Deliverable 1.3

Overview on Technology Push and Application Pull regarding Architectures and Services

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PU	Public	**X**
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Editor: Institution: E-mail:	Ursula Rauschecker Fraunhofer IPA ursula.rauschecker@ipa.fraunhofer.de

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[1] **R**=Report, **P**=Prototype, **D**=Demonstrator, **O**=Other

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Table of Contents

1 Executive Summary 4

2 Context and objectives 7

3 Analysis of research activities and recommendations 10

3.1 Current manufacturing IT research activities vs. current recommendations for research 10

3.2 Relevance and innovation potential of generic ICT research for manufacturing IT 13

4 Mapping of research topics to industrial needs 22

4.1 Impact of manufacturing IT research topics 22

4.2 Impact of generic ICT research topics 26

5 Mapping of trends to industrial needs 29

5.1 Successful response to megatrends 29

5.2 Successful response to manufacturing trends 31

6 Conclusion 34

1 Executive Summary

Context and content of this document

Whereas most previous deliverables constitute separate building blocks for establishing either the push perspective (D1.1, D1.2) or the pull perspective (D2.2. D2.3), this document is to analyse them jointly, thereby **joining push and pull perspective**. Beyond the material from previous deliverables, input received at two workshops with the Road4FAME Experts Group is also considered for the analysis.

Despite being intended to be a *summary of pull and push perspective*, this document shall not replicate the content of previous deliverables. Instead, it is to analyse their content jointly and present the **observations which can be made from this cross-analysis of push and pull** perspectives.

The following analyses are contained in this document:

- **Section 3.1:** A comparison of today's research activities (D1.1) against today's recommendations for what should be researched in the future (D1.2, section 3).
- **Section 3.2:** An assessment of the relevance of generic IT research topics (*generic* in the sense that they are not focused on manufacturing but may cross-fertilize manufacturing IT, see D1.2) for future manufacturing IT, as well as the degree of awareness for these topics and their degree of implementation in the manufacturing domain. Based on this comparison, the potential of each generic IT topic to cross-fertilize manufacturing IT innovation is assessed.
- **Section 4.1:** A mapping of manufacturing IT research topics (D1.1 and D1.2) against industrial needs (D2.2). For each research topic, an assessment is provided of how strongly it contributes to fulfilling industrial needs.
- **Section 4.2:** Overview on the contribution of the most important generic IT research topics which are not yet applied well in manufacturing IT and their impact with regard to the industrial needs identified in D2.2.
- **Section 5.1:** Mapping of industrial needs from D2.2 with megatrends from D2.3. Indications are provided for the potential of needs (if they are fulfilled) to respond to the respective trend.
- **Section 5.2:** Mapping of industrial needs from D2.2 with manufacturing trends from D2.3 and D3.2 (roadmapping workshop results). Indications are provided for the potential of needs (if they are fulfilled) to respond to the respective trend.

A short summary of the *observations and their assessment* from each section is presented on the following pages.

Relevance of this document

This document provides a cross-analysis of all content produced for establishing push and pull perspective, ensuring that a) the roadmap and derived recommendations align future research with the needs of manufacturing businesses (innovation pull) and furthermore that b) manufacturing businesses benefit from IT innovation which they have not even demanded (innovation push). The observations presented in this document constitute a major input for the Road4FAME roadmap.

Main observations

- Remaining research gaps: Most recommendations for future research which were identified in strategy documents and roadmaps (see D1.2) are already well addressed by current research activities (see D1.1) and the extent of today's research activities is well in line with how strongly these research activities are recommended.

  However, there are some considerable deviations, especially for activities related to non-functional technologies and concepts, i.e. *usability*, *standardisation*, *security*, *business models,* and *stakeholder education*. For functional technologies for which differences appear, the reasons are mainly that these topics (big data related topics, integration of manufacturing, product, and service business, as well as cloud manufacturing) are priority research topics which appeared during the past few years and still have to be adopted in research projects. Please read further in section 3.1.

- Underestimated potential of some generic IT research topics for manufacturing: Many generic ICT research topics are also relevant for manufacturing IT applications. For some ICT topics, their adoption and awareness about them is very well corresponding to their relevance for manufacturing IT – in practice as well as in research.

  However, there are also some generic ICT research recommendations which are not considered appropriately in manufacturing IT research, among them: Interoperability (beyond plug & produce manufacturing IT projects), change from system integration to information integration, complexity management, definition and evolution of system architectures, emergent behaviour, prototyping, and non-technical aspects such as establishment of trust, standardisation, regulatory measures, business models, demonstrations / living labs. This may be an indicator for underestimation of the potential of these topics. The relevance of these topics for manufacturing IT has been rated higher than their current appearance and consideration in research projects and state-of-the-art applications. For this reason, special attention may be laid on these topics in future manufacturing IT research. Please read further in section 3.2.

- Poorly addressed industrial needs: Comparing industrial needs against current manufacturing IT research topics it can be seen that all industrial needs seem to be addressed by at least one research topic which highly contributes to its satisfaction. The needs which are less addressed by current manufacturing IT research topics are *lower implementation costs for manufacturing IT innovation*, *management of heterogeneous manufacturing IT*, and *more intuitive system interaction / mobile devices*. Considering that these are precisely the needs which have been identified as most important ones in D2.2 (interviews with industry) but received a relatively low satisfaction score in the table above, it must be advised that additional focus should be laid on addressing these needs with future research. Please read further in section 4.1.

- Promising generic IT research fields: The generic IT research topics *complexity management*, *standardisation*, and *definition & evolution of system architectures* have been found to have considerable potential in manufacturing IT because they would well address some of the most important industrial needs. As the analysis shows, they would particularly well address the needs for *lower implementation costs of manufacturing IT innovation* and *management of heterogeneous manufacturing IT* which are precisely the needs which are today not well addressed. Please read further in section 4.2.
- Megatrends which manufacturing domain is least aware of: While most megatrends are well reflected in industrial needs, the megatrend *knowledge as key enabler* and *demographic change* which are not very well reflected in needs. Since these trends can be expected to have considerable impact on the manufacturing domain, but no needs have been expressed which relate to these trends, this points to a dangerous blind spot. Unless these trends are reflected by a felt need in the manufacturing domain, there is a danger that manufacturing businesses do not prepare sufficiently to respond to these megatrends when they become more prominent. Despite the fact that the manufacturing domain may not demand this (yet), strategic research is necessary so manufacturing IT can bring its contribution to responding to these trends, when they become more prominent. Please read further in section 5.1.
- Industrial needs which are strongly trend-driven: From the analysis it can be observed that the industrial needs *supply chain flexibility*, *flexible manufacturing*, and *monitoring and decision making for performance optimisation* are most strongly related with the manufacturing trends (high impact score). Since these industrial needs are responding to so many trends, it is rightfully so that the manufacturing domain considers them important (see D2.2). Please read further in section 5.2.
- Industrial needs which are weakly trend-driven: By contrast, the needs for *more intuitive system interaction / mobile devices* and *condition monitoring & predictive maintenance* (a sub-topic to monitoring and decision making for performance optimisation) seem to be only weakly related with any of the trends (low impact score). This means that, interestingly, these needs do not seem to be driven very much by any trends; they seem to exist independently from any trend which drives them. Please read further in section 5.2.
- Trends which manufacturing domain is least aware of: From the analysis, the trends *shortage of skilled staff*, *language barriers and cultural differences*, and *urban production* seem to only weakly translate into industrial needs. This may point to a blind spot of the manufacturing domain for these trends. Unless these trends are reflected by a felt need in the manufacturing domain, there is a danger that manufacturing businesses do not prepare sufficiently to respond to these megatrends when they become more prominent. Despite the fact that the manufacturing domain may not demand this (yet), strategic research is necessary so manufacturing IT can bring its contribution to responding to these trends, when they become more prominent. Please read further in section 5.2.

2 Context and objectives

This section describes the role and relevance of this document and the underlying work in the overall roadmapping process in Road4FAME.

Role of this document in the overall roadmapping process

The roadmapping process in Road4FAME is depicted in figure 1 and comprises three main phases:

- Phase 1: Establishment of push perspective and pull perspective, as a preparation for the core roadmapping process
- Phase 2: Core roadmapping process to join push and pull perspective and iteratively develop the roadmap
- Phase 3: Finalization of roadmap and development of recommendations

Whereas most previous deliverables constituted separate building blocks in establishing either the push perspective (D1.1, D1.2) or the pull perspective (D2.1, D2.2. D2.3), this document is to analyse them jointly, thereby **joining push and pull perspective**.

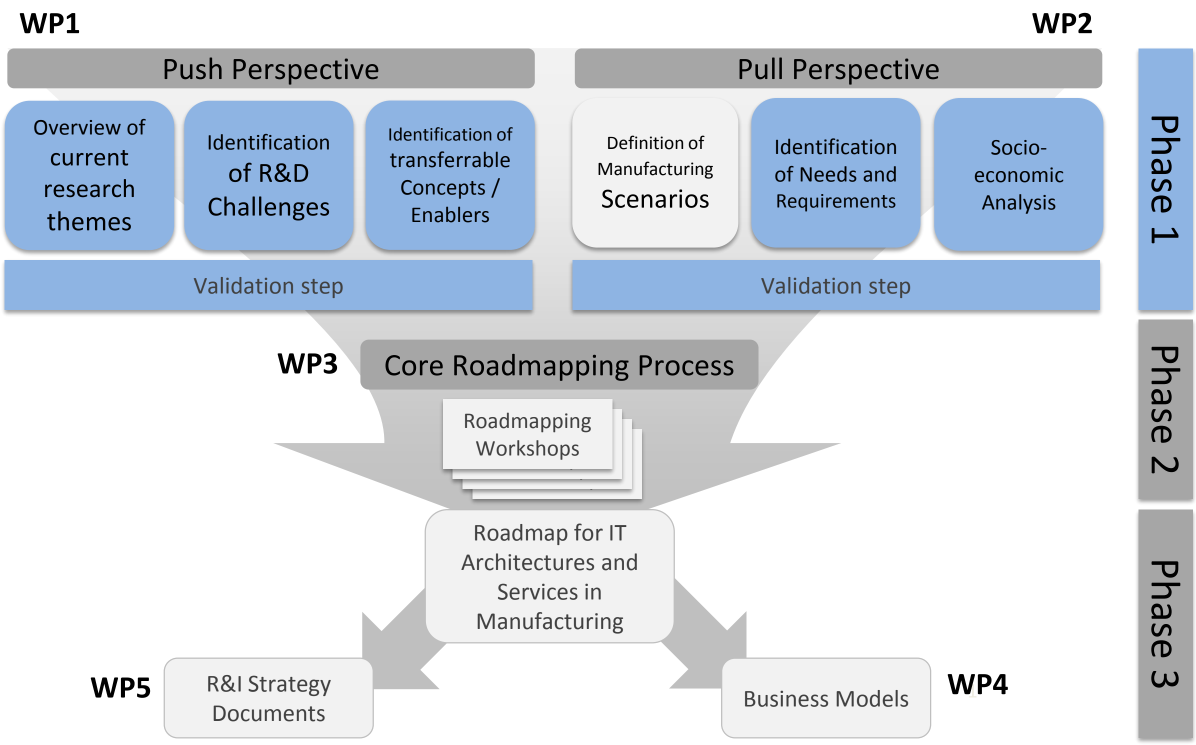

Figure 1: Road4FAME roadmapping process

Content of this document

Despite being intended to be a *summary of pull and push perspective*, this document shall not replicate the content of previous deliverables. Instead, it is to analyse their content jointly and present the **observations which can be made from this cross-analysis of push and pull** perspective.

Figure 1 highlights the data analysed in this document:

- Overview of *current* research themes (D1.1)
- Overview of *future* R&D challenges in manufacturing IT (D1.2)
- Overview of transferable concepts / *enablers*, defined as research fields in general computer science / IT which could cross-fertilize manufacturing IT (D1.2)
- Overview of industrial needs identified in a series of interviews (D2.2)
- Overview of megatrends and manufacturing trends (D2.3)
- Input received at First Road4FAME Expert Workshop in Brussels (March 6, 2014)
- Input received at Second Road4FAME Expert Workshop in Porto (May 23, 2014)

On this basis, the following analyses are presented in this document:

- **Section 3.1:** A comparison of today's research activities (D1.1) against today's recommendations for what should be researched in the future (D1.2, section 3).
- **Section 3.2:** An assessment of the relevance of generic IT research topics (*generic* in the sense that they are not focused on manufacturing but may well cross-fertilize manufacturing IT, see D1.2) for future manufacturing IT, as well as the degree of awareness for these topics and their degree of implementation in the manufacturing domain. Based on this comparison, the potential of each generic IT topic to cross-fertilize manufacturing IT innovation is assessed.
- **Section 4.1:** A mapping of manufacturing IT research topics (D1.1 and D1.2) against industrial needs (D2.2). For each research topic, an assessment is provided of how strongly it contributes to fulfilling industrial needs.
- **Section 4.2:** Overview on the contribution of the most important generic IT research topics which are not yet applied well in manufacturing IT and their impact with regard to the industrial needs identified in D2.2.
- **Section 5.1:** Mapping of industrial needs from D2.2 with megatrends from D2.3. Indications are provided for the potential of needs (if they are fulfilled) to respond to the respective trend.
- **Section 5.2:** Mapping of industrial needs from D2.2 with manufacturing trends from D2.3 and D3.2 (roadmapping workshop results). Indications are provided for the potential of needs (if they are fulfilled) to respond to the respective trend.

Relevance of this document

As shown in figure 1, establishing push and pull perspective takes place independently in Road4FAME. But at a certain step these two perspectives are jointly analysed for their mutual implications.

This document presents precisely this analysis of push and pull perspective and will thus make sure that:

a) The roadmap and derived recommendations align future research with the needs of manufacturing businesses (innovation pull)

b) Manufacturing businesses benefit from IT innovation which they have not even demanded (innovation push)

3 Analysis of research activities and recommendations

3.1 Current manufacturing IT research activities vs. current recommendations for research

Table 1 compares current research activities in manufacturing IT (D1.1) with research recommendations in manufacturing IT identified by current strategy documents (D1.2, section 3).

Especially, it makes visible deviations in research recommendations and related undertaken research activities which are marked red.

<u>Rating of research recommendation from strategy documents:</u>

2	**Strongly recommended**, i.e. recommended by *almost all* or *all* strategic documents which have been analysed
1	**Recommended by a relevant subset** of the analysed strategic documents
0	**Hardly recommended**, i.e. recommended by no or very few strategic documents

<u>Rating of how frequently this topic is addressed by current research activities:</u>

2	**Many research activities**, i.e. topic is addressed by **around 10%** of all projects analysed in D1.1 (total 138 projects)
1	**Several research activities**, i.e. topic is addressed by **around 5%** of all projects analysed in D1.1 (total 138 projects)
0	**Few research activities**, i.e. topic is addressed by **less than 3%** of all projects analysed in D1.1 (total 138 projects)

<u>Assessment of how well current research activities are in line with current recommendations for research:</u>

(green)	Research is well addressing recommendations (strongly recommended, many research)
(orange)	Topics recommended but addressed only by several research activities
(red)	Topics strongly recommended or recommended but addressed only by few research activities

Research topic	Rating of research recommendation from strategy documents	Rating of how frequently topic is addressed by current research activities	How well are current research activities in line with current recommendations?
Cyber-physical (production) systems / intelligent components	2	2	
Plug & produce / self-describing & easy-to-configure equipment	2	2	
Autonomous manufacturing system components	1	2	
Factory knowledge base	1	1	
Data analysis	2	1	
Decision making & Factory optimisation	2	1	
Usability	2	0	
Man-Machine Interaction	0	1	
Manufacturing-IT as a Service	1	1	
New manufacturing IT features	2	2	
Knowledge transfer between manufacturing and engineering	1	1	
Cloud manufacturing	1	0	
Integration of manufacturing, product, and service business	1	0	
Total customisation / ad-hoc production networks	2	2	
Optimisation and integration of production networks	2	2	
Migration strategies	0	0	
Performance assessment for future ICT applications	0	0	
Standardisation and reference architectures	2	0	
Security, privacy & legal aspects	2	0	
Business models and demonstrations	1	0	
Stakeholder education	1	0	

Table 1: Comparison of current research recommendations and activities

Observations and assessment

- Most recommendations already well implemented: Most recommendations for future research are already well addressed by current research activities and the extent of today's research activities is well in line with how strongly these research activities are recommended. The recommendations mainly further detail or describe next steps in the respective research.
- Remaining research gaps: However, there are some considerable deviations, especially for activities related to non-functional technologies and concepts, i.e. *usability*, *standardisation*, *security*, *business models,* and *stakeholder education*. Those topics are regarded as important in strategy documents or roadmaps but are mainly handled as sidelines in current projects. For functional technologies for which differences appear, the reasons are mainly that these topics (big data related topics, integration of manufacturing, product, and service business, as well as cloud manufacturing) are priority research topics which appeared during the past few years and still have to be adopted in research projects.

3.2 Relevance and innovation potential of generic ICT research for manufacturing IT

Table 2 shows a list of generic research IT topics – *generic* in the sense that these research topics or fields are not explicitly focused on advancing manufacturing IT (but may well cross-fertilize manufacturing IT, see D1.2).

For each generic IT topic, its potential relevance for manufacturing IT is assessed and also its degree of implementation in manufacturing IT research and practice. Based on this comparison, the potential of each generic IT topic to cross-fertilize manufacturing IT innovation is assessed.

Rating of how relevant an ICT topic could be for manufacturing IT:[3]

2	**ICT topic is *highly relevant* for manufacturing IT** and might enable considerable innovation and benefit in this area.
1	**ICT topic is *relevant* for manufacturing IT** and might enable some innovation and benefit in this area.
0	**ICT topic is *hardly relevant* for manufacturing IT**. It is doubtful if it could enable manufacturing IT innovation and benefits in this area.

Rating of how well a generic ICT topic is already taken-up in the field of manufacturing IT:[4]

2	**Research activities / industry applications** are already addressing the respective ICT topic quite well.
1	**Research / industry is aware** of the ICT topic but **does not implement** the related state-of-the-art.
0	**Research / industry does hardly undertake activities** related to this ICT topic.

Potential of each generic IT topic to cross-fertilize manufacturing IT innovation:

(green)	Awareness and implementation in research *AND* practice are responding to the relevance of a research topic for manufacturing IT appropriately.
(orange)	Awareness and implementation in research already respond to potential of the research topic for manufacturing IT. However, implementation in practice is lagging behind.
(red)	Awareness and implementation in research do not respond to the potential of the research topic for manufacturing IT appropriately (potential underestimated).

[3] Score is drawn from assessments by consortium members, see D1.2

[4] Score is drawn from assessment by consortium members, see D1.1

Research topic	Recommended activities	Rating of how relevant the ICT topic could be for manufact-uring IT	Implementation & awareness		Potential to cross-fertilize manufact-uring IT
			Research	Practice	
Infrastructure					
Communication channel Speed and connectivity	Smart antennas; real-time, low-latency communication, energy efficient communication; ad-hoc connections, security, robustness, etc.	1	1	1	
Real-time capabilities	Integration methods and validation approaches for correct and efficient integration of mixed real-time systems	2	2	2	
Smart Components	Miniaturisation of devices; Embedding smart functionality; energy efficiency; Awareness and cooperation; appropriate engineering methods	2	2	1	
Network technologies	Reliable, intelligent, auto-configured / self-managed, context-aware and adaptable network technology, network discovery, and network management; Network virtualisation techniques contributing to evolutionary deployment of IoT applications; Infrastructure for "network of networks" supporting dynamically small area and scale free connections and characteristics	1	1	0	
Computing technologies	High performance heterogeneous cloud infrastructures; federated cloud networking; dynamic configuration, automated provisioning and orchestration of cloud resources; mechanisms to increase trust, security, transparency for cloud computing; Low power computing	1	2	0	(Topic might be overestimated in current research.)
Interoperability among heterogeneous systems	Technical / syntactic and semantic integration, including component, service, and capability descriptions in a formalised way; Certification of systems which can be composed and support dynamic reconfiguration; Merging IoT, IoP, IoE, IoM, IoS (Internet of things, people, energy, media, services) to a common global IT platform of seamless networks and networked smart objects Intelligent inter-machine communication and configurable / low-effort integration of legacy systems and communications	2	1	0	

Software Services and algorithms	Service management including identity, relationship and reputation management, especially for distributed architectures and related mobile, adaptive, etc. components, service and device discovery, and semantic interoperability; Specific services such as virtualisation software, bio-inspired algorithms, solutions based on game theory, algorithms for optimal assignment of resources in pervasive and dynamic environments	2	1	0	
Big Data					
Smart sensors and sensor data fusion	Perception techniques for measurement, object and event recognition to increase context-awareness and intelligence; Sensors which monitor data quality (accurateness, robustness, durability, etc.) and perform advanced analysis to only transfer information which is really needed; sensor data fusion, i.e. treating, correlating, and reducing data from sensors (including gaining additional information by combining several sensor inputs)	2	2	1	
Knowledge generation / data analysis	Appropriate database technologies, analysis and correlation of distributed large data sets, information integration, data reduction mechanisms, novel data structures and data structure alignment, consideration of historical aspects of data, self-learning for analysis mechanisms, etc.	2	2	1	
Decision making	Visual representation of large amounts of complex data for decision support; Methods for uncertainty quantification, dealing with varying data quality; Continuous optimisation models reflecting current situations; Autonomous & safe decision making; Collaborative decision making considering global objectives / negotiations among sub-systems	2	2	0	
Forecasting	Planning and forecasting of (semi-)autonomous actions using multi-criteria situation evaluation (real-time analysis and evaluation of situations) and artificial intelligence	2	2	1	
Complexity management	System architectures supported by intelligent services for managing modularity, flexibility, service composition, etc. by exploiting Big Data and CEP techniques	2	1	0	

System engineering / design					
User-centred design	Usage simulation, quality of experience, quality in use, experience labs, usability engineering, integrated human- and system architecture models	1	1	0	
Multi-level modelling	Advanced requirements engineering considering all relevant aspects (model-based, iterative, etc.); Multi-domain modelling techniques and integrated tool chains, also for open systems / platforms, large, complex and data-intensive, autonomous and/or evolutionary systems and their management, which also consider dynamic behaviour; Gathering experience from system implementation and usage and use it for design rules / future system modelling	2	2	0	
Definition & Evolution of System Architectures	Design patterns and network typologies for low effort integration, abstract data models and interfaces and their binding to neutral technologies to ensure wide ranged applicability; Generic platforms and suites containing abstract components for easy roll-out of developments throughout various application domains;	2	1	0	
Prototyping	Prototyping within operating Systems / SoS rather than test beds; Creation, reconfiguration, extension of experimental infrastructures and exploitation of data gathered there; Experimentation-as-a-Service, virtual experimentation	2	1	1	
System behaviour					
Situation awareness	Gathering appropriate sensor data, set it in respective contexts, analyse it in real-time (potentially throughout distributed sensor networks)	2	2	1	
Measurement and metrics	Measuring System performance requires identification of appropriate KPIs and related data to be gathered, ensure comparability of data, effectiveness; Predictive measures, real-time measurement, traceability of measurements	2	2	1	
Resilience, adaptability, flexibility, and evolution of systems	Engineering and design approaches to deliver modularity, flexibility, adaptability, and resilience at run-time, under conditions not necessarily foreseen during the initial design phase; Interoperability, self-configuration, self-organisation, and self-healing mechanisms; Performance assessment for evaluation of system configurations and possible alternatives	2	2	0	

Distributed control	Avoidance of negative dynamic side effects caused by non-cooperating control units (e.g. via physical couplings) Dynamic ad-hoc control loops in cooperative networks; cooperative functionality monitoring to support dynamic re-routing and migration of control functionality in case of singular system failures System architectures to support distributed control and integration of control systems	1	1	0	
Autonomous systems	Situation awareness / interaction with the environment via sensors and actuators; distributed control & decision making (including related negotiations etc.); Finding the right balance (depending on the application case) for the distribution of functionality/intelligence between smart things and the supporting infrastructure	1	1	0	
Emergent behaviour	Understanding possibilities and limits of emergent behaviour and its prediction; Predictive techniques, modelling and simulation, tools for early warning, devise strategies to make emergent behaviour less unexpected and avoid undesirable, and allow for desirable emergent behaviour	1	0	0	
User interfaces / Human aspects					
Multimodal interfaces	Intuitive and transparent usage of systems; Joint control (by humans and machines) of open complex socio-technical systems; Multilingual speech processing, including semantics; Coping with spontaneous spoken language and gestural interaction; Augmented reality applications	2	1	0	
Situational awareness and user-specific adaption	Enable awareness of psychology, culture, organisational aspects, preferences, intentions, application context, etc. by sensors and intelligent mechanisms, and appropriate adaption of visualisation / user interaction; Modularity of user interaction components for individual interface composition	1	1	0	
Technologies for creative industries, social media and convergence	Improve collaboration and user-community interaction by understanding the dynamics of co-creative processes.	0	1	0	(Topic might be overestimated in current research.)
Human-centric digital age	Understanding how new technologies change societies; Exploration of fundamental notions such as identity, privacy, relationships, culture, reputation, motivations, responsibility, attention, safety, fairness, etc.	0	1	0	(Topic might be overestimated in current research.)

Human learning and teaching	Smart learning environments providing students with adaptive and personalised learning assessment, including multi-modal / multi-sensory interaction technologies and advanced interfaces.	1	1	1	(green)
Wearable technologies	Sensors, actuators, and visualisation technologies which can be integrated to clothing (miniaturisation, materials, supporting software solutions)	1	1	0	(orange)
Security-related topics					
Operational safety and reliability	Secure runtime environments; Consideration of physical, ethical, and cyber aspects of safety and security (including cross-reference to safe/secure decision making); Mixed criticality systems (compositions of applications with different safety requirements) and their integration, qualification, and incremental certification	2	2	2	(green)
Privacy and know-how protection	Security-capable hardware; Efficient, light-weight cryptographic techniques and protocols; Scalable security concepts (closed and open, modular / reconfigurable systems); Security by design, across all hardware and software layers of an ICT system; Authentication and authorisation for huge amounts of heterogeneous devices, across different administrative domains; Cross-referencing multiple identities of an object throughout domains; new effective addressing policies for reliable and consistent encoding and decoding of identifiers; decentralised authentication, access and use rights management; Integration of additional systems/components into privacy-preserving frameworks, evaluation of privacy-preserving effectiveness	2	2	1	(orange)
Establishment of trust	Enable technical transparency of systems (in usage and essential functionality); Transparent and effective management of privacy policies; Clearness about data ownership, legal and liability issues; Development standards and security regulations and related certifications	2	1	1	(red)
Consensus					
Governance modes / structures	Criteria, recommendations, structures and measures for centralised or decentralised control and decision making, considering fairness towards all applicants and avoidance of negative side-effects when every system optimises for its own purpose.	2	2	0	(orange)

Standardisation	Standards should be open and covering various aspects (legal, organisational, semantic, technical) Standards for interoperability of systems including domain models (formalised application knowledge, e.g. by means of ontologies and domain-specific description languages), requirements, functional models, reference architectures, interfaces, protocols, etc; Continuous learning / adapting mechanisms for optimisation of related context models; Transformation of models throughout domains. Harmonisation and efficient application of existing standards;	2	1	1	
Regulatory measures	Warranties; Responsibilities for data protection; Common validation, verification and certification guidelines; Establishing risk analysis and evaluation for complex systems and providing it as regulative measures; International / cultural harmonisation of regulations to cover common ethical, quality, security etc. aspects	2	1	1	
Industrial application					
Education of stakeholders	Education programmes to address the respective stakeholder groups appropriately	1	1	1	(Topic might be overestimated in current research.)
Business models	Determination and optimisation of risk-benefit ratio, i.e. potentially large investments which are necessary to establish new technologies / systems. In the future less investment may be necessary due to new business models; Governance of systems which consist of several independent components and where all stakeholders participate interactively; Development of new products / services / product-services, appropriate consideration of interactive cooperation, customer-orientation & individualisation of products / services, etc.	2	1	1	
Demonstrations / Living labs	Implementation of small-scale demonstrators constituting working examples and showing the related benefits of the new systems; Experimentation, i.e. implementation of systems and collection of data for evaluation, and evaluation of various (all relevant) aspects such as environmental, economic, social etc. impact; Bring together technology push and application pull, engage stakeholders.	2	1	1	

Web entrepreneurship and collaborative ideas management	Online platforms with new services, e.g. connecting existing local web entrepreneurship ecosystems and hubs, and build upon these in order to provide new services; Platforms going beyond technologies and applications to include necessary conditions for collaborative innovation.	0	1	0	
Other					
Thin, Organic and Large Area Electronics	Improve materials, functionality, manufacturability, etc.	0	0	0	
Optimisation of electronic sustainability	Increase recyclability of electronic components	0	0	0	
Cracking the language barrier	Improve quality and coverage (in terms of languages and text types) of machine translation	0	0	0	
Digital gaming / gamification technologies	Digital gaming technologies and components (including game engines, emergent narrative, 3D, textures, models for simulations, game design, learner profiles, emotional models, etc.) applicable into a wider scenario of use in non-leisure contexts	1	1	0	

Table 2: Comparison of ICT topics' relevance and adoption in manufacturing IT

Observations and assessment

- Many generic IT research topics are well taken up in manufacturing IT research and practise: As it can be seen from Table 2, many generic ICT research topics are also relevant for manufacturing IT applications. For some ICT topics, their adoption and awareness about them is very well corresponding to their relevance for manufacturing IT – in practice as well as in research. This is especially the case for essential IT features like real-time capabilities (for critical applications), communication channel speed and connectivity, and operational safety and reliability. In such cases, manufacturing IT applications are often already fulfilling requirements which are stated for research activities in generic ICT roadmaps. But also for minor topics which do not have appreciable impact on manufacturing, correspondence of relevance and implementation activities converge.

  For most of the generic ICT research challenges such as big data technologies, smart components, situation awareness, resilience, privacy and know-how protection, governance modes and structures, and network technologies, it can be said that their potential for manufacturing IT is quite well represented in current research activities, although state-of-the-art applications in productive factories are some steps behind. Research in these fields should be continued to really implement these topics in practice.

- Underestimated potential of some generic IT research topics for manufacturing: However, there are also some generic ICT research recommendations which are not considered appropriately in manufacturing IT research. This may be an indicator for underestimation of the potential of these topics.

  The most significant deviations between ICT research and adoption of technologies in manufacturing apply for:

  - Interoperability (beyond plug & produce manufacturing IT projects), change from system integration to information integration
  - Complexity management
  - Definition and evolution of system architectures
  - Emergent behaviour
  - Prototyping
  - Non-technical aspects: Establishment of trust, standardisation, regulatory measures, business models, demonstrations / living labs (refer to section 3.1: these topics are recommended for manufacturing IT, but underrepresented in research activities)

The relevance of these topics for manufacturing IT has been rated higher than their current appearance and holistically consideration in research projects and state-of-the-art applications. For this reason, special attention may be laid on these topics in future manufacturing IT research.

4 Mapping of research topics to industrial needs

4.1 Impact of manufacturing IT research topics

Table 3 shows the topics of manufacturing IT research (D1.1 and D1.2) against the industrial needs identified in D2.2 by means of interviews. For each research topic, an assessment is provided of how strongly it contributes to fulfilling the industrial needs.

Rating of how strongly a research topic contributes to fulfil an industrial need:[5]

2 Research in this field **strongly contributes** to address the respective need.

1 Research in this field **is relevant** to address the respective need.

0 Research in this field **is not relevant** to address the respective need.

The rightmost column contains an **impact score** as a metric of how strongly a research topic contributes to industrial needs.

The bottom line contains a **satisfaction score** as a metric of how strongly industrial needs are covered by manufacturing IT research.

Industrial Need / **Research Topic**	Lower implementation costs for manufacturing IT innovation	Manage heterogeneous manufacturing IT	Flexible manufacturing	Supply chain flexibility	Traceability	Monitoring & optimisation of resource efficiency	Monitoring and decision making for performance optimisation	Condition monitoring, predictive maintenance	More intuitive system interaction / mobile devices	**Impact Score**
Cyber-physical (production) systems	0	0	2	1	2	1	1	1	1	**9**
Plug & produce / self-descriptions etc.	1	1	2	0	0	0	1	1	0	**6**

[5] Ratings have been provided by manufacturing experts from the Road4FAME consortium

Autonomous systems	0	0	2	1	1	0	0	0	0	**4**
Factory knowledge base	0	1	1	1	2	1	1	1	0	**8**
Data analysis	0	0	0	0	1	2	2	2	0	**8**
Decision making & Factory optimisation	0	0	1	1	0	2	2	2	1	**9**
Usability	0	0	0	0	1	0	0	0	2	**3**
Man-Machine Interaction	0	0	0	0	0	0	0	0	2	**2**
Manufacturing-IT as a Service	2	1	1	1	1	1	1	1	0	**9**
New manufacturing IT features	0	0	1	1	0	2	1	1	1	**7**
Knowledge transfer (manufacturing to engineering)	0	0	1	2	1	1	1	1	0	**7**
Cloud manufacturing	0	0	0	2	1	1	1	0	0	**5**
Integration of manufacturing, product, and service business	0		0	1	0	0	1	2	0	**4**
Total customisation / ad-hoc production networks	0	0	0	2	0	0	1	0	0	**3**

Optimisation and integration of production networks	1	1	0	2	2	1	2	0	0	**9**
Migration strategies	2	2	1	1	1	0	2	0	0	**9**
Performance assessment for future ICT applications	2		0	0	0	1	2	1	0	**6**
Standardisation and reference architectures	1	2	2	2	1	0	0	0	0	**8**
Security, privacy & legal aspects	0	0	1	2	1	0	0	2	0	**6**
Business models and demonstrations	0	0	0	1	0	1	1	1	1	**5**
Stakeholder education	1	0	1	1	1	1	1	1	2	**9**
Overall need satisfaction	**10**	**8**	**16**	**22**	**16**	**15**	**21**	**17**	**10**	

Table 3: Relevance of research topics for addressing industrial needs

Observations and assessment

All industrial needs are covered: From the

- Table 3, it can be seen that all industrial needs seem to be addressed by research topics. Each need is addressed by at least one research topic which highly contributes to its satisfaction.
- Most strongly addressed industrial needs: The needs which are addressed best by current manufacturing IT research topics are *supply chain flexibility*, *monitoring and decision making for performance optimisation*, and *condition monitoring and predictive maintenance*.
- Poorly addressed industrial needs: The needs which are less addressed by current manufacturing IT research topics are *lower implementation costs for manufacturing IT innovation*, *management of heterogeneous manufacturing IT*, and *more intuitive system*

interaction / mobile devices. Considering that these are precisely the needs which have been identified as most important ones in D2.2 (interviews with industry) but received a relatively low satisfaction score in the table above, it must be advised that additional focus should be laid on addressing these needs with future research.

- Research topics most strongly responding to industrial needs: The research topics which have most impact on industrial needs are, according to the impact scores given:
    - Cyber-physical (production) systems
    - Decision making and factory optimisation
    - Manufacturing IT as a Service
    - Optimisation and integration of production networks
    - Migration strategies (hardly recommended, only few research activities)
    - Stakeholder education (recommended but only few research activities)

Most of them are already well represented in recommendations and current research activities. However, migration strategies are even not recommended, even if they seem to have high impact. This means that here an additional recommendation for future manufacturing IT research has been identified.

4.2 Impact of generic ICT research topics

Table 4 gives an overview on the contribution of the most important generic IT research topics which are not yet applied well in manufacturing IT (refer to

Table 2) and their impact with regard to the industrial needs identified in Deliverable 2.2.

Rating of how strongly a research topic contributes to fulfil an industrial need:[6]

2 Research in this field **strongly contributes** to address the respective need.

1 Research in this field **is relevant** to address the respective need.

0 Research in this field **is not relevant** to address the respective need.

The rightmost column contains an **impact score** as a metric of how strongly a research topic contributes to industrial needs.

The bottom line contains a **satisfaction score** as a metric of how strongly industrial needs are covered by manufacturing IT research.

[6] Ratings have been provided by manufacturing experts from the Road4FAME consortium

Industrial Need / ICT Topic not yet well-considered in manufacturing IT	Lower implementation costs for manufacturing IT innovation	Manage heterogeneous manufacturing IT	Flexible manufacturing	Supply chain flexibility	Traceability	Monitoring & optimisation of resource efficiency	Monitoring and decision making for performance optimisation	Condition monitoring, predictive maintenance	More intuitive system interaction / mobile devices	**Impact score**
Complexity management	0	2	2	2	1	0	1	0	1	**9**
Definition / evolution of system architectures	2	1	2	1	0	0	1	0	0	**7**
Prototyping	2	1	0	0	0	0	1	0	0	**4**
Emergent behaviour	0	1	1	1	0	0	1	0	0	**4**
Multi-modal interfaces	0	0	0	0	1	0	1	1	2	**5**
Establishment of trust	0	1	0	2	0	0	0	0	0	**2**
Standardisation	1	1	2	2	1	0	1	0	0	**8**
Regulatory measures	0	0	0	2	1	0	0	0	0	**3**
Business models	0	0	0	1	0	1	1	1	0	**4**
Demonstrations / Living labs	1	1	0	0	0	0	0	0	0	**2**
Overall need satisfaction	**6**	**8**	**7**	**11**	**4**	**1**	**7**	**2**	**3**	

Table 4: Selection of generic ICT research topics addressing industrial needs

Observations and assessment

- Promising generic IT research fields: From this table, it can be observed that the generic IT research topics *complexity management*, *standardisation*, and *definition & evolution of system architectures* are generic ICT topics which have considerable potential in manufacturing IT, too, because they well respond to industrial needs. This can also be used as validation of the findings from
- Table 2. Furthermore, it can be seen that the consideration of those generic ICT topics would also bring an improvement of the overall needs satisfaction for *lower implementation costs of manufacturing IT innovation* and the *management of heterogeneous manufacturing IT*, and herewith address the need for research observed in section 4.1.

5 Mapping of trends to industrial needs

5.1 Successful response to megatrends

Table 5 maps industrial needs from D2.2 with megatrends from D2.3 and indicates the potential of needs (if they are fulfilled) to respond to the respective trend.

Rating of how strongly a (fulfilled) need would respond to each megatrend:[7]

2 Industrial need **strongly responds** to the mega-trend

1 Industrial need **partially responds** to mega-trend

0 Industrial need has **no relevance** for the mega-trend

The rightmost column contains an **impact score** as a metric of how strongly a fulfilled industrial need would respond to the megatrends.

The bottom line contains an **overall response to trends score** as a metric of how strongly each megatrend would be responded to by fulfilled industrial needs.

Mega-Trends / **Industrial need**	Demographic Change	Globalisation	Innovation and new technologies	Knowledge as enabler	Language barriers and cultural differences	Sustainability (environmental, societal, economic)	Changes in economic purchasing power	**Impact score**
Lower implementation costs form manufacturing IT innovation	0	0	2	0	0	0	0	2
Manage heterogeneous manufacturing IT	0	0	1	0	0	0	0	1
Flexible manufacturing	1	1	1	0	0	0	2	5
Supply chain flexibility	1	2	1	0	1	0	2	7
Traceability	0	2	0	0	1	1	1	5
Monitoring & optimisation of resource efficiency	0	0	0	0	0	2	0	2

[7] Ratings have been provided by manufacturing experts from the Road4FAME consortium

Monitoring and decision making for performance optimisation	0	1	0	0	0	1	1	3
Condition monitoring, predictive maintenance	0	0	0	0	0	1	0	1
More intuitive system interaction / mobile devices	1	0	0	1	2	0	0	4
Overall response to trends	3	6	5	1	4	5	6	

Table 5: Mapping global mega-trends to industrial needs

Observations and assessment

- Industrial needs which are strongly megatrend-driven: Looking at the impact scores, it can be observed that the industrial needs *flexible manufacturing, supply chain flexibility*, and *traceability* are the industrial needs which are responding to the megatrends best. These topics are also already quite well addressed by research topics as it can be seen from the section 4 results.
- Megatrends which manufacturing domain is most aware of: Looking at the scores at the bottom of the table showing the overall response of industrial needs to each megatrend, it can be said that most of the megatrends are addressed well by industrial needs, especially the ones with obvious economic impact such as *globalisation*, *changes in economic purchasing power*, *innovation and new technologies*, and *sustainability*. The fact that these megatrends are well reflected in needs indicates that the manufacturing domain is well aware of these megatrends and how they will affect them.
- Megatrends which manufacturing domain is least aware of: This, however, seems to be different for the megatrends *knowledge as key enabler* and *demographic change* which are not very well reflected in needs. Since these trends can be expected to have considerable impact on the manufacturing domain, but no needs have been expressed which relate to these trends, this points to a dangerous blind spot. Unless these trends are reflected by a felt need in the manufacturing domain, there is a danger that manufacturing businesses do not prepare sufficiently to respond to these megatrends when they become more prominent. Despite the fact that the manufacturing domain may not demand this (yet), strategic research is necessary so manufacturing IT can bring its contribution to responding to these trends, when they become more prominent.

5.2 Successful response to manufacturing trends

Table 5 maps industrial needs from D2.2 with manufacturing trends from D2.3 and D3.2 (roadmapping workshop results) and indicates the potential of needs (if they are fulfilled) to respond to the respective trend.

Rating of how strongly a (fulfilled) need would respond to each trend:[8]

2 Industrial need **strongly responds** to the trend

1 Industrial need **partially responds** to trend

0 Industrial need has **no relevance** for the trend

The rightmost column contains an **impact score** as a metric of how strongly a fulfilled industrial need would respond to the trends.

The bottom line contains an **overall response to trends score** as a metric of how strongly each trend would be responded to by fulfilled industrial needs.

[8] Ratings have been provided by manufacturing experts from the Road4FAME consortium

Business trends / Industrial need	Individualisation & high quality	Shortage of skilled staff	Increasing demand for products and services	Increasing complexity of products, processes, supply	Shorter product lifecycles	Maintain competitiveness of high-wage countries	Local adaption / manufacturing close to markets	Companies increasingly focus on their core business	Environmental sustainability / green manufacturing	Urban production	New 32services / business models	**Impact Score**
Lower implementation costs form manufacturing IT innovation	0	0	0	0	1	2	0	1	0	0	1	**5**
Manage heterogeneous manufacturing IT	1	0	0	2	0	0	0	1	0	0	0	**4**
Flexible manufacturing	2	0	1	2	2	2	1	0	0	0	1	**11**
Supply chain flexibility	2	1	1	2	2	2	2	2	0	1	1	**16**
Traceability	1	0	0	1	0	1	2	1	0	0	1	**6**
Monitoring & optimisation of resource efficiency	0	0	0	0	0	1	0	0	2	1	1	**5**
Monitoring and decision making for performance optimisation	2	0	2	0	1	2	1	1	0	0	0	**9**
Condition monitoring, predictive maintenance	0	0	0	0	0	0	0	0	0	0	1	**1**
More intuitive system interaction / mobile devices	0	0	0	1	0	0	0	0	0	0	0	**1**
Overall response to trends	**7**	**1**	**4**	**8**	**6**	**10**	**6**	**6**	**2**	**2**	**6**	

Table 6: Mapping manufacturing trends to industrial needs

Observations and assessment

- Industrial needs which are strongly trend-driven: Looking at the impact scores, it can be observed that the industrial needs *supply chain flexibility*, *flexible manufacturing*, and *monitoring and decision making for performance optimisation* are most strongly related with the manufacturing trends (high impact score). Since these industrial needs are responding to so many trends, it is rightfully so that the manufacturing domain considers them important (see D2.2).
- Industrial needs which are weakly trend-driven: By contrast, the needs for *more intuitive system interaction / mobile devices* and *condition monitoring & predictive maintenance* (a sub-topic to monitoring and decision making for performance optimisation) seem to be only weakly related with any of the trends (low impact score). This means that, interestingly, these needs do not seem to be driven very much by any trends; they seem to exist independently from any trend which drives them.
- Trends which manufacturing domain is most aware of: Looking at the scores at the bottom of the table showing the overall response of industrial needs to each manufacturing trend, *maintain competitiveness of high-wage countries*, *increasing complexity of products, processes, supply networks*, and *individualisation and high quality* are addressed best by industrial needs. This indicates that the manufacturing domain is well aware of these trends and how they affect them today and in the future.
- Trends which manufacturing domain is least aware of: By contrast, the trends *shortage of skilled staff*, *language barriers and cultural differences*, and *urban production* seem to only weakly translate into industrial needs. This may point to a blind spot of the manufacturing domain for these trends. Unless these trends are reflected by a felt need in the manufacturing domain, there is a danger that manufacturing businesses do not prepare sufficiently to respond to these megatrends when they become more prominent. Despite the fact that the manufacturing domain may not demand this (yet), strategic research is necessary so manufacturing IT can bring its contribution to responding to these trends, when they become more prominent.

6 Conclusion

Whereas most previous deliverables constituted separate building blocks in establishing either the push perspective (D1.1, D1.2) or the pull perspective (D2.1, D2.2. D2.3), this document analysed them jointly, thereby joining push and pull perspective.

Interesting observations have been made in each section and it will be necessary to reflect them appropriately in the upcoming roadmapping work and recommendations. As these observations suggest, there is benefit in following a strict separation of push and pull perspective, at least in a first step.

As the presented observations show, there is great potential for future manufacturing IT revealed by innovation pull (industrial needs which are waiting to be address by research) as well as innovation push (future research which could deliver capabilities to manufacturing businesses). Furthermore, as the presented observations indicate, there is a strong need for targeted strategic research in the field of manufacturing IT in order for the European manufacturing domain to be well equipped to successfully respond to future trends.