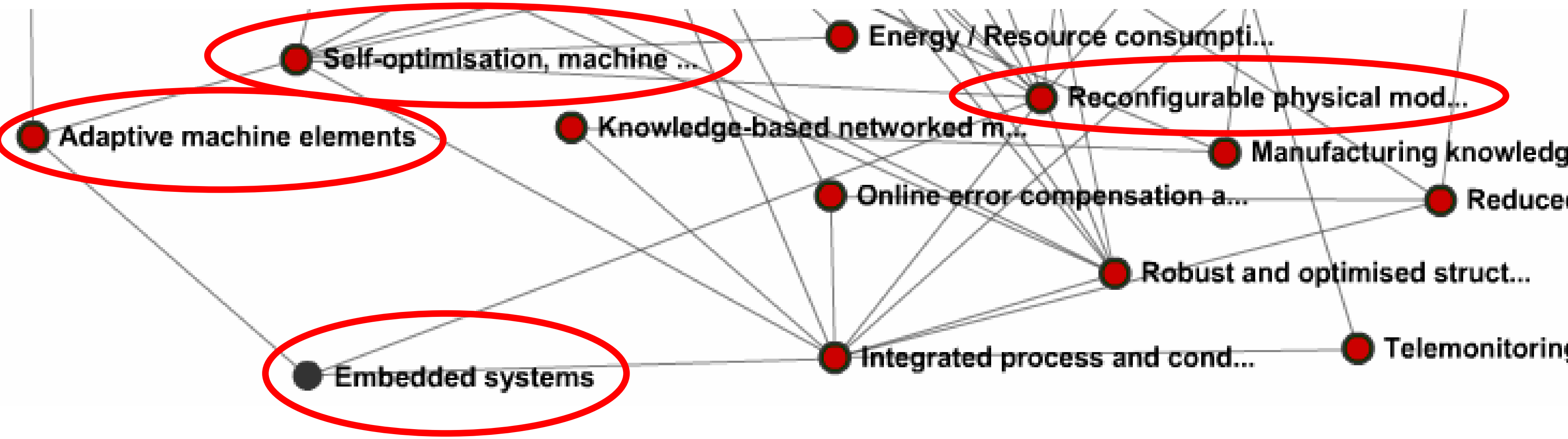
Flexibility enables rapid and robust change over to another task in case of rush orders or technology changes, in particular in case of small batch sizes, and it keeps lines operational during maintenance and cleaning.

It can be achieved by **introducing modularity, scalability and reconfigurability into the machine design**.

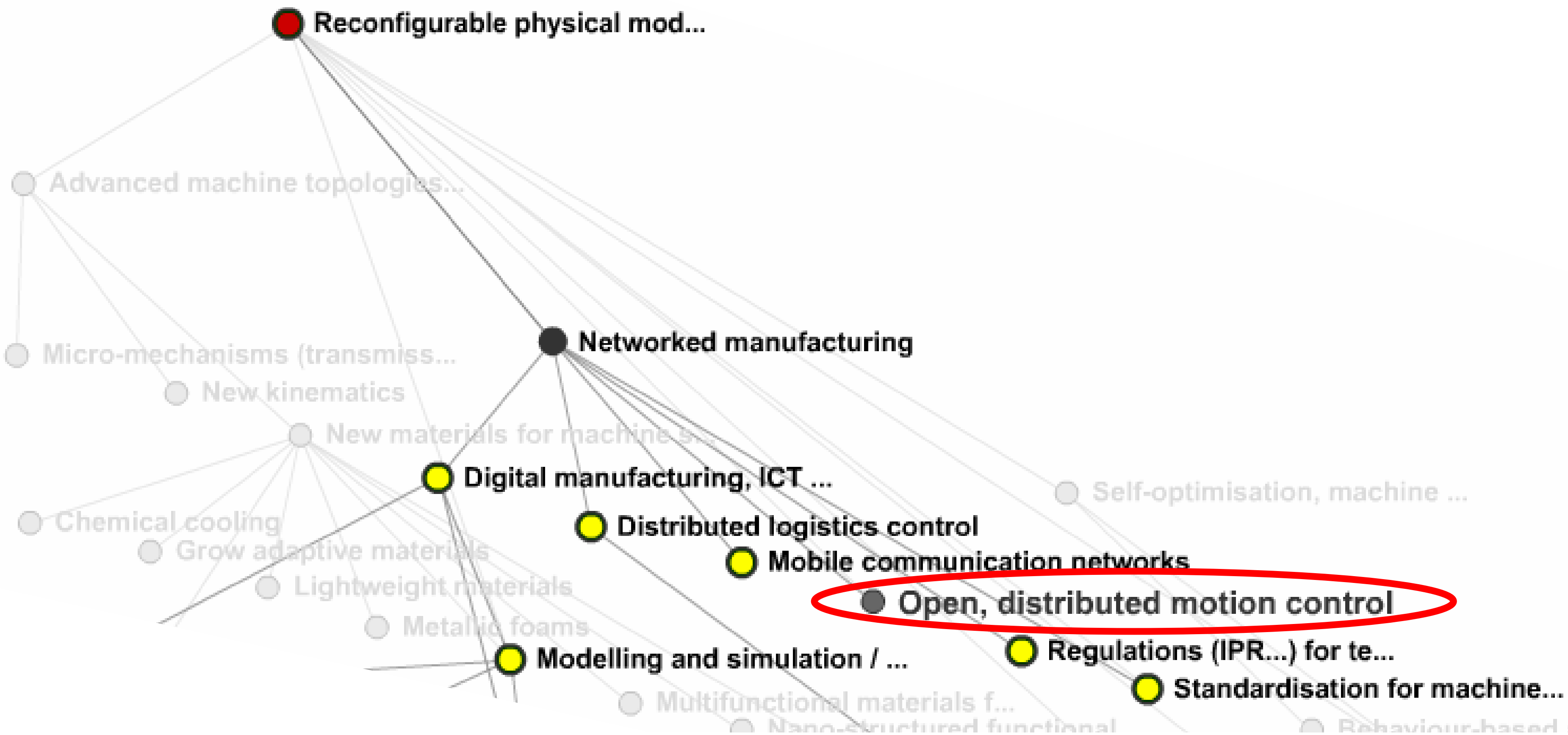
This not only enables short-time-to-market for the end-user, but also facilitates maintenance, troubleshooting and cleaning, as well as support of conceptual design of system & machine, provided consistent virtual engineering tools are available. It thus results in cost reduction for low volume production, maintenance/cleaning and (re-)design.


Healthy and safe human-mach...
Total life/cycle cost (incl...
Short time to market
Reliable production systems...
New Business models - Total...
Waste-free or contaminent-f...
Flexible production systems...
Ergonomic machinery
User-friendly production sy...
Customised machine
Autonomy
Cooperative systems - Share...
On-site fabrication of (lar...
Recyclability
Energy / Resource consumpti...
Self-optimisation, machine ...
Reconfigurable physical mod...
Adaptive machine elements
Behaviour-based and biologi...
Active bearings, guideways,...
Active discrete and distrib...
Adaptive optics
Integrated process and cond...
Compliance control of machi...
Chemical cooling
Embedded systems
Grow adaptive materials
Lightweight materials
New materials for machine s...
Metallic foams
Augmented and virtual reali...
Distributed simulation / co...
Modelling and simulation / ...
More advanced sensory feedb...
Multifunctional materials f...
Wireless sensing, transfer ...
Expert systems to manage co...
Nano-structured functional ...
Nanoparticles
Advanced sensors
Full digital mock-up of mac...
Lean and real-time data gen...
Energy scavenging
Intelligent material proper...
Micro-sensors

Reconfigurability - Flexibility



Reconfigurability - Flexibility



Reconfigurability - Flexibility

In order to realize flexibility attention is required for various kinds of **distributed and reconfigurable control** ranging from logistics automation (feedforward) to closed-loop motion control (feedback) and at different levels: production line, machine, components, etc.

Flexibility also requires the ability to automatically adapt to changes in module topology. This means that **control needs to be embedded in software units with specific objectives and own adaptive capabilities**. The **holonic, biologically inspired control algorithms** (e.g. based on ant colony engineering) for collaboration of these modules or agents should autonomously provide optimised operations and controls without jamming a centralised monitoring system.

Physical modularity requires **scalable** modules with **standardized physical interfaces**. This means Plug-and-Play technologies integrated into components, machines and their interfaces, for enhanced modularity and down-to-zero set-up time of machines and plants.

Reconfigurability - Flexibility

In turn this requires in-process sensing and measuring and consequently technologies and methods for machine condition monitoring, machine data collection, data mining, pattern recognition, decision-making, etc to improve process stability and machine reliability and precision by means of closed-loop, adaptive control

(with particular attention for algorithms to evaluate the current and planned operation modes and their predicted stability and effect on the machine reliability in an autonomous and adaptive ('learning') way)

Results in the field of **adaptive and learning control** theory should be further developed such that they can be used to automatically retune the controller in an optimal way after configuration changes in the process.

Reconfigurability - Flexibility

This means attention for **methods and tools for data structuring and handling inside each machine** (sensors, electrical signals, etc), to dynamically extract useful knowledge only and master increasing complexity, which enables the control of more complex and dynamic processes. **Methodologies and techniques for machines cooperating as intelligent devices in manufacturing networks**, with global production objectives are thus needed, as well as machines with capabilities related to decision-making on workload balancing.

In specific cases the flexible network and busses that follow from this approach can only be realized by **wireless connections** requiring battery operation. This requires sensors and actuators that can 'scavenge' their energy from the production or transport operations that are being monitored and controlled, preferably in an autonomous way.

This **also enables tele-monitoring and teleservicing, i.e. remote diagnosis**, for which new technologies and methods are to be developed, like ubiquitous machine control and information management: 'handset' devices controlling machines, contact-free power transmission, wireless sensors, etc.

Year 1

DRAFT

http://manufuture2006.fi/presentations/

Activity 4.3 **New Production** (10 topics)

LArge SMall SME

4.3.1 Development and validation of new industrial models and strategies (3 topics)

4.3.1-1 Beyond Lean Manufacturing – New industrial models for products and process life cycle - LA

4.3.1-2 New added-value user-centered products and product services – SME dedicated

4.3.1-3 Integrated risk management in plants, industrial parks, industrial systems and networks - LA

4.3.2 Adaptive production systems (2 topics)

4.3.2-1 Rapidly configurable machines and production systems - SM

4.3.2-2 Process intensification in chemical production - SM

4.3.3 Networked production (1 topic)

4.3.3-1 Innovative customer-driven product-service design in a global environment - SM

4.3.4 Rapid transfer and integration of new technologies into the design and operation of manufacturing processes (2 topics)

4.3.4-1 Rapid manufacturing concepts for small series industrial production – SME dedicated

4.3.4-2 Innovative pathways in Synthesis – improving efficiency by smart synthesis, design and reduction of the number of reaction steps - SM

4.3.5 Exploitation of the convergence of technologies (2 topics)

4.3.5-1 Processes and equipment for high quality industrial production of nano-surfaces - LA

4.3.5-2 Production technologies for micro-manufacturing - LA

Rapidly Configurable Machines and Production Systems

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Technical Content/Scope:

The main objective is to achieve optimal production system performance under varying conditions through the creation of radically new self-adaptive machine structures. Key development targets are: (1) "adaptronic" modules and interfaces integrating sensors, actuators, control and mechanical structures; (2) mechatronic modelling and simulation tools for rapid and optimised system configuration.

Funding Scheme: ***Small or medium-scale focused research projects***

Special Features: ***Industrial leadership; standardisation and interoperability***

Expected Impact: ***Reduced set-up, reconfiguration and maintenance time; increased small batch production productivity; reduced resources consumption***

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Multi-annual implementation plan

SEVENTH FRAMEWORK PROGRAMME

Adaptive Production Systems

Rapidly Configurable Machines and Production Systems

Self-learning Production Systems

…….

Industrialisation through new integrated processes

Scalable Control Systems for Adaptive and Responsive Factories

Process Intensification in Chemicals Production

Improving Quality and Reliability of Intensified Components and Devices

Process Intensification in Metals Production

Application of Alternative Forms of Energy for Process Intensification

…….

Intelligent complex manufacturing systems and equipment for processing and handling biological materials in the food industry

Manufacturing systems and technologies for 3D production of mass customised products based on flexible materials

Flexible small/single batch production

Optimal production

Continuos adaptation

Affordable intelligent technologies and components

Resource efficient, sustainable production

Y1 Y2 Y3 Y4 …

http://manufuture2006.fi/presentations/

New Consumer Oriented Business Models (LSCP) *(Manufuture ETP)*

- **Technical content / scope:** Definition and development of new business models able to cope with new product concepts: further transition from products to solutions; improved and increased involvement of the consumer in more parts of the value chain; increased importance of smaller businesses working in collaboration to form a value system.

Self-learning Production Systems (SSCP) *(Manufuture ETP)*

- **Technical content / scope:** To support reconfiguration of systems without end-user involvement: self-learning systems through the development of multi-layer controls and model-based real-time compensation routines, embedding process (e.g. machining) knowledge. (Note: topic linked with Y1 topic **Rapidly Configurable Machines and Production Systems)**

Scalable Control Systems for Adaptive and Responsive Factories (LSCP) *(Manufuture ETP)*

- **Technical content / scope:** Multilayer, interconnected distributed control systems in support of lower development, set-up and ramp-up costs & times – from product innovation management systems, over to factory level control (management information systems, digital factory, concurrent engineering) down to machine/process level control.

Supply Chain Integration and Real-Time Decision Making in Non-hierarchical Manufacturing Networks (LSCP) *(Manufuture ETP)*

- **Technical content / scope:** The objective is to support the supply chain integration and production/operation management in non-hierarchical company networks, which is a very complex issue as decision making is non-centralised and companies can be part of several production networks at the same time. Issues also include e.g. integrated maintenance and real time monitoring.

Interoperability of Technical and Business Solutions in Production Networks (LSCP) *(Manufuture ETP)*

- **Technical content / scope:** The formation and operation of production networks cover the whole life-cycle of a product (design, production, distribution, after sales services, reverse logistics) supporting the application in production networks across company borders. This requires a strong interoperability between the different technical but also organisational solutions applied by the different partners of these networks. The developed solutions and services for interoperability should integrate aspects of know-how protection.

Knowledge Based Manufacturing – Integration of Heterogeneous Data and Enhancement of Human Interactions in Manufacturing Environment (SSCP) *(Manufuture ETP)*

- **Technical content / scope**: Currently enterprises treat knowledge about their technology as support for production instead of treating it as a product in itself and using knowledge as a basis for innovation. This topic provides support for collecting, structuring and clustering all the information needed for the development of products, for the production processes, for distribution and services the products about their whole life-cycle, and transforming it into knowledge.

Rapid Design and Virtual Prototyping of Factories (multiannual call starting in Y2 or Y3, SSCP & LSCP) *(Manufuture ETP)*

- **Technical content / scope**: This multiannual topic aims at delivering a complete detailed framework for the Virtual Factory concept and tools for the quick, reliable and optimized design and prototyping of knowledge-based manufacturing systems and factories, enabling collaborative, interdisciplinary and multicultural design/analysis and optimisation of processes to be executed effectively and efficiently in global virtual company networks.

Development of a Virtual Factory Framework Concept (LSCP)

Development of Specific Plant and Product/Process Modelling, Simulation and Virtual Prototyping Tools within the Virtual Factory Context (SSCP)

Integration of VR/AR Technologies in the Virtual Factory (SSCP)

2nd year? – Self learning systems

- Why, where?
  - A lot of control theories are working around a working point. Systems should find optimal setting for varying working point.
  - For coping with aging phenomena, slow disturbances
  - Control optimisation, first time right (integrated quality assurance, control)
  - For obtaining higher bandwidth -> higher productivity)
  - For flexibility issues (on higher level than control loops)
  - Also on factory level (another level higher)
  - Distributed control applications
  - In applications with a lot of control parameters
  - ‘Virtual ramp up’ – no sensor data is available then
- How?
  - Using implicit model of the process (for repetitive process, using feedback)
  - Learning from sensor data

Reliability - Monitoring and diagnostics

Reliability - Monitoring and diagnostics

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- Short time to market
- Total lifecycle cost …

Machines that monitor their operation and indicate cause of failures (intelligence)

Energy efficient solutions for variable consumption patterns

Equipment/service Performance Requirements


Healthy and safe human-mach...
Total life/cycle cost (incl...
Short time to market
Reliable production systems...
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Energy / Resource consumpti...
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Embedded systems
Advanced sensors
More advanced sensory feedb...
Lean and real-time data gen...
Wireless sensing, transfer ...
Intelligent material proper...
Energy scavenging
Micro-sensors

Reliability - Monitoring and diagnostics

Machines that are both available and reliable will wear in use and may thus suffer either a long term degradation of performance or a catastrophic failure. It is thus desirable to provide a **prediction of when it will move outside the acceptable envelope of performance**.

The prognosis of this point allows for maintenance schedules to be planned in fallow periods. Rather than catastrophic failure, it is preferable if machines enter a regime of **graceful degradation**. In this case their performance degrades in a systematic and predictable manner allowing for production at reduced rates and eventual shutdown over a period of time (the so-called limp home concept).

The roadmap distinguishes three major research avenues;

- one that lies in the **design of machines which are inherently more reliable and degrade** in predictable ways;
- one which uses **condition monitoring** (embedded sensing and prognosis engines) which dynamically predict the current status and project timescales to disruption of the desired performance;
- and finally one which assumes **radical new concepts in which the monitoring system is used to modify the behaviour of actuators to maintain the performance envelope for the longest possible time**.

The first approach is short/medium term, the second medium term and the third medium/long term. A mechatronic design approach is key to all three avenues and there is likely to be hybrid integrations of two or more approaches in order to meet cost/performance targets for particular sectors and applications.

High (and reliable) performance

High and reliable performance

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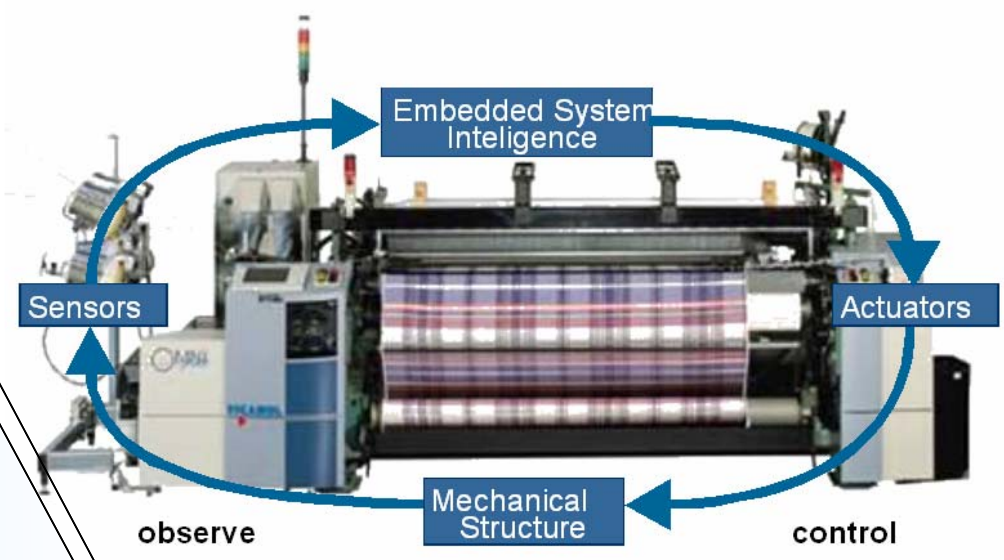
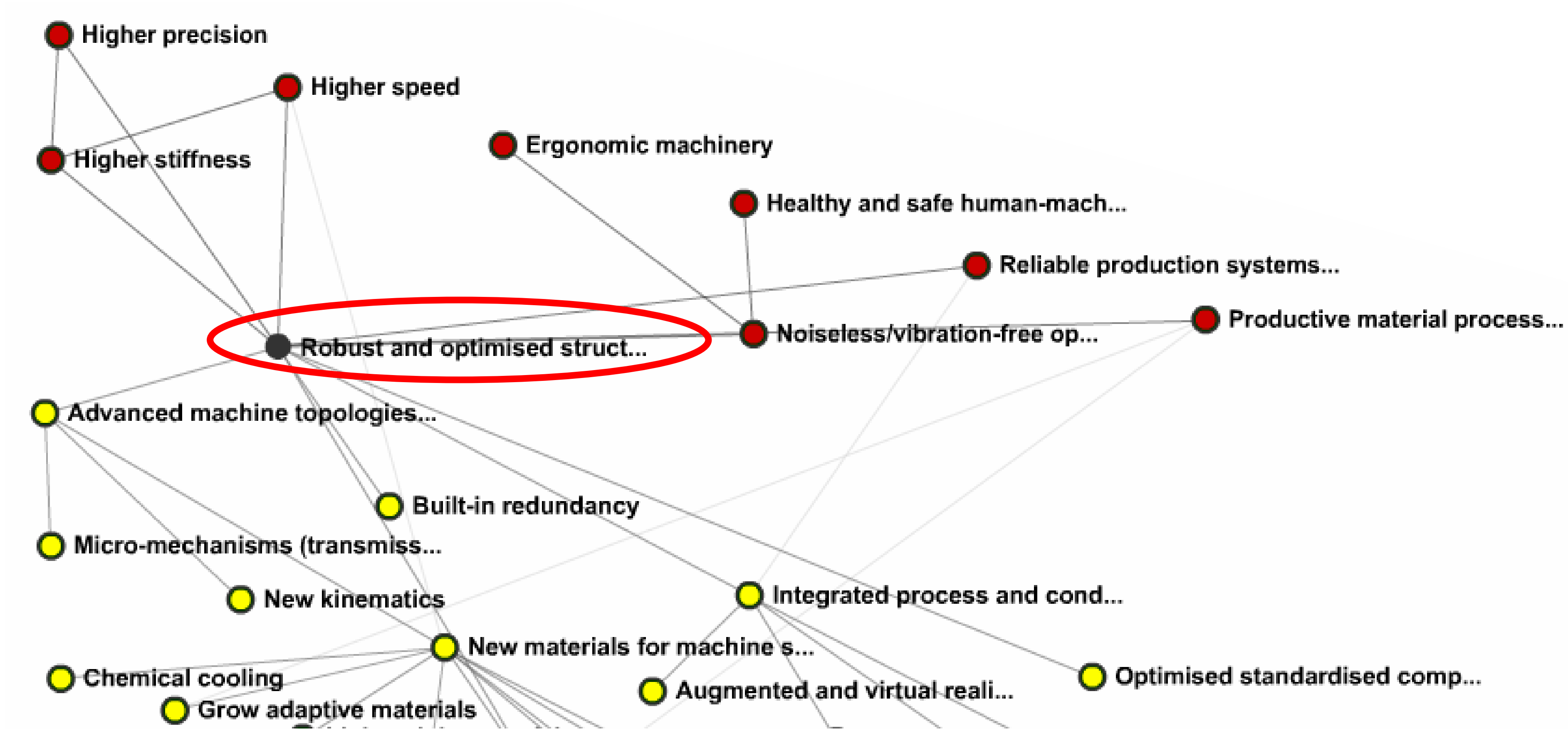
Faster machines with less vibrations and noise

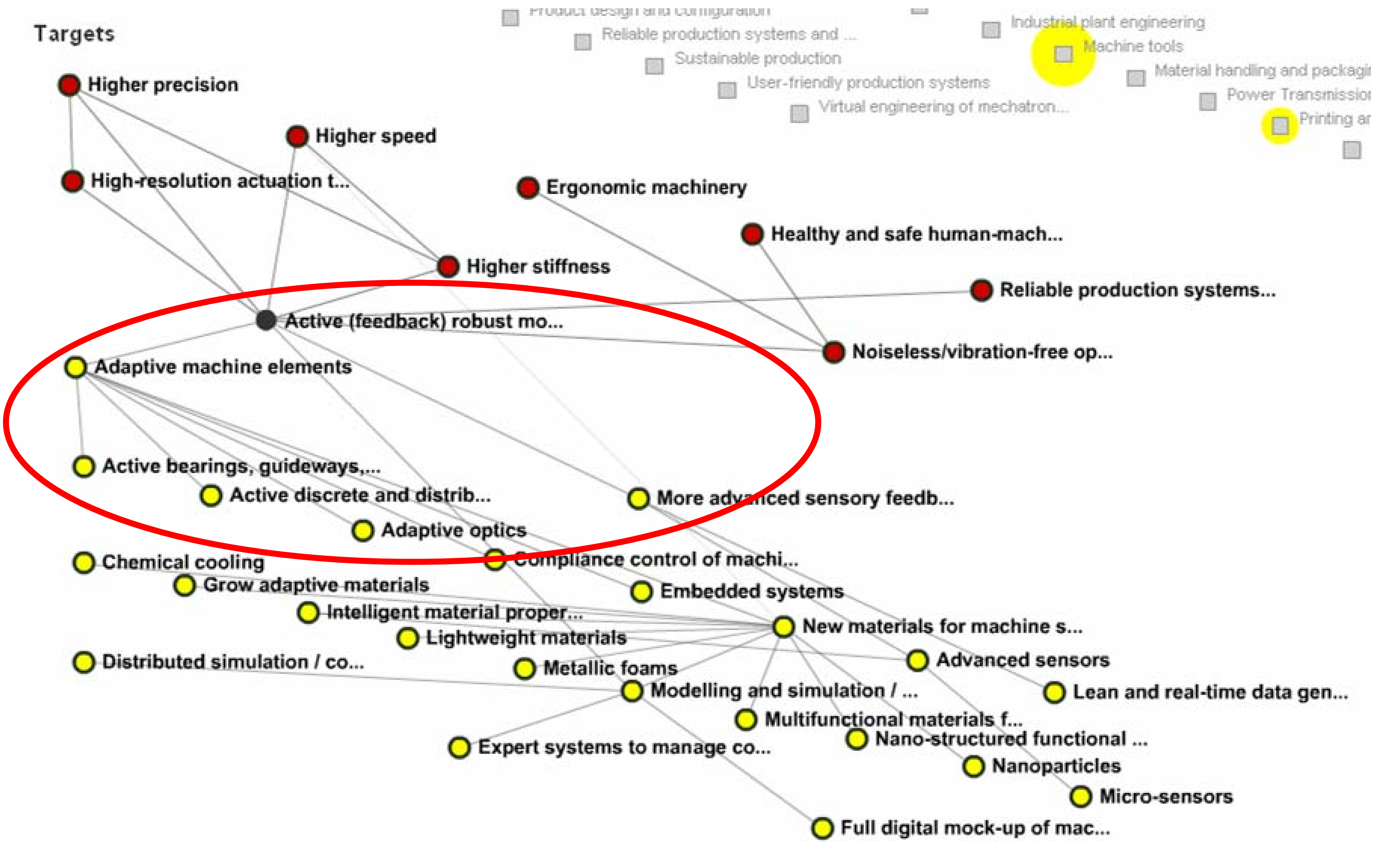


Equipment/service Performance Requirements

High (and reliable) performance



High (and reliable) performance



The major targets to achieve are obviously **higher machine precision and higher operation speed** – two characteristics that are often contradictory. Higher precision includes dimensional accuracy as well as surface quality of the end products. The required precision in products is increasing exponentially with time. This requires a corresponding increase in precision from the production systems, as expressed by the Taniguchi curves. Shorter time-to-market requirements and cost issues at the end-user impose needs for higher production speed.

The roadmap distinguishes **<u>three major development avenues</u>**;

- one that essentially builds on **design optimisation and control optimisation merely of existing machine architectures and improvements of current system components**;
- one that uses **new active and "intelligent" machine elements** e.g. to cope with disturbances, increase actuation resolution and eliminate vibrations;
- and finally one that assumes **completely new machine concepts and topologies**.

It is foreseen that commercial implementation according to this road map will entail solutions that are hybrid integrations of two or more of these approaches in order to reach cost efficient solutions and offer tailoring towards the requirements of particular sectors and applications.

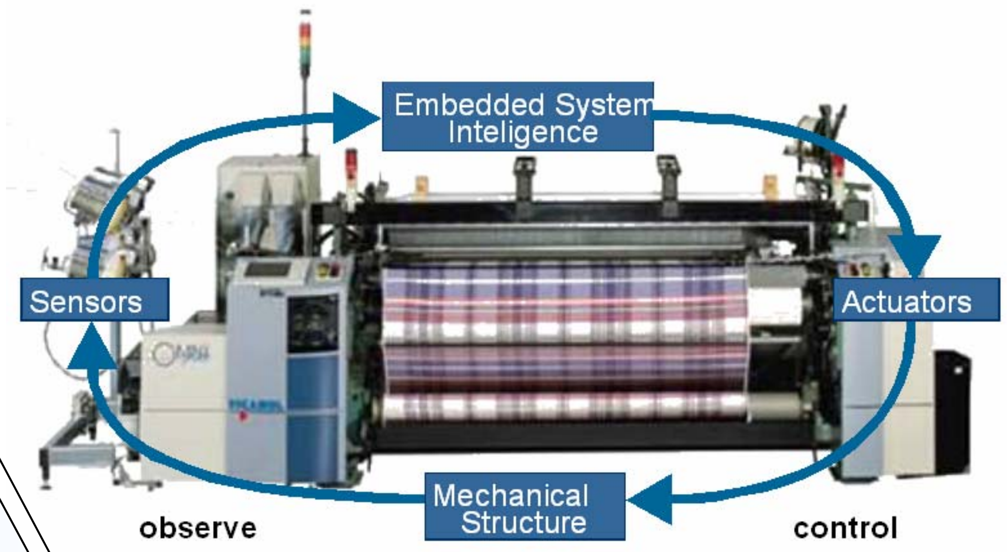
Abstracting away from details the roadmap points to the three most important areas of research in order to reach higher machine precision and speed, and to so in a cost-efficient way:

- **Design methods for robust and optimized structural design**.
- **More active, multifaceted and robust actuation, sensing and control, including active and adaptive machine elements.**
- **New innovative machine concepts and layouts.**

Intuitive man machine interaction

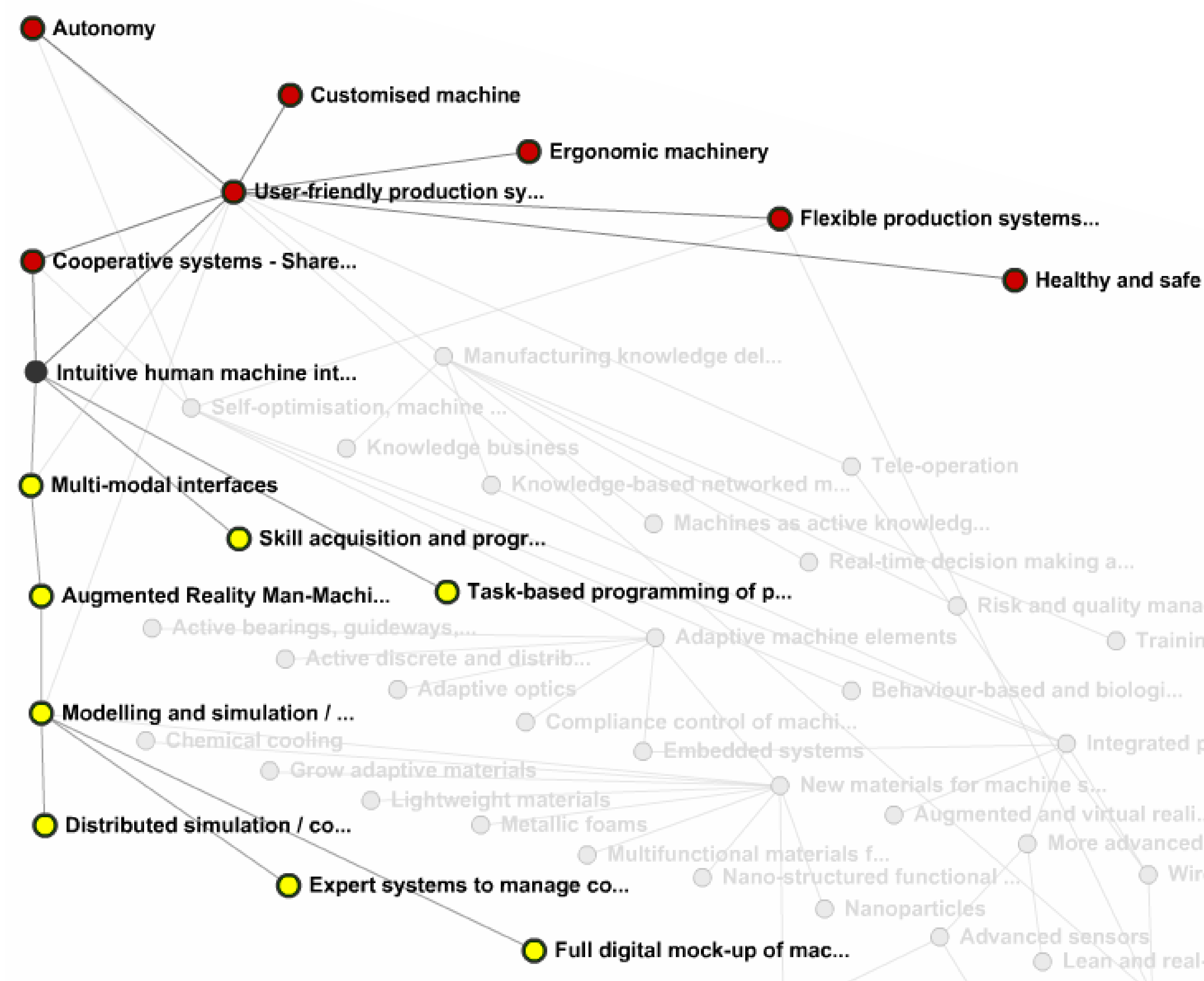
Intuitive man machine interaction

- Autonomy
- Customised machine
- Ergonomic machinery
- Flexible production …
- Healthy and safe …
- Higher precision
- Higher speed
- Miniaturisation of products …
- New business models …
- Productive material processing
- Reliable production systems
- Short time to market
- Total lifecycle cost …



Intuitive man machine interaction

Equipment/service Performance Requirements



Autonomy
Customised machine
Ergonomic machinery
User-friendly production sy...
Flexible production systems...
Cooperative systems - Share...
Healthy and safe
Intuitive human machine int...
Manufacturing knowledge del...
Self-optimisation, machine ...
Knowledge business
Tele-operation
Multi-modal interfaces
Knowledge-based networked m...
Machines as active knowledg...
Skill acquisition and progr...
Real-time decision making a...
Augmented Reality Man-Machi...
Task-based programming of p...
Risk and quality manag
Active bearings, guideways,...
Adaptive machine elements
Trainin
Active discrete and distrib...
Adaptive optics
Behaviour-based and biologi...
Modelling and simulation / ...
Compliance control of machi...
Chemical cooling
Embedded systems
Integrated p
Grow adaptive materials
New materials for machine s...
Lightweight materials
Augmented and virtual reali...
Distributed simulation / co...
Metallic foams
More advanced
Multifunctional materials f...
Nano-structured functional ...
Wire
Expert systems to manage co...
Nanoparticles
Advanced sensors
Full digital mock-up of mac...
Lean and real-

Key targets/technologies

- Intelligent equipment
  - Integrated process and condition monitoring, advanced sensors, real-time data management,
  - Digital manufacturing
- Total life-cycle cost
  - Energy efficiency, waste-free and contaminent-free production, tailored LCA-tools, material-efficiency
- Integrated, mechatronic system design
  - Total systems engineering, Virtual engineering
- High performance
  - High speed, high precision, robustness/reliability, miniaturisation
- New business models
  - Integrated services delivery
- Productive material processing
  - Enhanced and combined processes, new processes for metalworking and for working non-metallic and exotic materials, single-hit multifunctional machines
- Adaptive manufacturing systems
  - Adaptive equipment, adaptive factories, physical modularity, software modularity, scalability, interoperability

Questions?