Cyber-Physical Systems: imminent challenges

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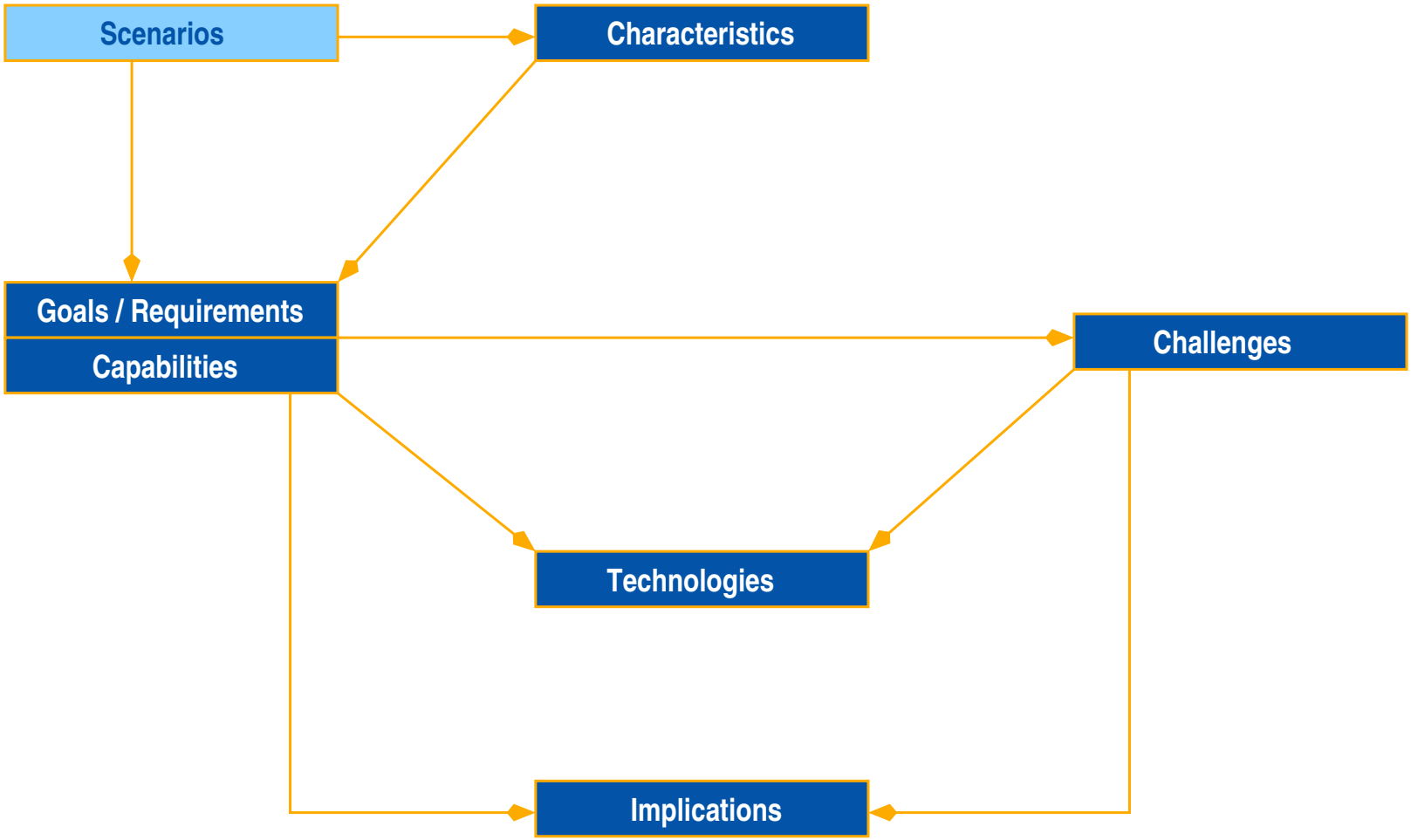
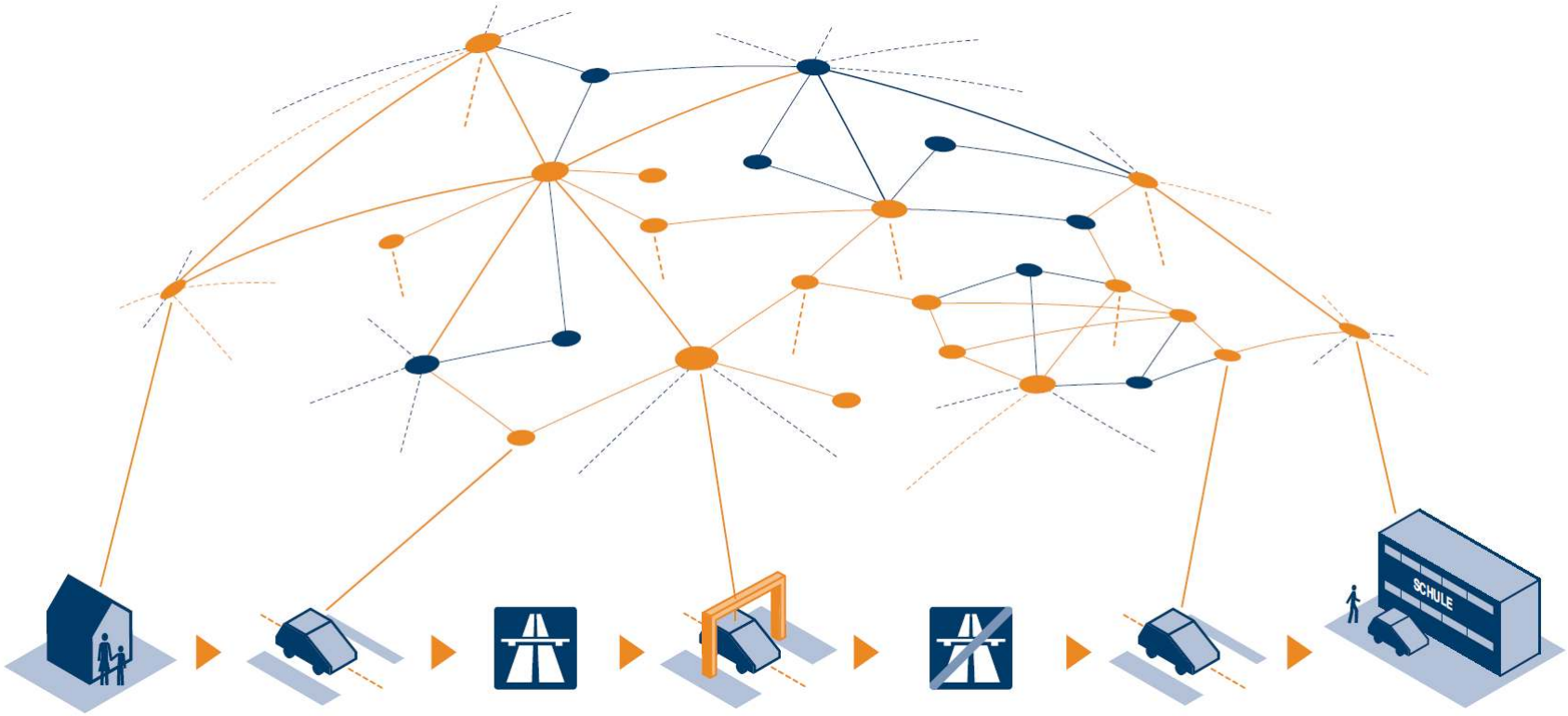
Project goal

The project aims at capturing technology trends and innovation potential in the context of Cyber-Physical Systems (CPS) in a holistic and systematic fashion, and at the derivation of implications for key research and action areas. By means of crucial application fields the significance is illustrated that CPS have for economy and society. Ultimate goal of the project is to strengthen and expand Germany's position in the field of CPS.

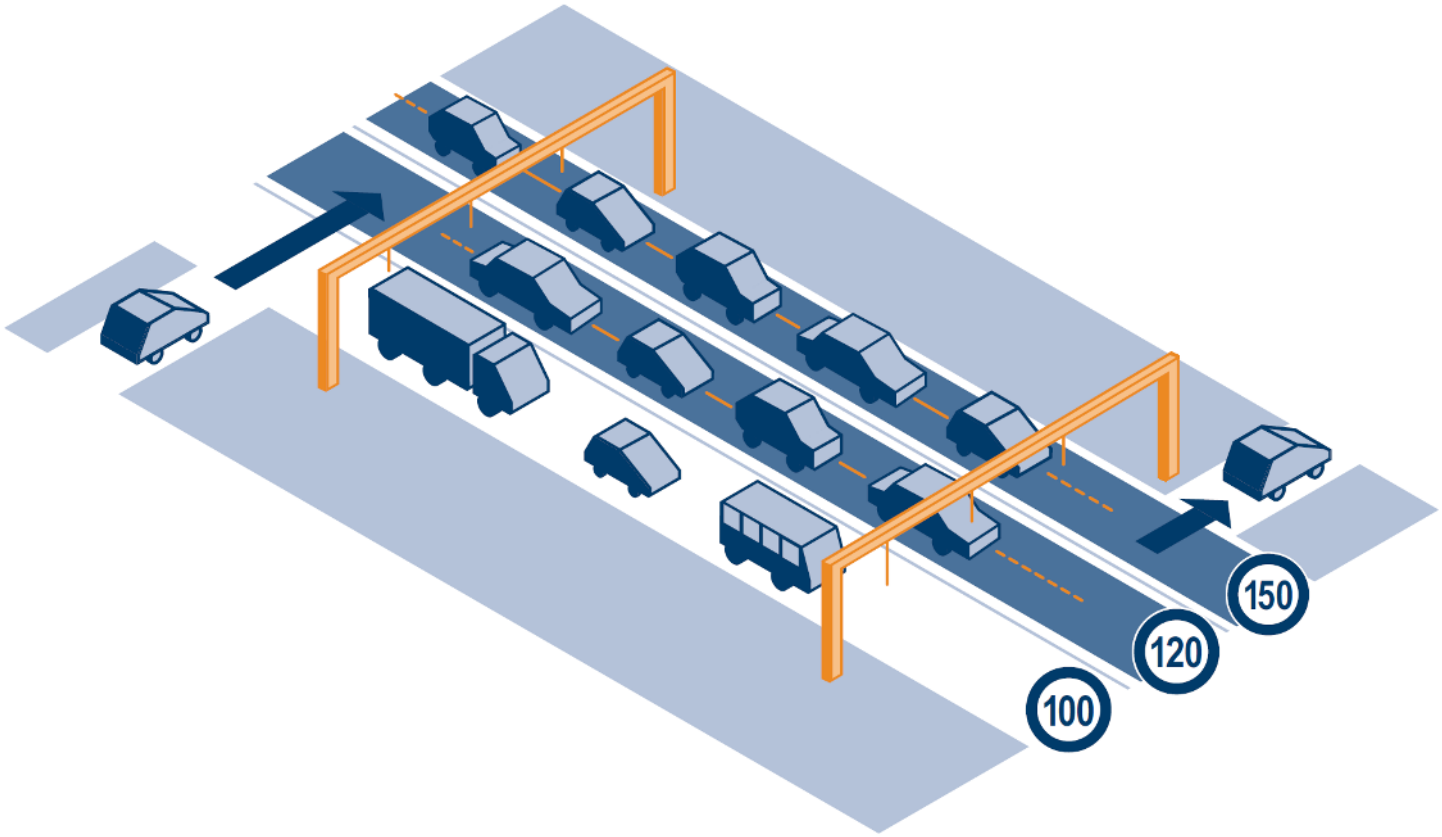
Project plan



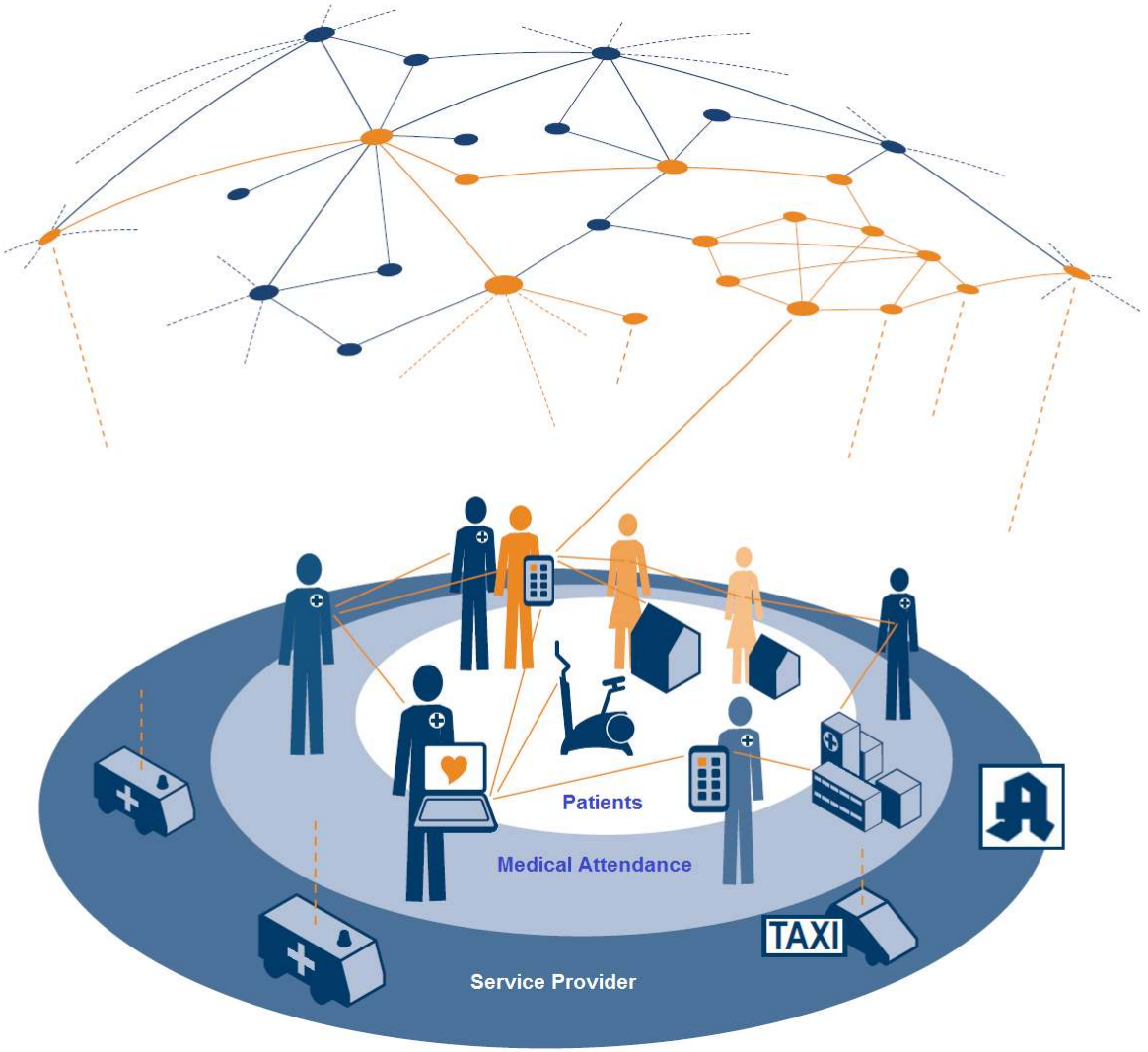
Scenario smart mobility



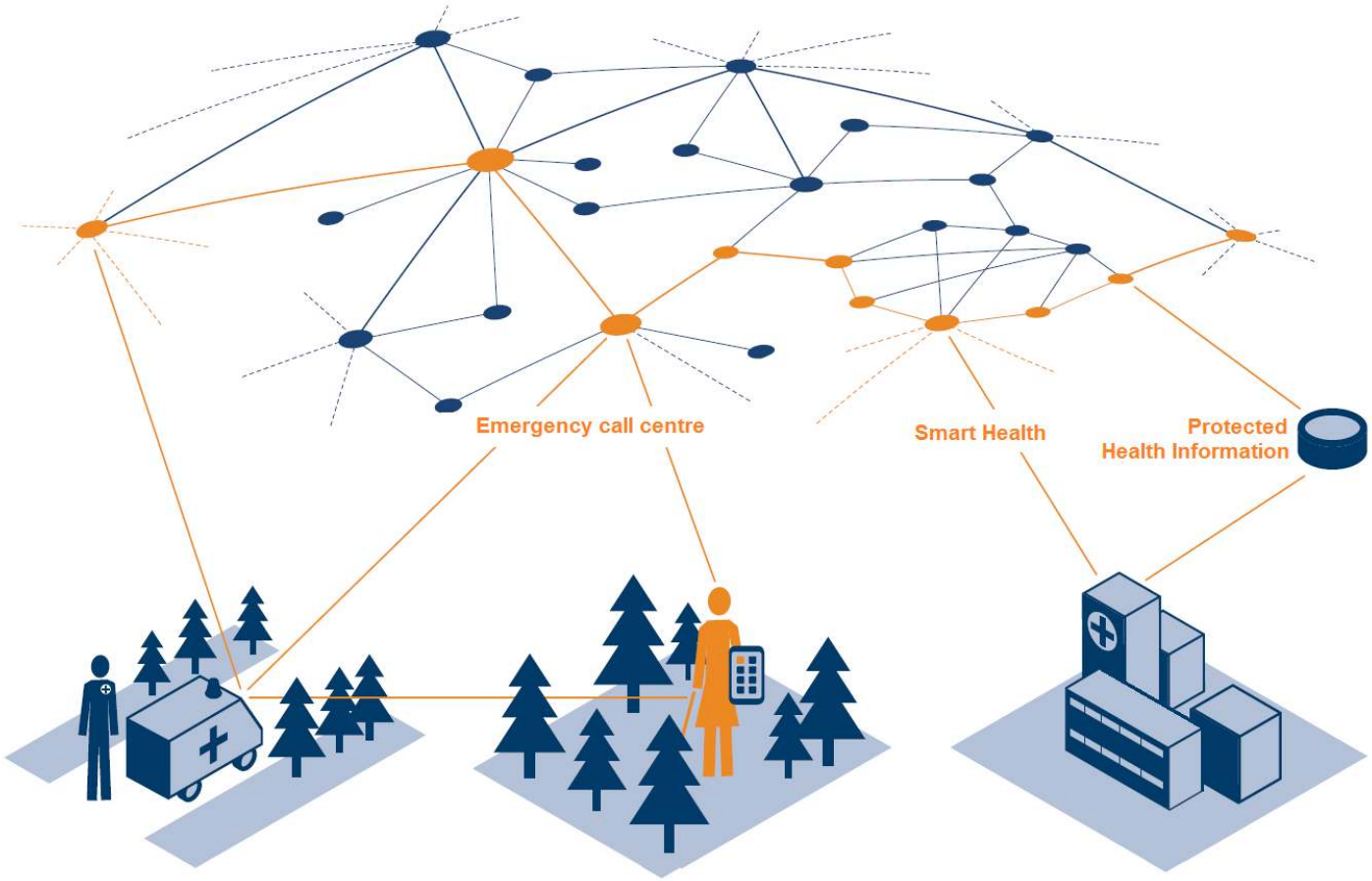
Scenario smart mobility (contd)



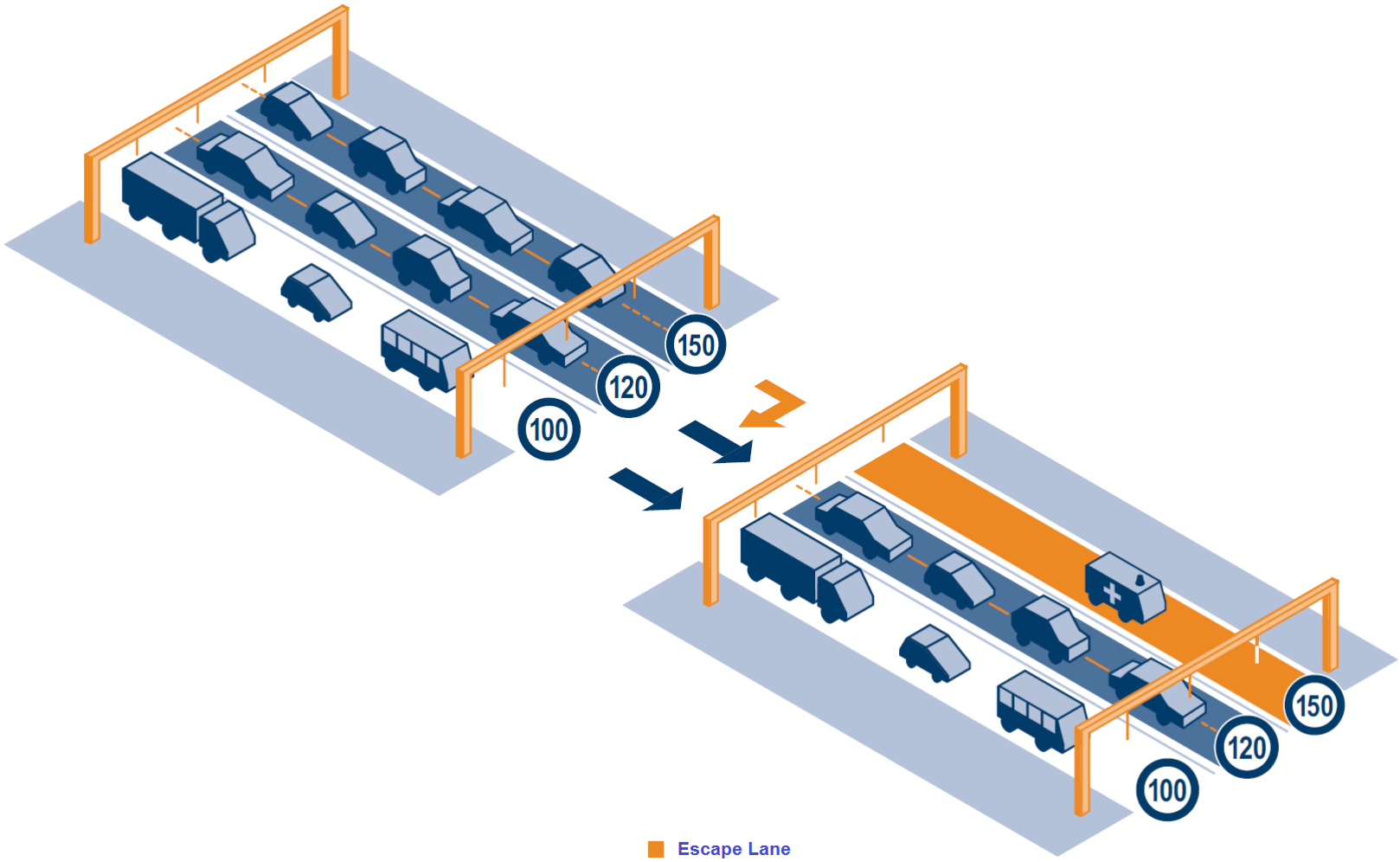
Scenario smart health



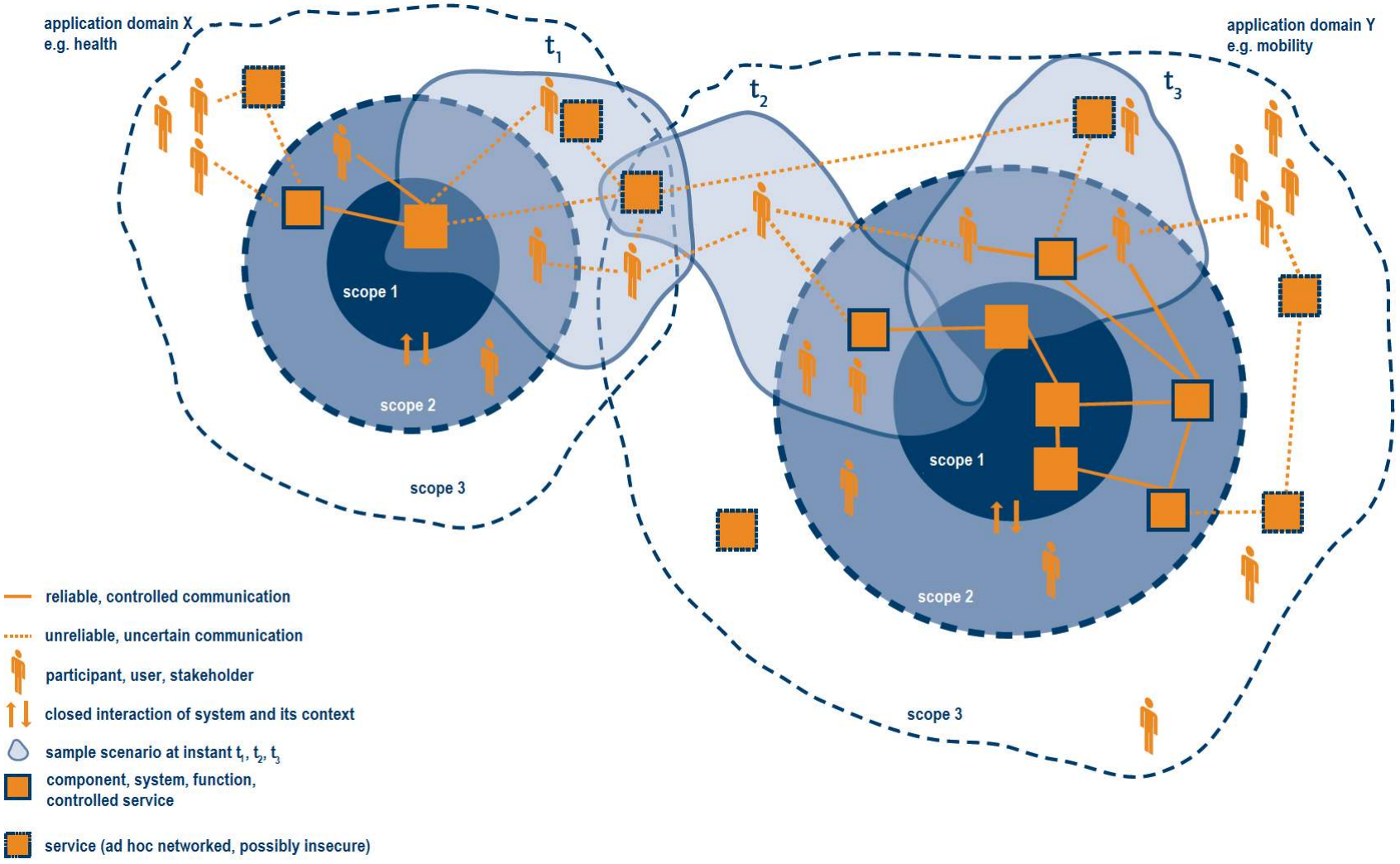
Scenario smart health (contd)



Scenarios smart mobility and smart health



CPS domain structure



CPS classification

According to social and spatial network structures (topologies):

(1) large-scale infrastructure systems and services (controlled area)

(2) social infrastructure systems and services (defined area)

(3) social application systems and services – including businesses;

demarcated area, spanning over diverse domains,
open to individual application systems and utilisation processes

CPS key drivers

Smart embedded systems, mobile services, ubiquitous computing

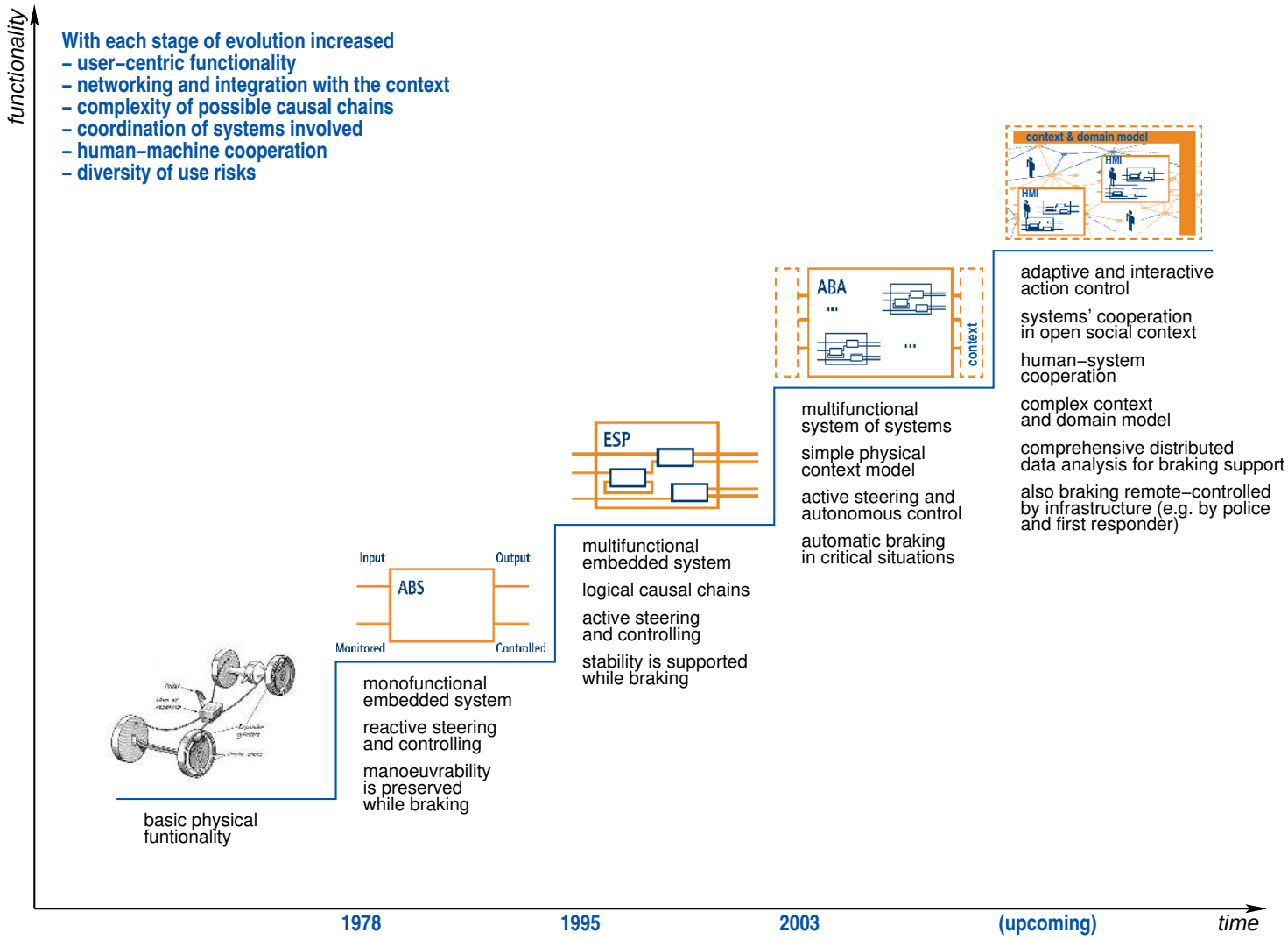
Internet as business web with two complementary forms:

- transfer to the "cloud"
- networked components (e.g., RFID technology)

Semantic Web, techniques of Web 2.0,
interactive design of integrated services through

- user-defined interaction, configuration of knowledge, integrated services
- communities of developers

Evolution towards CPS by means of the brake



CPS characterisation

By CPS,

physical and virtual, locally/globally networked systems are fused into

systems of systems with dynamically shifting boundaries

that are context-adaptive, partially or completely autonomous, and capable of active real-time control,

cooperative with each other under distributed, alternating control,

and able of comprehensive human-system cooperation.

CPS characterisation (contd)

CPS include embedded systems, logistics, coordination and management processes as well as Internet services that, using sensors, directly capture physical data and, through actuators, act on physical processes that are interconnected by means of digital networks, use globally available data and services, and have multimodal human-system interfaces.

CPS are open socio-technical systems that provide a range of new functionalities, services and features which go far beyond the current capabilities of embedded systems with controlled behaviour.

CPS capabilities

CPS are required to be

- x-aware and assimilable to their physical/social context,
- capable of learning and adaptable,
- transparent, equipped with predictable human-machine interaction,
- reliable, cooperative, strategic,
- subject to risk, target and quality analysis as well as QoS assurance.

CPS detailed capabilities

(1) Cyber-physical sensor and actuators technology, virtual, locally/globally networked, with real-time management	(2) Systems of systems (SOS), controlled network with dynamic boundaries	(3) Context-adaptive and (partially) autonomous systems	(4) Cooperative systems with distributed, alternating control	(5) Comprehensive human-system cooperation	Central abilities and non-functional requirements, quality in use, quality of service (QoS)

• Parallel acquisition (through sensors), fusion, processing of physical data from the local/global environment in real time (physical awareness)
• Interpretation of the situation w.r.t. the goal achievement and job completion of the CPS
• Acquisition, interpretation, deduction, prediction of faults, obstacles, risks
• Interaction, integration, rules and control of CPS components and functions
• Globally distributed, networked real-time control
	• Interpretation of data from context and situation over several levels, depending on application situations
	• Targeted selection, incorporation, coordination and use of services—depending on situation, local and global objective, and behaviour
	• Service composition and integration, decentralised controls: recognition of missing services, data and functions, and active search and dynamic incorporation of them
	• Evaluation of components and services to be incorporated regarding use and quality required for the application (QoS, overall quality) as well as possible risks
	• Reliability and compliance w.r.t. guaranteed QoS
	• Controlled access to system's own data and services
		• Extensive, continuous context awareness
		• Continual collection, observation, selection, processing, evaluation, communication of context data, situation data and application data (often in real time)
		• Targeted adaptation of the interaction, coordination, control with/of other systems and services
		• Recognition, analysis and interpretation of plans and intentions of systems and participating users
		• Model creation for application field, application domain, available services, tasks, and participants incl. their roles, objectives and requirements
		• Assessment of objectives and steps to achieve them, taking into consideration alternatives concerning costs and risks
		• Self-awareness in terms of knowledge about own situation, status and options for action
		• Learning of e.g. modified work processes, logistics, habits, interaction, etc., and corresponding behaviour adaption
		• Self-organisation
			• Distributed, cooperative and interactive perception and evaluation of the situation
			• Distributed, cooperative and interactive determination of the steps to be carried out—depending on the evaluation of the situation, of the objectives of individual participants and of the objectives of the community including these participants (local vs. global objectives)
			• In doing so, coordinated estimation and negotiation of the decision ultimately taken (i.e. own and shared control and decision-making autonomy)
			• Decision with uncertain knowledge
			• Cooperative learning and adaptation to situations and needs
			• Estimation of the quality of own and external services and abilities
			• Coordinated processing of mass data
				• Intuitive, multimodal, active and passive HMI support (simplified control)
				• Support of a further (time and space) and enlarged perception, capacity to act for individual and several persons (groups)
				• Recognition and interpretation of human behaviour including feelings, needs and intentions
				• Acquisition and evaluation of state and context of human and system (extension of perception and of evaluation skills)
				• Integrated and interactive decision making and action of systems and individual persons or multitudes
				• Ability to learn
					Required capabilities
					• "X" awareness (correct perception and interpretation of)
					  ○ situation and context
					  ○ self, third party, and human (state, objectives, intentions, ability to act)
					• Learning and adaption (behaviour)
					• Self-organisation
					• Cooperation, negotiation and decision-making (within precise boundaries—compliance)
					• Decisions with uncertain knowledge
					• Policy-making and, if applicable, compliance with QoS guarantees
					• Comprehensive safety and security policies
					• Transparent HMI, shared control & integrated situation evaluation and predictable action
					• Risk management
					• Proactive, strategic and reliable action
					• Privacy protection

➔ increasing openness, complexity, autonomy, "smartness" and evolution of the systems (with disruptive effects in the fields of application) ➔					

Technical challenges

Infrastructure and standards

Openness spanning over diverse domains

Formal & integrable requirements, context and domain modelling, hybridism; component and reference architectures

Situation and self awareness, adaption and evolution

Shared control, conflict and reconciliation handling

Human-system cooperation

Safety and security, personal data protection

Technologies

Physical situation recognition:
sensor fusion, pattern recognition, situational map

Planning & anticipatory, partially or completely autonomous behaviour:
multi-criterial situation assessment, artificial intelligence

Cooperation and negotiation: multi-agent systems

Human-machine interaction:
human-machine interface and interaction modalities, intention and plan recognition, user modelling, human awareness

Learning: machine learning and data mining

Evolution, strategies of self organisation and adaption:
self organising manufacture, self organising communication networks

Basic technologies

Domain modelling, ontologies and domain-specific languages

Sensor and actuator technology

Communication infrastructure and plattform

Efficient parallel processing units

Distributed stable controlling

Social challenges

Acceptance, which calls for participatory analysis and design of

– systems and services that are manageable, tailorable, trustworthy, fault tolerant, accountable

– capable of learning from user's behaviour

– ergonomic (cf. human factors)

– compatible with non-networked systems and services (as well as dropouts)

Inter- and transdisciplinary research and development

Economic ecosystems

Social guidelines and stipulations

Implications

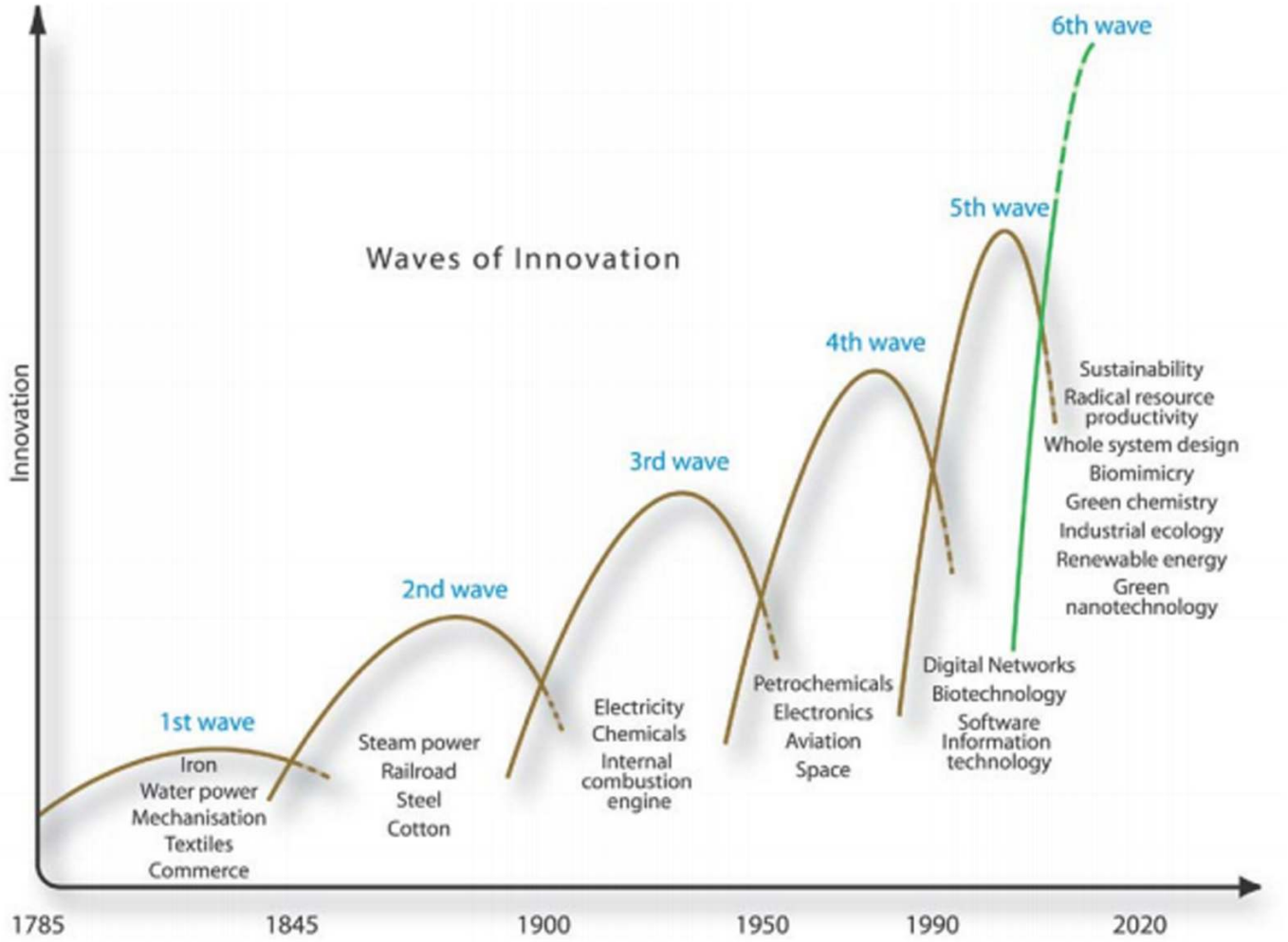
Great opportunity for academia, industry, business and economy:

- Challenges for technology
- Interdisciplinarity, value creation, innovation
- Changes in business, law, and politics

Contribution to accident prevention, smart use of limited resources, etc.

Implications (contd)

(Part of) Sixth wave of innovation



Download area

Position paper:

`www.fortiss.org/fileadmin/user_upload/downloads/agendaCPS_Position-paper.pdf`

Survey (in German):

`www.fortiss.org/fileadmin/user_upload/downloads/agendaCPS_Studie.pdf`