White-Paper

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Recognising simulation and forecasting technologies as a lever to increase manufacturing performance and acknowledging the need for a concrete road-map to clearly point out key challenges for these technologies future development, the EC in 2012 funded the Pathfinder CSA (www.pathfinderproject.eu).

This document reports the results of developed by the Pathfinder Consortium through numerous internal and external consultations over a period of 10 months, including discussions with representatives of the European Commission, workshops with advisory groups form industry and academia, and consultations with the "European Factories of the Future Research Association" (EFFRA).

http://www.pathfinderproject.eu/

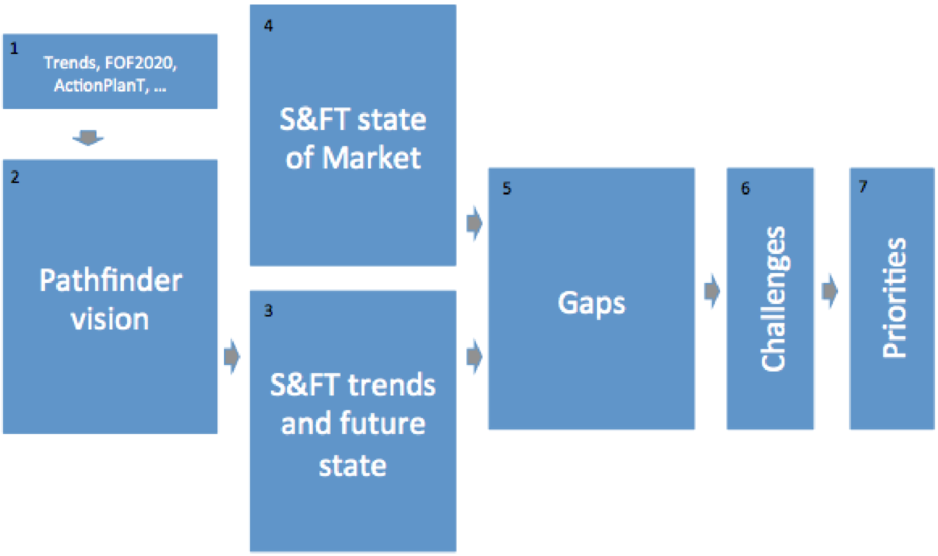
1. Executive summary

European leadership and excellence in manufacturing are being significantly threatened by the huge economic crisis that hit the Western countries over the last years. More sustainable and efficient production systems able to keep pace with the market evolution are of paramount importance in the recovery plan aimed at innovating the European competitive landscape. An essential ingredient for a winning innovation path is a more aware and widespread use of ICT in manufacturing-related processes. ICT is indeed the cornerstone of economic growth. By the early 2000s, several economists found evidence to support a link between ICT investment and industrial productivity: the impact of information and communication technology is of paramount importance since an investment in such sector generates a bigger return to productivity growth than most other forms of capital investment.

Europe has fallen behind the world leader in investment in ICT - the US - since 1991. The US increased its accumulated stock of ICT investment as a proportion of GDP from 9% in 1991 to 30% in 2010. Europe's ICT capital stock increased from 6-9% (near parity with the US) to around 20% over the same timeframe. The ICT investment disparity significantly affected Europe's relative productivity. From 2000-2010, annual US productivity growth accelerated to close to 2%. In Europe, annual productivity growth decelerated to around 1%.

Pathfinder investigates, in particular, the role of simulation and forecasting technologies (S&FT) as a lever to increase manufacturing performance and proposes the development of a roadmap capable to clearly point out key challenges for these technologies future development. Pathfinder is indeed intended to drive research and development activities in the Simulation and Forecasting Technologies arena, and, to this end, the roadmap must develop, through the analysis of current state of practice compared with the future state envisioned, a final list of research priorities to provide guidance for the key stake-holders. The process of roadmap building has been arranged into 7 logical blocks:

1. An analysis of trends, current road-mapping activities and national initiatives, set the basis for the definition of the pathfinder vision.
2. The Pathfinder vision has been developed in such a way to be consistent with current road-mapping efforts at national and international level (in order not to introduce a new vision on manufacturing itself, but to embrace existing activities).
3. From the vision, the current trends and future envisioned state of Simulation and Forecasting Technologies have been derived.
4. In parallel, the current state of market practice has been investigated.
5. By confronting the envisioned future state with the current state of market practice, the road-mapping activity has defined the related gaps. These can be considered as the missing link between what is currently available and the future envisioned manufacturing scenario.
6. Identified gaps, consolidated and grouped, are the main input for the identification of challenges that are expected to arise for the S&FT innovation need.
7. The identified challenges will be faced by addressing the research priorities identified by Pathfinder.



Pathfinder identifies, through experts consultation and through the analysis of current initiatives and roadmaps at national and European level, ***eight Research Areas***, meant to cluster the identified state of market, future state, gaps, and priorities.

RA1: Open and Cloud-based S&FT for High-performance Computing

RA2: Multi-disciplinary and Multi-domain Integrated S&FT

RA3: S&FT for Life-cycle Management

RA4: Multi-level S&FT Integration

RA5: S&FT for Real-Time Factory Controlling and Monitoring

RA6: Smart, Intelligent and Self-learning S&FT

RA7: Human-centred Simulation-based Learning & Training

RA8: Crowdsourcing-based S&FT

The identified gaps are a main input for the identification of challenges that, given the contextual factors, are expected to arise and to be faced by S&FT innovation. Although the list of challenges is expected to continuously evolve during the Pathfinder road-mapping activity, a preliminary list of challenges for Pathfinder has been already identified and is presented in what follows.

S&FT and Digital Continuity - Digital Continuity refers to the ability to maintain the digital information available all along the factory life-cycle, despite changes in purpose and tools, allowing data (the oil that fuels manufacturing) to be enriched and used as needed for that specific phase. This challenge addresses: Interoperable simulation and forecasting systems; Digital continuity across product and factory lifecycle of engineering information; seamless use and reuse of engineering data; Reduce modelling effort; ;Modelling of complex problems; Multidisciplinary integrated modelling; Standardization.

S&FT and Scalability - Scalability refers to the ability of an application to function efficiently when its context is changed in size or volume. This challenge addresses: Step-by-step integration and adoption of S&FT; S&FT solution scalable on different devices and platforms; from on-premises software to cloud-based services;

S&FT and Synchronization of Digital and Real World - Synchronization of Digital and Real World refers to the convergence of physical world and virtual world, where the second must closely mirror the first and where the first generates an unprecedented volume of data to be taken care of by the latter. This challenge addresses: Self-adjustment of digital models triggered by smart objects (embedded intelligence – Cyber Physical System paradigm); Co-simulation in real-time; Handling of big-data.

S&FT and Advanced Human-Machine Interfaces – Advanced Human-Machine Interfaces (HMI) must provide transparent insights into the digital-virtual world and must allow to interact with S&FT in an intuitive and natural way. This challenge addresses: intuitive, mobile, context-sensitive and collaborative user-interfaces.

S&FT and Digital Consistency & Security - Digital Consistency & Security refers to the fact that data originating from and travelling along the factory lifecycle should be safe and shouldn't contradict each other. This is a significant challenge especially in the context of the digital continuity, vertical integration and horizontal integration, where distributed and heterogeneous data sources will be linked and made available in an open and interoperable manner. This challenge addresses: optimised provision of consistent data, data security and privacy.

S&FT, Data and Knowledge - This challenge addresses: Big Data and Data Analytics; Ontologies definition; Relevant knowledge capture and reuse, also for training and education

The use of S&FT is more advanced in those sectors where, historically, this tools has been considered as a fundamental element to support the product and process development. Based on an industrial survey, Pathfinder identified also the relevance and impact of the S&FT gaps and challenges in various sectors, to make a distinction between gaps pointing to functionalities and tools already existent but with a restricted application area, and novel features calling for research actions.

Europe must consolidate its strengths in the ICT sector and, as pointed out, further invest: EU is still world-leader in ICT for manufacturing and has a leadership position in the field of S&FT with big players like Siemens and Dassault. The use of ICT for manufacturing is widespread in several sectors and among large and small-medium enterprises. Nordic European countries score in the top 10 in terms of ICT readiness level evaluated globally by the World Economic Forum thus showing their commitment for developing their digital potential. The ground is mature enough to further rely on ICT advancements as a lever to increase productivity and competitiveness. Also, the strong knowledge base developed in European research institutes and the high quality training standards guaranteed by leading technical universities in the area of simulation, analytics and forecasting technologies are driving the growth of a skilled generation that will master successfully these technologies in the manufacturing arena.

Data is what fuels progress in manufacturing. The digitalisation of manufacturing processes generates a large amount of data that is not – yet – used to any real extent and offers broad opportunities for the future. The priorities acknowledged by Pathfinder (par. 6.7) clearly reflect the challenges and research area identified, as mentioned above, and focus on three main topics: I- Digital Continuity, where huge operational and economic benefits are expected through linking all the steps in the product life cycle digitally – form product design, production planning and engineering, production execution and services – and to create a full lifecycle data loop; II- Synchronization of Digital and Real World, where the real world of production is accompanied by an equivalent in the digital world, so that products and production processes are simulated and optimized in detail before the real production is in place. The digital twin has the potential to monitor, adjust and optimize real processes, anticipate failures and thus to increase efficiency by orders of magnitude; III- Multidisciplinary integrated modelling and virtual validation of manufacturing equipment at design stage, and system-level simulation of mechatronic systems at production phase, prior to actual manufacturing, (thanks to integration of models from different domains) will ensure proper performance of equipment and processes. The seamless integration in the CAx tool chain will help to accelerate the integration of new materials into the production process and it will support new ways of manufacturing such as 3D printing.

2. Working-group members and technical experts

Pathfinder Advisory Board

Albrecht Christian – Steinbeis - Germany

Andrea Rizzoli – Istituto Dalle Molle di Studi sull'Intelligenza Artificiale - Switzerland

Carsten Poege – Volkswagen - Germany

Decubber Chris – EFFRA - Belgium

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European Commission Support and Counselling Group

Flamigni Francesca

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Riemenschneider Rolf

3. ICT in manufacturing

3.1. Numbers in ICT

In Europe, manufacturing is the largest of the NACE sections for the non-financial business. In 2008 it contributed with 24.2% of the workforce and 27.1% of the value added. 33 millions of persons are employed by 2.1 millions of manufacturing enterprises[1]. Out of them, 20.9 millions are SMEs accounting for two out of every three jobs[2]. But due to the huge economic crisis EU countries are undergoing, GDP is likely to stagnate and the economic growth is expected to be low in the near future. As a consequence, the social impact of the crisis in terms of unemployment rate is going to be exacerbated in 2014. Even tough SMEs are the leading job creators in the EU, following the economic crisis some 3.25 million jobs in SMEs have been already lost[2].

ICT is the cornerstone of productivity and thus of economic growth. Now, more than ever, Europe's need for productivity growth has become more pressing against both the low rate of economic growth and the international financial crisis that is clouding the outlook for all companies. By the early 2000s, several economists found evidence to support a link between ICT investment and industrial productivity. As reported by Oxford Economics[3] and by a recent study of the Lisbon Council[4], the impact of information and communication technology is of paramount importance since an investment in such sector generates a bigger return to productivity growth than most other forms of capital investment. Estimates show that while the returns on other forms of capital investment are about 15% on average, the ROI on ICT investments is typically between 20-25%.

But during the last two decades Europe has fallen behind the US, which is the world leading ICT investor. Whilst, the US increased its accumulated stock of ICT investment as a proportion of GDP from 9% in 1991 to 30% in 2010, Europe increased its own capital stock from 6-9% to 20% over the same time frame. This ICT investment disparity significantly affected Europe's relative productivity. From 2000-2010, annual US productivity growth accelerated to close to 2%. In Europe, annual productivity growth decelerated to around 1%. Again Oxford Economics provides a forecast on how much EU countries are expected to gain by 2020, in terms of GDP increase, should they match US ICT capital stock investment and learn how to integrate that into successful business strategies (EU column refers to EU-27)

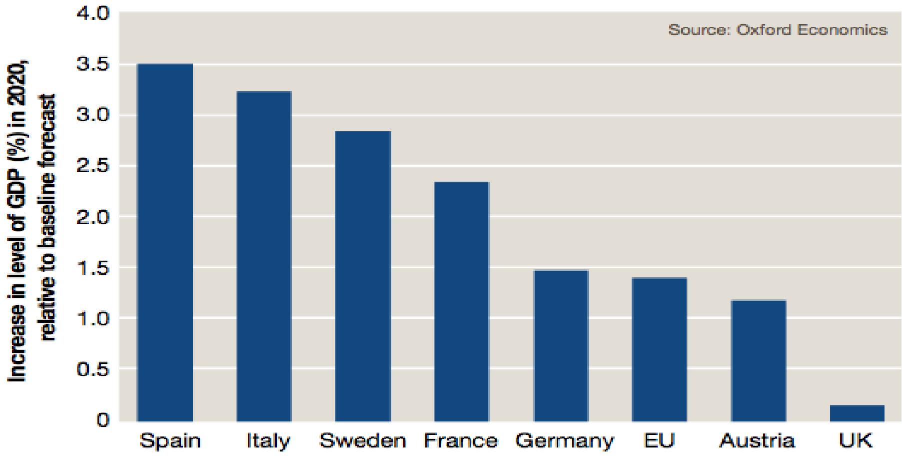

Fig. 1 – forecast on GDP increase level

Clearly, countries where the stock of ICT is low as a proportion of GDP have the most to gain: in Italy and Spain, the stock, measured as a proportion of GDP, is roughly half that of the US (Fig. 1)

Bridging this gap by raising European ICT investments toward 2020 to the same level of US is a big deal for Europe, as it corresponds to an increment of around 5% of GDP, equivalent to €760 billion for the EU as a whole, or €1500 per person.

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[1] Key Figures on European business with a special feature on SMEs. Eurostat pocketbooks, 2011 edition. Retrieved from: http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-ET-11-001/EN/KS-ET-11-001-EN.PDF

[2] Review of the "Small Business Act" for Europe COM(2011)

[3] Capturing the ICT Dividend: Using technology to drive productivity and growth in the EU. Oxford economics

[4] http://www.lisboncouncil.net/ - report The Lisbon Council Think Tank, 2014

3.2. What we know - statements

ICT is important for Manufacturing – because of its relevance in terms of number of companies at EU level and because the leverage that investments in ICT can achieve over productivity.

ICT is important for SMEs– because of the number of SMEs working on ICT

ICT is a key enabler for services *– because the ICT sectors represent the 4.8% of the European Economy. Efficiency through ICT can mean better services for less cost*[5]*.*

ICT is a research-intensive activity *- a total of 9,1 billion euro has been earmarked for the ICT in the FP7 (2007-2013)*[6]*. EU investments in ICTs are due to increase by about 25% in Horizon2020 compared to FP7*[7]*.*

3.3. Simulation and forecasting within ICT

Within ICT, the development of simulation and forecasting tools and methods, that could strategically support production-related activities during all the phases of the factory life-cycle, with the aim of promoting a sustainable manufacturing, is of capital importance[8]. The use of innovative tools can, in fact, support both the integrated design of the product – process - production system and the management of the factory. Main benefits are for example the possibility to compare alternative configurations during the system design reducing both time-to-market and cost of implementation as well as an effective and efficient connection with the shop floor. Simulation and forecasting tools are supposed to provide a holistic and coherent virtual model of the factory that is aligned with the social, environmental and economic context.

In the current highly competitive business environment, the manufacturing industry is facing constant challenges of producing innovative products at shortened time-to-market. The increasing trend towards globalisation and decentralisation of manufacturing[9] requires real-time information exchanges between the various areas concerned with the product and production development, e.g., design, ramp-up planning, production scheduling, machining, assembly, etc., as well as seamless collaboration among these areas. Product and production development processes are becoming increasingly more complex as products become more versatile, intricate and inherently complicated, and as product variations multiply to address to the needs of mass customisation10. Simulation modelling and analysis is conducted in order to gain insight into this kind of complex systems, to achieve the development and testing of new operating or resource policies and new concepts or systems, which live up to the expectation of modern manufacturing, before implementing them and, last but not least, to gather information and knowledge without disturbing the actual system11. It becomes evident from the total number of directly related papers (15,954) from the early 70s till today, that simulation is a continuously evolving field of research with undoubted contribution to the progress of manufacturing systems.

Hereby, two of the most prominent definitions of simulation in the context of manufacturing within ICT are presented and are adopted for the scope of the present work.

"Simulation modelling and analysis is the process of creating and experimenting with a computerised mathematical model of a physical system"[12].
"Simulation is the imitation of the operation of a real-world process or system over time. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented"[13].

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[5] "ICT as a key enabler for growth" – Neelie Kroes (Vice-President of the European Commission responsible for the Digital Agenda) - Speech/11/340
[6] ICT Research & Innovation: a driver for growth – http://www.ncpbrussels.be/eu-funding-opportunities/what-eu-funding-for-my-r-i-project/for-ict-projects/item/download/6_0ec939d441898e9b409588562bed1898
[7] http://ec.europa.eu/programmes/horizon2020/en/area/ict-research-innovation
[8] EFFRA (2012) Factories of the Future PPP FoF 2020 Roadmap Consultation document. Retrieved from: http://www.effra.eu/attachments/article/335/FoFRoadmap2020_ConsultationDocument_120706_1.pdf
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[12] Chung C., 2004, Simulation modelling handbook: a practical approach, 1st Ed., CRC press, Boca Raton.
[13] Banks J., Carson J. S., Nelson B. L., Nicol, D. M., 2000, Discrete event system simulation, 3rd ed. Englewood Cliffs

3.3.1. The Historical Trends of the Evolution of Simulation

Although the term “Monte Carlo method” was coined in 1947, at the start of the computer era, stochastic sampling methods were used long before the evolution of computers[14]. It is widely acknowledged that the contemporary meaning of simulation originated with the work of Comte de Buffon in the 18th century, who developed a Monte Carlo-like method and used it to determine the outcome of an experiment consisting of repeatedly tossing a needle onto a ruled sheet of paper. The aim of the experiment was to calculate the probability of the needle crossing one of the lines[15]. About a century later, Gosset used a primitive form of manual simulation to verify an assumption about the exact form of the probability density function for Students t-distribution. In the mid-1940s, simulation makes a significant leap with the contribution of the first general-purpose electronic computers. Ulam, von Neumann and Metropolis use Monte Carlo on computers to solve problems concerning neutron diffusion. Tochter and Owen develop the General Simulation Program in 1960, which is the first general purpose simulator to simulate an industrial plant that consists of a set of machines, each cycling through states as busy, idle, unavailable and tailed[16]. During the period 1960-1961, Gordon introduces the General Purpose Simulation System (GPSS)[17]. Simultaneously, Nygaard and Dahl initiate work on SIMULA and they finally release it in 1963[18] and Kiviat develops the General Activity Simulation Program (GASP). Although, a significant evolution of simulation is noticed, there are still problems concerning model construction and model analysis which are mentioned and addressed by. In the beginning of the 1980s, major breakthroughs take place, military flight simulators, naval and submarine simulators are produced and NASA develops relatively low-cost VR equipment[19]. In early 1990s, real-time simulations and interactive graphics become possible due to the increased computer power and commercial VR applications become feasible[20]. In addition, the development of high-resolution graphics focuses on gaming industry surpassing the military industry.

3.3.2. Types of Simulation Models

Simulation models are categorised based on three basic dimensions: 1) timing of change, 2) randomness and 3) data organisation. Based on whether the simulation depends on the time factor or not, it can be classified into static and dynamic. A static simulation is independent of time while dynamic simulation evolves over time. Dynamic simulation can be further categorised to continuous and discrete. In discrete simulation, changes occur at discrete points in time while in continuous, the variable of time is continuous.

In addition, discrete simulation is divided to time-stepped and event driven. Time-stepped consists of regular time intervals and alterations take place after the passing of a specific amount of time. On the other hand, in event-driven simulation, updates are linked to scheduled events and time intervals are irregular. As far as the dimension randomness is concerned simulation can be deterministic or stochastic. Deterministic means that the repetition of the same simulation will result to the same output, whereas, stochastic simulation means that the repetition of the same simulation will not always produce the same output. Last but not least, simulation is classified to grid-based and mesh-free according to data organisation. Grid-based means that data are associated with discrete cells at specific locations in a grid and updates take place to each cell according to its previous state and those of its neighbours. On the other hand, mesh free relates with data of individual particles and updates look at each pair of particles[21, 22].

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[14] Bielajew A., 2013, History of Monte Carlo, In:,Seco J. and Verhaegen F., eds. Monte Carlo Techniques in Radiation Therapy, Taylor and Francis, 342.
[15] Mourtzis D, Doukas M, Bernidaki D. Simulation in Manufacturing: Review and Challenges, 8th International Conference on Digital Enterprise Technology - DET 2014. March 25 – 28, 2014. Stuttgart, Germany; ISBN: 9783839606971.
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[19] Rosen K. The history of medical simulation. J Crit Care 2008;23:157-166.
[20] Lu SCY, Shpitalni M, Gadh R. Virtual and Augmented Reality Technologies for Product Realisation. Annals of the CIRP Keynote Paper 1999;48(2):471-494.
[21] Von Ronne J., 2012, Simulation: Overview and Taxonomy, Presentation.
[22] Sulistio A., Yeo C.S., Buyya R., 2004, A taxonomy of computer-based simulations and its mapping to parallel and distributed systems simulation tools, Software practice and experience, 34:653-673.

4. Eu Countries perspective over Simulation and Forecasting Technologies role

This chapter provides an overview of the innovation and road-mapping programmes across Europe at regional level, highlighting the role envisioned for Simulation and Forecasting Technologies within national initiatives. This analysis empowers an effective harmonization of the Pathfinder challenges with the activities running at regional level, promoting mutual empowerment and boosting potential impact of the future work-programme to which Pathfinder is expected to contribute.

Chapter 4 also identifies associations and centres of excellence specifically working in the field of S&FT.

4.1. Regional initiatives

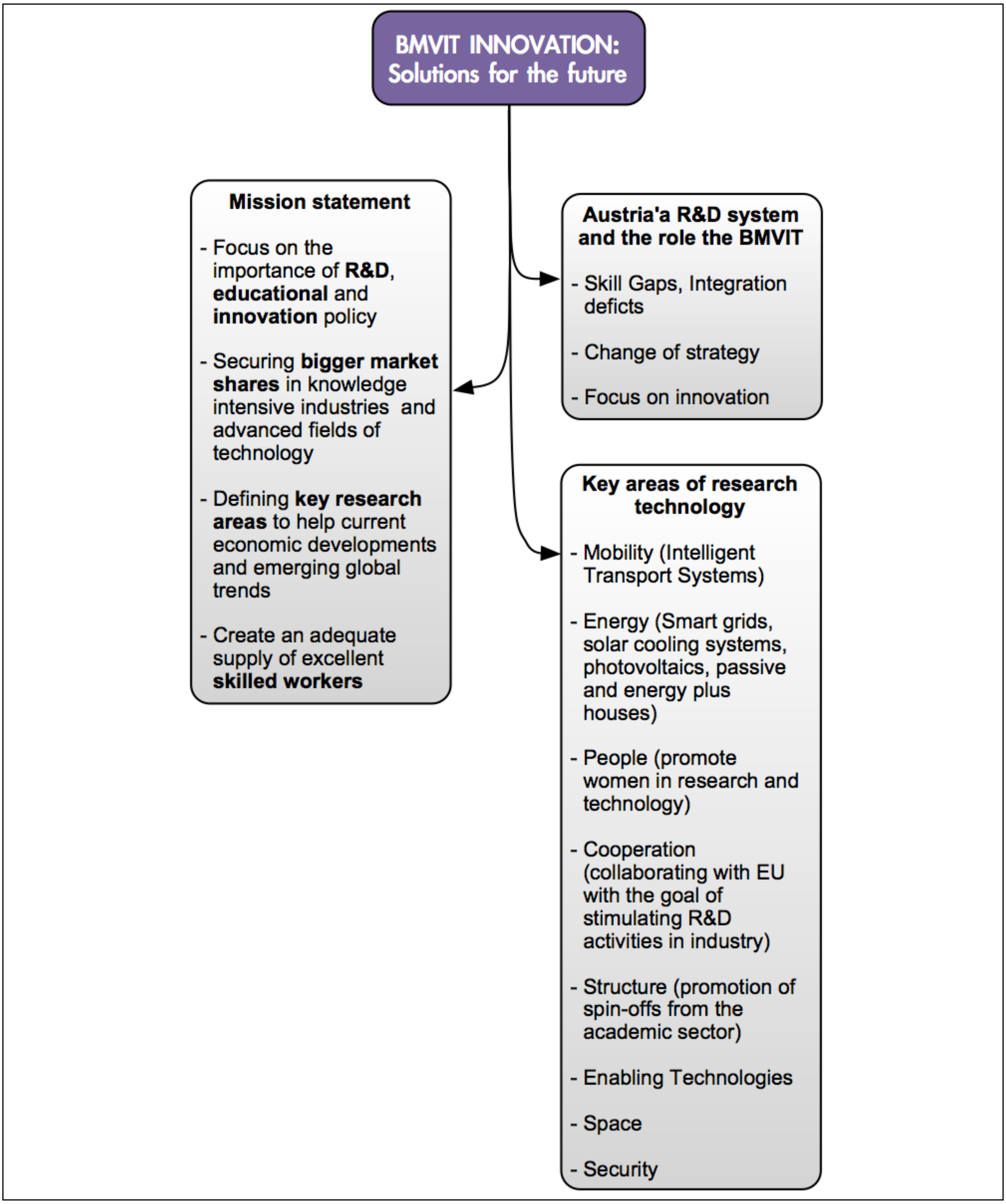
Out of the 28 European Countries, 11 road-mapping or innovation programmes have been addressed (Austria, Denmark, Finland, France, Germany, Ireland, Latvia, Netherlands, Sweden, UK). The analysis compares the manufacturing-of-the-future visions at single country level with those proposed at European level, identifying explicit and implicit references to S&FT. Those references have been linked to the Research Areas identified for the Pathfinder roadmap development (par 6.1.4). The following table provides the list of the addressed documents.

Country	Title	Link	Date of issue
Austria	BMVIT (Austrian Ministry for Transport, Innovation and Technology) Innovation: Solutions for the future	http://www.bmvit.gv.at/en/service/publications/downloads/bmvit_innovation_solutions.pdf	October 2009
Denmark	Manufacturing 2025: Five future scenarios for Danish manufacturing companies	http://www.manufuture.dk/digitalAssets/15/15567_manufacturing-2025_download.pdf	May 2010
Finland	Finland's regional development strategy 2020	https://www.tem.fi/files/27807/TEM_53_2010_netti.pdf	September 2010
France	France Europe 2020: A strategic agenda for research, technology transfer and innovation	http://cache.media.enseignementsup-recherche.gouv.fr/file/France-Europe_2020/18/3/AgendaStategique02-07-2013-EnglishLight_262183.pdf	February 2013
Germany	Recommendations for implementing the strategic initiative INDUSTRIE 4.0	http://www.plattform-i40.de/sites/default/files/Report_Industrie%204.0_engl_1.pdf	April 2013
Ireland	Making it in Ireland: Manufacturing 2020	http://www.djei.ie/enterprise/support/FinalForfasReport.pdf	2012
Latvia	Sustainable Development Strategy of Latvia until 2030	http://www.cbs.nl/NR/rdonlyres/B7A5865F-0D1B-42AE-A838-FBA4CA31674D/0/Latvia_2010.pdf	June 2010
Netherlands	Global Challenges Dutch Solutions	http://english.rvo.nl/sites/default/files/2014/01/Global%20Challenges-Dutch%20Solutions_ENG_2.pdf	2011
Netherlands 2	Smart Industry – Dutch industry fit for the future	http://www.clicknl.nl/wp-content/uploads/2014/06/Smart-Industry-.pdf	April 2014
Sweden	Swedish Production Research 2020	http://www.teknikforetagen.se/Documents/FoU/Swedish_production_research_2020.pdf	2008
United Kingdom	The future of manufacturing: a new era of opportunity and challenges for the UK	http://www.ifm.eng.cam.ac.uk/uploads/Resources/Future_of_Manufacturing_Report.pdf	2013

4.1.1. Austria – BMVIT INNOVATION: Solutions for the future

Aims and Scope	The BMVIT focuses mainly on sustainable, technological solutions that provide answers to societal challenges and strengthen Austria's position in International competition. As a result, the study documents the highly dynamic nature of research and development in Austria in recent years, but also reveals untapped potential. Furthermore, the report draws attention to skills gaps and emphasizes the importance of research training of university graduates, especially in the field of science and engineering, as they lay the foundation for innovation. In order to achieve improvements in Austria, it has been conducted a "system evaluation" which presents three areas that need to be improved: the number of companies that regularly engage in innovation activities remains small; research spending is concentrated upon a small group of companies;

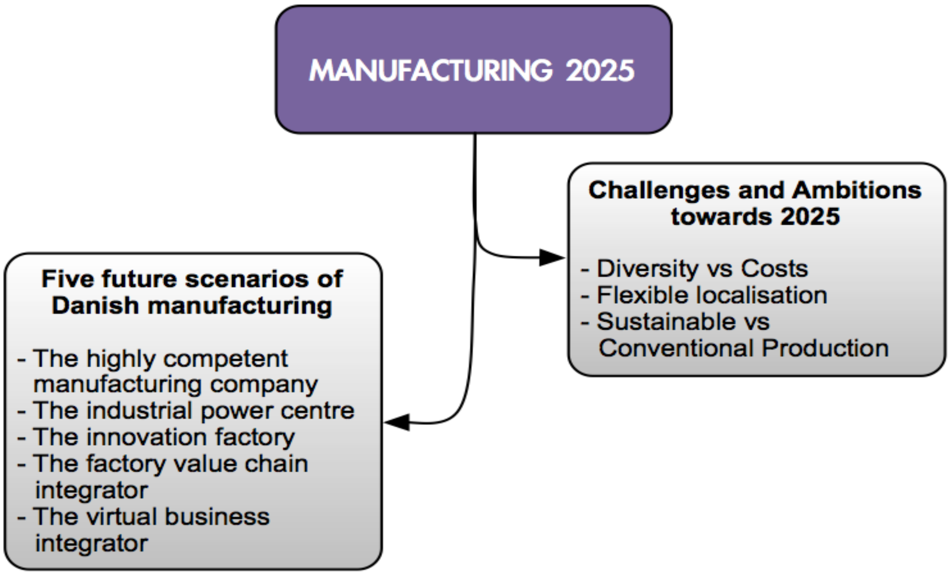
	the educational system does not provide the necessary support for innovation. To conclude, BMVT calls for a strategic change to Austrian innovation policy.
Actors / commitment	The Federal Ministry for Transport, Innovation and Technology (BMVIT) has developed this study relying on previous analysis such as “a thorough examination of the Austrian research funding system” that have been made by Austrian’s Universities and other partners. These analyses provide the basis upon which the BMVIT will initiate and support the forthcoming reforms.
Time horizon	2020
S&FT references	There is no explicit reference to the use of S&FT, but those technologies are an underlying key enabler for the Key Areas of Research Technology pointed out.



4.1.2. Denmark – Manufacturing 2025

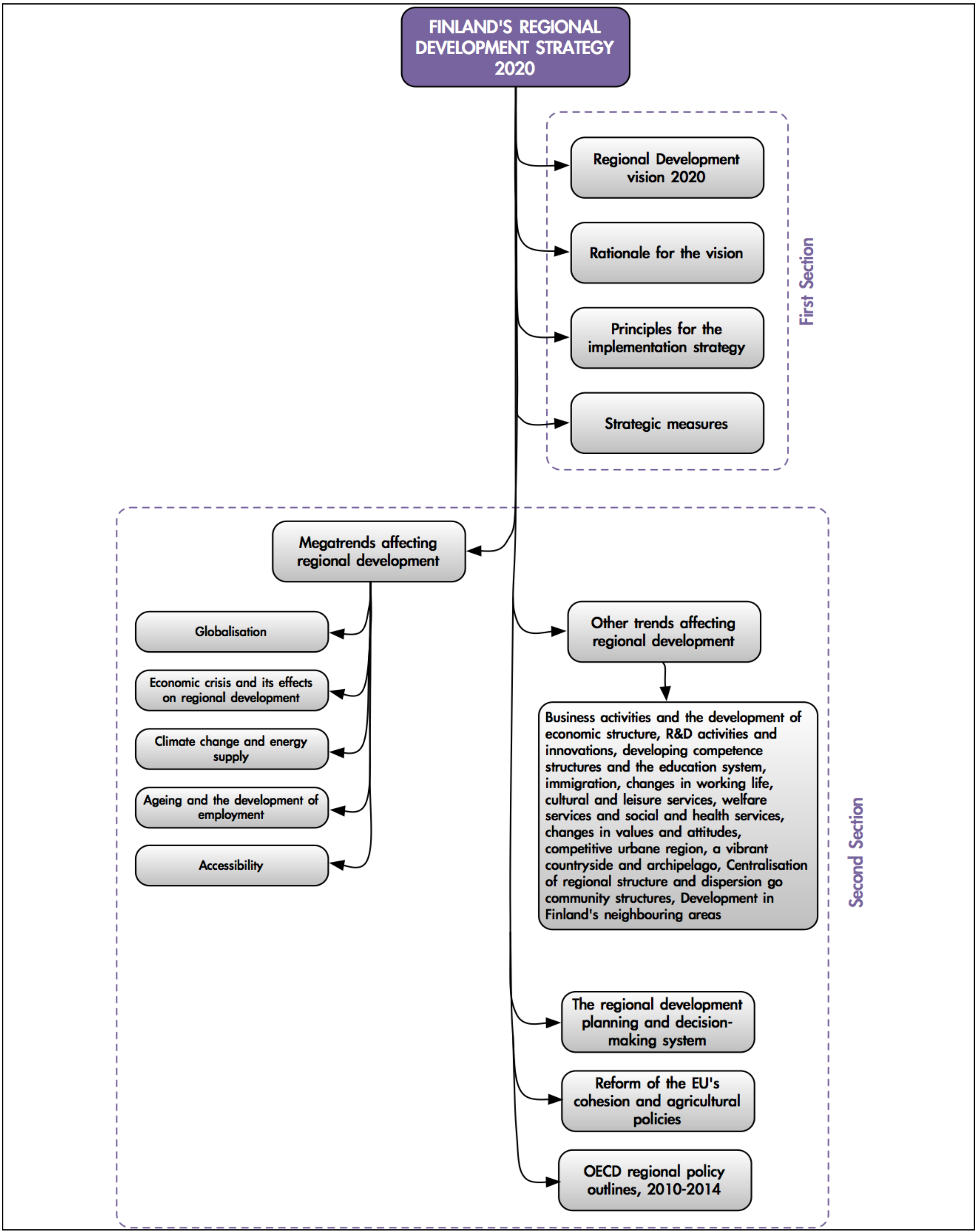
Aims and Scope	Manufacturing 2025 is meant to inspire Danish companies in their search for innovative solutions that will contribute to the development of competitive production based in Denmark. It examines how manufacturing companies of the future might look like and the consequent knowledge requirements. The examination thus provides an outline of what is required for Denmark to maintain a strong and competitive manufacturing sector in 2025. The publication shows how manufacturing companies in a Danish context can organise their resources and efforts to obtain

	an advantage in global competition by exploiting the special competences and business conditions that characterise Danish society. On the basis of the Danish advantages and challenges, five future scenarios of profitable and sustainable manufacturing in Denmark in 2025 have been elaborated. A common feature of these five scenarios is that production provides an important framework for product development and innovation. The five scenarios are proposals for successfully maintaining knowledge and innovative ability in Denmark.
Actors / commitment	This publication is supported by the Industrial Fund for Educational Development and Cooperation and the Danish Agency for Science, Technology and Innovation. Behind the study there are five Danish manufacturing companies, three universities and the two largest labour market organisations.
Time horizon	2025
S&FT references	“The virtual business connects the best global competences in virtual networks in order to quickly and effectively exploits more business opportunities and pools its resources of business creation, innovations, distribution, and production.” [Page 29] “The virtual business exists for as long as the product exists or a profitable business can be created.” [Page 29] “Explore the concept of ’the virtual business’, including technology enablers, culture, etc.” [Page 29]



4.1.3. Finland – Finland’s regional development strategy 2020

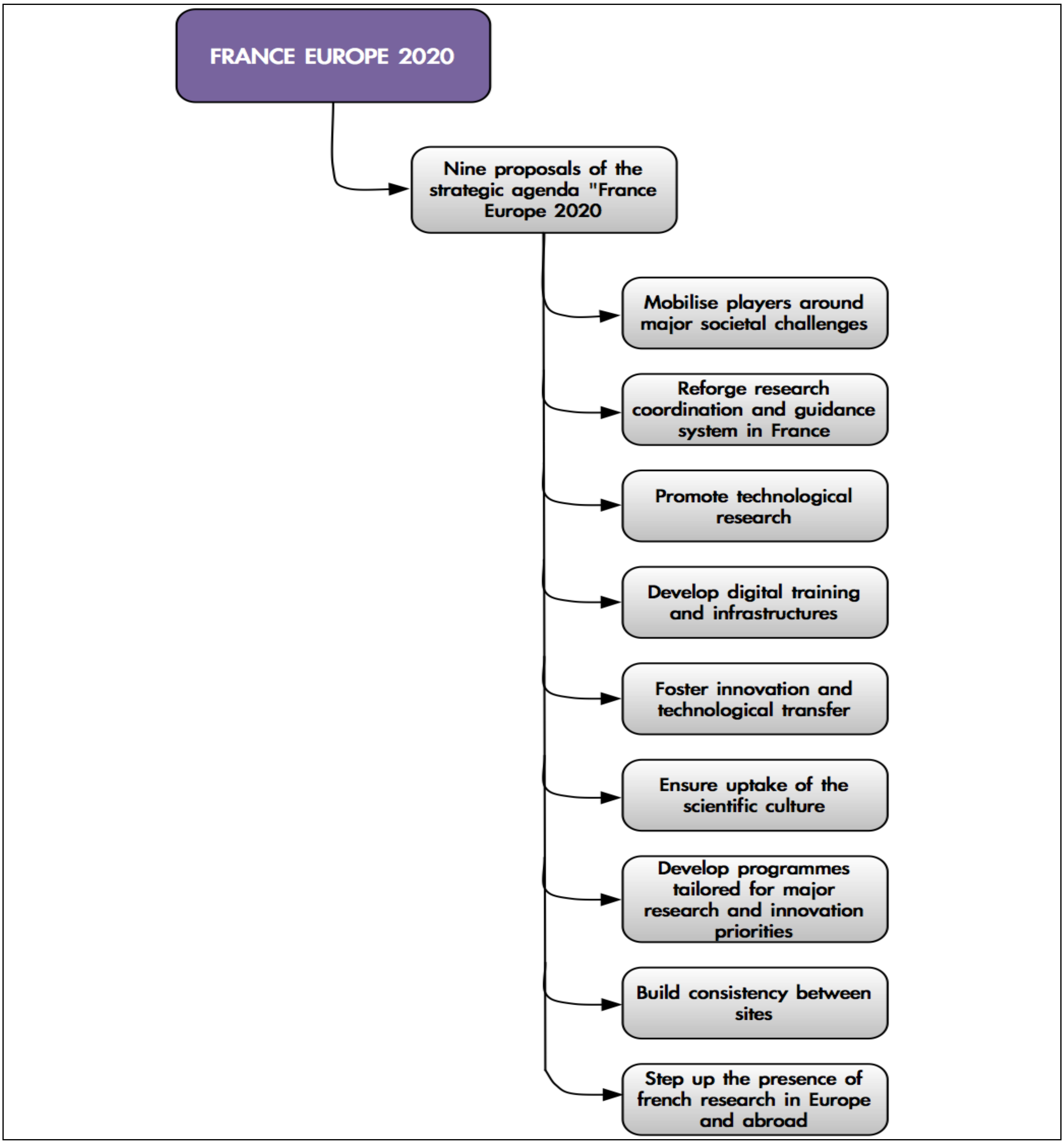
Aims and Scope	The Finnish Regional Strategy 2020 describes the challenges facing regional development in the 2010s and presents visions for the state of the Finnish regions and for the aims of nationwide regional development of the year 2020. The report is divided into two sections. The first section contains a reasoned regional development vision for the year 2020 and the basic principles of its implementation. This vision consists of an overall vision that is supported by thematic visions, principles for the implementation of the development strategy and propositions for strategic measures for the coming years. The second part of the regional Strategy 2020 consists of background material prepared for the presented vision. It contains an extensive analysis of the development trends of 2010s and their regional implications. These trends, developments and challenges are considered as phenomena that affect the regions of Finland. In addition to major trends, the memorandum takes notice of other important trends affecting regional development and the evolution of government structure.
Actors / commitment	In 2008 the Ministry of Employment and the Economy set up a working group to prepare the strategy for Regional Development until 2020. The working group was chaired by Veijo Kavonius, Director for Regional Development of the Regional Strategy Group in the Ministry of Employment and the Economy’s Regional Development Unit.
Time horizon	2020
S&FT references	There is no explicit reference to the use of S&FT. ICT is an underlying key enabler.



4.1.4. France - France Europe 2020, a strategic agenda for research, technology transfer and innovation

Aim and Scope	Through this Agenda, the aspiration is to collectively set out the priority areas for progress in

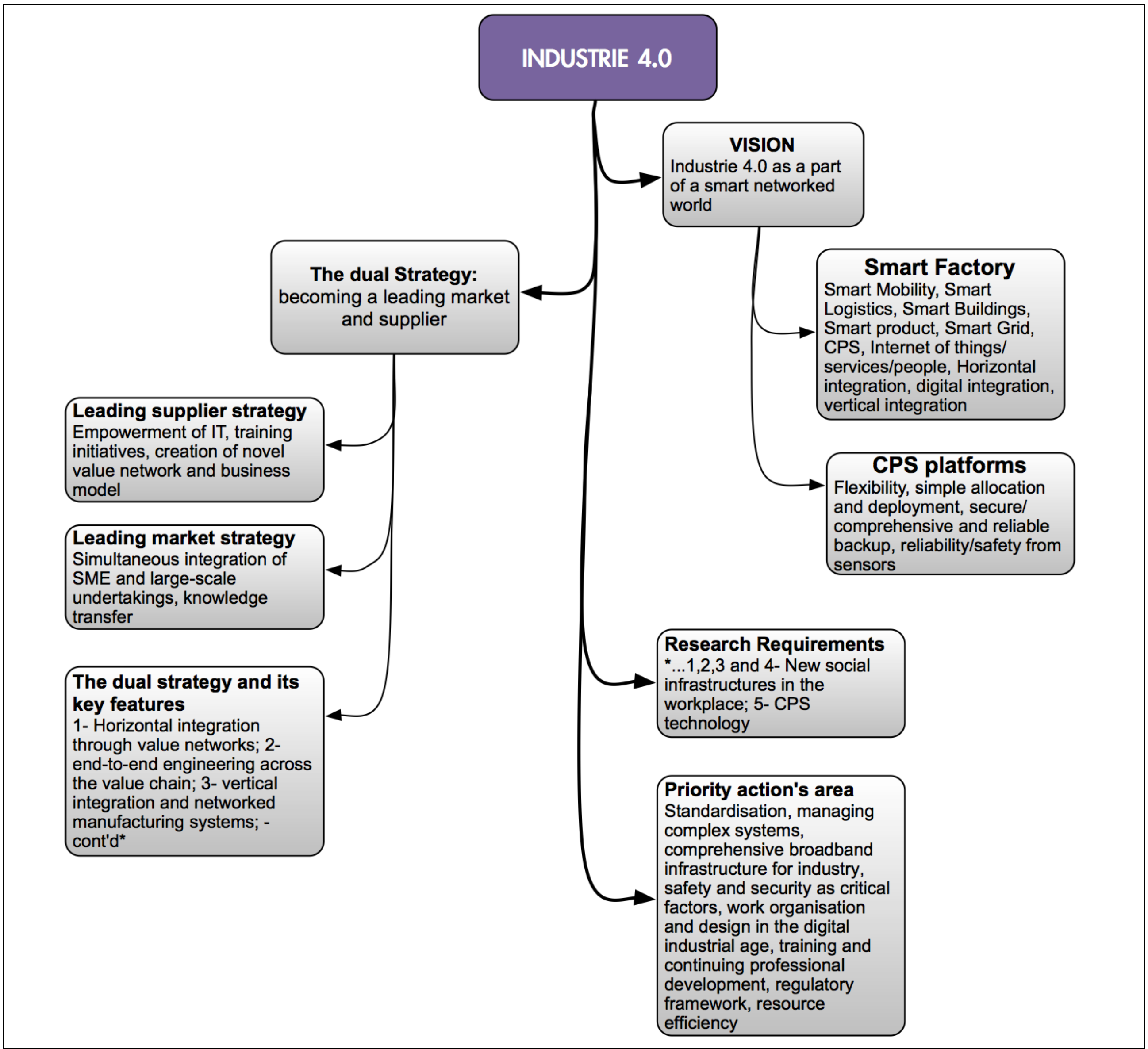
	knowledge and technology, taking into consideration the key challenges which the Nation faces, and to lay down the foundations needed for them to be implemented. The central aim of the "France Europe 2020" Agenda is to enable all areas of French research to better take on the scientific, technological, economic and societal challenges of the decades to come.
Actors / commitment	The study was conducted by the scientific community, social and economic partners, the relevant Ministries and local authorities. The National Research Strategy will be revised regularly, under the coordination of the Ministry of Research, and will be implemented through multi-year contracts concluded with research institutions, higher educations institutions, the National Research Agency's (ANR) planning department, and other public research funding agencies.
Time horizon	2020
S&FT references	"The digital sciences and technology have become the central nervous system to enterprises and companies. They have become and unimpeachable part of the lives of virtually every French citizen." [Page 51] "Digital is also a tool serving all sciences and all technologies. Digital simulation makes it possible to bring about spectacular strides in many scientific disciplines." [Page 51] "Digital simulation and big data mining are key enabling technologies and represent major issues for scientific and technological research, innovation and the nation's competitiveness." [Page 51] "The training offered in digital professions must thus be kept up, especially as Europe estimates that the lack of qualified personnel in this sector at 700.000, and between 7.000 and 10.000 in our country." [Page 51] "Modelling and predicting the development of ecosystems to better support the ecological transition." [Page 13]



4.1.5. Germany – Industrie 4.0

Aim and Scope	The first three industrial revolutions came about as a result of mechanisation, electricity and IT. Now, the introduction of the Internet of Things and Services into the manufacturing environment is ushering in a fourth industrial revolution. In the future, businesses will establish global networks that incorporate their machinery, warehousing systems and production facilities in the shape of Cyber-Physical Systems (CPS). In the manufacturing environment, these Cyber-Physical Systems comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently. The smart factories that are already beginning to appear employ a completely new approach to production. In Industrie 4.0, dynamic business and engineering processes enable last-minute changes to production and deliver the ability to respond flexibly to disruptions and failures on behalf of suppliers, for example. In addition, Industrie 4.0 will address and solve

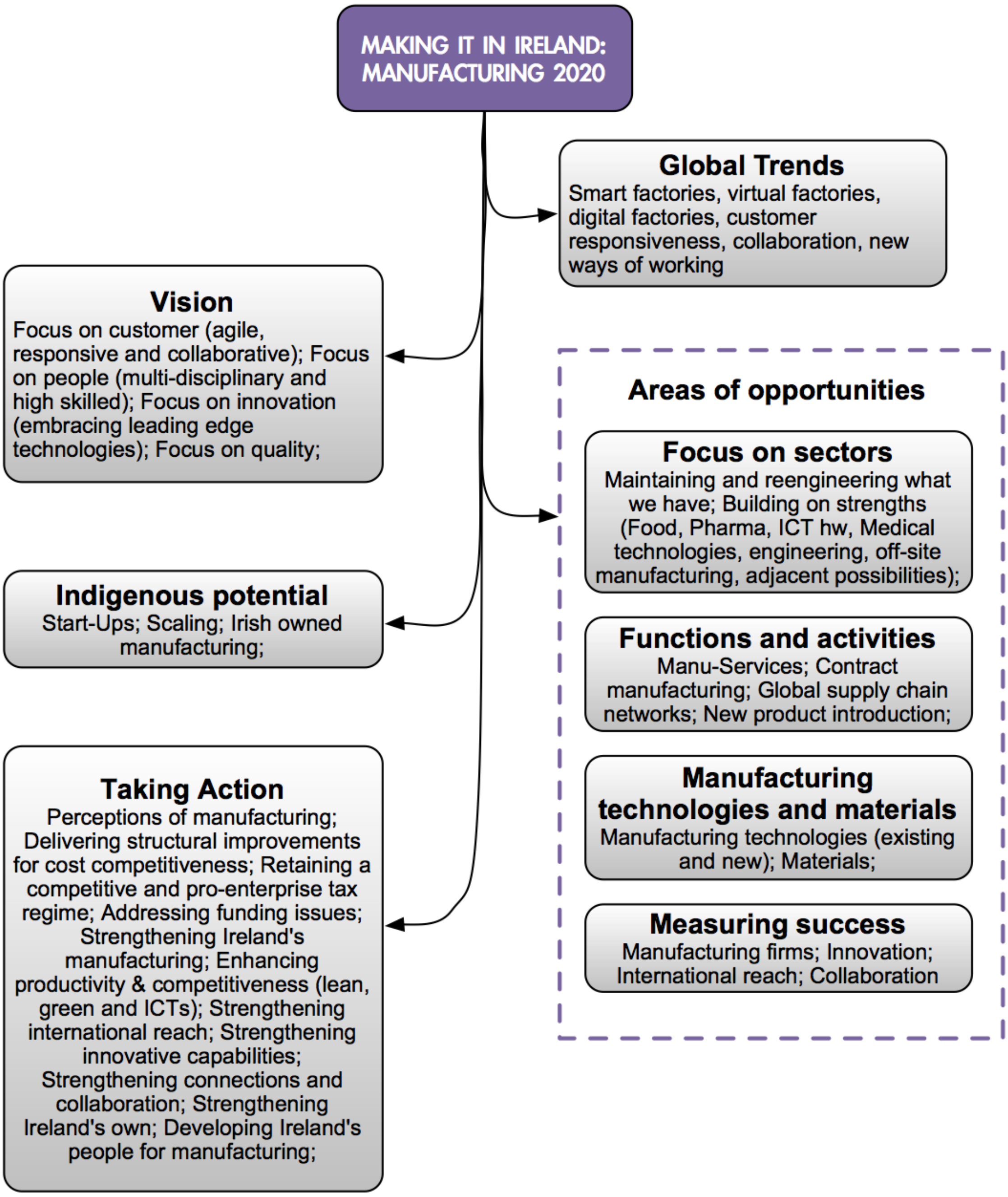
	some of the challenges facing the world today such as resource and energy efficiency, urban production and demographic change. Industrie 4.0 enables continuous resource productivity and efficiency gains to be delivered across the entire value network. It allows work to be organised in a way that takes demographic change and social factors into account. Flexible work organisation will enable workers to combine their work, private lives and continuing professional development more effectively, promoting a better work-life balance. In order to shift from industrial production to Industrie 4.0 relies on the following overarching aspects: • Horizontal integration through value networks • End-to-end digital integration of engineering across the entire value chain • Vertical integration and networked manufacturing systems Furthermore, the Industrie 4.0 Working Group believes that action is needed in the following eight key areas: Standardisation and reference architecture, managing complex systems, a comprehensive broadband infrastructure for industry, safety and security, work organisation and design, training and continuing professional development, regulatory framework, resource efficiency. http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/ Material_fuer_Sonderseiten/Industrie_4.0/ Final_report__Industrie_4.0_accessible.pdf
Actors / commitment	Industrie 4.0 is a strategic initiative of the German government that was adopted as part of the High-Tech Strategy 2020 Action Plan in November 2011. It was launched in January 2011 by the COMMUNICATION Promoters Group of the Industry- Science Research Alliance (FU). Its initial implementation recommendations were formulated by the Industrie 4.0 Working Group between January and October 2012 under the coordination of Acatech – National Academy of Science and Engineering.
Time horizon	2020
S&FT references	"The Industrie 4.0 Working Group recommends the establishment of a Working Group under the auspices of the Industrie 4.0 Platform to deal exclusively with the topic of modelling as a means of managing complex systems, particularly in the realm of manufacturing engineering." [Page 46] "Explanatory models describe existing systems in order to acquire knowledge about the system through the model. This typically involves using different analysis such as simulation. For example, simulation can be used to calculate a factory's energy consumption. Explanatory models are often used to validate engineers' design choices". [Page 42] "***Models*** are a representation of a real or hypothetical scenario that only include those aspects that are relevant to the issue under consideration". [Page 42] "***Modelling*** can act as an enabler for managing this growing complexity" [pag 42] "The use of models constitutes an important strategy in the digital world and is of central importance in the context of Industrie 4.0". [Page 42] "One major challenge for Industrie 4.0 will therefore be to raise awareness of models' potential among the wider engineering community and equip engineers with methods and tools for using appropriate models to depict real-world systems in the ***virtual world***." [Page 42] "***Models and simulation*** can only be carried out by qualified experts. It is therefore important that the relevant companies should provide these experts with the appropriate career opportunities." [Page 53] "In this regard, ***modelling*** plays a key role in managing the increasing complexity of technological systems" [Page 29] "…as a matter of priority with a view to developing methodologies and pilot applications in the field of automation engineering ***modelling*** and system optimisation" [page 28] "The services and applications provided by CPS platforms will connect people, objects and systems to each other and will possess several features. On them is the support for collaborative manufacturing, service, analysis and ***forecasting*** processes in business networks." [Page 24]



4.1.6. Ireland - Making it in Ireland: Manufacturing 2020

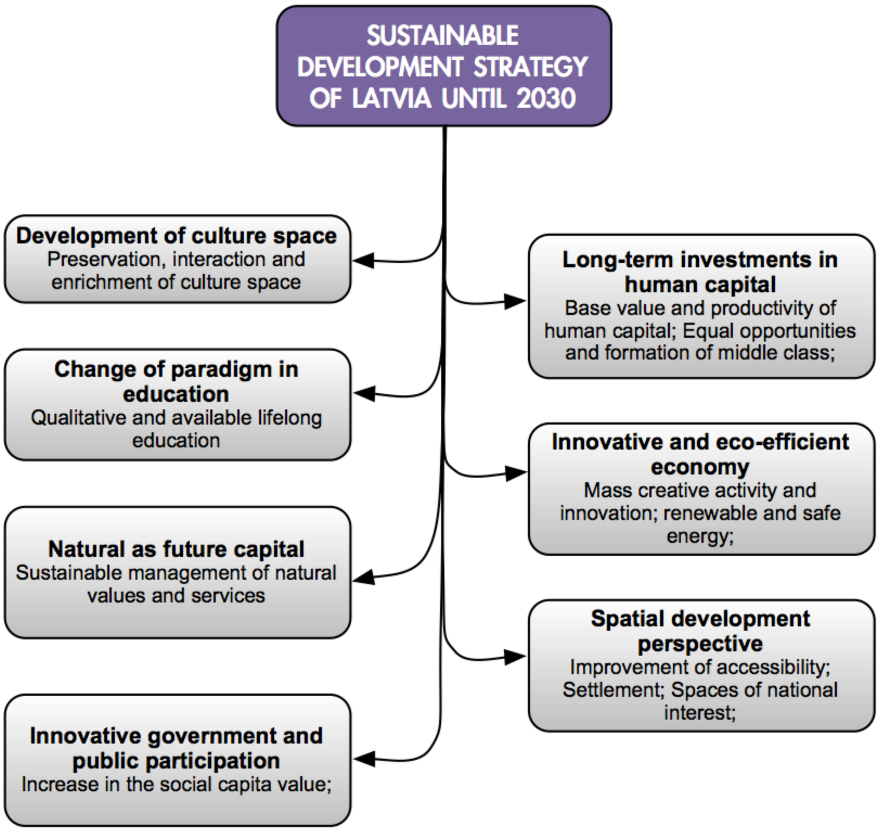
Aim and Scope	This report clearly sets out the potential for manufacturing in Ireland. It has been informed by people who are directly involved in manufacturing and captures their belief in the importance of the making of things to Ireland's economic recovery. The report provides a baseline analysis, sets out the areas of opportunity for manufacturing in Ireland across sectors and activities, places a focus on the indigenous sector, and details the supporting business environment for manufacturing.
Actors / commitment	The study was commissioned to Forfás, which is the Ireland's policy advisory board for enterprise, trade, science, technology and innovation. Forfás has consulted extensively with industry, enterprise development agencies, academia and key stakeholders in developing this strategy.
Time horizon	2020
S&FT references	"Smart Factories offer agile manufacturing (flexibility and short-time cycles) and customisation involving process automation control, planning, simulation and optimisation technologies, robotics, and tools for sustainable manufacturing; Smart factories are underpinned with Lean and ICT systems, characterised as energy efficient, reliable, and cost-effective production operations." [Page 5] "Digital Factories offer greater simulation, modelling, evaluation and knowledge management and deliver enhanced Product Lifecycle Management (PLM) from the product concept level through

	to manufacturing, maintenance and disassembly/recycling; and facilitate better real-time decision making and quality control throughout the production process.” [Page 5] “…Technologies encompass those used in the production process (including analytics, simulation, modelling, Lean techniques, CNC47, Computer Integrated Manufacturing etc.) as well as Information and Communications Technologies (Tracking & Tracing, Customer Relationship Management, Open Innovation etc.).” [Page 31] “The greater use of ICTs in production processes facilitates greater quality management and control, enhanced efficiencies, optimisation of energy and waste reduction through real time analytics, modelling and simulation.” [Page 13] “Virtual Factories are global networked operations built on pervasive ICT systems. Seamless integration of intelligence from all aspects of the business (regardless of where located and including external partners and suppliers) facilitate and drive decision-making. In simple terms, a complex global network of operations functions as one.” [Page 5]



4.1.7. Latvia – Sustainable development strategy of Latvia until 2030

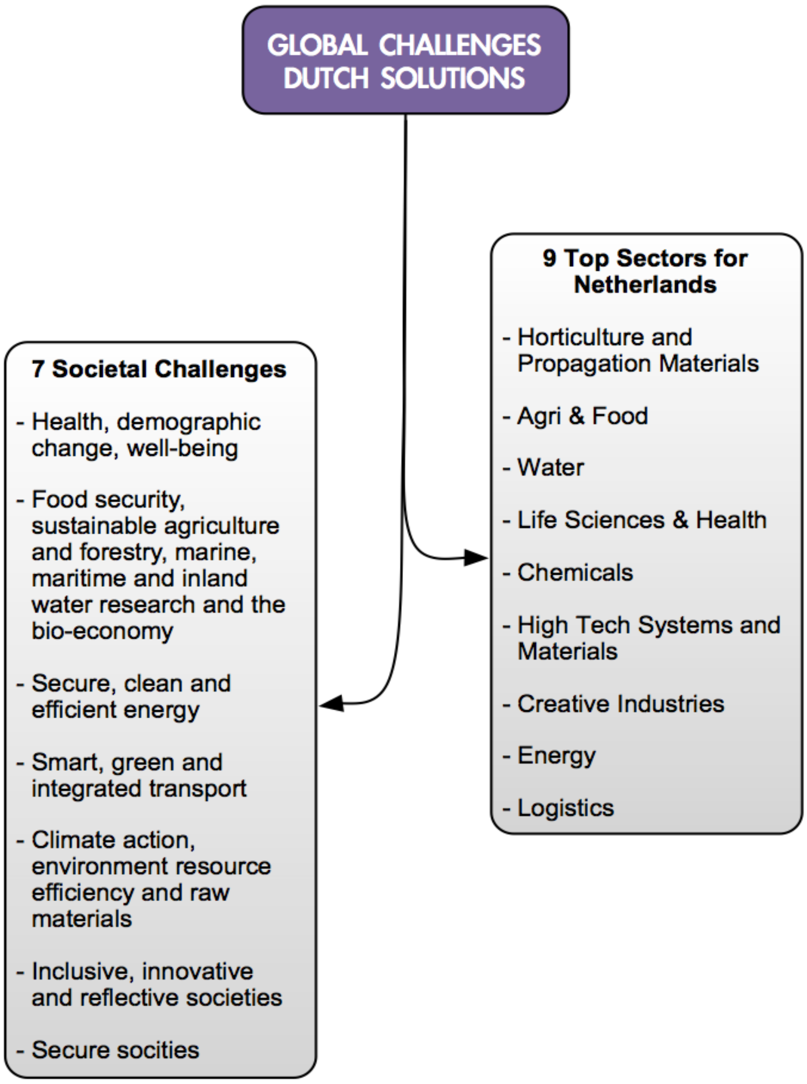
Aim and Scope	The development of this strategy began with the analysis of global development tendencies and their impact on Latvia. These factors strongly influence the challenges and threats that the country has to consider, and besides, they may outline new opportunities available. On the basis of the base value of the resources accessible in Latvia, there will be identified solutions, which reduce threats, use the opportunities as much as possible and transform the things, which have been viewed before as threats, into new opportunities. To do so, the study pays particular attention on environmental, social and economic issues, which are closely interrelated and should be solved jointly.
Actors / commitment	This project has included the work of a group of experts led by the associate professor Roberts Kīlis, in accordance with the task of the Ministry of Regional Development and Local Government.
Time horizon	2030
S&FT references	There is no explicit reference to the use of S&FT.



4.1.8. Netherlands – Global Challenges Dutch solutions

Aim and Scope	The document emphasizes Netherlands' Top Sectors which are strictly related to the societal challenges emerged from Horizon 2020. The Top Sectors policy aims to strengthen the position of nine economic sectors in which the Netherlands has a leading position internationally. It sets out an integrated policy for each sector. The key basic components of this integrated approach are: research and innovation, human capital, regulatory framework and the international dimension. There are a numbers of reasons why it is important that the Top Sectors address the societal challenges identified by Horizon 2020. Firstly, many of these challenges have pan-European and even global relevance, and individual countries cannot deal with them alone. Secondly, it will enable the Netherlands to benefit from the knowledge available in other Member States
Actors / commitment	For the research and innovation aspect, each Top Sector has signed an innovation contract, setting out what the priorities of the Top Sectors are in this field and which parties are responsible for which activities. Based on the innovation contracts, the Netherlands Organisation for Scientific Research (NWO), the Royal Netherlands Academy of Arts and Sciences (KNAW) and institutes of applied science (united under the flag of TO2), started programming their research.

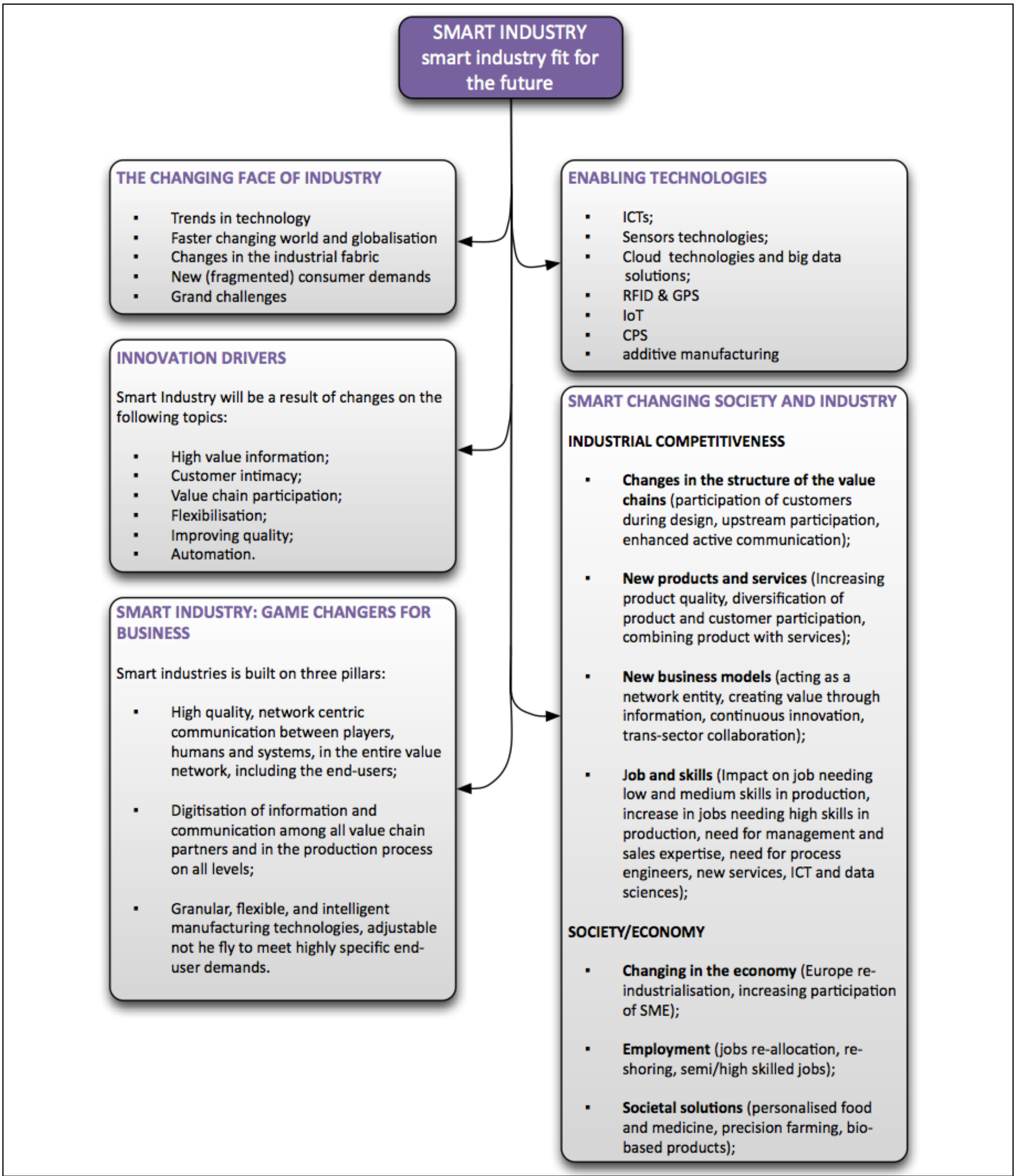
Time horizon	2020
S&FT references	“With the Design roadmap, the top sector creative industries is working on the application of light design for a safer built environment and crowd control. Research is developing lighting scenarios that make a contribution to de-escalation in emergency situations. The roadmap Games is focusing on serious games, which involves training and simulation to prepare for threatening situations; this is an important part of training for people working in the security sector.” [Page 51] “The ‘clean water’ programme in the roadmap Nanotechnology focuses on nanotechnology applications in water, and in particular ensuring clean water. Innovation in ICT and innovative use of ICT contributes to a more efficient use of raw materials (e.g. more digitisation means less paper) and more efficient production. Through the action line called "data, data, data" research is being done for improved processing of large amounts of data. This is important for simulations in climate models, among other things.” [Page 44] “The crisis response will benefit from systems and organisations that are in tune with each other. This project contributes to this by developing software, 3D simulations and advanced technologies for interaction between humans and computers.” [Page 50] “Monitoring dykes led to savings and deferred investment from water authorities. Less clay needs to be used in the construction of dykes because the flood forecast system (Early Warning System) is able to effectively find where weaknesses are located in the dyke.” [Page 41]



4.1.9. Netherlands – Smart Industry: Dutch industry fit for the future

Aim and Scope	This study was conducted in order to identify the challenges that the Dutch industry will face in the future with the transition towards the Smart Industry. The Dutch manufacturing industry is of paramount importance for the economic growth of the country. Even though, Dutch companies

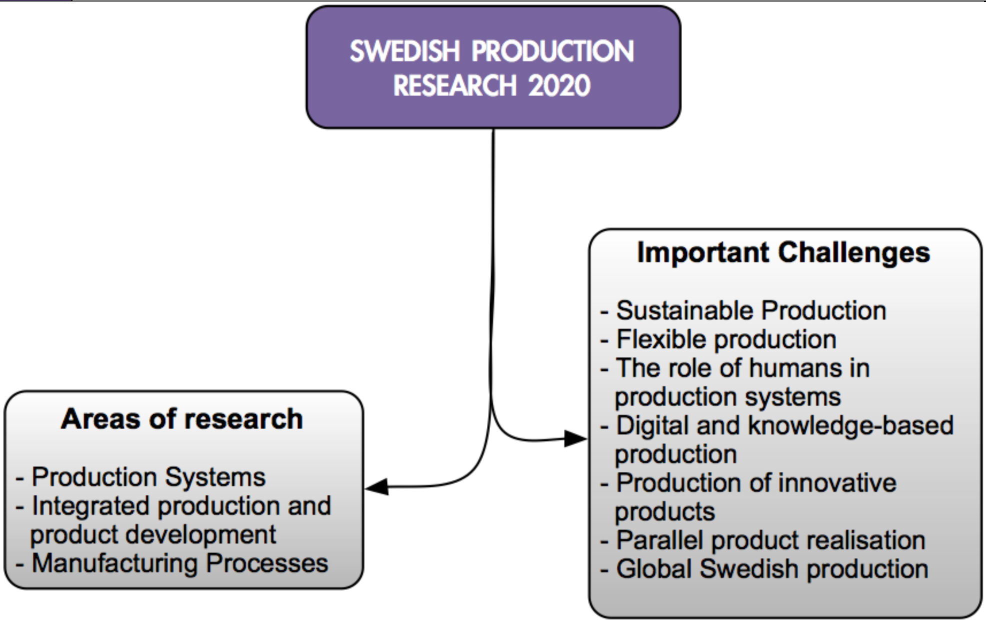
	have spent many efforts to engage with Smart Industry initiatives it is mandatory and possible to do more. Starting to develop a common strategy which will ensure the competitive position in European and global markets. The Smart Industry is the strategic vision of the future Dutch industry that will entail high flexibility in production thanks to a network-centric approach and relying on the value of information drive by ICT and innovative technologies. Furthermore, the study shows that there is a major challenge to adapt new emerging ICT, data and production technologies because this allow foster the production processes and the entire value chain.
Actors / commitment	This document was made using input from stakeholders across the country, collected by means of in depth interviews, workshops and validation sessions. We are immediately grateful for the fantastic contributions from more than 100 companies, knowledge institutions, government authorities and economic development organisations, called the triple helix.
Time horizon	-
S&FT references	"Digitisation will be taken to the next level. It is not only about sharing information. It is also key to further automation, together with next generation robots. New ways of pattern recognition, smart data modelling and computational technologies can even lead to fully automated facilities and to smart and automated ways to support production assistants." [Page 19] "Massive data generated by sensors and communicated across the value network, in combination with information handling technologies such as big data, data mining and predictive modelling, enables better control of production processes." [Page 50] "Through 'computational technologies', manufacturers can make a computer model of the needed chemical properties, which are then sent to the factory." [Page 45] "ICT-related technology, including Internet of Things, cloud technology, big data and data processing, embedded systems, cyber-physical systems, RFID, sensors. It concerns not only the hardware, but also the software and "data science". " [Page 59] "Cloud technology and Big Data solutions will collect, process, transport and store the massive amounts of information sensed and communicated by billions of devices." [Page 20]



4.1.10. Sweden – Swedish production research 2020

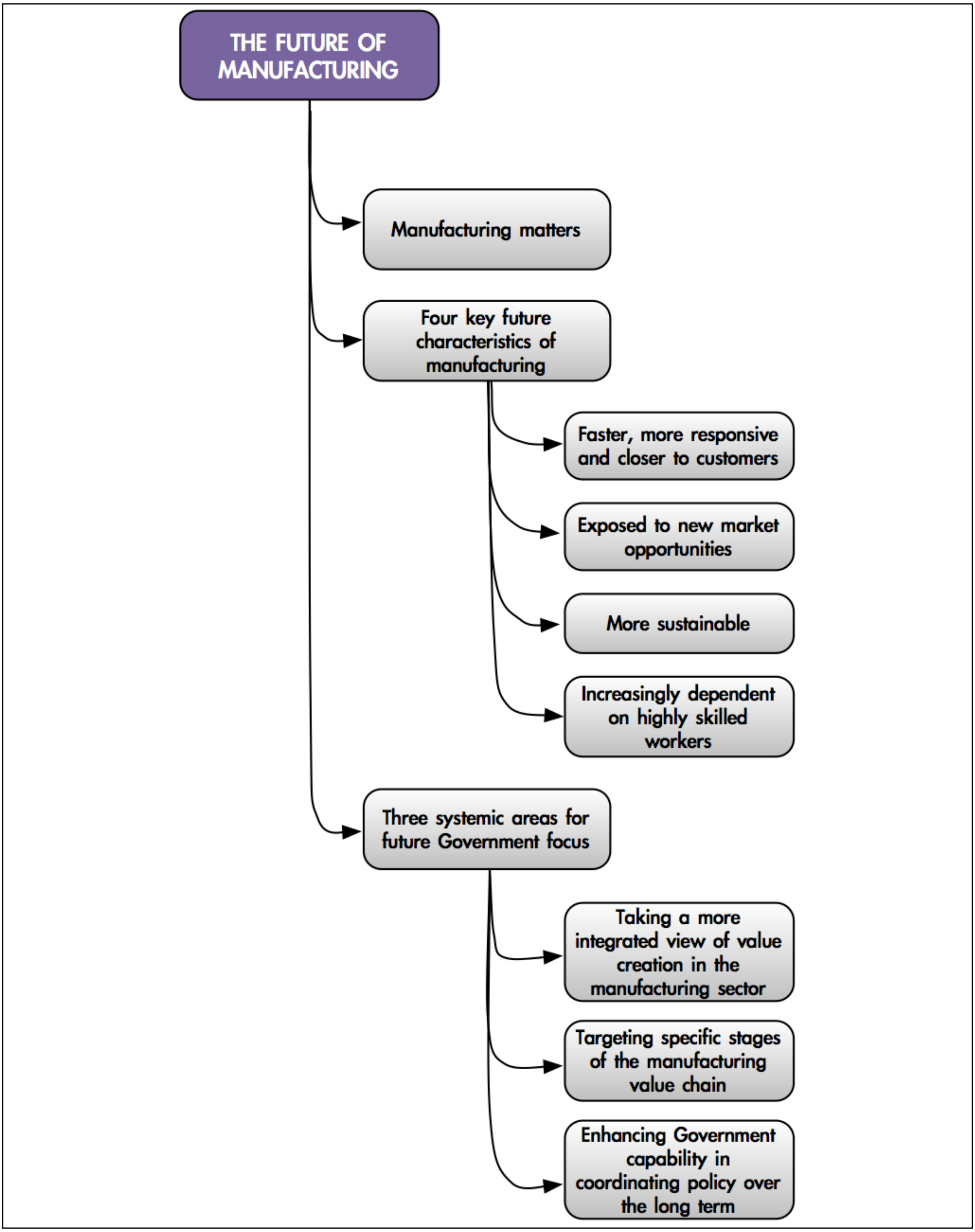
Aim and Scope	The presented agenda is a joint vision of industry and academia towards the year 2020. This agenda is designed to serve as a base for detailed research strategy, and it identifies a number of challenges facing Swedish manufacturing industry and points out the necessary research to overcome these challenges.

Actors / commitment	The present document has been realised in collaboration with Swedish industry, academia and research institutes to serve as a foundation for a strategy for Swedish production research towards the year 2020. This agenda is also a result of a close collaboration between Teknikföregaten, The Swedish Production Academy and Swerea IVF, and has been realized by Johan Stahre, Chalmers University of technology.
Time horizon	2020
S&FT references	“Simulations and virtual modelling are used to greatly reduce the time from design to production and replaces the use of physical models and tests. These new IT-tools make it possible to significantly shorten the development time for new products.” [Page 20] “Methods for geometric simulation can also be used to create products that are less sensitive to deviations in the geometry of single details, which in turn reduce the requirements for precision in the manufacturing process. An important challenge is to create virtual models that have the necessary yet manageable degree of specific detail to test new product constructions.” [Page 20] ”The development of decision support in the form of cost simulations is very important to be able to develop products with a high productivity.” [Page 20] “Simulation and visualisation tools can provide comprehensive overviews of very complex technical system of machines, people, product flows, production systems, workshops, and supplier networks. Virtual tools are therefore becoming increasingly effective support for co-operation between different specialist functions and a way to radically decrease the risk of future problems.” [Page 19] “Methods and tools must also include efficient ways to collect correct information and data for simulation models from the real production situation. A big challenge is to make the simulations visualise predicted disturbances that often occur in real operative situations.” [Page19] “Combinations of theoretical, practical and computer-aided learning are emerging fast, with tools such as simulation technology.” [Page 19] “Simulation and calculations for advanced manufacturing processes must be based on experimental material and process data.” [Page 25] “By developing process-like material characterisation it will be possible to increase the precision, speed and broad application of the simulation.” [Page 25] “Simulation of forming operations can make it possible for tools to give the desired result at the first attempt and thereby avoid delays.” [Page 24] “For a successful process simulation, and to be able to predict the pro- cess result, large experimental research initiatives are necessary. A clear example of this is simulation methods for cutting machining.” [page 24] “Other important areas of research are advanced user interfaces, mobile and ”hidden” information technology, social networks for problem solving, production ergonomics and virtual representations of humans in production simulations.” [Page 18] “Virtual tools are therefore becoming increasingly effective support for co-operation between different specialist functions and a way to radically decrease the risk of future problems.” [Page 17]



4.1.11. United Kingdom – The future of manufacturing

Aim and Scope	This report focuses on manufacturing, with a particular emphasis on the United Kingdom. The main purposes of this study are: • To identify and analyse important drivers of change affecting the UK manufacturing sectors; • To identify important challenges and opportunities that lie ahead and which require action by Government and Industry; • To advice how Government policy needs to be refocused and rebalanced so that it is better positioned to support the growth and resilience of UK manufacturing over coming decades. In so doing, a specific aim is to inform further development of the Government's industrial and sector strategies.
Actors / commitment	It has been developed by the Government Office of Science with the contribution of a multi-disciplinary Lead Expert Group (300 leading business people from 25 countries) and an Industry High Level Stakeholder Group who oversaw the technical aspects of the project, under the personal direction of the Government Chief Scientific Adviser.
Time horizon	2050
S&FT references	"Information and communications technology (ICT) - Modelling and simulation integrated into all design processes, together with virtual reality tools will allow complex products and processes to be assessed and optimized, with analysis of new data streams." [Page 21] "Big data and knowledge based automation – These will be important in the on-going automation of many tasks that formerly required people. In addition, the volume and detail of information captured by businesses and the rise of multimedia, social medial and the Internet of the things will fuel future increases in data, allowing firms to understand customer preferences and personalise products." [Page 21] "Advanced and autonomous robotics – Autonomous and near-autonomous vehicles will boost the development of computer vision, sensors including radar and GPS, and remote control algorithms. 3D measurement and vision will be able to adapt to conditions, and track human gestures." [Page 21] "Cloud computing – Computerised manufacturing execution systems (MES) will work increasingly in real time to enable the control of multiple elements of the production process. Opportunities will be creates for enhanced productivity, supply chain management, resource and material planning and customer relationship management." [Page 21]



4.1.12. Local Initiative compared with Pathfinder's Areas

The road-mapping documents have been analysed in order to identify their structure and building elements towards a direct comparison against the Pathfinder initiative to draw inspiration and for a conceptual harmonization and alignment. The national initiatives, where possible, have been mapped over the Pathfinder Research Areas, as shown in the table below.

	RA1 Open and Cloud-based S&FT for high-tech performance computing	RA2 Multi-disciplinary and multi-domain integrated S&FT	RA3 S&FT for life-cycle management	RA4 Multi-level S&FT integration	RA5 S&FT for real-time factory controlling and monitoring	RA6 Smart, Intelligent and self-learning S&FT	RA7 Human-centred simulation-based learning &training	RA8 Crowdsourcing-based S&FT
Denmark								X
France	X						X	
Germany	X	X	X	X		X	X	
Ireland	X	X	X	X	X	X		X
Netherlands	X		X		X		X	
Netherlands2	X		X	X	X	X	X	
Sweden	X		X		X	X	X	
United Kingdom	X		X			X	X	

4.2. Associations

In order to take into account multiple and diverse perspectives over future simulation technologies role, this and the following paragraph provide a mapping of relevant associations and research key players who distinguish themselves internationally for their competences and knowledge in S&FT. By highlighting their competences and scopes, Pathfinder search for current gap and future challenges for simulation and forecasting technologies is made consistent and shared among a larger group of stakeholders.

The following table points out the objectives of S&FT association at European Level

ESSA – The European Social Simulation Association
The European Social Simulation Association (ESSA) promotes the development of social simulation research, education and application in Europe. Founded on a manifesto signed by many social simulation researchers in 1993, the basis of the ESSA's Constitution was formed. ESSA has become the most important hub of social simulation worldwide. By collaborating with CSSSA, the Computational Social Science Society of the Americas, and PAAA, the Pacific Asian Association for Agent-based Approach in Economic & Social Complex Systems, ESSA has promoted international initiatives to build a bridge between regional groups and associations. The objectives of ESSA are to: • Encourage the development of social simulation in Europe and more widely • Promote international cooperation and develop the distinctiveness of European social simulation research • Grow a new generation of social simulation researchers capable of improving traditional fields and

discipline • Promote educational initiatives and support the development of European post-graduate courses and qualifications in social simulation • Favour applied social simulation research that responds to important stakeholders' needs • Support and organize regular regional and international conferences and workshops.? Link: http://www.essa.eu.org
EUROSIM - Federation of European Simulation Societies
EUROSIM, the federation of European Simulation Societies, was set in 1989. The purpose of EUROSIM is to provide a European forum for regional and national simulation societies to promote the advancement of modelling and simulation in industry, research and development. EUROSIM member societies may be regional and/or national simulation societies. At present it has 14 full members and 3 observer members. Link: www.eurosim.info
EUROSIS - The European Multidisciplinary Society for Modelling and Simulation Technology
The aim of **EUROSIS** (The European Multidisciplinary Society for Modelling and Simulation Technology) is to be the primary mover and initiator for and of European simulation and modelling projects, which bridge the gap between academic and industry based simulation and modelling research in Europe. This, by using the power of communication, dissemination of information and member sourcing. Secondly EUROSIS aims at stimulating simulation and modelling projects in various fields in Europe and beyond using its TC structure. Link: http://www.eurosis.org
SCS – European Council
ECMS, The European Council for Modelling and Simulation is an independent forum of European academics and practitioners dedicated to research, development, and applications of modelling and simulation. Link: www.scs-europe.net
ARGESIM - (Arbeitsgemeinschaft Simulation News) Working Group Simulation News
ARGE Simulation News (ARGESIM) is a non profit working group providing the infrastructure and administration for dissemination of information on modelling and simulation in Europe. ARGESIM organises: • ARGESIM Benchmarks for Modelling Approaches and Simulation Systems • Editing and publication of SNE - Simulation Notes Europe • Summer School Simulation Technique • Seminars on Simulation (TU Vienna) • Administration of ASIM (German Simulation Society) • Organisation of MATHMOD Conference Series • Administration of EUROSIM - Federation of European Simulation Societies Link: www.argesim.org

The following table points out the objectives of S&FT association at National Level

ASIM Arbeitsgemeinschaft Simulation	Austria, Germany, Switzerland
ASIM (Arbeitsgemeinschaft Simulation) is the association for simulation in the German speaking area. Organisationally, ASIM is a part of the GI - Gesellschaft für Informatik, the German Association for Informatics. ASIM is governed by an executive board consisting of elected members and of heads of Working Groups. ASIM is organised in Working Groups:	

• Methods in Modelling and Simulation; • Simulation in Environmental Sciences, Medicine and Biology; • Simulation of Technical Systems; • Simulation in Production and Logistics; • Simulation of Traffic Systems; • Simulation in Business Administration. Link: http://www.asim-gi.org	
CROSSIM – Croatian Society for Simulation Modelling	**Croatia**
CROatian Society for SIMulation Modelling was founded on 28 March 1992 as a non-profit society with the goal to promote knowledge and use of simulation methods and techniques, dissemination of information and development of education and training in simulation, particularly through organization of meetings, courses and workshops.	
CSSS – Czech and Slovak Simulation Society	**Czech Republic, Slovakia**
CSSS (The Czech and Slovak Simulation Society) has about 150 members in 2 groups connected to the Czech and Slovak national scientific and technical societies (Czech Society for Applied Cybernetics and Informatics, Slovak Society for Applied Cybernetics and Informatics - SSAKI). The main objectives of the society are: development of education and training in the field of modelling and simulation, organising professional workshops and conferences, disseminating information about modelling and simulation activities in Europe to its members, informing the members about publishing in the field of modelling and simulation. CSSS is a full member of EUROSIM since 1992. Link: http://www.fit.vutbr.cz/CSSS/	
DBSS – Dutch Benelux Simulation Society	**Belgium, The Netherlands**
The Dutch Benelux Simulation Society (DBSS) was founded in July 1986 in order to create an organisation of simulation professionals within the Dutch language area. DBSS has actively promoted creation of similar organisations in other language areas. DBSS is a member of EUROSIM and works in close cooperation with its members and is further affiliated with SCS International, IMACS, and the Chinese Association for System Simulation and the Japanese Society for Simulation Technology.	
FRANCOSIM – Société Francophone de Simulation	**Belgium, France**
FRANCOSIM was founded in 1991 and aims to the promotion of simulation and research, in industry and academic fields. Francosim operates two poles: • Pole “Modelling & simulation of discrete events systems” • Pole “Modelling & simulation of continuous systems”	
HSS – Hungarian Simulation Society	**Hungary**
The Hungarian Member Society of EUROSIM was established in 1981 as an association promoting the exchange of information within research, development, application and education of simulation in Hungary and also contributing to the exchange of information between the Hungarian simulation community and the simulation communities abroad. HSS deals with the organization of lectures, exhibitions, demonstrations, and conferences.	
ISCS – Italian Society for Computer Simulation	**Italy**
The Italian Society for Computer Simulation (ISCS) is a scientific non-profit association of members from industry, university, education and several public and research institutions with common interests in all fields of computer simulation. Its primary purpose is to facilitate communication among those engaged in all aspects of simulation for scientific, technical or educational purposes. ISCS, established in 1984, is a member of EUROSIM Federation and through the years organized a number of scientific events, including the EUROSIM Congress in 1992.	
LIOPHANT SIMULATION – International modelling and simulation group	**Italy**

Liophant is a non-profit association born in order to be a trait-d'union among simulation developers and users; Liophant is devoted to promote and diffuse the simulation techniques and methodologies; the Association promotes exchange of students, sabbatical years, organization of International Conferences, organization of courses and stages in companies to apply the simulation to real problems. Link: http://www.liophant.org	
PSCS – Polish society for computer simulation	**Poland**
IMS is the Scandinavian Simulation Society with members from the four Nordic countries Denmark, Finland, Norway and Sweden. The SIMS history goes back to 1959. SIMS is organised as federation of regional societies. There are **FinSim** (Finnish Simulation Forum), **MoSis** (Society for Modelling and Simulation in Sweden), **DKSIM** (Dansk Simuleringsforening) and **NFA** (Norsk Forening for Automatisering). Link: www.scansims.org	
SLOSIM – Slovenian Society for Simulation and Modelling	**Slovenia**
SLOSIM (**Slo**venian Society for **Si**mulation and **M**odelling) was established in 1994 and became the full member of EUROSIM in 1996. Currently it has 76 members from both Slovenian universities, institutes, and industry. It promotes modelling and simulation approach to problem solving in industrial as well as in academic environments by establishing communication and cooperation among the corresponding teams. Link: www.slosim.si	
UKSIM – United Kingdom Simulation Society	**UK, Ireland**
The UK Simulation Society (UKSim) counts more than 100 members throughout the UK from universities and industry. It is active in all areas of modelling and simulation and it holds an annual conference as well as regular meetings and workshops. Link: www.ducati.doc.ntu.ac.uk/uksim/	
CEA SMSG Spanish Modelling and Simulation Group	**Spain**
CEA is the *Spanish Society on Automation and Control* and it is the national member of *IFAC* in Spain. Since 1968 CEA-IFAC looks after the development of the *Automation* in Spain, in its different issues: automatic control, robotics, SIMULATION, etc. In order to improve the efficiency and to deep into the different fields of Automation, the association is divided into thematic groups, concretely eight groups at present. One of them is named “Modelling and Simulation”, constituting then the CEA-SMSG (CEA-IFAC Spanish Modelling and Simulation Group), which looks after the development of the “Modelling and Simulation” in Spain. This group works basically about all the issues concerning the use of Modelling and Simulation techniques as essential engineering tools for decision-making. Link: http://www.ceautomatica.es/en/portal	
LSS – Latvia Society for Simulation	**Latvia**
The Latvian Simulation Society has been found in 1990 as the first professional simulation organization in the field of modelling and simulation in the post-Soviet area. Its members represent the main simulation centres in Latvia, including both academic and industrial sectors, in particular, operating at Riga Technical University, Latvian University, the Latvian University of Agriculture, Transport and Telecommunication Institute, as well as at industrial companies DATI Exigen Group and Solvers, Ltd. Link: http://www.itl.rtu.lv/imb/	
SIMS - Scandinavian Simulation Society	**Denmark, Norway, Sweden, Finland**
SIMS is the Scandinavian Simulation Society with members from the four Nordic countries Denmark, Finland, Norway and Sweden. The SIMS history goes back to 1959. SIMS is organised as federation of regional societies. There are **FinSim** (Finnish Simulation Forum), **MoSis** (Society for Modelling and Simulation in Sweden), **DKSIM** (Dansk Simuleringsforening) and **NFA** (Norsk Forening for Automatisering). Link: www.scansims.org	
ROMSIM – Romanian Modelling and Simulation Society	**Romania**

ROMSIM has been founded in 1990 as a non-profit society, devoted to both theoretical and applied aspects of modelling and simulation of systems. ROMSIM currently has about 100 members from both Romania and Republic of Moldavia. The main objectives of ROMSIM are: development of new methods and instruments of modelling and simulation of systems, development of new application of modelling and simulation of both natural systems and those created by man, development of education and training in the field of modelling and simulation of systems. Another important objective of ROMSIM is organization of national scientific events in the field of modelling and simulation and participation at international conferences. In April 1999 ROMSIM has been accepted as an observer member of EUROSIM. Link: http://www.romsim.ici.ro	
BULSIM - Bulgarian Modelling and Simulation Associations	**Bulgaria**
Bulgarian Modeling and Simulation Association – BULSIM is a non-profit organization for public benefit, dedicated to spreading and recognition of the modelling and simulation “culture” in Bulgaria. It was founded by experts from Bulgarian Academic institutions, Bulgarian universities, Government organizations and representatives from IT companies with long standing experience in Modeling&Simulations. BULSIM stands for enforcement of high professional standards, lofty moral, loyalty and professionalism in Bulgarian specialists in modelling and simulation. Link: www.bulsim.org	
MIMOS – Italian movement for modelling and simulation	**Italy**
MIMOS has been created from an initiative of a group of Italian operators in the simulation field; during an informal meeting held in February 2000 in Turin, they agreed on the opportunity to increase the knowledge on Modelling and Simulation in Italy by exchanging reciprocal experiences. The idea was to proceed with the creation of a National Association on Modelling and Simulation acting as a reference point for all Companies, Organisations and Users involved, in any way and form, in such a field. The term Simulation is considered in a wide sense, including, besides the traditional training systems such as flight, driving and ship manoeuvring simulators, those, in quick development, related to Virtual Reality, Synthetic Environment and Virtual Prototyping, and to software modelling in the broadest applications. The Association, born on March, 5th 2002, comprises members from Industry, Research Centres, Universities, and Military Organisations. Beside their founders (Alenia Aeronautica SpA, Centro Ricerche FIAT, Cetena-Fincantieri, Datamat SpA, Euclida Logistica Ipercoop, No Real, Politecnico di Torino, S.I.A. Società Italiana Avionica, Università di Genova Dip. di Ingegneria della Produzione), MIMOS numbers many individual members and several Corporate Members (i.e. Organisation supporting the initiatives of the association. Link: www.mimos.it	
Simulation Team	**Italy**
The Simulation Team was established in early third millennium for Leading a Pool of HiTech Institutions active in Modelling & Simulation. The Simulation Team represents an Excellence Network involving top quality international institutions and Simulation Team members are able to guarantee an unique capability to develop multidisciplinary models for complex systems. Simulation Team is active in involved in the organization of several among the Major World Conferences in M&S such as I3M. The Simulation Team benefits from its structure, being able to support projects and initiative anywhere worldwide by direct involvement of high qualified representative based on local reference member and with the strong combined skills provided by the whole network. It provides a wide range of Innovative Products and Services for markets including aerospace, communications, construction, defense, electronics, engineering, health care, logistics, nutrition, petrochemical, power, retail, safety and security, shipping & transportation. The Simulation Team puts Modeling and Simulation to work by creating Outstanding Solutions Essential to a Better, Safer, Healthier and Wealthier Life operating worldwide; Link: www.simulationteam.com	

4.3. Centres of excellence

The identification of research centres of excellence is based on the resonance of produced scientific publications and results. The mapping of the excellence in the S&FT research supports the identification of the centre of gravity for the various topics that pose as a reference when weighting research priorities identification.

MISS-LSIS - Laboratories des Sciences de L'Information et des Systèmes	France, Marseille

With the establishment of the McLeod Institute of Simulation Sciences, LSIS Marseille creates a center of excellence in computer simulation. Through the creation of the Institute the LSIS Marseille recognizes a unique opportunity to develop a widely recognized institute engaging in state the art simulation research and instructional activities by virtue of a critical mass of exceptional faculty available to contribute to this effort. The establishment of the Institute provides a mechanism through which faculty from various disciplines and their students and associates can bring their talents to bear in the general area of computer simulation or can seek help with the application of simulation to new areas.

The Laboratory consists of 5 research teams:

- **COSI: Control and Simulation**

  Research topics: design of knowledge-based systems - modelling and simulation - industrial automation.

- **IMS: Engineering, Mechanics, Systems**

  Research topics: integrated and cooperative design and engineering - machines and intelligent systems.

- **INCA (Inference, Constraints et Applications)**

  Research topics: logical representation of knowledge and simulation of reasoning in IT systems - automatic demonstration and constraint satisfaction.

- **INCOD: Distributed Information and Knowledge**

  Research topics: design, cooperation, integration of component-based information systems, multi-agent simulation - security and cognition.

- **LXAO: Computer-aided Modelling, Design and Reconstruction**

  Research topics: modelling and control of forms - segmentation and recognition of forms - coherence of geometrical models.

Other cluster of projects by domain of LSIS (related to Pathfinder)**:**

- MOFED (Modèles et Formalismes à évéenements discrets)

  The research project Discrete Event Models and Formalims (DEMoF) aims to develop methodologies for design, verification and validation of discrete event models.

- IA3D (Application of Artifical Intelligence in 3D scan)
- G-Mod (MODélisation Gémétrique)

  Research topics: mesh processing and characterization, detection of characteristic lines, Digital Terrain Model, subdivision surfaces, parametric curves and surfaces, reconstruction.

- SimGraph (SIMulation GRAPHique)

  Research topics: Image Data Fusion, Image Analysis, Simulation, Pattern Recognition, Augmented Reality, Virtual Reality, Remote Sensing, Industrial Vision, Video Watching

- DYNI (DYNamiques de l'Information)

  Research topics: Information Dynamics, Integration Dynamics, Content Based Information Retrieval, Prediction, Machine Learning, XML Extension, Data Bases, Signal Processing, Artificial Perceptual Intelligence, Neurophysiology, Deep Learning, Semantic Gap, Cognition

- CODEP (COnnaissances, Decisions, Pilotage)

  Research topics: cognitive engineering, knowledge engineering, Game Theory, Multicriteria Analysis, Monitoring, Risk Management, Human Machine Interfaces, holonic systems, supply chains.

Link: http://www.lsis.org

ICSS – Institute for complex systems simulation	UK, University of Southampton
The Southampton Institute for Complex Systems Simulation (ICSS) provides a stimulating home for interdisciplinary research that combines complex systems ideas and tools with computational methods in order to address challenges within key application domains: • Physical & Engineered Systems Domain • Biological & Environmental Domain • Socio-Economic & Socio-Technological The Institute's application domains are unified in two important ways. First, they share a common concern with understanding how high-level phenomena arise from low-level interactions. Second, each application domain relies increasingly upon sophisticated simulation modelling to interpret data, understand emergent phenomena, generate theory and hypotheses, direct experimentation, optimise design, and predict system behaviour. The Physical & Engineered Systems Domain, which is the most related domain to the Pathfinder's project, is divided into **eight research themes**: • Complex Software Systems • Electrical Energy Systems • Multi-agent Systems • Nanodevices and Self Assembly • Quantum Dynamics and QCD • **Systems design and optimisation** (most related with pathfinder) • Transport and infrastructure • Turbulence The Systems design and optimisation theme is intended to model and simulate products' in order to predict behaviour. Computer simulation is the better way to reduce expensive physical testing. In this way, "value" metrics that trade off product performance, noise, emissions, cost, maintainability, flexibility, etc., are defined, modelled and understood, and can be used to optimise systems holistically. Link: www.icss.soton.ac.uk	
M&SRG-ETH - Modelling & Simulation Research Group (part of the ICOS unit of the Computer Science Department at the ETH in Zurich)	**Switzerland, Zürich**
The Modeling & Simulation Research Area forms part of the ICOS unit of the Computer Science Department at the ETH in Zurich. Research Areas: • Object Oriented Modelling of Physical Systems Using Bond Graphs: primary applications areas includes electronics, 3d mechanical systems and thermodynamics; • Modelling of Ill-defined Systems Through Fuzzy Inductive Reasoning: primary application areas include biomedical systems, water distribution networks, and macroeconomic models; • Mixed Symbolic and Numerical Solution of Differential and Algebraic Equation Systems.	
MSC-LES - Modeling & Simulation Center - Laboratory of Enterprise Solutions	**Italy, University of Calabria**
The Modeling & Simulation Center - Laboratory of Enterprise Solutions (MSC-LES) is a research laboratory at Department of Mechanical, Energy and Management Engineering of University of Calabria, Italy. The main goal of **MSC-LES** is the development of innovative ways to use Modelling & Simulation (M&S) to achieve new scientific advances in different application areas. **Research areas:** The MSC-LES research activities concentrates on Industry (with specific applications in manufacturing and production systems design and management), Logistics (logistics nodes design and supply chain management) and Defense (human behaviour modelling and multi-coalition systems). Advanced simulation models based on different simulation paradigms and architectures are developed both for	

decision-making and for training and education in complex systems.

Research Team:

The MSC-LES research team work with many national and international partners and it is fully involved in different research projects; it supports the organization of the major international conferences in the area of M&S and, every year, promotes different International Journals special isssues for diffusing the latest research advances in the M&S area.

The MSC-LES is member organization of the most important M&S networks worldwide including Simulation Team (a pool of HiTech world-wide institutions active in M&S), MS&Net (the McLeod *Modelling & Simulation Network*) a consortium of co-operating independent organizations active in professionalism, research, education, and knowledge dissemination in the modelling and simulation (M&S) domain and Liophant Simulation, a non-profit association born in order to be a trait-d'union among simulation developers and users.

MSRC-Örebro - Modelling and Simulation Research Center	Örebro University, Sweden

The Modelling and Simulation Research Center (MSRC) focuses on modelling and simulation in many forms and thus bundles expertise in an interdisciplinary stimulating environment. There is also a research school currently consisting several PhD and master students doing their research in various applications, using different methods in modelling and simulation. The research centre serves as a creative place where academic research meets with applied research and development in industry. The research centre - founded in 2007 - is located at the Campus Alfred Nobel in Karlskoga. Nevertheless it is part of the University of Örebro where it belongs to the strong research environment of the School of Science and Technology. Additionally, one can find already today a scientific tradition and strong high-technology knowledge in the region. The cooperation with the local industry, together with different other education facilities embeds the research school into a strong, dynamic environment.

Research areas:

- Multi-Agent Simulation: It basically means to use the concepts of Multi-Agent System for designing a simulation model. Typical domains are landuse simulation, traffic and transportation, social science, economic system analysis, hybrid human-machine systems, gaming,...
- CAD technology: The area of Computer Aided Design (CAD), incorporates methods and software design to accomplish generation of numerical models of 3-dimensional (3D), e.g., mechanical parts. The research is focused on (3D) measuring technology and automatic Geometric Reverse Engineering (GRE) of known and unknown objects.
- Wire technology: the research is focused on the wire drawing process and especially steel wire drawing, but we have carried out research on related issues as; heat treatment, wire rod preparation and rolling.

Link: http://www.oru.se/mos/

VERSIM - VERs une théorie de SIMulation (towards a simulation theory). VERSIM is part of the French research group I3 of the French CNRS (National Center of Scientific Research)	French

VERSIM objectives:

- to identify the elements common to future French research about Modelling and Simulation and about Computer Aided System Theory;
- to describe the state of the art in France;
- to give the precise situation of M&S French research within the M&S international research;
- to participate in projects and form research networks;
- to establish multidisciplinary group;
- Being accessible for any researcher from any domain that uses or develops problem solution methods based on simulation;

Link: http://www.lsis.org/versim/

Fraunhofer Society	Germany

The Fraunhofer Society is a German research organization with 67 institutes spread throughout Germany, each focusing on different fields of applied science. It employs around 23,000 people, mainly scientists and engineers, with an annual research budget of about €1.7 billion.

Fraunhofer promotes an alliance amongst 18 FHG institutes to pool expertise to address the development and improvement of simulation techniques. http://www.simulation.fraunhofer.de/

Relevant research institutes (related to pathfinder):

IGD – Institute for computer Graphics Research:

The institute: Fraunhofer IGD is the world's leading institute for applied research in Visual Computing. Visual Computing is image- and model-based information technology and includes computer graphics, computer vision, as well as virtual and augmented reality.

The research teams develop prototypes and complete solutions based on customer-specific requirements. Our research and development projects are directly applicable to current problems in the economy.

Research fields:

- Computer Graphics (CG)
- Modeling (MOD)
- Computer Vision (CV)
- (Interactive) Simulation (SIM)
- Human Computer Interaction (HCI)

The institute: Fraunhofer SCAI develops innovative methods in Computational Science and actively supports their take-up in industrial practice. The Institute combines mathematical and computational knowledge with a focus on algorithms – bringing benefits to customers and partners

Research fields:

Simulation Engineering, Numerical Software, Bioinformatics, Optimization, High Performance Analytics, Virtual Material Design, Computational Finance, Numerical Data-Driven Prediction, Meshfree Multiscale Methods.

The institute: The Fraunhofer Institute for Industrial Mathematics ITWM supports companies in the development and optimization of products, services, communication and working processes.

Research fields:

Transport processes, flow and material simulation, image processing, optimization, system analysis prognosis and control, financial mathematics, mathematical methods in dynamics and durability, competence center high performance computing.

Universitat Politècnica de Catalunya – Kowledge Engineering and Machine Learning Group - KEMLG	**Spain**

The Knowledge Engineering and Machine Learning group (KEMLg) belongs to the Software Department (LSI) of the Technical University of Catalonia (UPC). The group has been active in the artificial intelligence (AI) field since 1988.

Research fields:

- knowledge representation, ontologies, the semantic Web and Web services;
- software agents, electronic institutions and multi-agent systems;
- intelligent decision support systems;
- Machine Learning/Knowledge Discovery and Data Mining;
- Bayesian networks;
- case-based reasoning;
- knowledge-based systems;
- knowledge acquisition and knowledge discovery from structural analysis;
- simulation and analytical models.

DFKI – German Research Center for Artifical Intelligence	**German**

The institute:

The German Research Center for Artificial Intelligence, with sites in Kaiserslautern, Saarbrücken, Bremen (with an associated branch in Osnabrück) and a project office in Berlin, is the leading German research institute in the field of innovative software technology. In the international scientific community, DFKI ranks among the most recognized "Centers of Excellence" and currently is the biggest research center worldwide in the area of Artificial Intelligence and its application in terms of number of employees and the volume of external funds.

Research fields

- Cyber-Physical Systems:

  This research area includes circuit and system design, software development and dedicated applications of cyber-physical systems.

- Agent and Simulated Reality:

  The research department Agents and Simulated Reality (ASR) conducts research in the areas visual computing, multi-agent systems and formal methods for safe and secure systems in the context of interactive 3D simulations and visualizations as well as other applications. Using Simulated Reality, real-world scenarios can be accurately depicted and predictions about their behavior can be made.

- Augmented vision:

  The core activity of the research group “Argumented vision” is the development of innovative solutions in the fields of: computer vision, sensor interpretation and fusion, human-centred visualization, virtual and augmented reality.

The interest towards S&FT is spread all over Europe, with a higher presence of reference points in Germany, France, Italy, Spain and the UK. The mapping of research centres of excellence and their competences leads to the identification of links with the Pathfinder Research Areas as shown in the following table.

	RA1	RA2	RA3	RA4	RA5	RA6	RA7	RA8
	Open and Cloud-based S&FT for high-tech performance computing	Multi-disciplinary and multi-domain integrated S&FT	S&FT for life-cycle management	Multi-level S&FT integration	S&FT for real-time factory controlling and monitoring	Smart, Intelligent and self-learning S&FT	Human-centred simulation-based learning &training	Crowdsourcing-based S&FT
MISS-LSIS (France)	X	X	X	X	X	X	X	
ICSS (UK)	X							
M&SRG-ETH (Swiss)	X							
MSC-LES (Italy)			X				X	
MSRC (Sweden)	X							
Fraunhofer society (Germany)	X		X		X		X	
KEMLG (Spain)						X		X
DFKI (Germany)	X	X		X	X	X	X	
VERSIM (French)		X	X					X

5. Pathfinder Vision – A three layers approach

Pathfinder specifically focuses on the role of Simulation and Forecasting Technologies and does not propose a new vision for manufacturing as a whole. Pathfinder thus embraces the current efforts achieved by accredited industrial, institutional and academic groups, in the definition of a Manufacturing Vision for 2020. The roadmap proposes a three layer vision on SF&T that is progressively more detailed and takes up the efforts made by the aforementioned stakeholders.

5.1. Layer 1 - Manufacturing vision for 2020

The long term direction embraced by Pathfinder is consistent with the one anticipated within the "Factories of the Future Strategic Multi-Annual Roadmap" developed within EFFRA[23]. Four paradigms have been there identified as to guide the transformations of European Manufacturing:

I - Factory and Nature -> green - sustainable production

- Lowest resource consumption
- Closed loops for products
- Production and scares resources
- Sustainability in materials and production processes

II - Factory and the Neighbourhood -> production close to the worker and to the customer

- Manufacturing close to people (in cities / metropolitan areas)
- Factory integrated and accepted in the living environment

III - Factories and the value chain -> collaborative production

- Highly competitive distributed manufacturing (flexible, responsive, high speed of change)
- Design oriented products, mass customized products
- Integration of the product and process engineering

IV - Factory and Humans -> human centred production

- Human oriented interfaces for workers: process-oriented simulation and visualization
- Products and work for different type of skilled an aged labour, education and training with IT-Support
- Regional balance: work conditions in line with the way of life, flexible time- and wage- systems
- Knowledge development, management and capitalization

Pathfinder envisions current challenges and future role of Simulation and Forecasting Technologies as a key lever to empower this long term vision (Fig. 2)

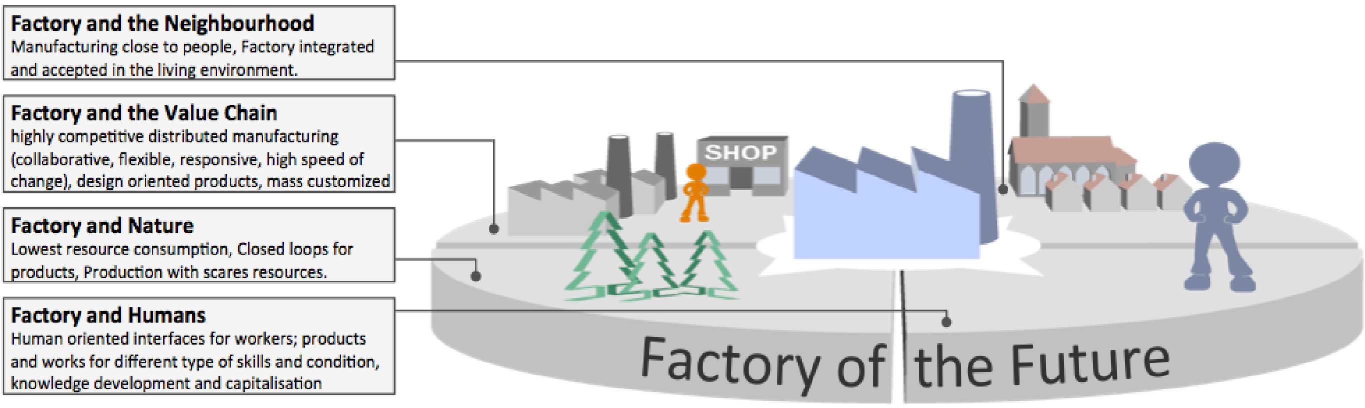


Fig. 2 - Factory of the Future layer

Within the "Factories of the Future Strategic Multi-Annual Roadmap", three cluster of ***manufacturing challenges*** are identified. Those challenges need to be efficiently addressed in order for the long term vision to come true:

[23] EFFRA – European Factories of the Future Research Association. Factories of the Future Strategic Multi-Annual Roadmap. www.effra.eu

I - Economic sustainability of manufacturing

- Addressing economic performance across the supply chain
- Realising reconfigurable, adaptive and evolving factories capable of small scale production
- High performance production, combining flexibility, productivity, precision and zero-defect while
- remaining energy- and resource-efficient Resource efficiency in manufacturing - including addressing the end-of-life of products.

II - Social sustainability of manufacturing

- Increase human achievements in future European manufacturing systems
- Creating sustainable, safe and attractive workplaces for 'Europe 2020'
- Creating sustainable care and responsibility for employees and citizens in global supply chains

III - Environmental sustainability of manufacturing

- Reducing the consumption of water and other process resources
- Near to zero emissions, including noise and vibrations, in manufacturing processes.
- Optimising the exploitation of materials in manufacturing processes
- Co-evolution of products-processes-production systems or 'industrial symbiosis' with minimum need
- of new resources

In order to efficiently tackle the previously identified challenges and opportunities, the EFFRA roadmap classifies ***6 groups of key technologies*** and enablers for the factories of the future:

I - advanced manufacturing processes

II - mechatronics for advanced manufacturing systems

III - information and communication technologies

IV - manufacturing strategies

V - modelling, simulation and forecasting methods and tools

VI - knowledge-workers

The "Factories of the Future Strategic Multi-Annual Roadmap" identifies eventually the research priorities to be addressed in order to develop the key technologies and enablers afore mentioned. Those priorities are grouped in six domains:

DOMAIN 1 - Advanced manufacturing processes

DOMAIN 2 - Adaptive and smart manufacturing systems

DOMAIN 3 - Digital, virtual and resource-efficient factories

DOMAIN 4 - Collaborative and mobile enterprises

DOMAIN 5 - Human-centred manufacturing

DOMAIN 6 - Customer-focused manufacturing

Pathfinder focuses the fifth set of Key Technologies and Enablers (modelling, simulation and forecasting methods and tools) and further details the research priorities addressed in Domain 3 and, to a lesser extent, Domain 1, 4 and 6.

5.2. Level 2 - Industrie 4.0 vision

The high level vision afore introduced, that depicts the future relations among the factory, humans, neighbourhood and value chain, must be framed in a lower level vision capable to endow it. Pathfinder supports the foresight brought forward by the Industrie 4.0 Initiative[24], as a consistent framework for the actual fulfilment of the Factory of the Future vision.

[24] Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Final report of the Industrie 4.0 Working Group. www.plattform-i40.de

Industrie 4.0 envisions a fourth industrial revolution. The first three industrial revolutions came about as a result of mechanisation, electricity and IT. Now, powerful and autonomous microcomputers are increasingly being wirelessly networked with each other and with the internet. This is resulting in the convergence of the physical world and the virtual world in the form of Cyber-Physical Systems (CPS). CPS are ICT systems (sensing, computing, actuating, communicating) embedded in interconnected physical objects providing applications and services. This means that it is now possible to network resources, information, objects and people to create the Internet of Things, Services and Brains. In the realm of manufacturing (where CPS comprise smart machines, storage systems and production facilities capable of autonomously exchanging information, triggering actions and controlling each other independently), this technological evolution is described as the fourth industrial revolution. In conjunction with smart production, smart logistics, smart grids and smart products, this revolution will transform value chains and lead to the emergence of new business models.

Industrie 4.0 thus depicts the factory as part of a smart networked world (Fig. 3)

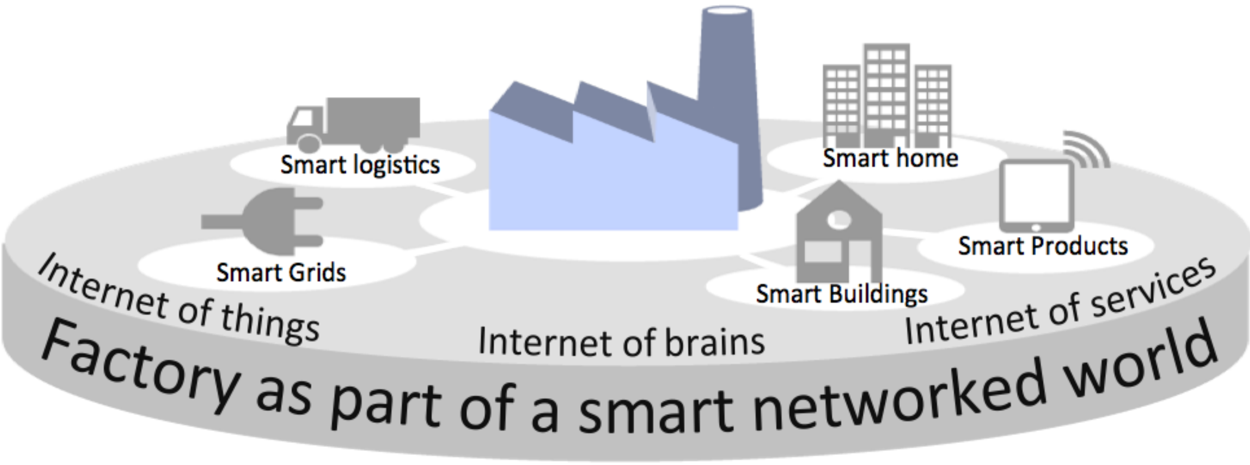


Fig. 3 - Factory as Part of a smart networked world

5.2.1. <u>Future Factory Settings</u>

Clear trends, shaping the future settings for manufacturing, can be derived from Industrie 4.0 analysis:

- Prevalence of Internet technologies also at manufacturing level. Communication everywhere and every time, where future infrastructure will also support access to information without any specific installation / parameterization needs.
- Prevalence of Cyber-Physical Systems for monitoring & controlling. Powerful, autonomous microcomputers (embedded systems) increasingly wirelessly networked with each other along with the Internet allow the convergence of the physical world and the virtual world (cyberspace) in the form of Cyber-Physical Systems.
- Big Data Everywhere (world, enterprise, shop-floor). The availability of technologies able to efficiently gather and process large quantities of data and the increasing use of data-intensive technologies at every level of the factory will enable a faster and more insightful decision-making.
- Increasing Complexity (also system of systems). Increasing functionality (e.g. coming from System of Systems, that is a collection of task-oriented systems that pool their resources and capabilities together to create a new, more complex system which offers more functionality and performance), increasing product customization, increasingly dynamic delivery requirements, increasing integration of different technical disciplines and organizations and the rapidly changing forms of cooperation between different companies make more and more complex the products and their associated manufacturing systems.
- Vertical Collaboration (shop-floor and enterprise systems). End-to-end digital integration of actuator and sensor signals across different levels right up to the ERP level will allow the setting of IT configuration rules that make possible a case-by-case reconfiguration of the manufacturing structure that will not be fixed and predefined anymore.

- Horizontal Collaboration (system-to-system). New business strategies, value networks and business models will exploit a higher, IT-based integration through different stages of the value chain to deliver end-to-end solutions.
- Rapidly evolving technologies (additive manufacturing, high precision manufacturing, etc) and systems (integration standards, no-vendor-lock, no monolithic systems, mobile system integration, etc.). The ever-rapidly-changing technological infrastructure will lead to the use of flexible and non-monolithic IT systems whose evolution is facilitated by the introduction of integration standards.

5.3. Level 3a - The evolution of the automation pyramid

The rapid advances in computational power, coupled with the benefits of the Cloud and its services, has the potential to give rise to a new generation of service-based industrial systems whose functionalities reside in-Cloud (Cyber) and on-devices and systems (Physical). Cloud-based CPS and SOA may lead to a new information-driven infrastructure where the traditional hierarchical view is complemented with a flat information-based architecture that depends on a big variety of services exposed by the CPS, and their composition (on-device or in the cloud).[25]

The Automation pyramid concept is used to describe the different system levels of an overall automation solution[26] (Fig. 4)

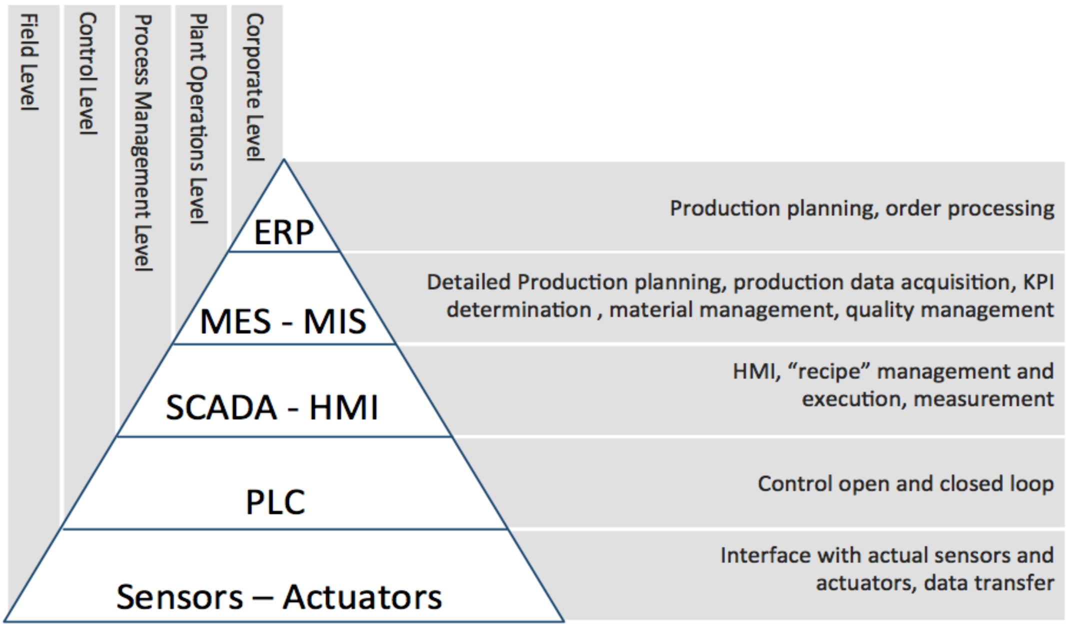


Fig. 4 – The automation pyramid

The current classical approach, as depicted above, has been recently addressed several times (Manufuture2013[27], ICT2013 conference[28], CPS workshop[29]) and deemed by RTD experts and industrial key players to be inadequate to cope with current manufacturing trends and in need to consequently evolve.

Pathfinder acknowledges that CPS intrinsic existence defies the concept of rigid hierarchical levels, being each CPS capable of complex functions across all layers. Pathfinder thus proposes an updated version of the pyramid representation, where the field level features CPS capable of articulated functions (thus in contact with all the pyramid layers) while still a hierarchical structure is preserved (Fig. 5).

[25] A. W. Colombo, T. Bangemann, S. Karnouskos, J. Delsing, P. Stluka, R. Harrison, F. Jammes, and J. Lastra, (Eds.) Industrial Cloud-based Cyber- Physical Systems: The IMC-AESOP Approach, Springer, 2014, ISBN: 978-3-319-05623-4, URL: http://www.springer.com/engineering/production+engineering/book/978-3-319-05623-4.
[26] IEC 62264, ISA-88.01, ISA-95
[27] ManuFuture 2013 - www.manufuture2013.eu - Vilnius, 6th – 8th October 2013
[28] ICT2013 Conference - ec.europa.eu/digital-agenda/en/ict-2013 – Vilnius, 6th – 8th November 2013
[29] Cyber-Physical Systems: uplifting Europe's innovation capacity. Brussels, 29th – 30th October 2013

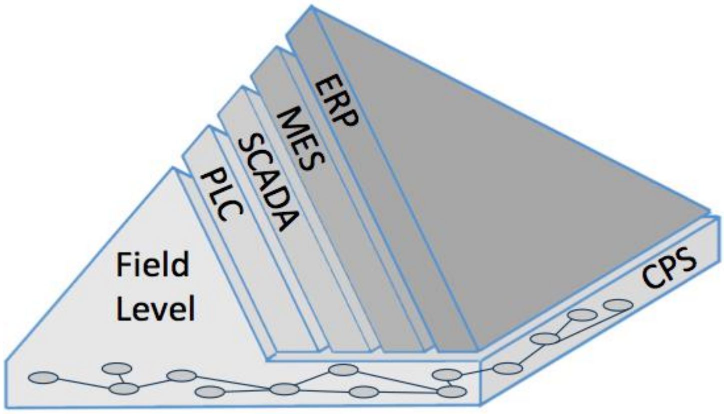


Fig. 5 - The evolved pyramid

5.4. Level 3b - Product & factory lifecycle and its digital representation

The representation of the factory and product lifecycles as per the picture below (Fig. 6) has been extensively discussed (e.g.[30] and later[31]) and it is today well understood. The horizontal set of arrows depicts the factory's life along the Design, Engineering, Construction and Ramp-up, Production, and Dismantling Refurbishment phases. Simultaneously, the product, which will be manufactured in the factory, are traced vertically passing through the main phases of its life cycle: Design, Product Development, Engineering, Production, Usage and Service and the Recycling phase. The central part of Figure, the overlapping of the factory life-cycle and of the product life-cycle is indeed the production phase. It is today widely accepted that Simulation and Forecasting tools support simultaneously both the life-cycles.

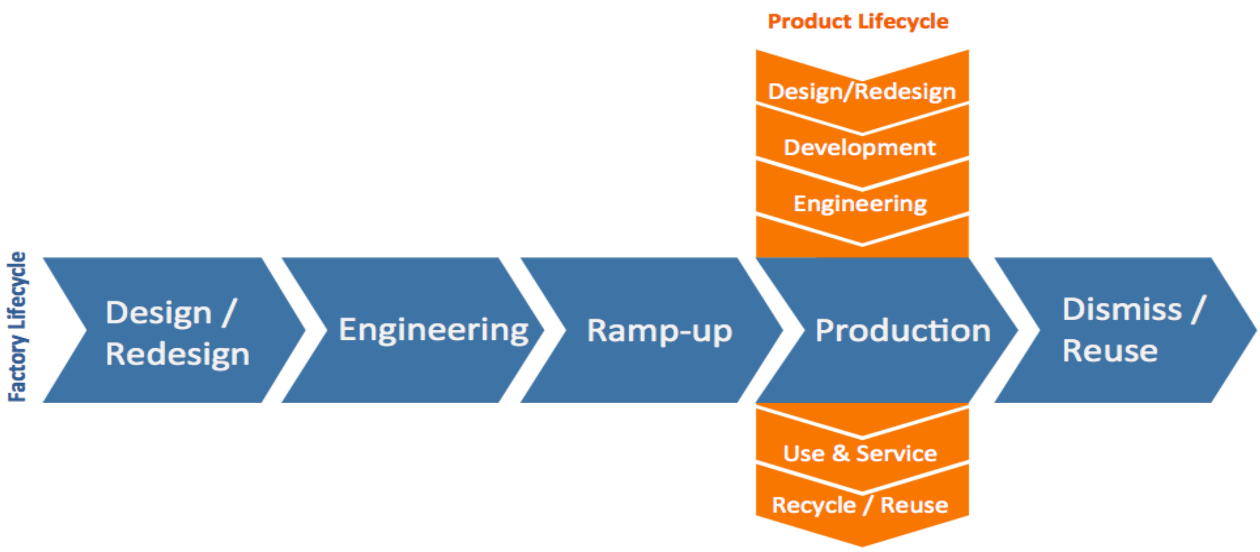


Fig. 6 - Product and Factory life-cycles

Focusing on the Factory life-cycle (Fig. 7), at the very beginning the factory exists only in its digital representation. Through the later phases, also the real factory comes into existence, defined by the digital tools used. In production the real and digital factory interacts in order to make manufacturing possible and efficient. While in the early phases the digital representation of the factory is prominent, it logically paves the way for the real equipment development and role later in manufacturing.

[30] Westkämper, E., Constantinescu, C.,and Hummel, V. "New Paradigm in Manufacturing Engineering: Factory Life Cycle", Production Engineering, 2006, 1,143-146.

[31] P.Pedrazzoli, D.Rovere, C.Constantinescu, J.Bathelt, M.Pappas, P.Dépincé, G.Chryssolouris, C.R.Boër, E.Westkämper, "High value adding VR tools for networked customer-driven factory", 4rd International CIRP Sponsored Conference on Digital Enterprise Technology 2007

Fig. 7 - Digital and Real Factory interaction over the factory life-cycle

The evolutionary concept of the automation pyramid, afore presented, refers to the production phase, as it represents a novel CPS based manufacturing. The following picture (Fig. 8) provides a synoptic view over the product-process life-cycles, the interaction of digital and real factory and the automation pyramid. The overall framework of factory operations is defined by the future factory settings defined in paragraph 5.2.1.

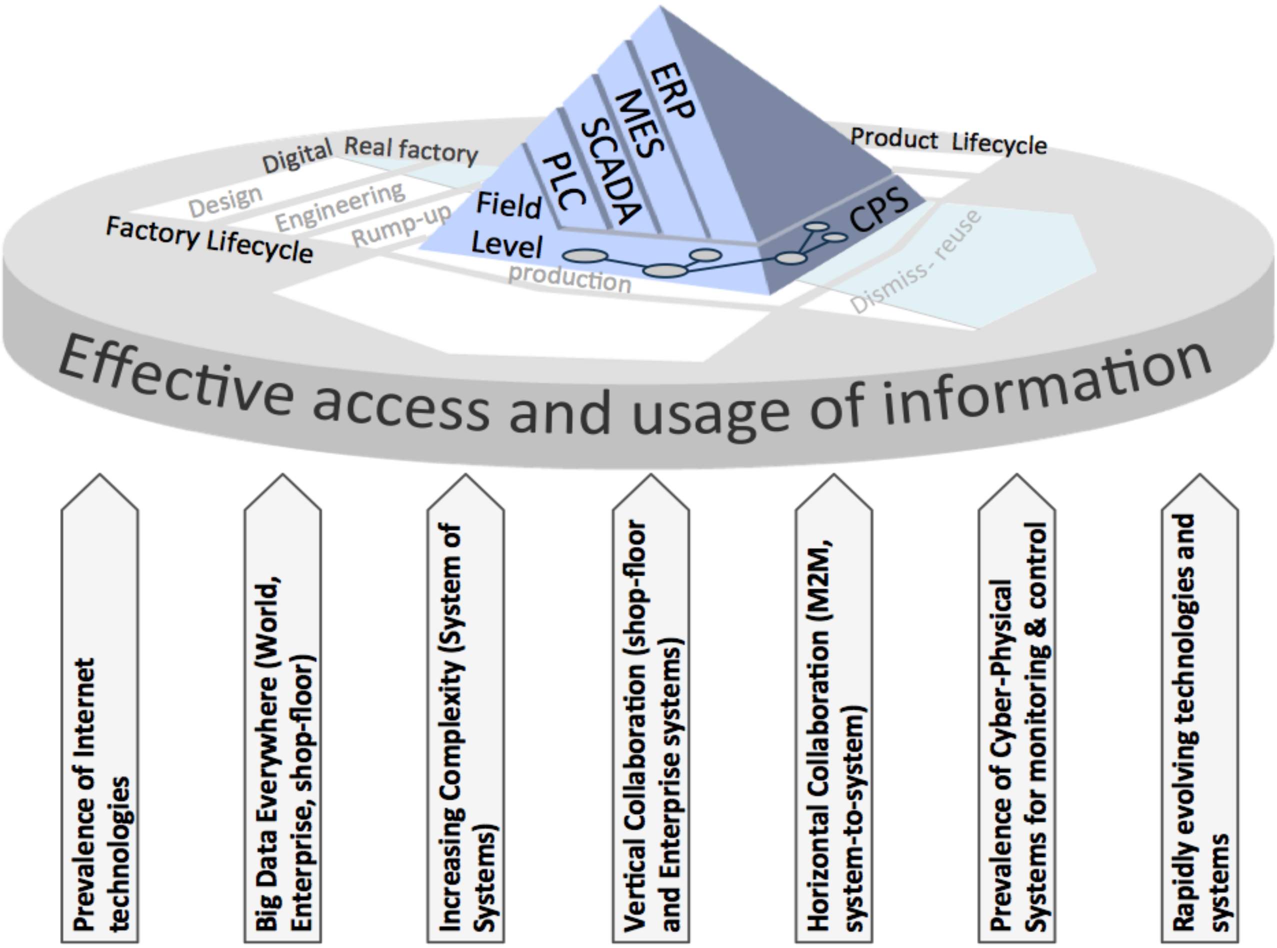


Fig. 8 - Evolved pyramid in relation to the Factory and Product life-cycles

5.5. Pathfinder synopsis

The high level vision presented in paragraph 5.1, that depict the future relations among the factory, humans, neighbourhood and value chain, is embraced by Pathfinder, and recognized as the long term goal. This vision must be positioned in a lower level framework, capable to endow it, as presented in paragraph 5.2 and brought forward by the Industrie 4.0 Initiative. The accordingly envisioned Factory, whose production phase happens at the cross-over intersection of product and factory life-cycles as presented in paragraph 5.4, bases its manufacturing operations on the convergence of physical world and virtual world in the form of Cyber-Physical Systems, framed in the contexts of the evolved automation pyramid, as depicted in paragraph 5.3. This synoptical view is introduced in Fig. 9.

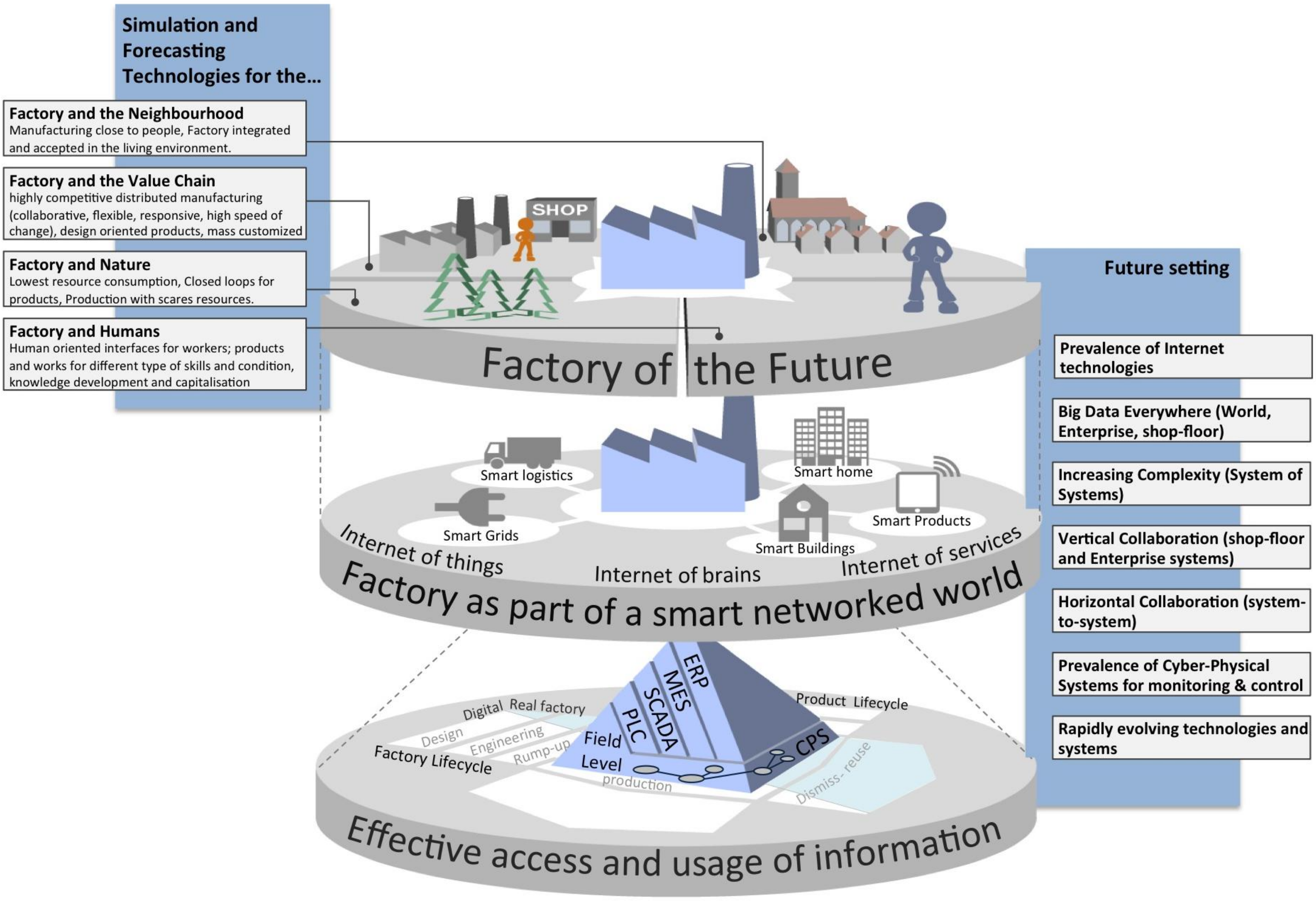


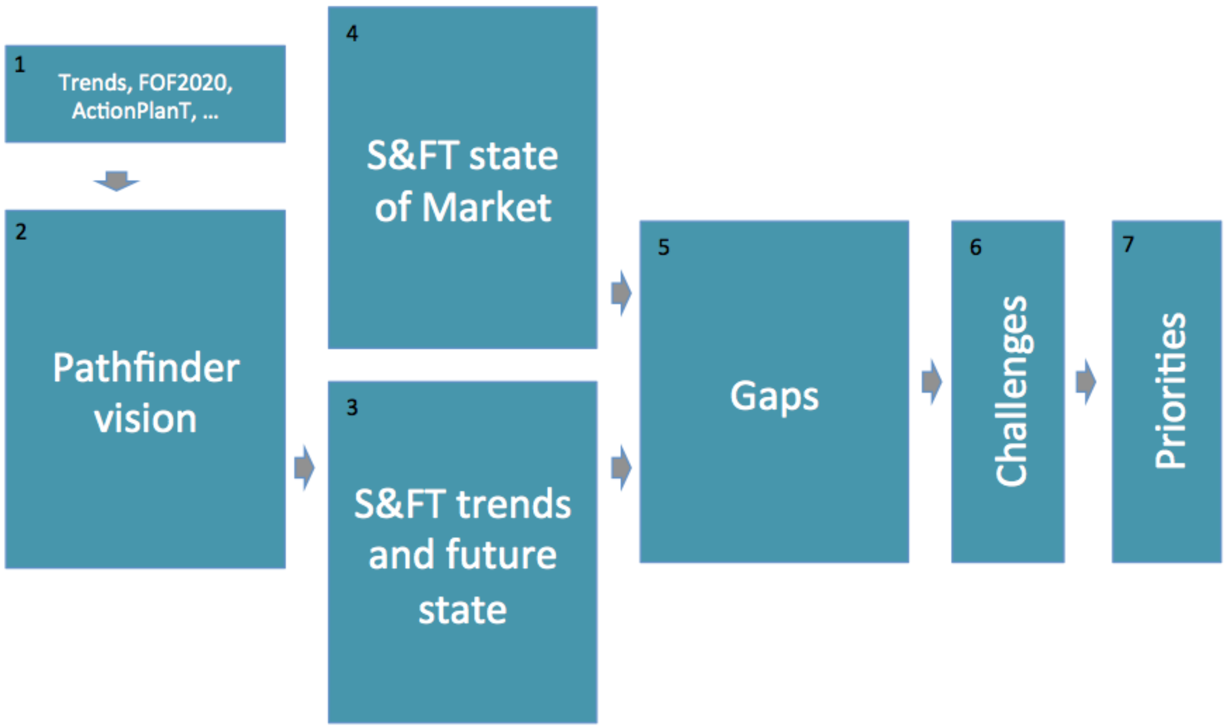
Fig. 9 - Pathfinder synopsis

6. Pathfinder roadmap

The Pathfinder Roadmap is intended to drive research and development activities in the Simulation and Forecasting Technologies (S&FT) arena. To this end, the roadmap must develop, through the analysis of current state of practice compared with the future state envisioned, a final list of research priorities to be used by the key stake-holders.

This chapter is meant to present the roadmap building blocks and their interrelation, towards the effective presentation of the identified challenges and research priorities for future S&FT. To this scope and to clearly draw a shared path, the roadmap has been arranged into 7 logical blocks, hereinafter presented:

1. An analysis of trends, current road-mapping activities and national initiatives, set the basis for the definition of the pathfinder vision.
2. The Pathfinder vision has been developed in such a way to be consistent with current road-mapping efforts at national and international level (in order not to introduce a new vision on manufacturing itself, but to embrace existing activities).
3. From the vision, the current trends and future envisioned state of Simulation and Forecasting Technologies have been derived.
4. In parallel, the current state of market practice has been investigated.
5. By confronting the envisioned future state with the current state of market practice, the road-mapping activity has defined the related gaps. These can be considered as the missing link between what is currently available and the future envisioned manufacturing scenario.
6. Identified gaps, consolidated and grouped, are a main input for the identification of challenges that are expected to arise for the S&FT innovation need.
7. The identified challenges will be faced by consistently addressing the research priorities identified.



6.1. Block1 – Trends and previous roadmaps

This section presents the analysed roadmaps at European Level, while the national initiatives have been presented into paragraph 4.1, in order to point out what are the elements concurring to the definition of their research priorities, how they are linked to each other and how they impact on S&FT future development. Three prominent roadmaps have been taken into account: FOF2020 roadmap[32], ActionPlanT[33] and IMS2020[34]

6.1.1. Factory of the future 2020 (FOF2020)

The roadmap investigates the manufacturing world and tries to depict research lines to be followed in order to support European companies in their evolutionary path towards 2020.

Grand societal challenges point out the main challenges that society as a whole has to deal with in the future: it is recognized that manufacturing is a key enabler towards achievement of grand societal challenges, because it provides the means to produce innovative products that address them over many aspects. The impact of manufacturing evolution on these challenges has to be considered in a roadmap. Along with grand societal challenges, the environment where manufacturing will be evolving is described by means of the **mega trends**. They impact over manufacturing and drive structural changes in nearly all sectors.

Both grand societal challenges and mega trends lead to the definition of **manufacturing challenges**. They describe how the manufacturing of the future should look like in order to evolve harmoniously with the society and, at the same time, to improve the competitiveness of European companies. These challenges can be considered as target scenarios that need to be addressed by researchers and companies as well when looking forward the evolution path to follow. There are three categories of challenges according to the three dimensions of sustainability (economic, social and environmental).

The roadmap takes then into consideration innovative elements of a technological nature that need to be developed as enablers (**key technologies and enablers**). They will empower and generate impact in terms of challenges and opportunities. One enabler worth of mention in Pathfinder context is, for instance, “Modelling, simulation and forecasting methods and tools”.

In order for key technologies and enablers to support the achievement of social challenges, they have to be deployed through a set of research directions. **Research & innovation priorities** are thus the last and main building block of the roadmap. The list of these topics is thought to drive the research in the manufacturing field in the future. Six domains of priorities are identified and each one of them is further detailed in topics. Out of them, the ones that explicitly address simulation and forecasting technologies have been extracted and analysed, in order to defined Pathfinder Research Areas.

Main blocks of the framework of the FOF roadmap are shown in Fig. 10, along with their links as they have been summarized in a mind map.

[32] http://effra.eu/index.php?option=com_content&view=category&layout=blog&id=85&Itemid=133
[33] http://www.actionplant-community.org/home/
[34] http://www.ims2020.net

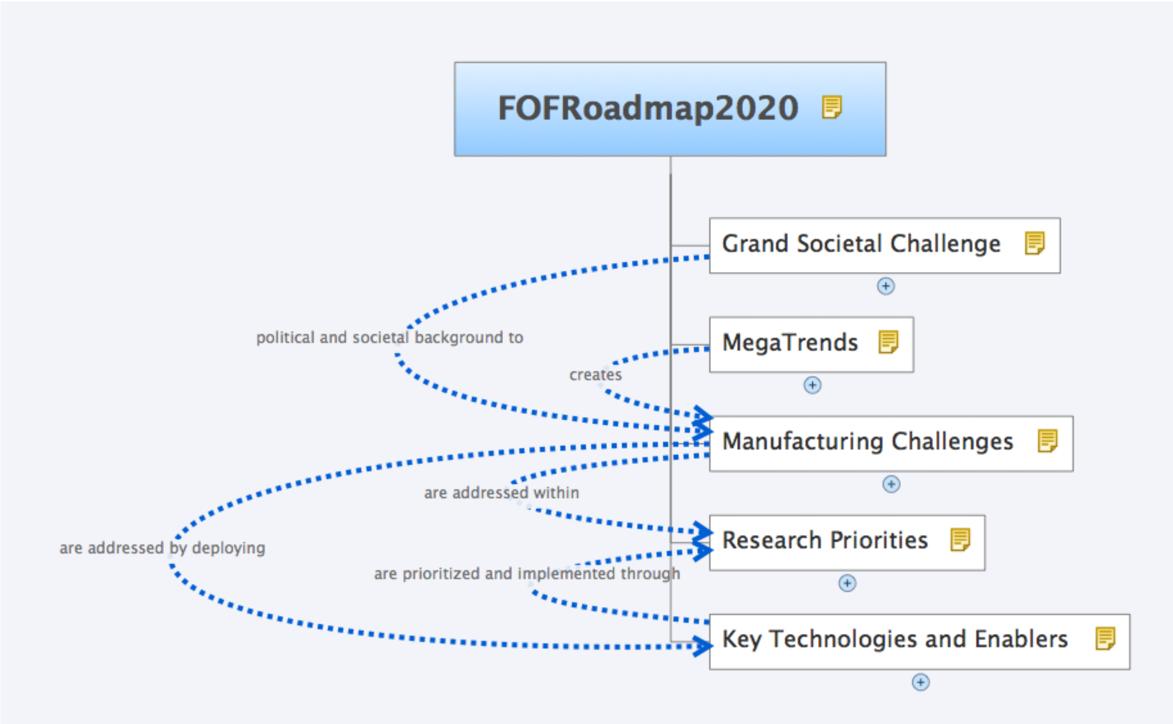


Fig. 10

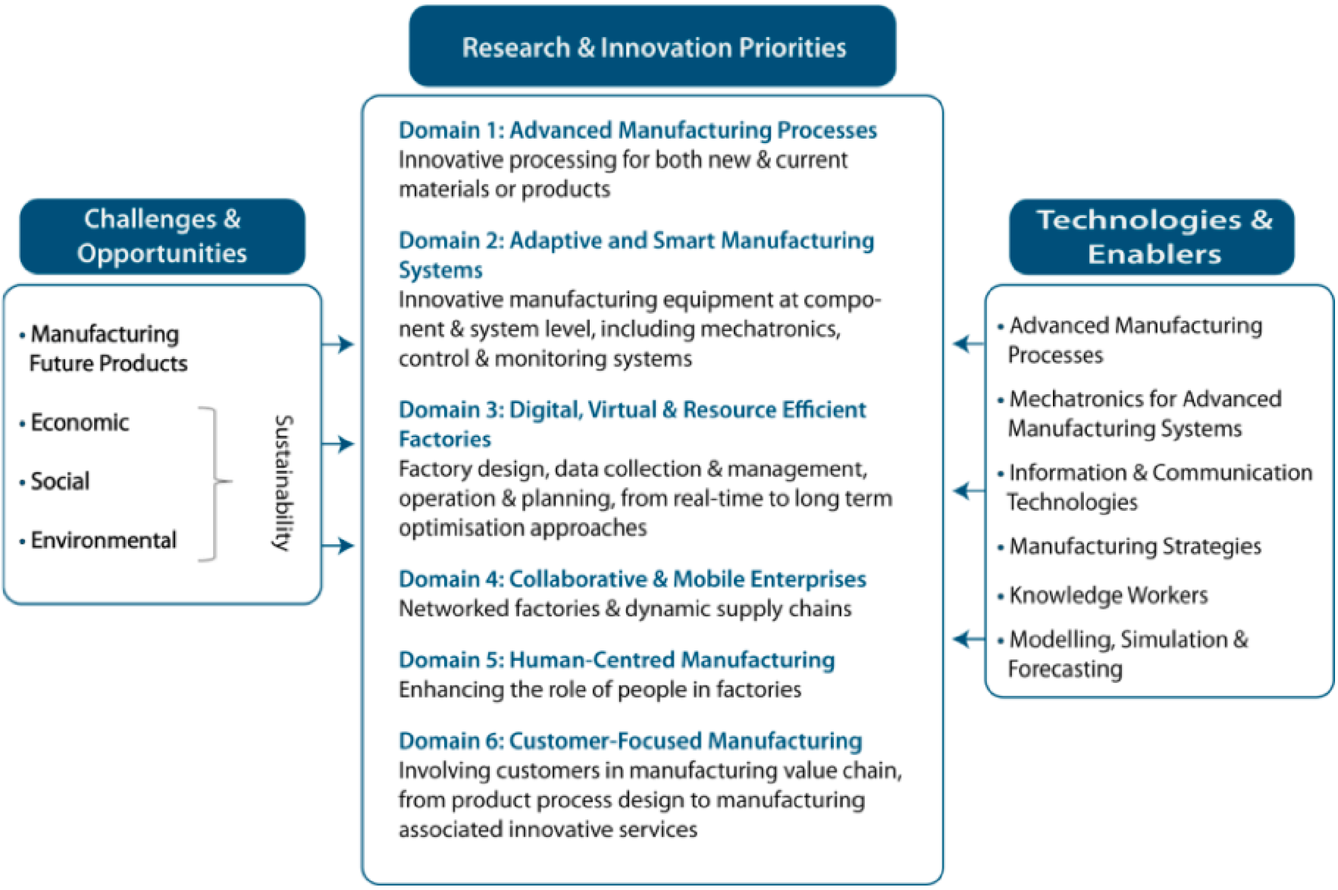


Fig. 11 – FOF2020 reference schema

6.1.2. ActionPlanT

ActionPlanT is a roadmap investigating how ICT has to evolve in order to support the manufacturing world. Its focus is thus on identifying research lines related to ICT tools.

In first instance**, megatrends** are introduced to characterize the evolution of the competitive context. Both socio-economic and technological megatrends are listed, but technological ones only are then taken into consideration to develop the remaining part of the roadmap.

Whilst megatrends depict how the society is evolving, **ambitions** are the elements that define in a vision-like way the main features of the manufacturing of the future. According to them, the manufacturing of the future will be on-demand, green, human-centred, optimized and innovative. Ambitions need to be fulfilled through the deployment of the research priorities identified by the roadmap itself.

A central building block of the roadmap is related to the definition of **key recommendations**. Taking a technology-push approach, the roadmap derives a set of 15 key ICT recommendations from the four ICT megatrends that can bring about disruptive changes in European manufacturing industry and open up new channels of revenue generation for large enterprises and SMEs. They are identified thanks to the involvement of experts and are categorized into three groups, namely operational-, content- and consumption-related. A recommendation that is strictly related with Pathfinder is the following: “high performance simulation and analysis in the cloud”.

Finally, the last block of the map is introducing the **research priorities**. They have an impact and, in turn, are influenced by the technological megatrends, fulfil ambitions and implement key recommendations. In so doing they are the fundamental element of this roadmap linking all the other blocks and providing hints on how to innovate ICT tools field in order to support the manufacturing of the future. A research priority identifies either ICT breakthroughs needed to overcome a certain existing problem in the manufacturing domain or new revenue generation possibilities by introducing a new ICT recommendation.

Research priorities outline detailed implementation strategies for recommendations. Each research priority is described in detail in the documents by listing:

- ICT research requirements (they represent the most detailed information about specific ICT elements that need to be developed);
- industrial challenges (current obstacle to the manufacturing 2.0 implementation);
- potential outcomes;
- impact assessment on the level of achievement of the ambitions (ambition radar, impact factor, technology readiness level)

Main blocks making up the framework of the ActionPlanT roadmap are shown in Fig. 12, along with their links as they have been summarized in a mind map.

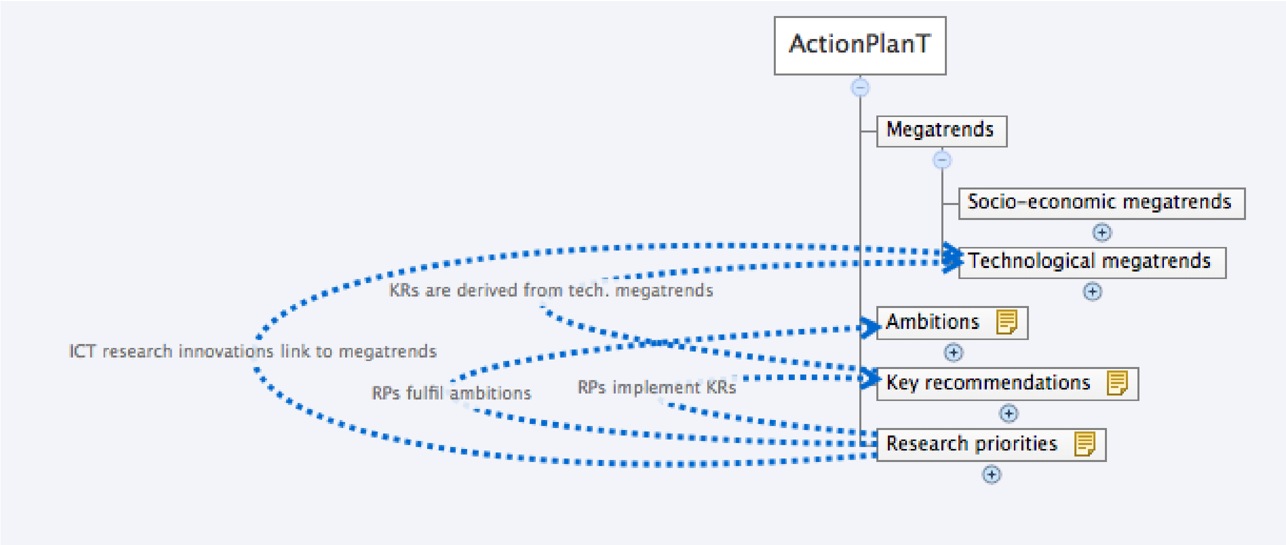


Fig. 12

6.1.3. IMS2020

The roadmap has been developed within the IMS2020 project and focuses on the identification of relevant manufacturing research topics and supporting actions which need to be fostered through international cooperation between 2001 and 2013 that, when implemented, will allow the achievement if the IMS2020 vision.

The first block of this roadmap is the definition of the vision summarized into three elements:

- rapid and adaptive user-centered manufacturing, which leads to customized and eternal life cycle solutions;
- highly flexible and self-organizing value chains, which enable different ways of organizing production systems, including infrastructures, and which reduce the time between engaging with end users and delivering a solution;
- sustainable manufacturing possible due to cultural change of individuals and corporations supported by the enforcement of rules and a regulatory framework co-designed between governments, industries and societies.

The second part of the roadmap is developed in such a way the fields of interest are detailed more and more. First, 5 **key research areas** are identified: sustainable manufacturing, products and services; energy efficient manufacturing; key technologies; standards and innovation, competence development and education. Three different documents are then developed drafting as many roadmaps: one covering the three first areas, one for the standard and one for the innovation, competence development and education.

A tree-like structure is then used to detail the three key areas into more detailed topics. More specifically, two further levels are used: **research actions** and **research topics**.

Main blocks of the framework of the IMS roadmap are shown in Fig. 13, along with their links as they have been summarized in a mind map.

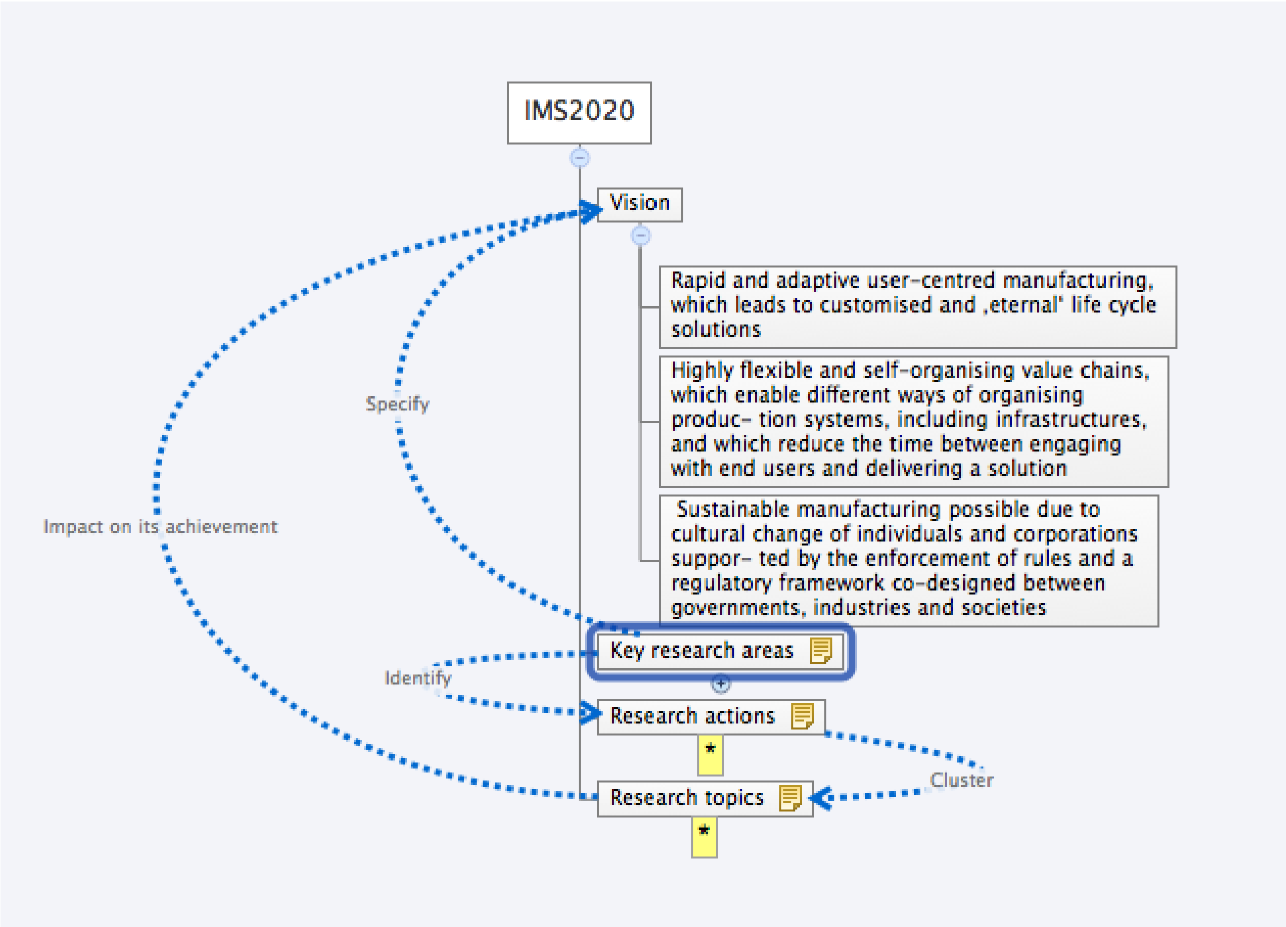


Fig. 13

6.1.4. Definition of the Pathfinder Research Area

By analysing the challenges and research priorities related with S&FT, pointed out by the analysed road-mapping activities, the Pathfinder Research Areas have been defined. The following table summarizes the commencing of the Research Areas with direct reference to the roadmap analysed.

Emerging Themes and Priorities from current Road-Maps	Pathfinder Research Areas
• Leveraging "infrastructure as a service" IaaS in cloud infrastructure for simulation and analytical operations on factory data. Facilitating SMEs to access high-performance simulation and analytical services through a manufacturing app store (RP 2.3 ActionPlanT) • Leveraging IaaS paradigms for clouds for processing complex simulation and analytical algorithms (RP 2.5 ActionPlanT) • A MBW deployment would open up possibilities to exploit the distributed infrastructure using the IaaS paradigm for performing high-performance simulation, forecasting, and analytics operations. (RP 4.1 ActionPlanT; 7.4.1 FoF 2020) • Leveraging the cloud-computing IaaS offering to perform outsourced simulation and analytics, especially for the SMEs (RP 5.5 ActionPlanT) • ICT solutions for technical and historical data storage and knowledge mining for factory level operations are required that will analyze and process the data collected from an integration of factory information systems as well as product life-cycle management solutions. For performing these high-performance simulation and analytics operations, IaaS offered by cloud computing paradigms should be exploited in order to particularly assist SMEs (7.3.3 FoF 2020)	RA1: Open and Cloud-based S&FT for High-performance Computing
• Develop multidisciplinary models and tools for designing flexible and easily reconfigurable systems and machines, including dynamic simulation and monitoring of consumption of energy and other resources(RP 1.1 ActionPlanT) • Multidisciplinary modeling and virtual validation of manufacturing equipment at design stage, including system-level simulation of mechatronic systems and integration of models from different domains prior to any actual manufacturing step, is the key for ensuring proper performance of such equipment without involving unforeseen and undesired reactive maintenance actions during their lifecycle. (7.1.9 FoF 2020) • Modeling methods and tools are needed to support the configuration of production systems since the early conceptual design phase, where the selection of the production resources and the development of the entire automation system are tackled. In this phase, different closed loop simulation instruments, visualization tools, knowledge-based systems and optimization algorithms should be applied and integrated according to the available set of data and the expected level of details of the configuration solution. (7.3.11 FoF 2020) • Technologies and tools for rapid and cost effective modeling, simulation and virtual prototyping that contribute to a deeper understanding, quick set up and increased optimization of the behavior of machines, manufacturing processes and products (IMS 2020 RT3.11) • Sustainable supply chain design supported by serious games based on powerful simulation technique.(IMS 2020 RT1.21)	RA2: Multi-disciplinary and Multi-domain Integrated S&FT
• Methods and tools for design and simulation of de- manufacturing plants along their lifecycle, separation technologies and new equipment (fixed or mobile) for dismantling, repairing and rebuilding. (7.3.14 FoF 2020)	RA3: S&FT for Life-cycle Management

• Intelligent cognitive elements to learn, diagnostic features of the actual situation of the systems in real time and develop in-situ simulations to support modular assembly/disassembly production systems (IMS 2020 RT3.01)	
• Development of simulation applications that support usability at different levels from operators to managers, with different objectives - economic performance, logistics, operation, energy consumption, etc. Collaborative simulation tools and advanced visualization tools - such as dashboards, reports and forecasts (RP 2.5 ActionPlanT) • Holistic approaches for visualization of multi-scale models and simulation results of manufacturing systems for better human understanding (RP 3.1 ActionPlanT; 7.5.8 FoF 2020) • For all custom manufacturing, it is necessary to have quick realization from design to production in one process step as well as economic production systems down to single and small lot sizes. Research should also address the need for seamless data integration across the process chain (e.g. CAD, production planning, simulation and process) (7.1.1 FoF) • Integrated multi-level simulation and analytics will facilitate enhanced factory modeling by enabling views and interpretations from different perspectives that are aimed at providing stakeholders with different representations of relevant information (7.3.5 FoF 2020) • Development of integrated, scalable and semantic virtual factory models (7.3.12 FoF 2020) • The integration of methods and tools requires interoperability between the various models dealing with specific problem in the factory hierarchy. (7.3.13 FoF 2020)	RA4: Multi-level S&FT Integration
• Real-time simulation embedded in the control involving high-performance computing (RP 1.3 ActionPlanT) • Knowledge-based, intelligent and high-performance simulation tools for production processes and energy consumption assessment (RP 2.3 ActionPlanT)Real-time data collection and analysis from assets, devices and products for synchronization of real-world and virtual resources (RP 2.5 ActionPlanT) • Global optimization and simulation algorithms for calculating KPIs and understanding holistic parameters influencing supply networks (RP 4.6 ActionPlanT) • Multi-criteria analysis and optimization based on new standardized virtual model and eco-design related KPIs within the production-lifecycle simulation tool (RP 5.2 ActionPlanT) • Development of simulators using developed mockups during job executions to have real-time control of continuing work (RP 5.5 ActionPlanT) • The development of integrated scalable and semantic factory models with multi- level access features, aggregation of data with different granularity, zoom in and out functionalities, and real-time data acquisition from all the factory resources (i.e. assets, machines, workers and objects) will enable the implementation of support decision-making processes, activity planning and operation controlling and facilitate faster ramp up through decreased time- to-market for future factories. The semantic models should be holistic in nature and be able to represent all levels of production functions and equipment. For real-time data acquisition, the connectivity paradigm offered by the IoT should be exploited and complemented with mobile decision-making apps that will assist plant managers in getting a holistic overview of KPIs computed on collected data (7.3.1 FoF 2020) • Software-based decision-support systems as well as energy management, monitoring and planning systems will lead to overall reduced energy	RA5: S&FT for Real-Time Factory Controlling and Monitoring

consumption, more efficient utilization and optimized energy sourcing (7.3.4 FoF 2020) • Simulation models that represent the interaction between a production machine and the related technological process including the processed material will be able to forecast productivity and part quality in front of varying environmental conditions and phenomena like wear and partial damage in mechanical components or tools and dies. (7.3.10 FoF 2020) • Multi-criteria analysis and optimization based on new standardized virtual model and eco-design-related KPIs within the product life-cycle simulation tools (7.6.2 FoF 2020) • Developing a framework for lifecycle simulation and for digital mock-ups of product and services in their environment in order to optimize product and services value as well as impact from a financial, environmental and social point of view (7.6.5 FoF 2020) • Novel simulation and fast testing methodologies are also required to assure that properties of such innovative products are compliant with common product quality requirements (i.e. reliability, safety, environmental-friendliness etc).(7.6.12 FoF 2020) • Integrate simulation systems into MES and machine and process control. To develop advanced tools for modeling integrated and optimized system configurations that will be based on a mechatronic simulation with respect of the expected performance (IMS 2020 RT3.02) • New production systems can guarantee “zero-defect” parts through the development of new manufacturing methods, the use of modeling and simulation tools and/or the integration of monitoring and control techniques.(IMS 2020 RT3.07) • Develop supporting tools and methodologies such as, for example, “plug and interoperate” devices, interfaces for interoperability, fast simulations and re-programming tools, methods to improve the plant control, assembly and disassembly aspects (IMS 2020 RT3.19)	
• Self-learning systems to enable self-adaptation of simulation attributes from historical and real-time data (RP 2.5 ActionPlanT) • Predictive data analytics techniques should be developed to aggregate and process the massive amount of data captured by intelligent devices from the field on-the-fly (7.3.2 FoF 2020 • Enterprises have to respond faster to demand and supply fluctuations and increase forecasting capability on the one hand and reducing cycle time and supply chain costs on the other (7.4.6 FoF 2020)	RA6: Smart, Intelligent and Self-learning S&FT
• Virtual and simulation environments for role game-based learning (RP 3.4 ActionPlanT) • Real time life cycle assessment support thorough training of designers supported by serious game/simulation (IMS 2020 RT1.03) • Methods and tools should be exploiting technologies such as VR/AR and digital mannequins to support multi-criteria based process and layout simulations and decision-making, on the basis of worker capabilities (7.5.3 FoF 2020)	RA7: Human-centred Simulation-based Learning & Training
• Semantic technologies for collecting, understanding and analyzing customer expectations through social networks and HMI technologies - such as visual, language-independent 3D model for customer's product interaction, 3D simulation and comparison between models proposed by different designers, opinion and sentiment analysis using text mining and emotional recognition. Enhancement of demand-sensing technologies leveraging social networks and the cloud, and demand models allowing what-if simulations. (RP 5.4 ActionPlanT)	RA8: Crowdsourcing-based S&FT

6.2. Block2 – the vision

The role that S&FT will play in the future cannot be envisaged if not in conjunction with the European manufacturing world evolution. In fact, S&FT represent one of the available enablers the manufacturing relies on to move into the future and cannot be considered independently from the whole manufacturing context. The development of the Pathfinder manufacturing vision as it has been described in Chapter 5 and as it is here recalled in Fig. 14, finds now proper placement within the Roadmap structure.

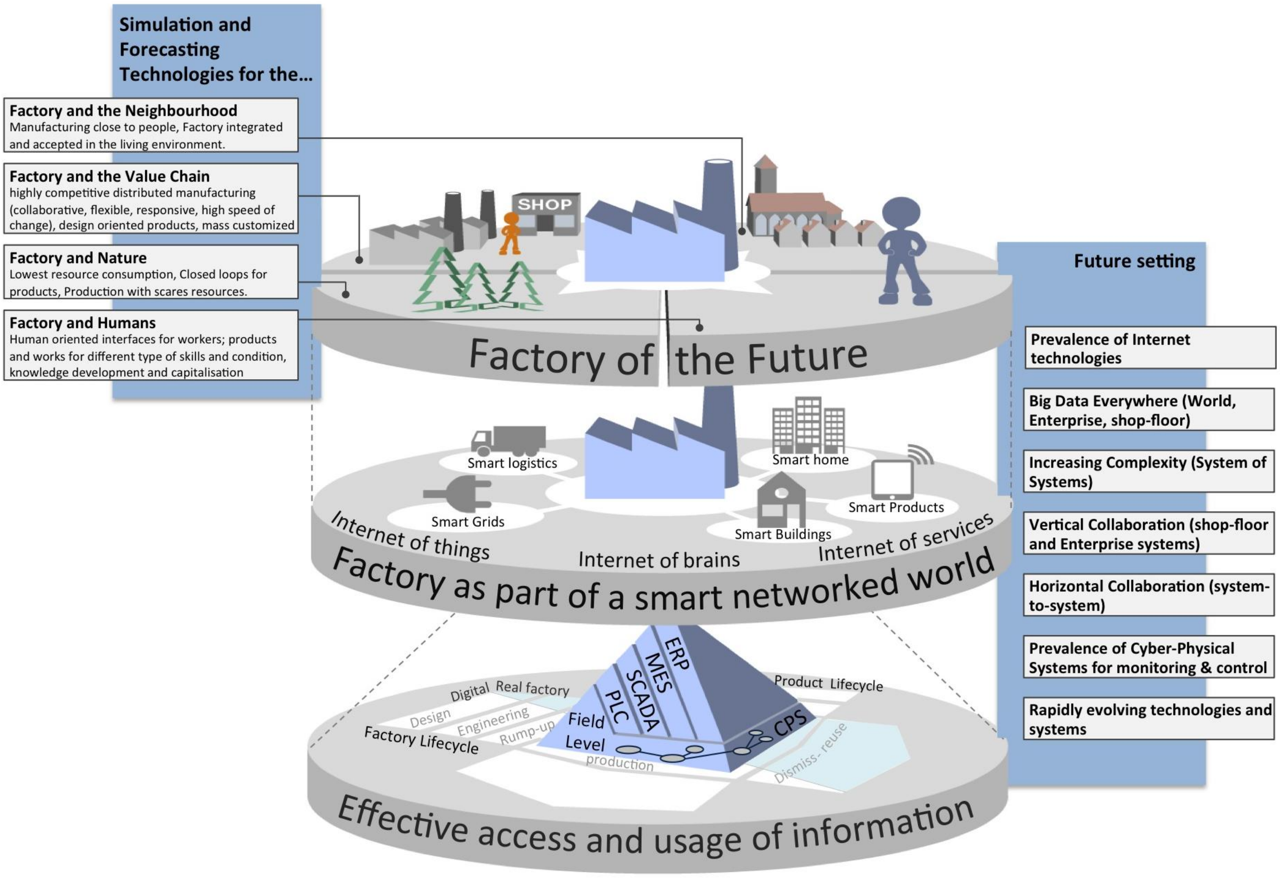


Fig. 14 – Pathfinder Vision

6.3. Block3 – S&FT trends and future state

While Pathfinder is the first roadmap specifically focused on Simulation and Forecasting Technologies, significant references to possible evolution in this area have been already introduced in previous roadmaps (see paragraph 6.1.4. - Definition of the Pathfinder Research Area). This block, within the Pathfinder roadmap, takes into account the Pathfinder vision, its envisaged settings for future manufacturing and the previous roadmap contribution in order to provide a clear picture of the expected S&FT trends and future state, grouped by the 8 Pathfinder Research areas.

Pathfinder Research Area	Trends and future state
RA1: Open and Cloud-based S&FT for High-performance Computing	• Exploit IaaS in cloud infrastructure for high-performance and complex simulation, forecasting and analytics • Facilitating SMEs to access high-performance and complex simulation, forecasting and analytics through a manufacturing app store
RA2: Multi-disciplinary and Multi-domain Integrated	• Develop multidisciplinary models and tools for designing flexible and easily reconfigurable systems, integrating models from different domains able to monitor consumption of energy and

S&FT	other resources and prevent unforeseen and undesired reactive maintenance • Development of closed loop simulation tools to be used in the design phase • Use simulation for the sustainable supply chain design
RA3: S&FT for Life-cycle Management	• Simulation tools for the de-manufacturing phase (dismantling, repairing and rebuilding)
RA4: Multi-level S&FT Integration	• Multi-level simulation applications that support usability at different levels aimed at providing different representations of relevant information (multi-level access features, aggregation of data with different granularity, zoom in and out functionalities) • Simulation tools enhancing data integration across the process chain • Advanced visualization tools for better human understanding
RA5: S&FT for Real-Time Factory Controlling and Monitoring	• Real-time data collection from all the factory resources and synchronization of real-world and virtual resources • Knowledge-based and intelligent simulation tools able to assess performance at both factory level (energy consumption, productivity, production processes and quality) and supply chain level • Performance assessment in real-time and predictive considering varying environmental conditions and phenomena • Product-life cycle simulation tools that could support the decisional process providing KPIs • Integrating simulation tools with MES • Real-time data collection from all the factory resources and synchronization of real world and virtual resources • Developing digital mock ups of product and services in their environment to improve the control done by simulation tool • Simulation tools used to guarantee production systems delivering “zero defect” parts
RA6: Smart, Intelligent and Self-learning S&FT	• Self-learning systems to enable self-adaptation of simulation attributes from historical and real-time data • Development of predictive data analytics techniques and forecasting capabilities to process the massive amount of data
RA7: Human-centred Simulation-based Learning & Training	• Virtual and simulation environment for role game-based learning and training • Tools to support the decision-making on the basis of worker capabilities
RA8: Crowdsourcing-based S&FT	• Simulation tools interacting with social networks and HMI supporting the comparison between models and allowing a what-if analysis (interaction with customers)

6.4. Block4 – S&FT state of market analysis

The future expectations and current trends previously highlighted represent the target that S&FT should aim at. In order to identify the interventions which are needed to get to that envisioned future state, a clear idea of what is currently available is needed. Tools available in the market and their functionalities have been analysed to outline the current state of market.

6.4.1. Simulation and Forecasting Technologies along the factory lifecycle

Each analysed S&FT tool has been mapped to the phases of the factory lifecycle that it is mostly relevant to (see paragraph 5.4). This investigation includes: Shop-floor Layout Design; Shop-floor Planning; Manufacturing Network Design and Planning; Customer Demand and Market Developments; Worker Behaviour; Control Programs; Product Design; Production monitoring and Key Performance Indicators' Prediction; Material flow; Energy Consumption and Environmental Impact.

The following paragraphs will shortly detail each Simulation and Forecasting Technology. Full details are provided in the Pathfinder "Framework and State of the Art" deliverable, available on the Roadmap website. The commercial software list mentioned in each section is by no means meant to be exhaustive, but is intended, through these examples, to clearly point out the category addressed by the paragraph.

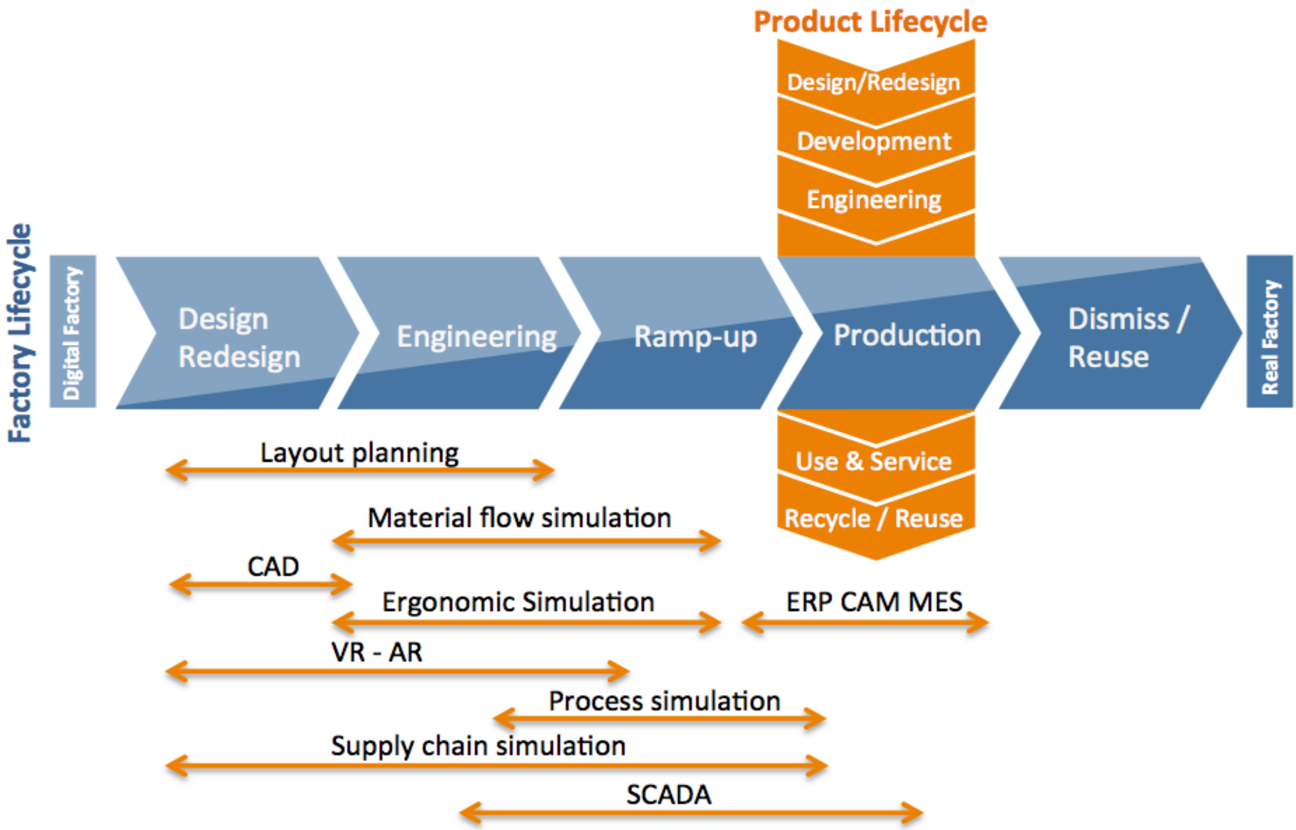


Fig. 15 - Mapping of Key-Enabling Technologies on Product and Production lifecycle [lifecycle phases adapted from EFFRA FoF 2020 Consultation Document] [35]

6.4.2. Layout Planning Simulation

Definition

Facility Layout Planning (FLP) refers to the design of the allocation plans of the machines/equipment in a manufacturing shop-floor[36].

Importance for the industry

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[35] EFFRA (2012) Factories of the Future PPP FoF 2020 Roadmap Consultation document. Retrieved from: http://www.effra.eu/attachments/article/335/FoFRoadmap2020_ConsultationDocument_120706_1.pdf

[36] Jiang S., Nee A.Y.C., 2013, A novel facility layout planning and optimization methodology, CIRP Annals-Manufacturing Technology, 62:483–486

Factory layout design is a multidisciplinary, knowledge-intensive task that is of a vital issue to the survival of manufacturers in today's globally competitive environment. The need to design and construct a new factory layout or reconfigure the current one has increased largely because of the fast changes in customer demand both from product quantity and product variety aspects. This requires companies to be more agile to plan, design and reconfigure the factory layout to be able to introduce new products to market and keep their competitive strength[37]. A 3D layout model can be implemented and provide the user with the ability to move through factory mock-ups, walk through, inspect, and animate motion in a rendered 3D-factory model[38].

Commercial Software Tools

DELMIA by Dassault Systemes – Tool URL: http://www.3ds.com/products-services/delmia/portfolio/delmia-v5/latest-release/

Siemens Tecnomatix Plant Simulation – Tool URL: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/plant_design/plant_simulation.shtml#lightview-close

Flexsim - Tool URL: www.flexsim.com

Visual Components - Tool URL: www.visualcomponents.com

DDD libraries: Tool URL: http://www.ttsnetwork.net/en/ddd-libraries

Challenges

Today, in the field of layout design simulation, some commercial software represent data from 3D model and export them in XML or HTML format. While capability is a step towards interoperability, this cannot solve the interoperability and extensibility issues since this depends on how the different software and users define contents of data models[37].

6.4.3. Material Flow Simulation

Definition

Materials flow within manufacturing is the movement of materials through a defined process or a value stream within a factory or an industrial unit for the purpose of producing an end product[39].

Importance for the industry

In today's changing manufacturing world with new paradigms such as mass customization and global manufacturing operations and competition, companies need greater capabilities to respond quicker to market dynamics and varying demands. The adoption of suitable production and materials flow control (PMFC) mechanisms, combined with the implementation of emergent technologies, can be of great value for improving performance and quality of manufacturing and of service to customers[40].

Commercial Software Tools

Siemens Tecnomatix Plant Simulation – Tool URL: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/plant_design/plant_simulation.shtml#lightview-close

Visual Components Software suite by Visual Components– Tool URL: http://www.visualcomponents.com/

ARENA by Rockwell Automation – Tool URL: http://www.arenasimulation.com/Products_Products.aspx

Flexsim - Tool URL: www.flexsim.com

Further references: https://www.informs.org/ORMS-Today/Public-Articles/October-Volume-40-Number-5/Simulation-Software-Survey-Simulation-a-better-reality).

Challenges

While the steady decline in computational cost renders the use of simulation very cost-efficient in terms of hardware requirements, commercial simulation software has not kept up with hardware improvements. Concerning material flow simulation, it can be very time-consuming to build and verify large models with

[37] Shariatzadeh N., Sivard G., Chen D.,2012, Software Evaluation Criteria for Rapid Factory Layout Planning, Design and Simulation, Procedia CIRP, 3:299-304.

[38] Kühn W., 2006, Digital Factory- Simulation enhancing the product and production engineering process, Proceedings of the 2006 Winter Simulation Conference, pp. 1899-1906.

[39] Ad Esse Consulting Ltd., 2007, Materials Flow in Manufacturing Processes [online], Ad Esse Consulting Ltd., URL: http://www.ad-esse.com/media/11502/materials_flow.pdf [Accessed 13 November 2013].

[40] Fernandes N., do Carmo-Silva S., 2006, Generic POLCA—A production and materials flow control mechanism for quick response manufacturing, International Journal of Production Economics, 104/1 :74-84.

standard commercial-off-the-shelf (COTS) software. Efficient simulation-model generation will allow the user to simplify and accelerate the process of producing correct and credible simulation models[41].

6.4.4. Computer Aided Design - CAD

Definition

Computer-Aided Design (CAD) is the technology concerned with the use of computer systems to assist in the creation, modification, analysis and optimization of a design[42]

Importance for the industry

The strong competition in today's market increases the level of requirement in terms of functionality and quality of products and production means. At the same time, the complexity of the design process is increasing, whereas product development time is decreasing. Such constraints on design activities require efficient CAD systems and adapted CAD methodologies. The evolution towards Life Cycle-CAD (LC-CAD) provides an integrated design of a product and its life-cycle, manages the consistency between them and evaluates their performance concerning the environment and the economy with the use of simulation[43].

Commercial Software Tools

PTC Creo by Parametric Technology Corp. – Tool URL: http://www.ptc.com/product/creo/

Product Design Suite by AutoDesk – Tool URL: http://www.autodesk.com/suites/autocad-design-suite/overview

CATIA by Dassault Systems – Tool URL: http://www.3ds.com/products-services/catia/

NX by Siemens – Tool URL: http://www.plm.automation.siemens.com/en_us/products/nx/

SolidWorks by Dassault Systemes – Tool URL: http://www.solidworks.com/

PowerSHAPE CAD by Delcam – Tool URL: http://www.powershape.com/

Challenges

Current deficiencies and limitations of present CAD tools are the complexity of menu items or commands, the limitation of active and interactive assistance while designing in CAD and the integration of informal conceptual design tools in CAD. Moreover, current tools include inadequate human–computer interface design; focused on functionality but not on usability and fixation on design routines[44].

6.4.5. Ergonomics Simulation

Definition

Ergonomics is the applied science of equipment and workplace design intended to maximize productivity by reducing operator fatigue and discomfort.

Importance for the industry

In the past, workplace ergonomic considerations have often been reactive, time-consuming, incomplete, sporadic, and difficult. Ergonomic experts who were consulted after problems occurred in the workplace examined data from injuries that had been observed and reported. There are now emerging technologies supporting simulation-based engineering to address this in a proactive manner. These allow the workplaces and the tasks to be simulated even before the facilities are physically in place[45].

Commercial Software Tools

ADAPS (Anthropometric Design Assessment Program System) by TU Delft – Tool URL: http://dined.nl//ergonomics/3d.html

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[41] Lee J.Y., Kang H.S., Kim G.Y., Noh S.D., 2012, Concurrent material flow analysis by P3R-driven modeling and simulation in PLM, Computers in Industry, 63/5:513-527.

[42] Conway, J.H., B.M. Johnson and W.L. Maxwell, 1960, An Experimental Investigation of Priority Dispatching, Journal of Industrial Engineering, 2/3

[43] Umeda Y., Fukushige S., Kunii E., Matsuyama Y., 2012, LC-CAD: A CAD system for life cycle design, CIRP Annals - Manufacturing Technology, 61/1:175-178.

[44] Nee A.Y.C., Ong S.K., Chryssolouris G., Mourtzis D., 2012, Augmented reality applications in design and manufacturing, CIRP Annals- Manufacturing technology, 61:657-679.

[45] Jayaram U., Jayaram S., Shaikh I., Kim Y., Palmer C., 2006, Introducing quantitative analysis methods into virtual environments for real-time and continuous ergonomic evaluations, Computers in Industry, 57/3:283-296.

Jack and Process Simulate Human by Siemens – Tool URL: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/assembly_planning/jack/

RAMSIS by Human Solutions – Tool URL: http://www.human-solutions.com/mobility/front_content.php?idcat=252

SAMMIE CAD by SAMMIE CAD Ltd – Tool URL: http://www.lboro.ac.uk/microsites/lds/sammie/home.htm

Challenges

Many advances have been made during the last decades, and the amount of possible applications is growing in the field of ergonomics. Yet much research has still to be conducted for many open issues. Systems' complexity and number of features are only increasing and ways of effectively implementing them should be explored. The interaction between models is required, as well, for an integrated approach of common daily design problems which is directly related to an integration of models into an encompassing DHM. Moreover, techniques for measuring human quantities, which has not become easier despite the evolution of the technical means, should be evolved. Another issue is the harmonisation of the data representation in different disciplines. Without such agreement it will remain extremely difficult to develop integrated models[46].

6.4.6. Enterprise Resource Planning - ERP

Definition

An Enterprise Resource Planning system is a suite of integrated software applications used to manage transactions through company-wide business processes, by using a common database, standard procedures and data sharing between and within functional areas[47].

Importance for the industry

The Enterprise Resource Planning systems are becoming more and more prevalent throughout the international business world. Nowadays, in most production / distribution companies ERP systems are used to support their production and distribution activities. Moreover, they are designed to integrate and partially automate financial, resource management, commercial, after-sale, manufacturing and other business functions in to one system around a database[48].

Commercial Software Tools

SAP ERP by SAP – Tool URL: http://www.sap.com/pc/bp/erp.html

Oracle ERP - https://www.oracle.com/applications/enterprise-resource-planning/index.html

Microsoft Dynamics - http://www.microsoftbusinesshub.com/products/Dynamics_ERP

Challenges

Future trends of ERP systems, on technological level, include software as a service, mobile technology and tightly integrated business intelligence. The tendency of being able to obtain ERP functionality as a service has to be mentioned. Especially in the mid-market, the ERP suites will no longer be hosted internally but instead will be obtained as a service offered by the ERP provider. New ways of providing software are to be investigated, mainly linked with the development of cloud computing[49]. In addition, access to information with the use of mobile devices has become a reality even for end consumers over the last years. The ERP system providers should face these challenges by offering mobile-capable ERP solutions[50, 51]. Another important issue is the reporting and data analysis which grows with the information needs of users. Business Intelligence (BI) is becoming not only easier to use over time but also tighter integrated into ERP suites[48].

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[47] Aloini D., Dulmin R., Mininno V., 2012, Risk assessment in ERP projects, Information Systems, 37/3:183-199
[48] Mourtzis D., Papakostas N., Mavrikios D., Makris S., Alexopoulos K., 2012, The role of simulation in digital manufacturing-Applications and Outlook, DOI:10.1080/0951192X.2013.800234.
[49] Borovskiy V. and Zeier A., 2009, Enabling enterprise composite applications on top of ERP systems, Services Computing Conference, APSCC 2009 IEEE Asia-Pacific, pp. 492-497.
[50] Schabel S., ERP - Mobile Computing, Thesis, Wien: Universität, Wien, 2009.
[51] Su C. J., 2009, Effective Mobile Assets Management System Using RFID and ERP Technology, WRI International Conference on Communications and Mobile Computing, CMC, pp. 147-151.

6.4.7. Computer Aided Manufacturing - CAM

Definition

Computer Aided Manufacturing (CAM) can be defined as the effective utilization of computers in manufacturing[52]. CAM supports the use of computer systems to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with the plant's production resources. In other words, the use of computer system in non-design activities but in manufacturing process is called CAM[53].

Importance for the industry

The application of CAM in the production offers advantages to a company to develop capabilities by combining traditional economies of scale with economies of scope resulting in the desired flexibility and efficiency[54].

Commercial Software Tools

CATIA by Dassault Systems – Tool URL: http://www.3ds.com/products-services/catia/

NX by Siemens – Tool URL: http://www.plm.automation.siemens.com/en_us/products/nx/

GibbsCAM by Gibbs and Associates – Tool URL: http://www.gibbscam.com/solutions/gibbscam-modules

MasterCAM by CNC Software Inc. – Tool URL: http://www.mastercam.com/Products/Camfinder/Default.aspx

CADDS Version 5 by PTC – Tool URL: http://www.ptc.com/product/cadds5

PowerMILL by Delcam – Tool URL: http://www.powermill.com/

SurfCAM Version 6.0 by Surfware Inc. – Tool URL: http://www.surfcam.com/

Alphacam by Planit – Tool URL: http://www.alphacam.com/

Tebis CAM by Tebis – Tool URL: http://www.tebis.com/cms/index.php?id=20&L=10

Challenges

As a result of the dynamically changing and evolving manufacturing environment, the need is presented for effective coordination, collaboration and communication amongst all the aspects of production, from humans to machines. The future CAM systems need to focus on collaborative technics, effective communication and efficient data exchange[54]

6.4.8. Manufacturing Execution Systems (MES)

Definition

A Manufacturing Execution System (MES) is a system that helps manufacturers attain constant product quality, comply with regulatory requirements, reduce time to market, and lower production costs[55]. MES work in real time to enable the control of multiple elements of the production process (e.g. inputs, personnel, machines and support services).

Importance for the industry

As manufacturers strive to become more competitive and provide world-class service to their customers, emphasis has been placed on total quality management (TQM) programs. The need for a quality manufacturing system solution is a driving factor creating the demand for MES. The functions of MES are consistent with the goals of TQM applied to industrial manufacturing companies[55]. On the shop-floor, often RFID devices are used in order to track and trace manufacturing objects and acquire real-time production data and identification and control of disturbances[56].

Commercial Software Tools

SAP Manufacturing Execution by SAP – Tool URL:
http://www.sap.com/solution/lob/manufacturing/software/execution/index.html

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[52] Groover M P (1987) Automation Production Systems and Computer-Aided Manufacturing, 1st ed. Prentice-Hall, Englewood Cliffs, New Jersey

[53] Elanchezhian C, Selwyn T S and Sundar G S (2007) Computer-Aided Manufacturing, 2nd ed. Laxmi Publications LTD, New Delhi

[54] Makris S., Mourtzis D., Chryssolouris G., 2012, Computer Aided Manufacturing (CAM), CIRP Encyclopedia of Production Engineering, Luc Laperrière and Gunther Reinhart (Eds).

[55] Deuel A.C., 1994, The benefits of a manufacturing execution system for plantwide automation, ISA Transactions, 33/2:113-124.

[56] Zhong, R.Y., Dai Q.Y., Qu T., Hu G.J., Huang G.Q., 2013, RFID-enabled real-time manufacturing execution system for mass-customisation production, Robotics and Computer-Integrated Manufacturing, 29/2:283-292.

Siemens http://www.automation.siemens.com/mcms/automation/en/manufacturing-execution-system-mes/Pages/Default.aspx

More references at http://www.supplychainmovement.com/mes-product-survey/

Challenges

In the turbulent manufacturing environment, a key issue of modern Manufacturing Execution Systems is that they cannot plan ahead of time. This phenomenon is named decision myopia and causes undoubtedly significant malfunctions in manufacturing.

6.4.9. Virtual Reality - VR

Definition

Virtual reality is defined as the use of real-time digital computers and other special hardware and software to generate the simulation of an alternate world or environment, believable as real or true by the users[57].

Importance for the industry

Virtual reality (VR) is a rapidly developing computer interface that strives to immerse the user completely within an experimental simulation, thereby greatly enhancing the overall impact and providing a much more intuitive link between the computer and the human participants. Virtual reality has been applied successfully to hundreds if not thousands of scenarios in diverse areas including rapid prototyping, manufacturing, scientific visualisation, engineering, and education. Currently, new semantic-based techniques are introduced in order to facilitate the design and review of prototypes by providing usability and flexibility to the engineer / designer[58].

Commercial Software Tools

Unity by Unity Technologies – Tool URL: http://unity3d.com/

3DVIA Studio pro by Dassault Systemes – Tool URL: http://www.3ds.com/products-services/3dvia/3dvia-studio/

Challenges

VR tools should be integrated not only in the central planning phases, but in every phase of the factory planning process. VR should not only be used for visualisation means, but also for collaborative and communicative means[59]. VR is now used in many industrial applications and cuts costs during the implementation of a PLM. The main challenges are a result of the following drawbacks. Implementation of a CAE simulation is a time-consuming process and VR systems used in industry focus on one or a few particular steps of a development cycle (e.g. design review), and may be used in the framework of the corresponding product development project review. There is no VR tool in the current state of the art which enables us to deal globally with the different steps of the PLM and the corresponding projects reviews[60].

6.4.10. Augmented Reality - AR

Definition

Augmented Reality (AR) as a real-time direct or indirect view of a physical real-world environment that has been enhanced/augmented by adding virtual computer-generated information to it. AR systems aim at enhancing the way the user perceives and interacts with the real world[61]. This is succeeded through the supplementation of the real world with 3D virtual objects that are incorporated in the real world. AR systems should blend real and virtual objects in a real environment, should be real-time interactive and last but not least, should be registered in 3D which means that both real and virtual objects should be accurately aligned.

Importance for the industry

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[57] Lu S. C. Y., Shpitalni M., Gadh R., 1999, Virtual and Augmented Reality Technologies for Product Realization, Annals of the CIRP Keynote Paper, 48/2:471-494

[58] Makris S., Rentzos L., Pintzos G., Mavrikios D., Chryssolouris G., 2012, Semantic-based taxonomy for immersive product design using VR techniques, CIRP Annals - Manufacturing Technology, 61/1:147-150.

[59] Menck N., Weidig C., Aurich J. C., 2013, Virtual Reality as a Collaboration Tool for Factory Planning based on Scenario Technique, Procedia CIRP, 7:133-138.

[60] Fillatreau P., Fourquet J.-Y., Le Bolloc'h R., Cailhol S., Datas A., Puel B., 2013, Using virtual reality and 3D industrial numerical models for immersive interactive checklists, Computers in Industry, 64/9:1253-1262.

[61] Azuma R., Baillot Y., Behringer R., Feiner S., Julier S., MacIntyre, 2001, Recent advances in augmented reality, Computers and Graphics, 21/6:34-47.

The increasing trend of globalized manufacturing environments requires real-time information exchanges between the various nodes in a product development life cycle, e.g., design, setup planning, production scheduling, machining, assembly, etc., as well as seamless task collaboration among these nodes. Product development processes are becoming increasingly more complex as products become more versatile and intricate, and inherently complicated, and as product variations multiply with the trend of mass customization. An innovative and effective solution to help solve these problems is the application of augmented reality (AR) technology to simulate, assist and improve these manufacturing processes before they are carried out**.** The challenge is to design and implement integrated AR-assisted manufacturing systems that could enhance the manufacturing processes, as well as product and process development, leading to shorter lead-time, reduced cost and improved quality.

Commercial Software Tools

Unity by Unity Technologies – Tool URL: http://unity3d.com/

Metaio by Metaio GmbH – Tool URL: http://www.metaio.com/products/creator/overview/

Challenges

AR applications in manufacturing and design require a high level of accuracy in tracking and superimposition of augmented information. Very accurate position and orientation tracking will be needed in operations such as CNC simulation and robot path planning. Computer-vision-based tracking will not be able to handle high frequency motion as well as rapid camera movements. Hybrid systems using laser, RFID and other types of sensing devices will be required. Another basic issue in AR is the placing of virtual objects with the correct pose in an augmented space. This is also referred to as Registration. As different tracking methodologies possess their own inherent deficiencies and error sources, it is necessary to study the best tracking method for a particular application which could be subject to poor lighting condition, moving objects, etc. AR displays require an extremely low latency to maintain the virtual objects in a stable position. An important source of alignment errors come from the difference in time between the moment an observer moves and the time the corresponding image is displayed. This time difference is called the end-to-end latency, which is important as head rotations can be very fast and this would cause significant changes to the scene being observed. Further research should focus on the setup of an AR environment which consists of four essential elements: target places, AR content, tracking module and display system[62].

6.4.11. Process simulation

Definition

A manufacturing process is defined as the use of one or more physical mechanisms to transform the shape of a material's shape and/or form and/or properties[63]

Importance for the industry

Newly emerging composite manufacturing processes, where there exist only limited industrial experience, demonstrate a definite need for process simulations to reduce the time and cost associated with the product and process developments[64].

Commercial Software Tools

NX by Siemens – Tool URL: http://www.plm.automation.siemens.com/en_us/products/nx/

GibbsCAM by Gibbs and Associates – Tool URL: http://www.gibbscam.com/solutions/gibbscam-modules

MasterCAM by CNC Software Inc. – Tool URL: http://www.mastercam.com/Products/Camfinder/Default.aspx

PowerMILL by Delcam – Tool URL: http://www.powermill.com/

SurfCAM Version 6.0 by Surfware Inc. – Tool URL: http://www.surfcam.com/

Alphacam by Planit – Tool URL: http://www.alphacam.com/

Tebis CAM by Tebis – Tool URL: http://www.tebis.com/cms/index.php?id=20&L=10

Challenges

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[62] Nee A.Y.C., Ong S.K., Chryssolouris G., Mourtzis D., 2012, Augmented reality applications in design and manufacturing, CIRP Annals- Manufacturing technology, 61:657-679.

[63] Chryssolouris G., 2006, Manufacturing Systems: Theory and Practice, 2nd Edition, 606p, Springer-Verlag, New York

[64] Mohan R. V., Tamma K.K., Shires D.R., Mark A., 1998, Advanced manufacturing of large-scale composite structures: process modeling, manufacturing simulations and massively parallel computing platforms, Advances in Engineering Software, 29/3–6:249-263.

The planning, the data transfer and the optimisation of manufacturing process chains must be integrated into a common model. Moreover, the macro-scale manufacturing process chains are optimised with simulation tools using numerical techniques such as the FEM while the micro-scale manufacturing process chains are mainly optimised by experimental approaches. This shows that the macro-scale manufacturing process chains are more mature than the micro-scale manufacturing process chains in terms of modelling and simulation which indicates that modelling and simulation of micro-scale manufacturing process chains is still a challenge. Also, the macro-scale manufacturing processes chains are not fully understood and there are still challenges for improving the manufacturing process chains related to different industries and development of new manufacturing process chains for new emerging applications.

6.4.12. Supply Chain simulator

Definition

A supply chain system is a chain of processes from the initial raw materials to the ultimate consumption of the finished product spanning across multiple supplier-customer links[65].

Importance for the industry

Modern manufacturing enterprises must collaborate with their business partners through their business process operations such as design, manufacture, distribution, and after-sales service. Robust and flexible system mechanisms are required to realize such inter-enterprises collaboration environments.

Commercial Software Tools

WITNESS by Lanner Ltd. – Tool URL: http://www.lanner.com/en/witness.cfm

ARENA by Rockwell Automation – Tool URL: http://www.arenasimulation.com/Products_Products.aspx

Challenges

Identifying the benefits of collaboration is still a big challenge for many supply chains. Confusion around the optimum number of partners, investment in collaboration and duration of partnership are some of the barriers of healthy collaborative arrangements that should be surpassed[66].

6.4.13. SCADA (Supervisory Control And Data Acquisition)

Definition

SCADA is a system operating with coded signals over communication channels so as to provide control of remote equipment. It is a type of industrial control system.

Importance for the industry

Early simulation of manufacturing systems interaction with SCADA is expected to shorten rump-up time and deliver first time right production. SCADA systems are applied worldwide in critical infrastructures, ranging from power generation, over public transport to industrial manufacturing systems[67].

Commercial Software Tools

OCTAVE (Operationally Critical Threat, Asset and Vulnerability Evaluation) by Software Engineering Institute Carnegie Mellon – Tool URL: http://www.cert.org/octave/

CORAS – Tool URL: http://coras.sourceforge.net/

Challenges

Whilst SCADA systems are generally designed to be dependable and fail-safe, the number of security breaches over the last decade shows that their original design and subsequent evolution failed to adequately consider the risks of a deliberate attack. Although best practices and emerging standards are now addressing issues which could have avoided security breaches, the key problems seem to be the increased connectivity and the loss of separation between SCADA and other parts of IT infrastructures of organisations[67].

[65] Dugal, L.F., Healy M., Tankenton S.. 1994, Supply Chain Management: A Challenge to Change, Coopers & Lybrand Report

[66] Ramanathan U., 2014, Performance of supply chain collaboration – A simulation study, Expert Systems with Applications, 41/1:210-220.

[67] Nicholson A., Webber S., Dyer S., Patel T., Janicke H., 2012, SCADA security in the light of Cyber-Warfare, Computers & Security, 31/4:418-436.

6.4.14. Knowledge Management

Definition

Knowledge Management (KM) is defined as the process of continuously creating new knowledge, disseminating it widely through the organisation, and embodying it quickly in new products/services, technologies and systems[68].

Importance for the industry

KM is about facilitating an environment where work critical information can be created, structured, shared, distributed and used. To be effective such environments must provide users with relevant knowledge, that is, knowledge that enables users to better perform their tasks, at the right time and in the right form. KM has been a predominant trend in business in the recent years[69].

Commercial Software Tools

DELMIA by Dassault Systemes – Tool URL: http://www.3ds.com/products-services/delmia/portfolio/delmia-v5/latest-release/

SAP Knowledge Warehouse – Tool URL: http://scn.sap.com/docs/DOC-8992

Challenges

Agent-oriented approaches to knowledge management and collaborative systems need further development. Methodologies are needed that support the analysis of knowledge management needs of organisations and its specification using software agents and agent societies. Also, reusable agent-oriented knowledge management frameworks, including the description of agent roles, interaction forms and knowledge description should be developed. The existence of agent-based tools for organisational modelling and simulation that help determine the knowledge processes of the organisation is crucial. Finally, research should focus on the role of learning in agent-based KM systems, namely, how to use agent learning to support and extend knowledge sharing[69].

6.4.15. Synthesis of the current state of Market in S&FT

Pathfinder investigated what is currently available in the S&FT domain. Tools available in the market and their functionalities have been analysed to outline the current situation. Full details are provided in the Pathfinder "Framework and State of the Art" deliverable, available on the Roadmap website.

A synthesis of features characterizing the state of market, according to the 8 Pathfinder Research Areas, is provided in the following table.

Pathfinder Research Areas	Current State of Market
RA1 - Open and Cloud-based S&FT for High-performance Computing	• Early adoption of cloud-computing IaaS paradigm; • High-performance simulations requires high-performance CPU; • Applications run only single device;
RA2 - Multi-disciplinary and Multi-domain Integrated S&FT	• Only dedicated application object libraries for fast and efficient modeling of typical scenarios; • Incremental model building allowing in-process debugging; • Limited product data exchange across different domains; • Many domains specific models; • Many tools available for specific functions or phases of the factory lifecycle; • Few/No common standards or integrated frameworks;
RA3 - S&FT for Life-cycle Management	• Poor modelling-simulation of life-cycle issue; • Limited, specialized de-manufacturing applications (only for specific product types); • Usage of S&FT tools is limited to white collar workers (feedback loops to the

[68] Nonaka I., Takeuchi H., 1995, The knowledge creating company: how Japanese companies create the dynamics of innovation, Oxford University Press, New York

[69] Dignum V., 2006, An Overview of Agents in Knowledge Management, In Proceedings of INAP-05, M. Umeda et al. (Eds), Springer, pp. 175-189.

	shop-floor/blue collar workers are missing) • Few applications consider product life cycle costs and environmental issues; • Existing process modelling applications used to evaluate remanufacturability of design (non tailored for de-manufacturing)
RA4 - Multi-level S&FT Integration	• Object-oriented, hierarchical model of plants, encompassing business, logistic and production processes exist; • Direct interface with CAD, DBMS (ORACLE, SQL Server, Access, etc.) direct spreadsheet link in/out, XML save format, HTML reports;
RA5 - S&FT for Real-Time Factory Controlling and Monitoring	• Expensive data collection; • Only early adoption of virtual factory models; • Increase of heterogeneous information sources and IT systems in the factory due to vertical integration; • Gap between the state of the real world and its digital representation;
RA6 - Smart, Intelligent and Self-Learning S&FT	• Inbuilt algorithms for automated optimization of system parameters; • Many custom models used; • Some knowledge-based advisory system in use; • Excellent analytical simulation and forecasting capabilities in continuous processing industries; • Application based on empirical or past data;
RA7 - Human-centered Simulation-based Learning & Training	• VR- and AR-based training and learning applications are used only in specific sectors and usecases (e.g. in aviation and automotive for special training); • Limited access to training and learning applications for blue collar workers; • Current training tools are expensive and time consuming in setup and usage; • Many-domain specific tools;
RA8 - Crowdsourcing-based S&FT	• Existing crowdsource-source frameworks used in the design phases; • Complex tools require high-skill & long processing time;

6.5. Block5 – Gaps

The next conceptual step towards the Pathfinder roadmap development is the identification of existing gaps. These can be considered as the missing link between what is currently available (block 4) and the future envisioned manufacturing scenario (block 3). The identification of gaps is the result of a formalized comparison between the future and the present state of S&FT with reference to the 8 identified Pathfinder Research Areas, as presented in the following table. Details on this analysis can be found in the “Report on Identified Gaps” deliverable, available on the Pathfinder website.

Gaps may refer to different level of disparities between current status and future scenario, calling either for Innovation Actions (where technologies are already mostly developed, but adoption, extension to specific sectors or full potential exploitation is hindered) or Research Actions (where specific knowledge is missing).

Closer to Market Actions primarily consist of activities directly aiming at producing arrangements or designs for newly extended or improved technologies, include prototyping, testing, demonstrating, piloting, and large-scale validation. A ‘demonstration or pilot’ aims to validate the technical and economic viability of an improved technology, product, process, service or solution in an operational (or near to operational) environment.

Research Actions primarily consist of activities aiming to establish new knowledge and/or to explore the feasibility of a new or improved technology, service or solution. For this purpose they may include basic and applied research, technology development and integration, testing and validation on a small-scale prototype in a laboratory or simulated environment.

	Gaps	Description
RA1 - Open and Cloud-based S&FT for High-performance Computing	**G1.1** - Poor maturity level of use of cloud-computing in S&FT - RA	In S&FT there are only few vendors that offer powerful and entire cloud-based service. Although the research efforts and some early adoptions, there is still a low commitment towards these technologies in S&FT.

	G1.2 - Missing of multi-device and platform independent applications - RA	At the moment almost all the tools analyzed can be run only by a single device application. Hence, the multi-device applications are missed. This need is reinforced by the growing trend of embedding and transferring new communication technologies like smartphones and tablets of the consumer goods market into the industrial environment for an effective usage as human machine interfaces and working tools.
RA2 - Multi-disciplinary and Multi-domain Integrated S&FT	**G2.1** - Missing of multi-disciplinary and multi-domain models - CMA	In S&FT there is a limited ability to use S&FT models in one domain/discipline that were created in a different domain/discipline. This statement leads the inability to integrate different domain/discipline models and this lack triggers the missing of multi-disciplinary and multi-domain models.
	G2.2 - Lack of integration from different domain/discipline models - CMA	
	G2.3 - Few standards for multi domain models building & integration - CMA	In the majority of the S&FT analyzed there are: no conventions or standards for common representation schemes to collectively manage different types of resources; S&FT tools usually have implicit semantics with only one level of abstraction geared towards experts; no means of aggregating detailed data into a high-level model; and no common understanding or definition of the terms used by the different tools.
	G2.4 - No integration between tools - CMA	
RA3 - S&FT for Life-cycle Management	**G3.1** - Poor modeling simulation of life-cycle issue - CMA	There are few S&FT models and tools that consider lifecycle issues. Lifecycle cost modeling is limited and often not complete assessed by the considered tools. Few tools support environmental analyses.
	G3.2 - Limited modeling of product life cycle costs - CMA	
	G3.3 - Environmental issue are barely considered - CMA	
	G3.4 - De-manufacturing not completely assessed and only for specialized product type - RA	The main concerns, in this cluster, are about the de-manufacturing phase such as dismantling, repairing and rebuilding. However, this phase is barely considered and rarely complete assessed from the analyzed tools.
RA4 - Multi-level S&FT Integration	**G4.1** - Shortage of multi-level SF&T models - CMA	The shortage of multi-level models triggers the limited integration and interoperability across the process and product chain. Despite the use of object-oriented models and the multiple interface and integration capacities, the digital continuity across level is still far away to exist.
	G4.2 - Limited integration and interoperability across the process and product chain - CMA	

RA5 - S&FT for Real-Time Factory Controlling and Monitoring	**G5.1** - Real-time data collection and synchronization barely used - CMA	Some vendors offer the possibility to operate an accurate virtual production system to track real-time production. However, real-time data are barely collected and rarely have a linkage with actual data. This is due to the fact that data gathering is expensive and time consuming. Additionally, for real-time factory controlling, the need for simulated data feedback to the manufacturing process increases. The still-existing gap between the state of the real world and its digital representation proves to be an obstacle to a parallel-operation and predictive simulation and optimization of the factory. The direct connection to and synchronize with cyber-physical systems allow for a direct insight into the current status of the products, processes and systems on real time basis.
	G5.2 - Limited linkage to actual and real-time data - CMA	
	G5.3 - Poor maturity level of use of virtual factory models - CMA	Many researches and projects have been carried out towards virtual factory models. Nevertheless their application and their use seem to be still embryonic.
RA6 - Smart, Intelligent and Self-Learning S&FT	**G6.1** - Missing of self-optimizing and self-learning models - RA	Despite the recent advances in the S&FT field, the idea to have self-learning, intelligent and smart tools is still a faraway target.
	G6.2 - Poor use of knowledge-based systems - CMA	Knowledge-based systems nevertheless are mature technologies, are barely used.
	G6.3 - Poor maturity level of use of smart objects - RA	A smart object is an object that can describe its own possible interactions. Despite their strong advantages these kinds of objects are not frequently used.
RA7 - Human-centered Simulation-based Learning & Training	**G7.1** - Limited use on large-scale - RA	The large-scale use of these technologies is difficult because they are expensive and time consuming set-up and usage.
	G7.2 - Lack of generic tools for human-centered simulation-based learning and training - CMA	The use of simulation-based learning and training is limited in specific S&FT domains such as military training and aeronautically training.
RA8 - Crowdsourcing-based S&FT	**G8.1** - Missing of crowd source-based framework for simulation ad forecasting tool - RA	So far the crowd source is mainly used in the design rather than in S&FT due to the fact that there is a lack of specific frameworks.
	G8.2 - Lack of integration with social networks - RA	Although the use of social networking is an increasing trend, in S&FT the interaction with them is still missed. Digital models and data must be extensively made available for collaboration and social communication processes.

6.6. Block6 – challenges

Identified gaps are a main input for the identification of challenges that, given the contextual factors, are expected to arise for the S&FT innovation. Gaps provide hints for the identification of what are the weaknesses that need to be address to get the future vision. Each gap is thus translated into an objective to be fulfilled and these objectives are, in turn, expressed in form of challenges. Challenges thus outline the key points that require careful attention during the S&FT development since they are crucial to empower the Factory of the future vision

Even tough the list of challenges is expected to continuously evolve during the Pathfinder road-mapping activity, a preliminary list of challenges for Pathfinder has been already identified and is presented in what follows.

S&FT and Digital Continuity - Digital Continuity refers to the ability to maintain the digital information available all along the factory life-cycle, despite changes in purpose and tools, allowing data (the oil that fuels manufacturing) to be enriched and used as needed for that specific phase. This challenge addresses: Interoperable simulation and forecasting systems; Digital continuity across product and factory lifecycle of engineering information; seamless use and reuse of engineering data; Reduce modelling effort; ;Modelling of complex problems; Multidisciplinary integrated modelling; Standardization.

S&FT and Scalability - Scalability refers to the ability of an application to function efficiently when its context is changed in size or volume. This challenge addresses: Step-by-step integration and adoption of S&FT; S&FT solution scalable on different devices and platforms; from on-premises software to cloud-based services;

S&FT and Synchronization of Digital and Real World - Synchronization of Digital and Real World refers to the convergence of physical world and virtual world, where the second must closely mirror the first and where the first generates an unprecedented volume of data to be taken care of by the latter. This challenge addresses: Self-adjustment of digital models triggered by smart objects (embedded intelligence – Cyber Physical System paradigm); Co-simulation in real-time; Handling of big-data.

S&FT and Advanced Human-Machine Interfaces – Advanced Human-Machine Interfaces (HMI) must provide transparent insights into the digital-virtual world and must allow to interact with S&FT in an intuitive and natural way. This challenge addresses: intuitive, mobile, context-sensitive and collaborative user-interfaces.

S&FT and Digital Consistency & Security - Digital Consistency & Security refers to the fact that data originating from and travelling along the factory lifecycle should be safe and shouldn't contradict each other. This is a significant challenge especially in the context of the digital continuity, vertical integration and horizontal integration, where distributed and heterogeneous data sources will be linked and made available in an open and interoperable manner. This challenge addresses: optimised provision of consistent data, data security and privacy.

S&FT, Data and Knowledge - This challenge addresses: Big Data and Data Analytics; Ontologies definition; Relevant knowledge capture and reuse, also for training and education

6.7. Block7 – Research Priorities – RP

A first set of Research Priorities has been identified and mapped over the Research Challenges afore mentioned. Additionally, to analyse and compare research priorities, the impact on the manufacturing performance dimensions identified within the ActionPlant roadmap has been introduced. S&FT is closely related to the evolution of the manufacturing context and, being one of the enablers for the manufacturing of the future, S&FT role cannot be evaluated independently from future manufacturing expected performances.

The core elements of future manufacturing are described as follows in the ActionPlant roadmap:

- **Agile manufacturing processes**: The issues of systems interoperability would no longer be a deterrent to integrating disparate systems for design, manufacturing process control and operation, and business processes in Manufacturing 2.0 enterprises. These systems would integrate seamlessly and exchange data through standardized interfaces. Real-world resources such as connected objects, devices and advanced robots would leverage advances in the Internet of Things domain to communicate, collaborate and organize themselves autonomously. Furthermore, manufacturing processes would react in real-time to changes within an enterprise ecosystem – such as availability of equipment, assembly lines and dynamic configuration of process parameters. To achieve this, Manufacturing 2.0 enterprises would be capable of applying advanced computing operations to process large volumes of real-time manufacturing data, perform analyses and forecasting on productivity, throughput and downtime. Lastly, these real-time changes and decisions would be executed by plant managers on their smart phones which will process enterprise and manufacturing data to facilitate efficient management-by-exception.
- **Seamless factory lifecycle management**: Product lifecycle management is well understood, but manufacturers struggle to put factory lifecycle management into practice. Enhanced information management will be applied for control and holistic planning in future factories. In Manufacturing 2.0 enterprises, assets and inventories together with assembly lines and machinery would be dynamically monitored, configured and maintained. As a prerequisite for advanced factory lifecycle management, visibility, real-time tracking and predictive maintenance information would be made available to plant managers and operators. Furthermore, managers would be able to drill down into any production area and observe throughput, use and consumption through intuitive key performance indicators (KPIs) even when on the move.
- **Workers at the forefront**: Human-centric ambition will become a reality in Manufacturing 2.0 enterprises with workers given more opportunity for continuous development of skills and competences through novel knowledge-delivery mechanisms. Future enterprises will not only be better equipped for transferring skills to a new generation of workers but also proficient in assisting older workers with better user interfaces, intuitive user-experience-driven workflows and other aids, such as mobile and service robots. Furthermore, Manufacturing 2.0 enterprises would be equipped with interactive e-learning tools to facilitate students, apprentices and new workers gaining understanding of advanced manufacturing operations involving new ICT paradigms.
- **Collaborative supply chain**: Manufacturing 2.0 enterprises will define a new collaboration paradigm between stakeholders in the manufacturing supply chain, including but not limited to original equipment manufacturers (OEM), suppliers and subcontractors. Manufacturing processes will run across organizational boundaries of OEMs and subcontractors with complete visibility of production, inventory and materials available while guaranteeing security and privacy for all stakeholders. As part of the extended collaboration paradigm, OEMs will be able to sell 'products as a service' and certified suppliers or subcontractors will be able to offer value-added services – such as maintenance or upgrades – to customers. So-called 'capability-based' contracts will offer use-based billing instead of requiring upfront investments in machinery by subcontractors. Remote service management will help improve equipment uptime, reduce costs such as travel for servicing, increase service efficiency – like first-visit-fix-rates – and accelerate innovation processes, for example by remote updating of device software.
- **Bringing customers into the loop**: Another level where Manufacturing 2.0 enterprises would excel is in customer engagement. Carmakers already mine customer feedback data on motoring blogs to improve design and performance. Taking this as an inspiration, Manufacturing 2.0 enterprises would extract customer feedback from social media and incorporate it into engineering and manufacturing processes. Product sustainability will take precedence in the future with customers preferring to buy greener products out of environmental consideration, to obtain tax breaks or both. However, sustainable products would not be acceptable at the cost of quality and performance. Manufacturing

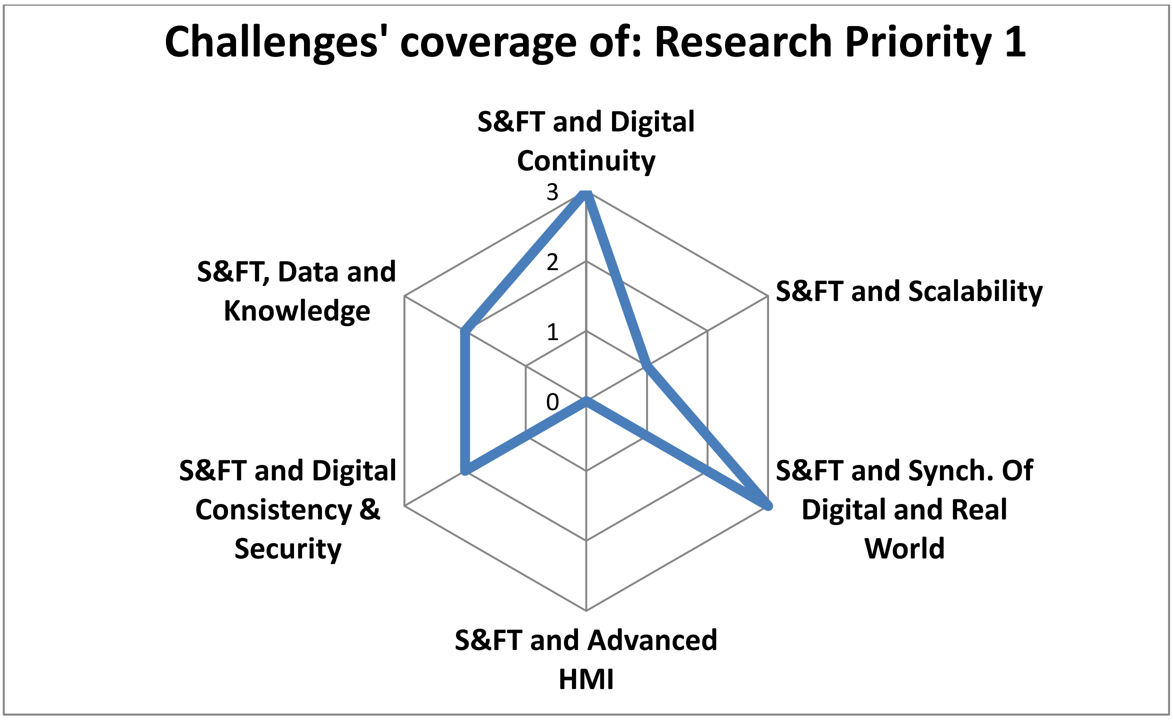
2.0 enterprises would be able to attain the quality-price-sustainability trade-off by intelligent product design through customer collaboration as well as through state-of-the-art approaches such as design thinking. Furthermore, Manufacturing 2.0 enterprises would be able to mitigate barriers in 'make-to-order' production and deliver individualized products with increased complexity and variability to customers.

A preliminary list of performance dimensions (see below), grouped according to the above-mentioned core elements of future manufacturing, has been identified.

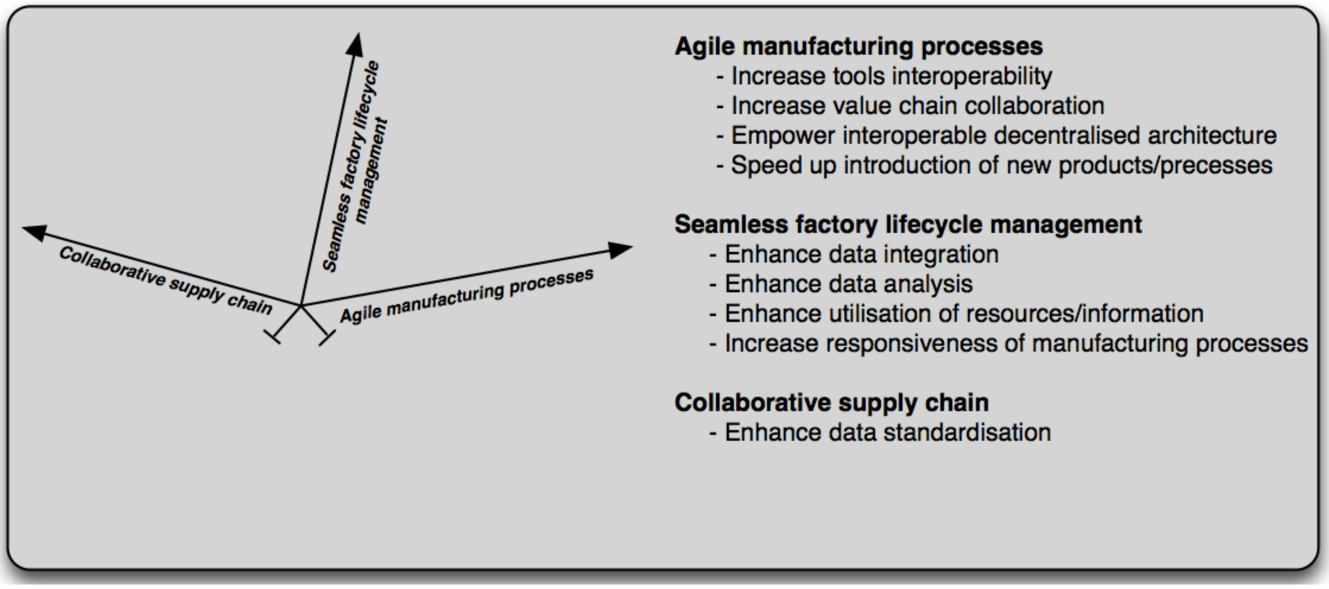
Core elements of future manufacturing	Performance dimensions
Seamless factory lifecycle management	Enhance utilization of resources/Information
	Enhance control/monitoring of machine parameters
	Enhance data integration
	Enhance data analysis
	Enhancing tools usability (i.e. visualization)
	Increase responsiveness of manufacturing process chains
Workers at the forefront	Increase people commitment
	Increase attractiveness work environment
Collaborative supply chain	Enhance data standardization
	Enhancing product customization
Agile manufacturing processes	Increase tools interoperability
	Increase value chain collaboration
	Empower interoperable de-centralized architecture
	Speed up introduction of new products/processes
	Enhancing capacity utilisation
	Supporting reuse/recycle of materials
Customers in-the-loop	Reduce emissions
	Decrease wastes
	Reduce energy consumption
	Decrease material usage

The current is expected not to be exhaustive. It will be continuously updated during the evolution of the Pathfinder road-mapping activity.

RP1 - Simulation and modelling methods and tools are needed to support the whole lifecycle of production systems, integrating diverse simulation technologies and models from different domains and disciplines, since the early conceptual design phase, where the selection of production resources, production processes and the entire automation system are to be tackled. The information developed in this early phase is to be maintained all along the entire factory life-cycle, despite changes in purpose and tools, allowing data to be enriched, updated, synchronized with the real factory and used as needed in each specific phase.

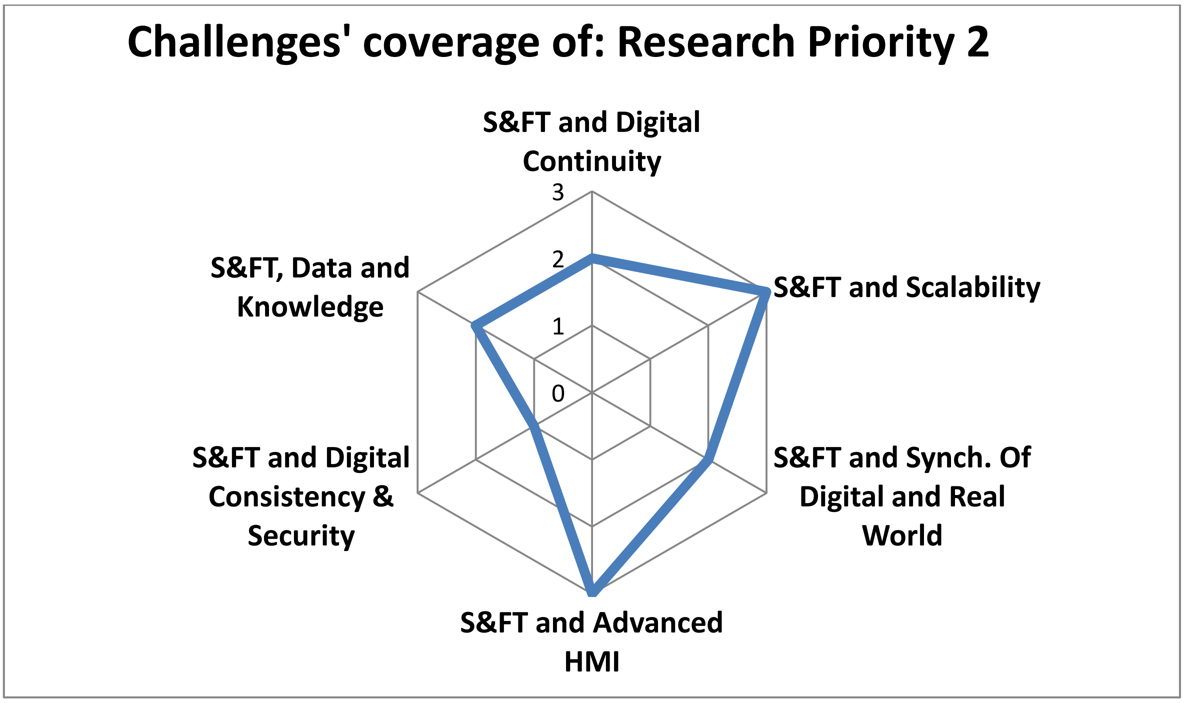


Research Priority 1 impact on the Pathfinder challenges

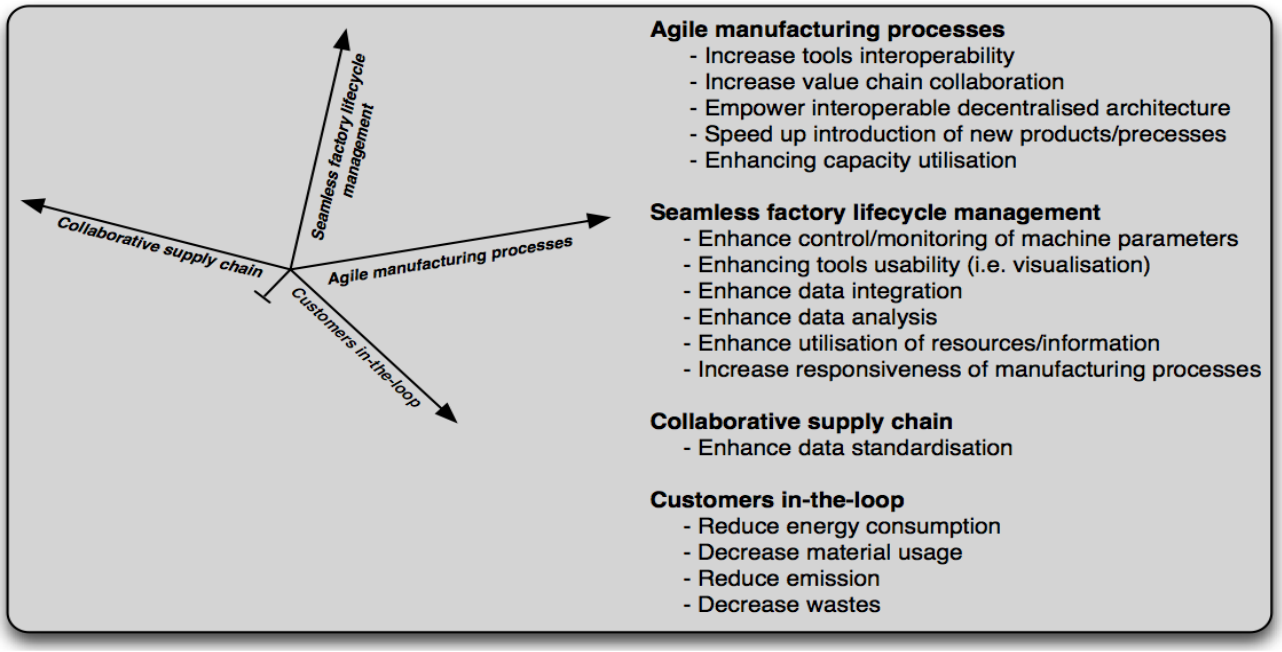


Research Priority 1 impact on core elements of future manufacturing

RP2 - The development of collaborative simulation applications that support access and usability at different levels from operators to managers, with different objectives (economic performance, logistics, operations, energy consumption, etc.) is of paramount importance to support the decision-making processes, activity planning and operation controlling. The development of integrated scalable factory models with multi-level access features, aggregation of data with different granularity, zoom in and out functionalities, and real-time data acquisition from all the factory resources (i.e. assets, machines, workers and objects) will be the key enabler. For real-time data acquisition, the connectivity concept offered by the CPS – cyber physical systems – paradigm should be exploited.

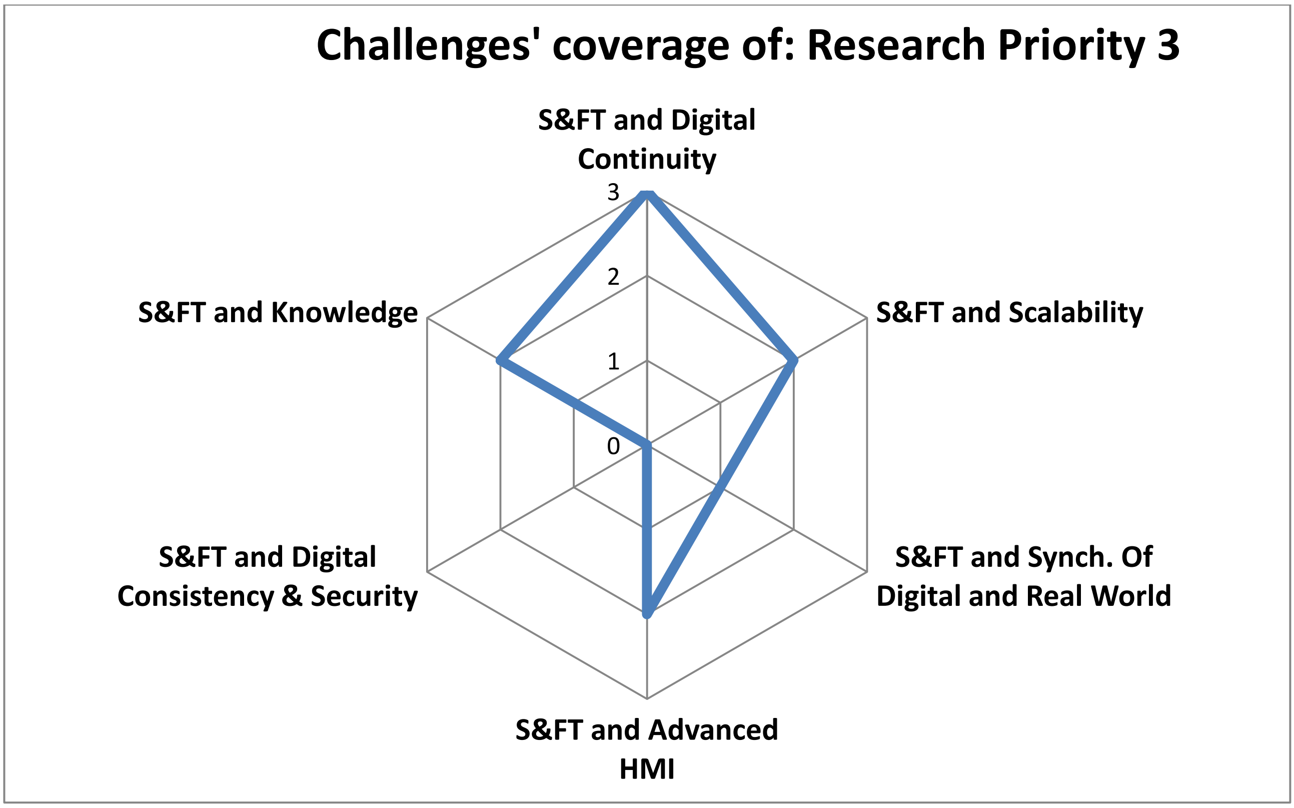


Research Priority 2 impact on Pathfinder challenges

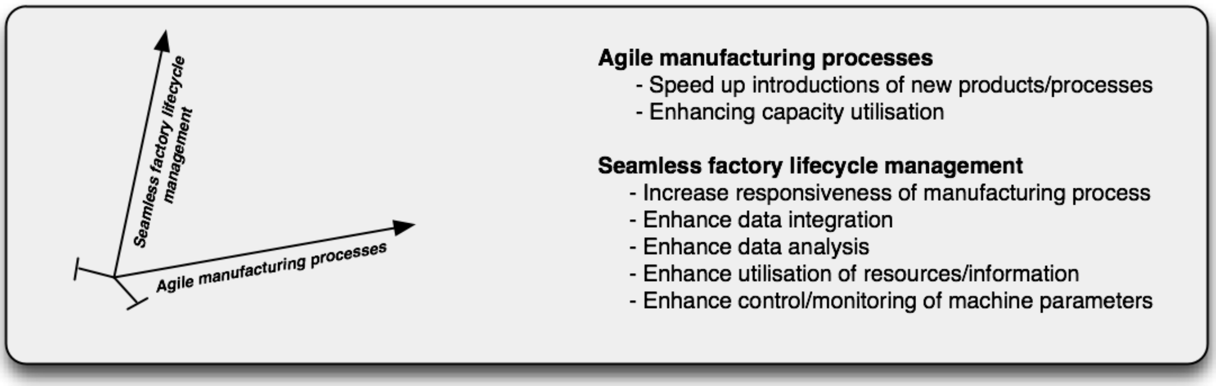


Research Priority 2 impact on core elements of future manufacturing

RP3 - Highly reconfigurable production means (lines or work-centres) and manufacturing networks are requested to accomplish dynamic production goals (in terms of production mix, time schedule and unplanned event management) to address the highly complex market landscape. That implies a huge complexity in the design, planning, and management tasks (considering also that operational performance parameters can vary time-wise, that flexible maintenance policies can be benefitted from, and that different configurations of the system can accomplish the same task). To this purpose, simulation tools must be able to model the production means and the manufacturing network behaviour and to update this model by acquiring data from the field (tools, inventories, logistics, etc.) through smart embedded devices, to provide process owners, operators and production plan managers with reliable predictive scenarios, to take informed decisions.

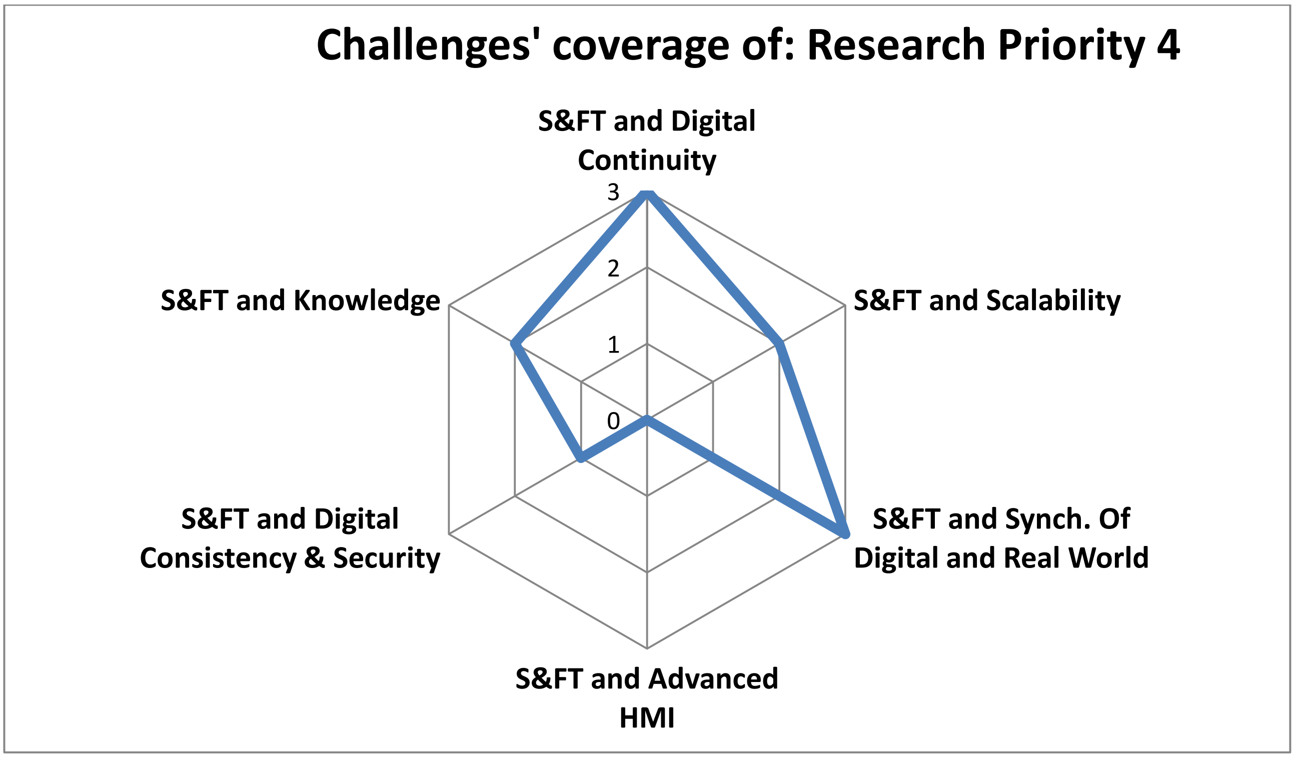


Research Priority 3 impact on Pathfinder challenges

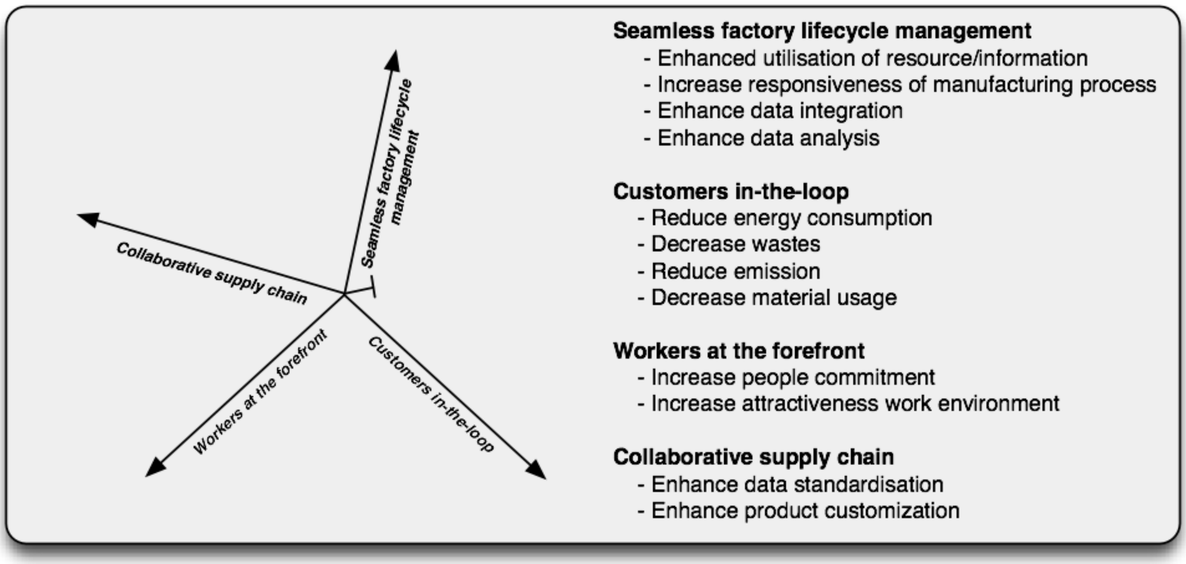


Research Priority 3 impact on core elements of future manufacturing

RP4 - Efficient utilization of energy and resources, minimal environmental impact and complete awareness of how these factors are related to the product lifecycle, not only in the production phases, but all along the complete life-cycle till the disposal and re-cycling, require novel tools to design and simulate the product/process behaviour in different scenarios. Simulation tools, connected to the physical world according the Internet of Things paradigm, will continuously collect data to provide direction to the factory system to produce in more sustainable way products with reduced environmental footprint.



Research Priority 4 impact on Pathfinder challenges



Research Priority 4 impact on core elements of future manufacturing

RP5 –The development of the factory environment will be accompanied by changing tasks and demands for the human working in that factory. As the most flexible entity in cyber-physical production systems, workers will be faced with a large variety of jobs ranging from specification and monitoring to verification of production strategies. Through technological support it is guaranteed that workers can realize their full potential and adopt the role of strategic decision-makers and flexible problem-solvers. A mediating interface between user and cyber-physical systems (CPS) must be created, through virtual and augmented reality, to simulate and interactively explore the behavior of a CPS-based production system. Key enablers will be mobile platforms, such as smartphones, tablets, and smart-glasses, which will be the most beneficial tools for interacting with CPSs.

RP6 – An essential prerequisite for an interoperable use of simulation data and models is that they are firstly formalized and machine readable, secondly explicitly described which means formal semantics of all statements and thirdly at the right level of abstraction and suitable for the intended use. For the implementation of a semantic factory, where simulation data and models can be shared, combined and reused across simulation application and sector boundaries, various steps have to be addressed. These shall include, in particular, the reuse and sharing of digital factory models by raising the level of explicit semantics (e.g. by using ontologies), the support of intuitive modeling tools, the development of holistic factory models with relevant standardization activities, methods and mechanisms to increase the quality of data across the distributed factory in terms of accuracy, completion, currency and non-duplication as well as improvements of data mining, filtering and reasoning capabilities to better exploit digital simulation models in dynamic design, validation, optimization and decision making processes.

7. Industrial sectors analysis

7.1. Scope of the analysis

The use of S&FT is more advanced in those sectors where, historically, this kind of tools has been considered as a fundamental element to support the product and process development. The relevance and impact of the identified S&FT gaps and challenges is therefore less impacting in these contexts that can be taken as a reference to make a distinction between gaps pointing to functionalities and tools already existent but with a restricted application, and features calling for research actions since not yet developed. Case studies have been grouped according to the sector of application so to provide also a map of S&FT usage focused on sectors that complement the geographical map presented in the previous section.

Driven also by the experts' opinion, the most important sectors where the use of S&FT is widespread have been identified, and for each one, the most important companies (in terms of revenues and employees) at the European level have been considered. Testimonials of advanced use of S&FT have been then searched. The analysed sectors are the following:

- Aerospace & defense
- Automotive
- Engineering and Electronics
- Chemicals
- Pharmaceuticals
- Metals
- Food & Beverage

For each sector, case studies representing noteworthy uses of S&FT have been identified and analysed by comparing the reported use of S&FT against the list of gaps so far identified in Pathfinder (they are listed in paragraph 6.5). In so doing, it has been possible to identify those gaps for which some kind of industrial application exists even tough a wide scale application is not feasible yet.

The list of case studies, if not exhaustive, is very useful to add insights for the mapping of European S&FT stakeholders.

7.2. Best practice in the use of S&FT

In this section, the analysed case studies are grouped on the basis of the sector: they are presented individually and, then, a summarizing schema pointing out the covered Pathfinder gaps at the sector level is shown. A brief presentation of the company is provided before moving to the discussion of S&FT use.

7.2.1. Aerospace & defence

EADS

EADS is a global leader in aerospace defence and related services. The Group includes Airbus, Airbus Military Eurocopter and EADS Astrium.

Vortex Drives EADS robot simulator for the Belgian army

(http://www.cm-labs.com/sites/default/files/finder/Customer Stories/Vortex-EADS-Customer-Story.pdf)

Description	S&FT role:
This study analyses the realization of a 3D-simulator for training conditions with Explosive Ordnance Device (EOD) robots. EOD robots perform essential but very difficult work. They are very expensive to build and a challenge to operate in these conditions, posing many training issues. Thanks to the simulation capabilities EADS accelerated development, exceeded requirements, and delivered a superb training solution.	3D-simulation for training. **Pathfinder gaps coverage:** G7.2

EADS Astrium Satellites UK

(http://www.plm.automation.siemens.com/CaseStudyWeb/dispatch/viewResource.html?resourceId=20475)

Description	S&FT role:
In this case study many simulation software of Siemens have been used in order to reduce the satellite development lead-time, which is usually one year including 6 months of simulation. Modelling is key to the high standards of quality demanded for space applications, the cost efficiency required by customers and the timely delivery they expect. Therefore, Astrium uses Femap (simulation software of Siemens) extensively for the iterative process of creating, checking and viewing models, processing model results and exploring alternatives in order to achieve concurrent engineering with the purpose of reducing the time by half.	Reduce development lead-time, cost efficiency, high quality, achieve concurrent engineering. **Pathfinder gaps coverage:** G3.1, G3.2, G4.1, G5.3, G2.1

Training simulation of the manipulator vehicle tEODor for Explosive Ordnance Disposal (EOD) and Improvised Explosive Device Disposal (IEDD)

(http://www.cm-labs.com/sites/default/files/finder/Customer Stories/EADS-ITEC-2010-tEODor-Vortex-Simulation-Paper.pdf)

Description	S&FT role:
The simulation of manipulator vehicles is a challenge in the field of EOD and IED disposal training. The focus in such vehicle simulations is to reproduce the behaviour of the vehicle in terms of control and movement and also to simulate interactions with the environment in order to prepare the user for real operations. In this contribution an approach has been presented to ensure the quality of the implemented robot simulation for IED disposal training purposes. It could be shown that the simulation behaviour and the real performance of the robot have a very strong correlation.	Training, modelling behaviour of vehicles **Pathfinder gaps coverage:** G7.2, G5.2

BAE SYSTEMS

BAE Systems plc is a British multinational defence, security and aerospace company headquartered in London in the United Kingdom and with operations worldwide.

Simulating FAB Business Improvement at BAE SYSTEMS

(http://www.lanner.com/en/case-study.cfm?theCaseStudyID=C918A74A-15C5-F4C0-9905634B4AC88E70)

Description	S&FT role:
BAE Systems used simulation software (Witness from Lanner) to improve production of advanced imaging devices at its semiconductor manufacturing facility. Witness has been integral to a business improvement programme that has halved product cycle times and increased capacity of some processes by more than 50%. As a result, the company has reduced the overall cycle-time from 90 to 35 days, increased by 60% the capacity of the ceramic stages. Furthermore, the simulation helped to remove bottlenecks and therefore to identify which machines could be optimized.	reduce cycle time, remove bottlenecks, production capacity optimization. **Pathfinder gaps coverage:** G3.1, G3.2

The virtual factory – witness models munitions facility for BAE SYSTEMS

(http://www.lanner.com/en/case-study.cfm?theCaseStudyID=C9C4586A-15C5-F4C0-99CE8CCBE1808F2D)

Description	S&FT role:
In this study a simulation software was used at the project's inception in order to determine initial unit costs, the likely effectiveness and form of the processes to be used, the requirements for capacity and customer demand, the possible time pressures and resource limitations and the breadth and volume of materials to be used, and for all points it proved extremely useful in supporting the initial capital investment proposals.	Life cycle costs, resource planning, project management. **Pathfinder gaps coverage:** G3.1, G3.2

AIRBUS DEFENCE AND SPACE

As one of the three divisions of the Airbus Group, Airbus Defence and Space is Europe's No.1 defence and space company. Worldwide, it ranks second for space and is among the top ten defence companies, with revenues of approximately €14 billion per year.

Airbus speed CAD design with witness

(http://www.lanner.com/en/case-study.cfm?theCaseStudyID=C8FCF6C9-15C5-F4C0-994AEE55C8D8A7A1)

Description	S&FT role:
Simulation was used to provide more than traditional "what if" simulation. An evolving sequence of models was built to optimise the layout and operation of the proposed plant. The software was used in effect as an animated event-based CAD tool, and the contractor's working drawings were derived directly from the final model.	Layout and operations optimization, event-based CAD tool. **Pathfinder gaps coverage:** G5.3

The following graph (Fig. 16) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Automotive sector.

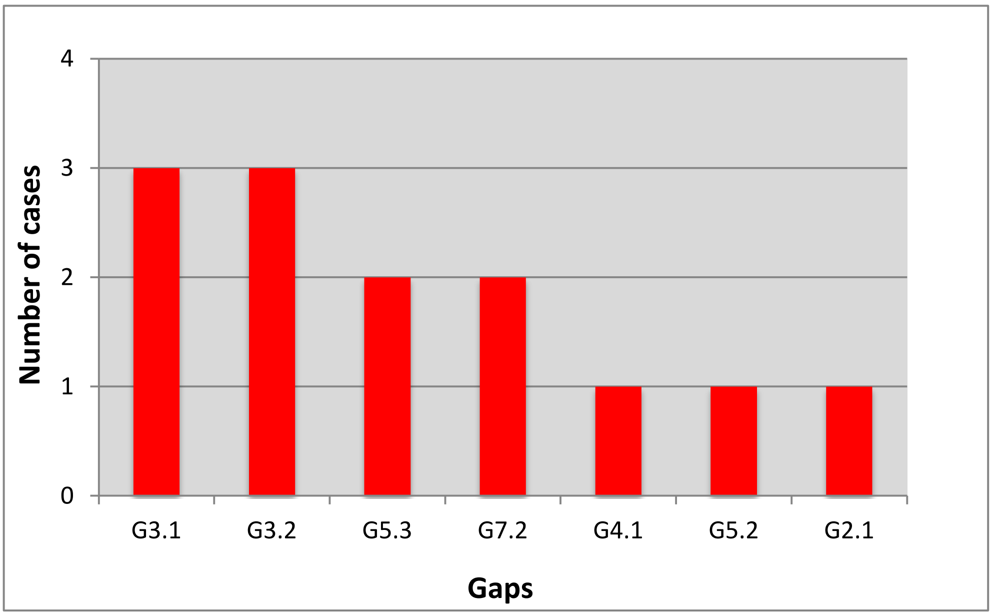


Fig. 16 Gaps covered in the: Aerospace & Defence

7.2.2. Automotive

VOLKSWAGEN

Volkswagen is a German automobile manufacturer headquartered in Wolfsburg, Lower Saxony, Germany. Volkswagen is the top-selling and original marque of the Volkswagen Group, the biggest German automaker and the second largest automaker in the world.

Role of simulations in the process from design to production

(http://www.hightechevents.nl/fileadmin/uploads_redactie_bc/docs/MDD13/Jan_Harmen_Wiebenga.pdf)

Description	S&FT role:
The role of simulation in the automotive-based manufacturing is emphasized by the following examples: • Application of simulation driven design in the dashboard development of the VW Polo • Analysis of product performance using simulations • Automatic and structured design optimization in product development • Virtual testing of interior design VW Polo **Example 1** • Case: virtual testing of air vent performance at crash	Simulation driven design, product performance assessment, design optimization, virtual testing. **Pathfinder gaps coverage:** G3.1, G3.2

- Why: predict crack propagation at impact
- Goal: design optimization with respect to safety

Example 2

- Case: virtual testing of the dashboard with respect to safety
- Why: replace experimental dashboard tests
- Goal: design optimization w.r.t

Increased efficiency through digital planning

(http://www.solucionesplm.com/wp-content/contents/teamcenter/Siemens-PLM-Volkswagen.pdf)

Description	S&FT role:
Simulation has been used to increase the efficiency of vehicle body production planning and achieve increased planning requirements without adding staff. This allows planners to drag-and-drop a robot into a planning scenario where it is seen immediately within the 3D plant layout, in a faster and more transparent manner. Digital tools make possible the implementation of many optimization tools, which in turn leads to more precise data models. The study has shown that computer-simulated production planning reduced costs permit optimal use of resources and minimized problems at start-up.	3D plant layout, increase efficiency, improve data models, computer-simulated production planning **Pathfinder gaps coverage:** G2.2, G2.4, G4.2, G5.1, G5.2, G5.3

SimPlan optimizations supports Volkswagen Slovakia A:G within a project about digital factory

(http://www.simplan.de/images/stories/download/Fachartikel/2008_09_ForumDigFab_EN.pdf)

Description	S&FT role:
The study encompasses all the stages within the welding process at Volkswagen. Simulation is of paramount importance in such a process because enables to previously detect and eliminate problems that otherwise would have required costly and time consuming correction measures during commissioning; to minimize the investments, optimize and make robust complex systems with many parameters. With this purpose, there has been used a simulation-based software which has the following main features: • Process Designer: which integrates 3D product data, working operations and resources. • Process Simulation Spot: which uses inverse kinematics to determine the joint values needed to reach a given target location. Process Simulate Spot Program consists of a path of target locations (position and orientation) with associated attributes. • Plant simulation: that allows the creation of a dynamic	Timely detection and elimination of problems, minimize investments, optimize complex systems, process designer, 3D product data, process simulation spot, plant simulation, what-if scenarios. **Pathfinder gaps coverage:** G2.1, G2.2, G2.4, G3.1, G3.2, G4.1, G4.2, G5.3

computer model of a complex system (e.g production) to explore its characteristics and optimize the performance of the system. The computer model enables the user to run experiments and what-if scenarios without disturbing any existing production or long before the real systems is installed.	

Volvo uses witness to optimise efficiency and productivity in gent plant

(http://www.lanner.com/en/case-study.cfm?theCaseStudyID=0D7DC11F-15C5-F4C0-99A7CE4A98EC8274)

Description	**S&FT role:**
In order to maintain, and continuously improve upon its credentials for efficiency and quality in manufacturing, Volvo relies upon simulation technology. Simulation supports major business decisions through mapping out scenarios in a virtual environment. In taking this approach, Volvo's Gent plant can build business cases and de-risk decisions prior to investment being committed.	Improve efficiency/quality, decision making support, mapping scenarios, virtual environments, risk management **Pathfinder gaps coverage:** G3.1, G3.2

Process planning tools support Volvo Cars' expansion to Asia Pacific region

(http://www.plm.automation.siemens.com/CaseStudyWeb/dispatch/viewResource.html?resourceId=25856)

Description	**S&FT role:**
Engineering simulation plays a central role whenever an automotive company decide either to increase production line flexibility to support multiple car models or even for revisiting engineering processes to support operations and deliver innovative products. In this case, Volvo was able to meet these challenges because of its engineers' high level of expertise, employing a Process Simulate tool and using its offline programming and realistic robot simulation capabilities. By doing so, the company is able to generate very accurate robot programs that require only slight modifications on the shop floor.	Increase production line flexibility, revisiting engineering processes, realistic robot simulation capabilities, increase robot programs accuracy. **Pathfinder gaps coverage** G3.1, G4.1

SEAT

SEAT, S.A. is a Spanish automobile manufacturer with its head office in Martorell, Spain. It was founded on May 9, 1950, by the Instituto Nacional de Industria, a state-owned industrial holding company.

Moving toward digital manufacturing

(http://www.plm.automation.siemens.com/CaseStudyWeb/dispatch/viewResource.html?resourceId=10609)

Description	**S&FT role:**
The purpose of Seat was to increase the efficiency through the New Product Development process in order to reduce time-to-market and improve speed and clarity of data access. The usage of digital manufacturing computer-based simulation allowed to reach	Reduce time-to-market, improve data access, manufacturing computer-based

these targets and to minimize development time.	simulation. **Pathfinder gaps coverage:** G3.1, G5.2, G5.3

BOS automotive products ltd

BOS Automotive products Ltd. deals with production and distribution of interior accessories for automobiles, such as storage systems, in particular bags and ski bags, sun visors for the windows, blinds covering the luggage compartment, safety and protective nets and various other accessories and luggage room.

Optimization of layout using discrete event simulation

(http://www.ibimapublishing.com/journals/IBIMABR/2011/180343/180343.pdf)

Description	**S&FT role:**
The aim of this project was to optimize the layout of the two production lines for Daimler and VW Group products by the BOS Automotive Products ltd, in particular, to reduce the spatial arrangement of the cargo loader production hall, where storage systems for automobiles are produced. To achieve such an objective, there were evaluated several variants of the new layout by means of a multi-criteria decision approach. To verify the selection of the new variant carried out with the multi-criteria evaluation, a Discrete Event Simulation (DES) software was chosen. It helped to create digital models and to explore the system characteristics in order to optimize their performance. This kind of simulation was suitable because it offers extensive analysis tools such as; bottleneck analysis, statistics and charts to evaluate or optimize production processes in a virtual environment. In conclusion, the simulation model led to confirm the accuracy of evaluation of variants using the multi-criteria method. With such a simulation software it was possible to try many variants of space arrangement without real movement of machines and start the real project only when the best variant is discovered.	Evaluation of variants, layout optimization. **Pathfinder gaps coverage:** G3.1, G5.3

BMW

Bayerische Motoren Werke AG, commonly known as BMW or BMW AG, is a German automobile, motorcycle and engine manufacturing company founded in 1916. BMW is headquartered in Munich, Bavaria, Germany.

Entire vehicle in the product development

(http://link.springer.com/article/10.1007/BF03247106 - page-1)

Description	**S&FT role:**
BMW has developed an entire vehicle simulation model to understand and improve energy flows in the vehicle. A model structure has been derived from this objective and implemented in a suitable simulation environment. The modular structure of the	Entire vehicle simulation modelling, improve energy flows in the vehicle, support

vehicle model makes it easy to implement subsystems with different levels of detail. Vehicle simulation enables energy analysis to be performed in all development phases. It allows complex problems and interactions in the vehicle to be understood, analysed and solved. In this way, the energy flows can be optimised and the fuel consumption can be lowered. Thus, vehicle simulation is an important tool in the product development	product development. **Pathfinder gaps coverage:** G3.1, G3.3

CONTINENTAL AG

Continental AG is a leading German automotive manufacturing company specializing in tires, brake systems, automotive safety, powertrain and chassis components, tachographs, and other parts for the automotive and transportation industries.

Changing production requirements are handled easily with digital factory software

(http://www.plm.automation.siemens.com/CaseStudyWeb/dispatch/viewResource.html?resourceId=25134)

Description	**S&FT role:**
The purpose of this study was to achieve a greater manufacturing flexibility and to optimize material flows during situations of frequent product alterations and quantity changes. As a result, digital material flow simulation allowed to acquire these objectives by making what-if simulations to compare alternate production line scenarios.	Greater manufacturing flexibility, optimize material flows, digital material flow simulation, what-if simulations. **Pathfinder gaps coverage:** G3.1.

The following graph (Fig. 17) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Automotive sector.

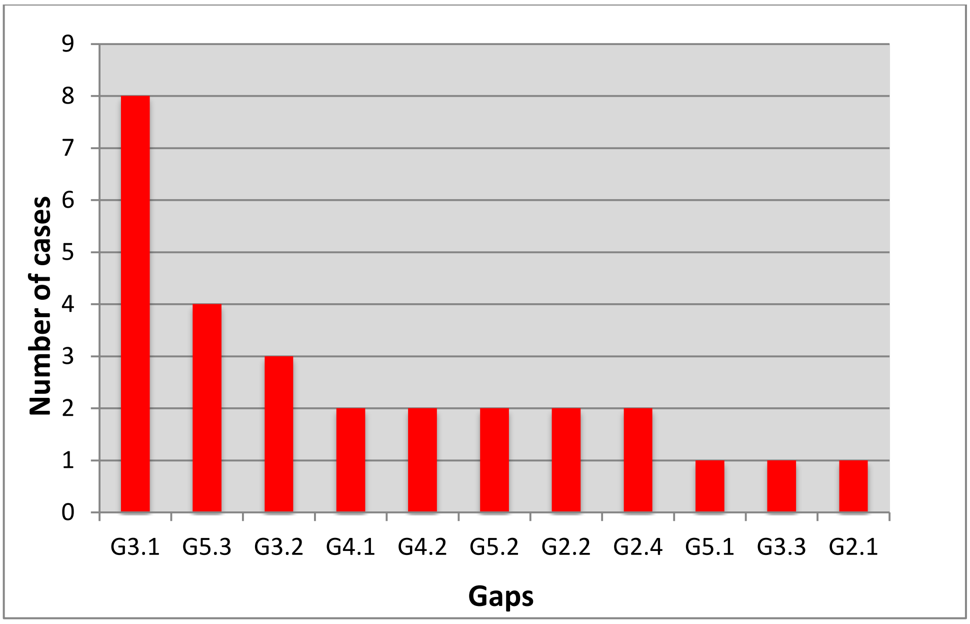


Fig. 17 Gaps covered in the: automotive

7.2.3. Engineering and Electronics

ABB

ABB is a multinational corporation headquartered in Zurich, Switzerland, operating in robotics and mainly in the power and automation technology areas.

Operator Training Simulator

(http://www.abb.ch/industries/ap/db0003db004333/c125739a0067cb49c1257026003d4a31.aspx)

Description	S&FT role:
In order to perform successful operation of a highly complex high voltage transmission network is needed a control centre staff having both knowledge and experience in its operation. The Operator Training Simulator (OTS) is the modern tool to achieve that goal. Training of operators has become an increasingly important requirement in the implementation and continued operation of Control Centres. Furthermore, the advent of the Smart Grid will make the need for OTS even more important in the near future.	Operator training simulator. **Pathfinder gaps coverage:** G7.2

GridView – Modelling to predict economic value

(http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/581366a0c212c93ac1256fda00488562/$file/gridview brochure.pdf)

Description	S&FT role:
GridView is a powerful energy market simulation and analysis tool designed to deal with the most challenging issues facing decision makers in the electric energy industry today. It uses state-of-the-art modeling technology to simulate security constrained unit commitment and economic dispatch in large-scale transmission networks. It produces unit commitments and economic dispatches that respect the physical laws of power flow and transmission reliability requirements. Therefore, GridView coupled with graphic interface and easy-to-use system makes it a unique analytical tool for decision-making.	Energy market simulation, analytical tool for decision making. **Pathfinder gaps coverage:** G3.1, G3.2

SCHNEIDER ELECTRIC

Schneider Electric SA is a France-based multinational corporation that specializes in electricity distribution, automation management and produces installation components for energy management.

Schneider Electric Oil & Gas – Liquids Pipeline Solutions

(http://www.schneider-electric.com/solutions/ww/en/med/28714433/application/pdf/1619_liquids_pipeline_solutions_overview_usletter_.pdf)

Description	S&FT role:
Schneider Electric SimSuite Pipeline is a transient pipeline modelling and simulation system for gas and liquids pipelines. It is	Pipeline simulation system, greater efficiency, virtual world.

the most technologically advanced and dependable pipeline simulation system in the industry. Schneider Electric SimSuite optimizes management of your pipeline operations for greater efficiency, effectiveness and an improved bottom line. In a virtual world, it can be proven that your pump stations, compressor stations, injection/ delivery stations, tank farms, valves and control logic work flawlessly before the real world puts them to the test.	**Pathfinder gaps coverage:** G3.1

Impact of Oil and Gas pipeline simulators on controller training and regulatory compliance

(http://www2.schneider-electric.com/documents/support/white-papers/oil-and-gas/Oil-pipeline-simulator-training.pdf)

Description	S&FT role:
Regulatory compliance is an expensive and critical business issue for oil and gas pipeline operators. Any approach that expedites compliance efforts saves time and money and also improves safety. Computer-based simulators are seen by regulatory agencies as an effective tool for operators, and can help expedite regulatory compliance. This paper examines a range of simulator types and offers guidance for how controllers can be trained using such tools.	Controller training. **Pathfinder gaps coverage:** G7.2

Liquids pipeline leak detection and simulation training

(http://www.schneider-electric.com/solutions/ww/en/med/28862720/application/pdf/1660_liquids_leak_detection_simulation_2012.pdf)

Description	S&FT role:
A computational pipeline monitoring (CPM) system uses real-time information from the field – such as pressure, temperature, viscosity, density, flow rate, product sonic velocity and product interface locations – to estimate the hydraulic behaviour of the product being transported and create a computerized simulation. Computerized simulation has demonstrated to provide more comprehensive and effective training for a specific pipeline than on-the-job training. Indeed, training simulations are recognized as one of the best tools to maintain appropriate knowledge and skills for a specific pipeline. A simulator provides a repeatable, unbiased assessment of all controllers' skills and abilities and can be a highly valuable part of a comprehensive controller training/qualification program for not only leak detection procedures and practices but also other loss preventions systems.	Computational pipeline monitoring, real-time information, computerized simulation, effective training. **Pathfinder gaps coverage:** G7.2, G5.1

Energy management specialist streamlines product development process using a system simulation approach

(http://www.plm.automation.siemens.com/CaseStudyWeb/dispatch/viewResource.html?resourceId=36323)

Description	S&FT role:
Schneider Electric has been using simulation tools for a long time.	Multi-domain system for R&D,

The company has well-established solutions for each specific physical domain. Taken individually, each kind of simulation software helped the company to solve issues. However, Schneider Electric recognized that needed a standard tool covering all domains to support them in:

- Making the product synthesis with different physical couplings
- Evaluating the impact of a design choice on the overall system
- Comparing the efficiency of different design architectures
- Recording all engineering knowledge gained during the design phase
- Rapidly evaluating evolving demands for product features

Schneider Electric had three main objectives for this analysis: first, to understand how it would have helped to make greater use of a multi-domain system simulation tool during the research and development (R&D) phase; second, to track the effectiveness of electronic simulation; and third, to provide a simulation package to continuous engineering team for the products. Having this knowledge would help the engineering team rapidly and easily perform an analysis on evolving requests from customers.

evaluating impact of design choice, recording engineering knowledge.

Pathfinder gaps coverage:

G2.2, G2.3, G2.4, G3.1, G4.1, G4.2, G6.2

PHILIPS

Koninklijke Philips N.V. is a Dutch diversified technology company headquartered in Amsterdam with primary divisions focused in the areas of Healthcare, Consumer Lifestyle and Lighting.

Simulation project for a new distribution centre of Philips

(http://www.google.ch/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0CDQQFjAC&url=http%3A%2F%2Fsupport.incontrolsim.com%2Fen%2Fed-showcases%2F83-showcase-philips-english%2Fdownload.html&ei=0Ph5U7-oNsGc0AX3tIC4Dg&usg=AFQjCNErS2bGJ5JuVOgg0HoKEC95pgzoHg&bvm=bv.66917471,d.d2k)

Description

The goal of this simulation project was in the first place to validate the already performed calculations on the required number of reach trucks and order pick trucks. In the second place what- if scenarios where defined to identify possible bottlenecks situations. Furthermore Philips Lighting wanted to have a 3D representation of the warehouse to use as a reference material and educational purposes.

S&FT role:

What-if scenarios, identify bottlenecks, 3D representation.

Pathfinder gaps coverage:

G3.1, G5.3

The following graph (Fig. 18) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Engineering & Electronics sector.

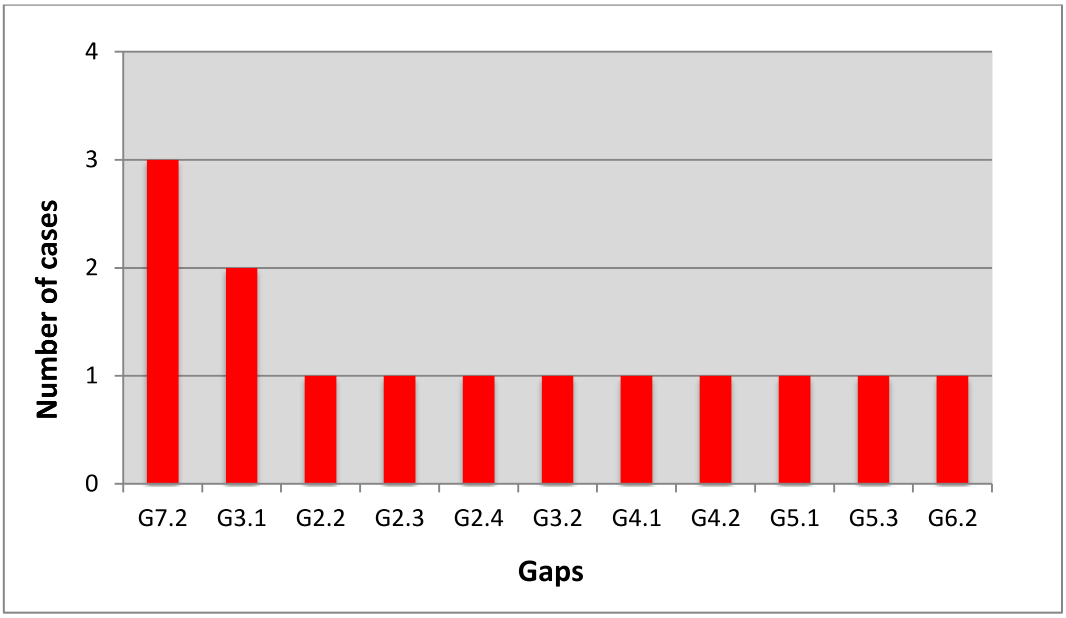


Fig. 18 Gaps covered in the Engineering and Electronicssector

7.2.4. Chemicals

BASF

BASF SE is the largest chemical company in the world and is headquartered in Ludwigshafen, Germany. BASF originally stood for Badische Anilin- und Soda-Fabrik.

Virtual commissioning in practice

(http://www.industry.siemens.com/topics/global/en/magazines/process-news/engineering-service/pages/basf-se.aspx)

Description	S&FT role:
BASF is currently conducting a pilot project together with Siemens to make the vision of virtual commissioning of a process plant a reality. In the virtual commissioning pilot project, BASF is now testing an automation application in a virtual plant, which maps plant behaviour with the help of a simplified process model simulation environment. By doing so, the process could be tested intensively, both during normal operation and also, to some extent, in exceptional situations. It will help to detect errors early in the implementation of automation logic with consequent increase productivity and return on investment.	Virtual commissioning, plant behaviour modelling, scenario analysis. **Pathfinder gaps coverage:** G5.3

Production simulation and process optimization make Ineos Köln one of the most effective petrochemical sites

(http://www.aimms.com/aimms/download/case_studies/c_2008_3-ineos-k-ln-4.pdf)

Description	S&FT role:
Ineos conducted a pilot study to simulate part of several chemical	Modelling chemical production

production processes in order to compute the day-to-day production and stock levels, and transport needs, for the coming two years, in a reasonable amount of time. The link between the simulation model and the central SQL database server ensures that new inputs are retrieved and the simulation results are forwarded for action. With the combination of simulation, SQL Server, and SAP, a complete and transparent overview of the past, actual, and future production rates and stock levels is available. As a result, anyone within the entire INEOS organization can access all the information related to production at INEOS Köln. After implementing the AIMMS-based DISPO system, INEOS Köln has become one of the most effective petrochemical sites. Bottlenecks are foreseen at an early stage, allowing INEOS to take appropriate preventive actions, and enabling INEOS to avoid, or at least minimize, losses in utilization.	process, operations planning, integration with other systems **Pathfinder gaps coverage:** G3.1, G5.1, G5.2, G5.3

AKZO NOBEL

Akzo Nobel N.V., trading as AkzoNobel, is a Dutch multinational, active in the fields of decorative paints, performance coatings and specialty chemicals.

AkzoNobel uses Assima technology to train over 100,000 employees and customers quickly and cost-effectively on its new paint-mixing application, in 13 languages

(http://www.assima.net/images/resources/case-studies/cs-assima-akzonobel-2013-us.pdf)

Description	**S&FT role:**
In this case study AzkoNobel was dealing with a problem concerning the industrial coatings and paint used by manufacturers, engineering firms and automotive repair shops. For all these businesses, the ability to identify, match and order the right colour tones for specific products is critical. With the goal of enhancing relationships with thousands of existing customers and winning new market share, global chemical, paint and industrial coating leader AzkoNobel, developed and launched a new version of its professional paint mixing application, Mixit Pro. To accelerate uptake of Mixit Pro, AzkoNobel needed to train more than 100,000 employees and customers on the new application globally, in 13 different languages. After evaluating training solutions from ten companies, AzkoNobel chose to deploy Assima Training Suite. Basically, it captures clones of an application's interface and creates centrally stored, fully interactive, multilingual training exercises, which relies on Simulation-based training exercise, with remote online access for employees and customers. This led to a fast, cost-effective training for 100,000 end users who have improved their skills and confidence.	simulation-based training exercise, cost effective training. **Pathfinder gaps coverage:** G7.2

The following graph (Fig. 19) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Chemicals sector.

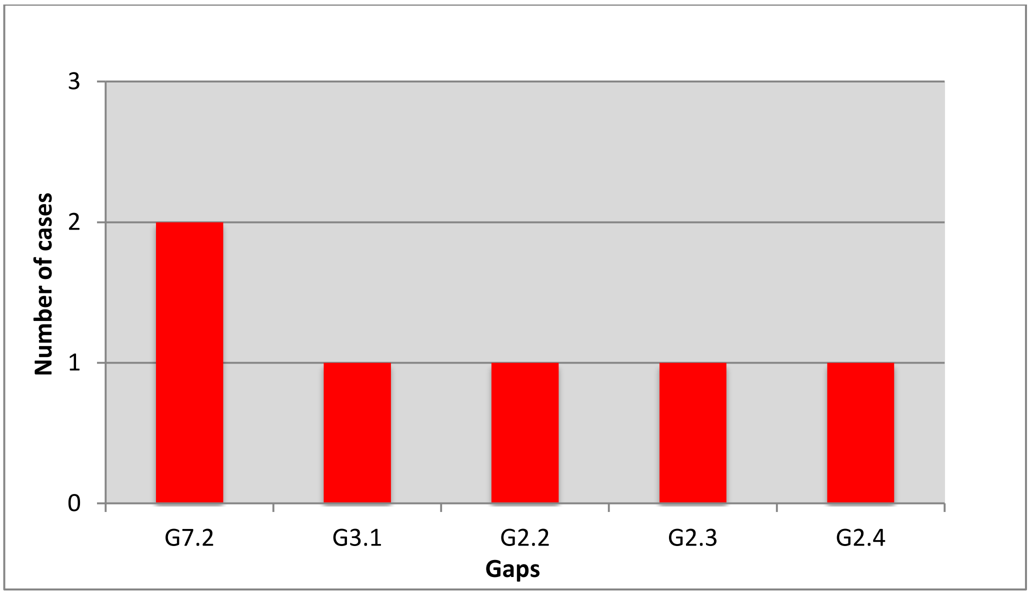


Fig. 19 Gaps covered in the: Chemicals

7.2.5. Pharmaceuticals

NOVARTIS

Novartis International AG is a Swiss multinational pharmaceutical company based in Basel, Switzerland, ranking number one in sales among the world-wide industry in 2013.

Modeling & Simulation department

(http://www.novartis.com/innovation/getting-drugs-to-patient/modeling-and-simulation.shtml)

Description	**S&FT role:**
The Modelling & Simulation department at Novartis Pharma AG supports the optimal development of therapeutic drugs through the application of mathematical models. Principles of biology, pharmacology, and statistics are integrated in order to explain and to predict the quantitative consequences of decisions. Novartis M&S has very strong experience in model development, development of computational tools for simulation and analysis, and the application of models and their simulation across the complete drug discovery and development process.	Optimal development, mathematical modelling, process development **Pathfinder gaps coverage:** G3.1, G5.1

Hoffmann – La Roche

F. Hoffmann-La Roche Ltd. is a Swiss global health-care company that operates worldwide under two divisions: Pharmaceuticals and Diagnostics. Its holding company, Roche Holding AG, has bearer shares listed on the SIX Swiss Exchange.

Challenges and opportunities with modelling and simulation in drug discovery and drug development

(http://proline.physics.iisc.ernet.in/home/images/a/aa/SE-302-challenges.pdf)

Description	**S&FT role:**

The study shows how modelling and simulation can add value at various stages of the research and development process, can help to create a continuous feedback loop between pre-clinical and clinical stages, and can contribute to scientifically and rationally guided drug discovery and development. The benefits of modelling and simulation at the pre-clinical stage can be realized though formal and realistic integration of data obtained from the various functions supporting project teams.	Data integration, continuous process feedback loop. **Pathfinder gaps coverage:** G3.1, G5.1

Modelling and simulation of pharmacokinetic and pharmacodynamics systems – approaches in drug discovery

(http://www.beilstein-institut.de/bozen2004/proceedings/MacDonald/MacDonald.pdf)

Description	**S&FT role:**
This report states that modelling and simulation based on the principles of pharmacokinetics and pharmacodynamics are useful tools in drug development. Systematic use of these tools should lead to better clinical drug-candidates and a corresponding reduction in attrition during the far costlier clinical phases of drug.	Drug development **Pathfinder gaps coverage:** G3.1

Role of modelling and simulation in phase in drug development

(http://www.gmp.asso.fr/Documents/Biblio/Simulation%20COSTB15.pdf)

Description	**S&FT role:**
Modelling & simulation fulfils an important role in reshaping the early trials of drug development by more effective extraction of information from studies, better integration of knowledge across studies and more precise predictions of trial outcome, thereby allowing more informed decision making. Modelling may enable the pharmaceutical industry to move into patient studies faster and safely. Already standard in other knowledge-based industries, computer simulation is increasingly being used to aid clinical trial development.	Drug development, knowledge integration, development time reduction. **Pathfinder gaps coverage:** G3.1, G5.1, G5.2

SANOFI

Sanofi S.A. is a multinational pharmaceutical company headquartered in Paris, France, as of 2014 the world's fifth-largest by prescription sales.

Increasing the strategic value of kinetic and dynamic data through unified modelling, higher productivity, and regulatory compliance

(http://www.pharsight.com/library/sign_in/Modeling%20&%20Simulation%20and%20FDA_March%202007%20Seminar.pdf)

Description	**S&FT role:**
Productivity in clinical development continues to decline, and the inability to increase efficiency has resulted in a pipeline, which is	Support decision making process, model based drug

impeded. Some of the causes of this problem are the following:

- Inefficient decision making processes (lack of information, decision not based on quantitative inputs, focus on the wrong areas, loss of knowledge due to changes in staff and assignments, inability to capture information)
- Lack of efficient utilization of technology

These lacks lead to the need for model based drug development such as computer assisted trial simulation. After Sanofi turned to a computer model, using its own animal and human test data, Sanofi was able to simulate later-stage clinical trials. Based on that simulation, the researcher stopped funding the development of the compound. The ratio between the therapeutic benefit and side effect demonstrated that this compound was not enough beneficial. An estimation conducted by Sanofi states that the computer model enable to save Sanofi $50M to $100M, the cost of later-stage clinical trials.

development.

Pathfinder gaps coverage:

G3.1, G5.1, G5.2.

The following graph (Fig. 20) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Pharmaceutical sector.

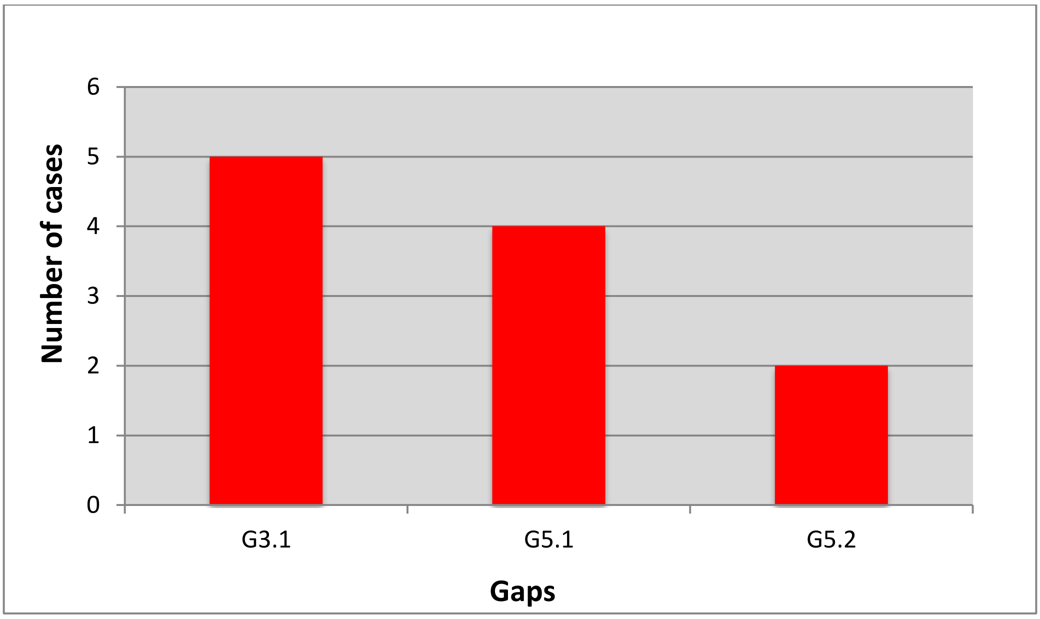


Fig. 20. Gaps covered in the Pharmaceutical sectors (full name of each gap is reported

7.2.6. <u>Metals</u>

<u>ARCELOR MITTAL</u>

ArcelorMittal S.A. is a multinational steel manufacturing corporation headquartered in Avenue de la Liberté, Luxembourg.

Operational simulation model of the raw material handling in an integrated steel making plant

(http://www.informs-sim.org/wsc09papers/297.pdf)

Description	S&FT role:
This article is focused on the design and implementation of an operational simulation model (OSM) of the handling of raw material in an integrated steel making plant, considering operations of receiving, unloading, stocking, handling and supplying the different raw materials related to the production process with an operational perspective. The aim of this focus is to help in the decision making of the team controlling the inventory.	Operational simulation model, production process. **Pathfinder gaps coverage:** G5.1

Cutting-Edge Simulation Improves Industrial Processes

(http://members.questline.com/Article.aspx?articleID=24799&accountID=1863&nl=13990&userID=291818)

Description	S&FT role:
ArcelorMittal needed help to optimize blast furnace fuel utilization and campaign life; increase energy efficiency of the billet reheat furnace; and improve uniformity of strip heating. In each case CFD simulation provided valuable insight into the complex heat transfer and fluid flow phenomenon occurring in these processes, leading to significant process improvements. ArcelorMittal also discovered process development time could be shrunk in half or more by using such technologies. The company found that advanced simulation and 3D VR avoided costly mistakes, such as an improperly designed furnace being built for manufacturing carbon anodes. Construction was halted until the redesign was finalized.	Reduce process development time, 3D VR. **Pathfinder gaps coverage:** G3.1, G5.3

ANGLO AMERICAN PLC

Anglo American plc is a British multinational mining company headquartered in London, United Kingdom.

Maintenance framework to address the interaction of components using simulation

(http://www.informs-sim.org/wsc11papers/065.pdf)

Description	S&FT role:
Simulation technique is used in the maintenance management of a complex system. The model considers the most important interaction between the components in a production chain: the lack of material feed and the blockage states. Both occur as a result of corrective maintenance (generated randomly) and preventive maintenance (scheduled) activities. The purpose of the model is to provide the visibility of the system, measuring performance in terms of productivity, identifying bottlenecks generated by the maintenance schedule and identifying policies which deliver the best production rate and higher service level.	Maintenance management of a complex system, identification of bottlenecks. **Pathfinder gaps coverage:** G3.1, G5.1, G5.2

Anglo American Thermal Coal: Technical Solutions Simulation of trucking operation

(http://www.shangoni.co.za/Cms_Data/Contents/shangoniDB/Media/documents/ANGLO%20Greenside%20Colli ery/Draft%20Scoping%20Report/Appendix%20E/E4/E4.pdf)

Description	S&FT role:
A simulation model was constructed in order to create a realistic high-level representation of the logistics value chain with the purpose of enhancing, by means of animation, the understanding of the interaction of the different process interdependencies and determine the worst case scenario.	Modelling the logistics value chain, identification of process interdependencies, scenario analysis. **Pathfinder gaps coverage:** G4.1, G4.2

The following graph (Fig. 21) summarizes the level of coverage of Pathfinder gaps by the sampled cases in the Metals sector.

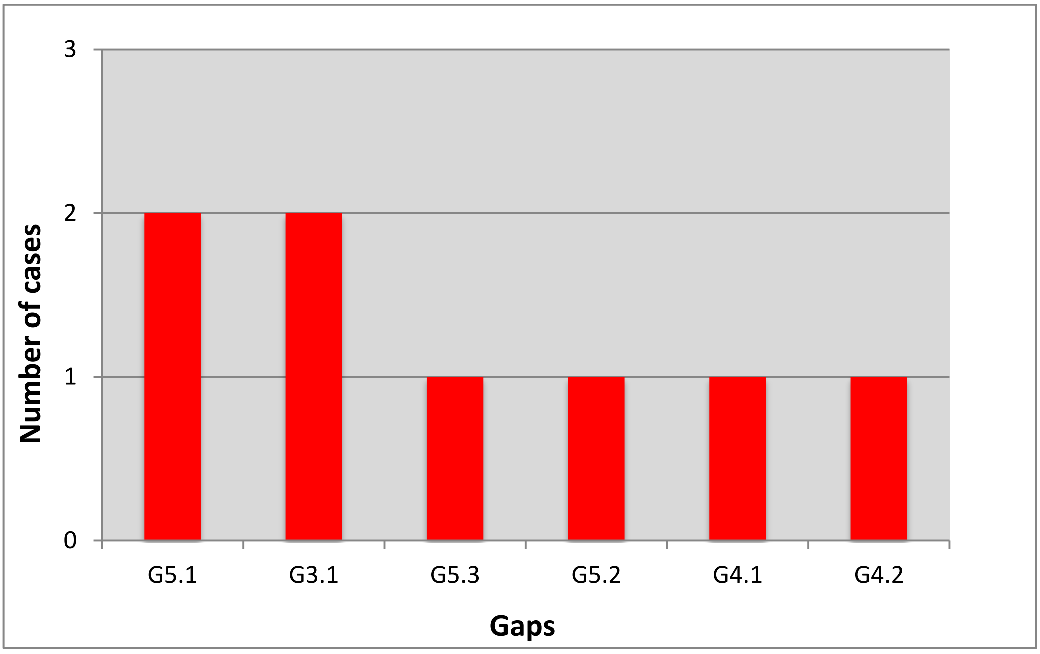


Fig. 21 Gaps covered in the Metals sector

7.2.7. Food & Beverage

UNILEVER

Unilever is an Anglo–Dutch multinational consumer goods company co-headquartered in London, England and Rotterdam, Netherlands. Its products include food, beverages, cleaning agents and personal care products.

Delivering innovation and intelligence in product design

(http://resources.altair.com/pdd/images/en-US/CaseStudy/Unilever-Delivering-Innovation-and-Intelligence-in-Product-Design.pdf)

Description	S&FT role:
An initiative is on going at Unilever to define and reel out a new design approach driven by CAE for the packaging design. Packaging must fulfil many roles throughout the lifecycle of the	Packaging design, sustainability assessment, product life cycle consideration, accuracy of the prediction,

product, roles that vary significantly depending on the target region, product and consumer driven requirements. In addition to cost, sustainability is a big driver for reducing packaging material, and considering new recyclable options. The technical challenges are many, ranging from capturing complex material response to capturing the process behind accessible user interfaces that can be deployed in a richly varied global business. Unilever is committed to yielding the greatest value from the design technology through employing it as early as possible in the product development cycle. To ensure accuracy of the predictions, materials need to be characterised at a level of detail previously reserved for detailed research activities.

Detailed predictions of primary, secondary and tertiary packaging performance are made possible through use of advanced simulation technology. Design optimization is then employed using the modelling as a virtual testing ground for design variants. The approach provides clear design direction, an opportunity for wider experimentation, helps to improve performance and reduces uncertainty in the development process.

virtual testing.

Pathfinder gaps coverage:

G3.1, G3.2, G3.3

Simulation-Based Business

(http://gallery.mailchimp.com/64046555706f8710f36a6eac1/files/MTP_Business_Challenge_Case_Study_2012.pdf)

Description

MTP plc, Accenture, and Enspire Learning joined forces to design a simulation-based business acumen training program for Unilever, one of the world's largest consumer products companies, and to deliver that program virtually to a global sales audience.

With rising competition in the consumer goods market, brand name consumer goods companies such as Unilever are increasingly under pressure to make financially sound decisions at all levels and in all functional areas of the company. Nowhere is that pressure felt more strongly than in sales. To sell effectively, sales managers must understand the financial consequences of decisions around pricing, marketing, and new product launches – both the impact on their own business's financials, and on those of their customers.

At the same time, today's multinationals operate across the world, and need training programmes to be delivered across the same wide range of geographies.

Unilever needed the training to be high-quality, consistently delivered and tailored towards their needs – but pressures of work and tight budgets would not allow sales people to take whole days away from their work, nor to travel. The solution would have to be delivered virtually. Unilever turned to Accenture to find vendors capable of designing a business acumen training program that could be delivered entirely virtually, without compromising

S&FT role:

Learning/training programs,

Pathfinder gaps coverage:

G7.2

effectiveness and engagement. This program has shown that engaging, effective learning programs can be delivered virtually to a global audience. Final proof of the program's business value is the fact that Unilever has begun to roll out a variation on it to a wider management audience within the organization.	

Customized Solutions to Reduce Packaging Waste

(http://www.altairproductdesign.com/pdd/images/en-US/CaseStudy/PD_caseStudy_Unilever2_041211.pdf)

Description	**S&FT role:**
With increasing pressures on all manufacturers to reduce the environmental impact of their products, consumer goods giant, Unilever, needed a way to minimize the material used in its packaging while ensuring that it remained strong enough to withstand transportation loads and a variety of use conditions. Advanced virtual simulation technology was needed to optimize Unilever's packaging designs but, at the time, Unilever did not employ many computer aided engineering (CAE) users, instead having an extremely talented team of CAD engineers at their disposal. The custom Atlas system from Altair ProductDesign's process automation team has allowed Unilever's CAD engineers to perform a wide variety of simulation studies in an accessible but powerful user environment. Innovative packaging designs can be generated and explored, while new materials can be checked for manufacturing feasibility and cost without the need for expensive physical trials. The system has helped Unilever to compress packaging design development time while simultaneously reducing the amount of material required during manufacture.	Minimize material use, virtual simulation technology, packaging design, sustainability assessment. **Pathfinder gaps coverage:** G3.1, G3.2, G3.3

The following graph (Fig. 22) summarizes the level of coverage of Pathfinder gaps by the samples cases in the Food&Beverage sector.

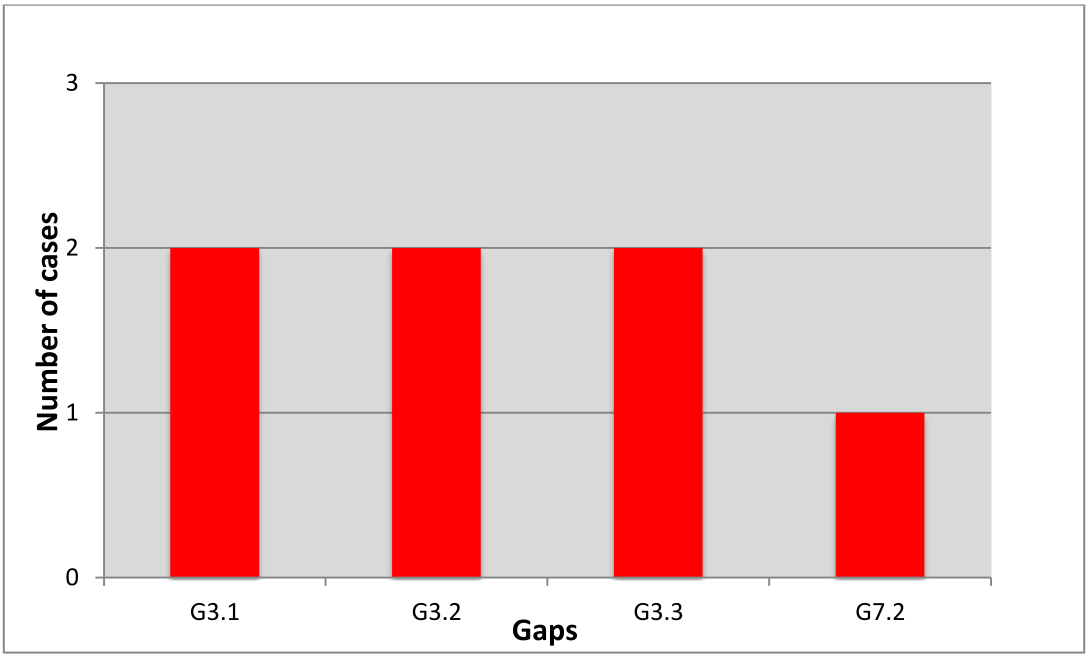


Fig. 22 Gaps covered in the Food & Beverage

7.3. Overview on the level of gaps coverage

The analysis at sector level showed what are the main gaps already addressed by each sector. A final overview of the overall level of coverage is presented in the following table, where all the findings are summarized. The automotive sector resulted to be the one addressing more gaps simultaneously thus showing that this sector is at the forefront of the research in S&FT and making it a reference point to monitor first advances of innovative tools. The engineering and electronics sector follows in terms of number of addressed gaps.

Moving the discussion to the analysis of gaps, it is possible to see that a certain number of gaps have never been found in the analysed cases (G1.1; G1.2; G3.4; G6.1; G6.3; G7.1; G8.1; G8.2). These gaps are the ones that most likely will need more attention from the research point of view, since, if not impossible, it is harder to find examples of application.

On the contrary, some of the gaps have already met the interest of different sectors meaning that some existing solutions are already in place. On top of the most considered gaps is the gap 2.1 (poor modelling simulation of life-cycle) for which at least one case for each analysed sector has been found. This means that the need of tools allowing the life-cycle simulation is common to different scenarios. Most likely, the real gap to be filled in this case is not the lack of technological solution, but the lack of scalable solutions that allows even SMEs to take advantage of these functionalities. Not surprisingly, the modelling of product life-cycle costs is another highly addressed topic. Once the life cycle modelling works, it can be used to evaluate the associated costs. Not all sectors are ready or interested in applying S&FT in this field. Indeed, research is called in this area to link the modelling with the cost evaluation. A quite widespread element among the sampled cases is the use of virtual factory models. Their utility in the design and management of production system is evident, yet their development and maintenance require too much effort to be affordable by the smaller companies.

To sum up, the sectorial-driven perspective adopted in this section add some more elements to map the European stakeholders as far as S&FT advancements are concerned. State-of-the-art applications in their sector of adoption have been analysed to provide an overview of where to look for advances solutions to be then applied in other contexts.

S&FT Gaps	Aerospace & Defense	Automotive	Engineering & Electronics	Chemicals	Pharmaceuticals	Metals	Food & Beverage	Total	Total (%)
G1.1									
G1.2									
G2.1	1	1						2	2,30%
G2.2		2	1					3	3,45%
G2.3			1					1	1,15%
G2.4		2	1					3	3,45%
G3.1	3	8	2	1	5	2	2	23	26,44%
G3.2	3	3	1				2	9	10,34%
G3.3		1					2	3	3,45%
G3.4									
G4.1	1	2	1			1		5	5,75%
G4.2		2	1			1		4	4,60%
G5.1		1	1	1	4	2		9	10,34%
G5.2	1	2		1	2	1		7	8,05%
G5.3	2	4	1	2		1		10	11,49%
G6.1									
G6.2			1					1	1,15%
G6.3									
G7.1									
G7.2	2		3	1			1	7	8,05%

G8.1									
G8.2									
Total (NO.)	13	28	14	6	11	8	7	87	100,00%
Total (%)	14,94%	32,18%	16,09%	6,90%	12,64%	9,20%	8,05%	100,00%	

Summary of S&FT gaps coverage by each sector. In the cells the number of cases found in the corresponding sector dealing with that gap (full name of gaps is deta