Deliverable 1.2

Preliminary Overview on Technology Push regarding Architectures and Services

DISSEMINATION LEVEL		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
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SEVENTH FRAMEWORK PROGRAMME

COVER AND CONTROL PAGE OF DOCUMENT	
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[1] **R**=Report, **P**=Prototype, **D**=Demonstrator, **O**=Other

[2] **PU**=Public, **PP**=Restricted to other programme participants (including the Commission Services), **RE**=Restricted to a group specified by the consortium (including the Commission Services), **CO**=Confidential, only for members of the consortium (including the Commission Services)

Change Control

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1.0	2014-02-28	Complete draft	Ursula Rauschecker	Fraunhofer IPA
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1 Introduction

The intention of this document is to provide an overview of the *push perspective* which serves as a main input for the roadmapping process of the Road4FAME project.

Elements forming the push perspective

The push perspective is established from three elements:

1. An overview of *ongoing and recent research* in the field of manufacturing IT (established in Task 1.1)
2. An overview of *future research challenges* in the field of manufacturing IT reported by current roadmaps, research agendas, and similar strategy documents (established in Task 1.2)
3. An overview of IT topics gathered from roadmaps, research agendas, and similar strategy documents which do *not* have an explicit manufacturing orientation but could cross-fertilize manufacturing IT (established in Task 1.3). These are referred to as *IT enablers*.

Element 1 of the push perspective is contained in deliverable D1.1. Element 2 is presented in this document and element 3 will be provided with a planned update of this document.

A defined approach to select relevant roadmaps, research agendas, and similar strategic documents to extract relevant information from them, to summarise and cluster the current research topics, future research challenges, and IT enablers was followed. Each step of the approach, including its results, is described in this document (D1.2).

Interfaces to the roadmap

The content of this document will populate the IT requirements, services, architectures, and infrastructure layers of the initial roadmap (refer to Figure 2). The planned update of this deliverable (overview of IT enablers) will contain the topics to populate the respective layer in the initial roadmap (labelled "ICT research" in figure 2).

The so-established push perspective populates all time periods of the roadmap, from the state-of-the-art and short-term columns to the medium and long-term, since it covers both recent and current research, as well as future research challenges which are not resolved yet.

Together with the socio-economic trends identified in Deliverable 2.3, and the results of the analysis of current research projects described in Deliverable 1.1, this report on research challenges and the following update about IT enablers will form a sound basis for further detailing and validating research challenges and enabling technologies, involving external experts from the Road4FAME Experts Group.

Since Road4FAME develops a roadmap for *IT architectures and services* in manufacturing, the consortium analysed the research challenges described in various strategic documents with regard to their implications/relevance for IT architectures and services for manufacturing. The relevance of each research challenge extracted is explained where applicable in order to be able to validate, prioritise and appropriately consider the topics during the roadmapping process.

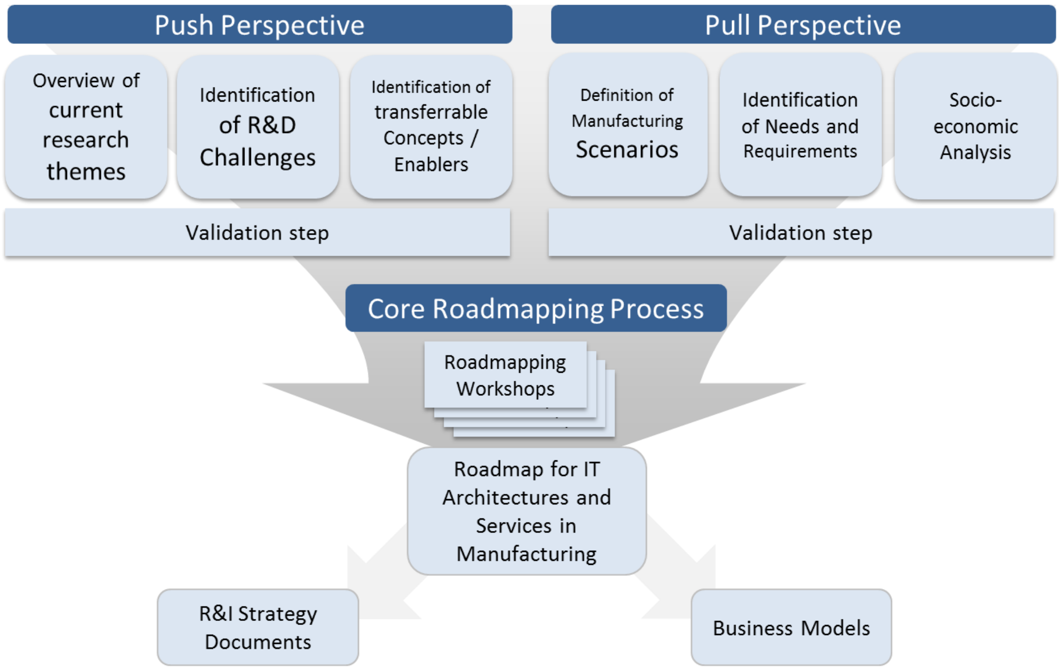

Figure 1: Road4FAME Work Plan Structure and Roadmapping Approach

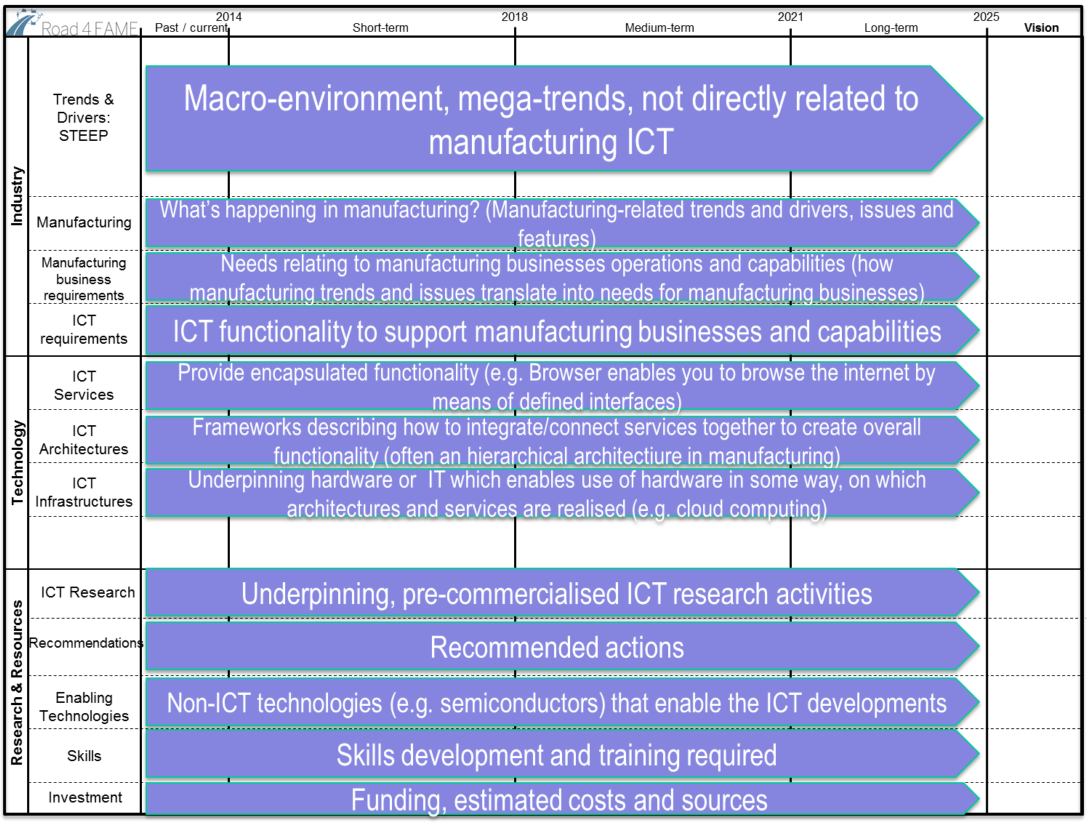

Figure 2: Roadmap Architecture as agreed during the 6-months meeting on November 12-13, 2013

2 Approach

In order to address the objectives of tasks 1.2 ("Identification of R&D challenges") and tasks 1.3 ("Identification of Key Enabling Technologies[3]") appropriately, an approach has been defined to enable a traceable and well-documented procedure.

To realise efficient analysis of strategic documents focusing on manufacturing IT and IT in general, the scope for analysis has been defined to limit the search space for strategic documents to an extent feasible for analysis. Overall, 6 strategic documents have been analysed in detail up to now.

2.1 Scope of analysis and information sources

In principle, two kinds of strategic documents are considered to be relevant in the context of tasks 1.2 and 1.3:

a) Strategic documents covering research challenges in manufacturing IT, e.g. regarding services/capabilities, architectures, or infrastructures to serve a certain purpose in manufacturing environments.

b) Strategic documents without explicit manufacturing orientation, covering a multitude of IT fields, which might provide concepts for future application in the manufacturing domain (spill-over / transfer).

Considered were the following a)-type documents:

- The ActionPlanT Roadmap for Manufacturing 2.0
- EFFRA Factories of the Future PPP Fof 2020 Roadmap
- German Industry 4.0 action recommendations document
- Portugese Technology roadmap
- A landscape for the future of HVM in the UK
- Road2SoS roadmap (production-specific part)

This set of documents provided a good sample to gain an overview of currently reported research challenges in manufacturing IT from. Altogether, several hundred research challenges are reported in these documents and were analysed in detail. Significant overlap was found among the topics reported in these documents.

[3] The consortium is aware that the term is used incorrectly here. Objective of this task is the identification of IT Enablers, namely IT technologies which could cross-fertilize manufacturing IT.

The extension of this analysis with regard to b)-type documents, and the validation of the research challenges and enabling technologies analysis is foreseen as described in section 4.

2.2 Analysis of relevant strategic documents

Since the detailed analysis work for the strategic documents and related research challenges was divided up among consortium members, a common structure for documentation of the results has been used to ensure that the individual results are easily comparable. This structure was represented within a table structure covering the following aspects:

- Source / Strategic Document reference
- Research challenge / topic
- Timeline (state-of-the-art, short, medium, or long term)
- Why should research be executed / what are the benefits?
- State-of-the-art / Why is research necessary?
- What should be researched (more detailed explanation)
- Relevance for architectures / services in manufacturing IT

2.3 Analysis boundaries

Strategic documents and research challenges focussing on PLM-related topics, i.e. mainly CAx and simulation as well as their integration, were not considered during the analysis, since they are thought to be relevant for the Pathfinder project[4] which is executed in parallel to Road4FAME and generates a roadmap for this topic.

2.4 Validation and prioritization of findings

The findings were clustered according to their occurrence throughout typical production system hierarchies. As a first validation step, a review of the results, their descriptions including innovative aspects and potential benefit, comments about the state-of-the-art, etc. was done by manufacturing experts in the consortium in order to have a sound basis for the involvement of project externals.

The involvement of external experts for validation will take place after the submission of this deliverable in the form of workshops where first roadmap drafts, including the results reported in this deliverable, are validated and extended. While doing so, the findings reported in this deliverable will be prioritised according to their potential industrial relevance, i.e. impact, and their innovativeness. This is thought to give an overview on the relevance of the identified research challenges.

[4] http://www.pathfinderproject.eu/

2.5 Execution of research challenge analysis

Overall, 6 strategic documents were analysed, by partners CMF, SEZ, IfM, and IPA along the information structure presented in section 2.2.

From these individual document analyses, the most relevant topics and strands were identified and merged appropriately. The result of this work is documented in the following sections.

3 Manufacturing-focused research challenges

From the 6 strategic documents focusing on manufacturing IT research challenges, research challenges were extracted and clustered appropriately. These clusters ("research themes") are presented in this section.

The research challenges extracted from the strategic documents were clustered according to the structure already developed for Deliverable 1.1, representing the major levels of manufacturing environments.

Note that in D1.1, the themes are clustering *current and recent research topics*, whereas the themes in this document are clustering future research challenges. In this document, the timelines put the future research challenges into context with current research.

3.1 Factory level results and concepts

3.1.1 Cyber-physical (production) systems / intelligent components

Objective / Purpose of development: Making manufacturing environments more intelligent and flexible, i.e. able to provide relevant data, e.g. to exploit analysis potentials, and to enable more sophisticated control mechanisms. The expected benefits range from additional information to be used for maintenance prediction or optimisation of product development to reduction of latency times, and increase of process quality or production flexibility.

Innovative aspects in current projects: In order to realise the integration of intelligence to products, carriers, tools, fixtures, machines, transport systems, etc. in manufacturing environments research is executed on

- Sensor and actuator systems which are able to be integrated to these objects. In this regards, aspects like energy autarkic systems, miniaturisation, or integration of innovative measurement and actuating technologies in order to extend the range of potential applications, data to be gathered, etc. is of relevance.
- Easy integration of CP(P)S to production environments. In this regard, appropriate communication infrastructures, interfaces (protocols, syntax, and semantics) and services (CPS and service registries, analysis of data which is gathered, appropriate control mechanisms, etc.) have to be developed and standardised.
- Security / access rights when intelligent components move throughout the supply chain. An example is the access restriction of tracking data when products are delivered to customers and store respective data by themselves.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to CP(P)S / intelligent components:

- Development of low-power embedded distributed control system architectures
- Data-processing and data-mining technologies capable of extracting the knowledge and model of intelligent components (e.g. machines) and process parameters across the lifecycle.
- Development of methods and tools for CP(P)S modelling and design, simulation and validation of overall systems, virtual prototyping, smart systems integration
- Development of distributed systems capable of real-time communication
- Distributed Internet-of-Things-based M2M connectivity leveraging future cloud deployments to different classes of devices across the shopfloor

Timeline: long-term

3.1.2 Plug & Produce / self-describing and easily (re-)configurable equipment and components

Objective / Purpose of development: Minimum effort for equipment integration during ramp-up or reconfiguration of manufacturing environments. Besides easy integration of components, also their reconfigurability and reusability play an important role here in order to support fast reaction on market changes.

Innovative aspects in current projects:

- Equipment self-descriptions or adapter components which are representing knowledge about the equipment / manufacturing facilities and their components. The descriptions or adapters should be able to be easily interpreted by higher-level IT systems in order to enable fast access to the manufacturing capabilities provided by the equipment in order to exchange data, i.e. commands and parameters as well as events and measurement results with them.
- Automated generation and update of equipment self-descriptions or configuration of adapter components and associated mapping mechanisms would increase the benefit of self-descriptions and adapter components considerably. First of all, it obviously decreases integration effort since the descriptions and mappings do not have to be created manually. But even more important is the up-to-date-ness which is ensured by this and would probably suffer during system changes otherwise.
- In order to further decrease integration efforts, this approach could go beyond description of protocols, input / output parameters etc., e.g. by representing further equipment characteristics, process knowledge, etc.
- Additionally, easy programming or configuration of machines plays a role here. This could e.g. take place via the automated generation of machine programs based on product and process specifications.

- Flexible concepts to stepwise increase the degree of automation in manufacturing are also to be mentioned. They could e.g. be based on manual workplaces which can easily be extended with automation equipment when throughput increases and vice versa.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to flexible and reconfigurable manufacturing equipment:

- Development of multi-disciplinary models and tools for designing flexible and easily reconfigurable systems and machines, including dynamic simulation and monitoring
- Development of open IT platforms for integration and networking of control systems. This includes aspects like service-oriented control system architectures
- Development of local intelligence and signal-processing solutions for self-adjustment and correction. This item may also concern item 3.1.6 "Decision making / Factory optimisation".
- A formal knowledge repository for designing flexible and reconfigurable systems and machines including available settings, best practices, etc. This item also concerns item 3.1.4 "Factory Knowledge Base".
- Universal adapters to interface devices with middleware and translate data collected from them. Adapters should (semi-)automatically integrate with underlying legacy systems.
- Development of generic M2M workbench which will serve as the platform-independent design time environment for decision makers to monitor and manage distributed assets.
- On-demand modular and replicable models for faster factory initialisation. This includes appropriate ontologies, data and modelling approaches for different domains (material flow, IT architectures, management structures, equipment-behaviour description, etc.), tools for collaborative modelling of facilities, and tools for managing and monitoring the deployment in a closed-loop way.
- Manufacturing systems should be able to be conceived from scratch as combinations of smart and exchangeable mechatronic modules. To do so, electro-mechanical and learning controllers for adapting the system behaviour to changing environments and system degradations have to be developed.

Timeline: mid-term

3.1.3 Autonomous manufacturing system components

Objective / Purpose of development: The objective of implementing autonomous manufacturing system components such as products, carriers, machines, robots, or transport systems is mainly to increase flexibility and agility in manufacturing environments. The manufacturing system components are intended to self-organise and act autonomously, i.e. without being strictly controlled by higher-level systems.

Innovative aspects in current projects:

- Implementation of agent-based concepts in production systems. In detail, this means that system components, e.g. specific machines, carriers, or transport vehicles act on their own following a specific objective. For successful implementation of such concepts, it is necessary to also consider the following aspects:
    - In order to be able to act autonomously, the components have to be aware about their environment and current situations. Appropriate sensors and intelligence / interpretation mechanisms have to be integrated to components, together with the ability consider historical data.
    - Since concepts for autonomous systems do not foresee top-down/external commands to be received by the system components to be executed, the components have to make decisions on their own. To achieve this, on the one hand, it is necessary for systems to be aware of the current digital and physical situation. On the other hand, well-defined local objectives have to be available which fit into the global objectives of the overall manufacturing environment.
- Cooperation and self-organization: To avoid conflicts among several autonomous components all dealing with the same or similar tasks, it can be useful to create component groups, i.e. groups of autonomous components which are able to talk to each other in order to align tasks with each other or even share them.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to autonomous manufacturing system components:

- n.a.

Timeline: n.a.

3.1.4 Factory knowledge base

Objective / Purpose of development: To collect and store data gathered throughout the manufacturing environment in order to make it available for further analysis and optimisation tasks. Together with the following two topics, factory knowledge bases contribute to the implementation of Big Data in production.

Innovative aspects in current projects:

- Appropriate information structures and data models have to be developed which represent the manufacturing context of a certain factory / production environment appropriately. In order to enable easy access to the information stored within such structures, the respective services have to provide standardised interfaces to request specific data sets. Besides this, the information structures and data models representing factory knowledge have to be extendable in order to ensure that they are applicable not only for specific cases and can be adapted to changing manufacturing environments (e.g. when machines are reconfigured, product changes are made, etc.)

- Furthermore, it may be useful to map the factory-specific data gathered to consistent, standardised models, e.g. by means of semantic mapping mechanisms, in order to make them usable also for applications or services which are not implemented or customised for the specific production environment. Related semantics would have to represent production functions and equipment appropriately.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to knowledge management in manufacturing:

- New distributed perception architectures for handling large amounts of data from sensors, filtering at different levels and sensor-data fusion and aggregation.
- Real-time event repository based on fast in-memory processing technologies which can be parsed with minimal lag and resolved against particular exception conditions.
- Real-time synchronisation of factory models for production lifecycle management by means of real-time data acquisition from shop floor level.
- Distributed data consistency across backend business systems, intermediate mobility infrastructure, and frontend systems such as mobile apps.
- Semantic technologies, digital libraries and intelligent information retrieval for manufacturing knowledge capitalisation from different interconnected legacy systems and user interfaces.

Timeline: mid-term

3.1.5 Data analysis

Objective / Purpose of development: There is a wide range of objectives which require analysis of available production data. Examples are performance assessment, energy monitoring, maintenance prediction, etc. All of them have in common that additional information needs to be extracted from data gathered from manufacturing environments in order to become aware of certain conditions, initialise events e.g. based on exceeded thresholds, etc.

Innovative aspects in current projects:

- Data gathering by means of additionally available/integrated systems and appropriate data monitoring tools for various application cases.
- Beyond transferring Business Intelligence concepts to the production level, a major challenge dealing with data analysis in production is the analysis of data in “real-time”, i.e. fast enough to have results available within seconds or minutes and herewith having a sufficiently up-to-date digital representation of the physical factory (e.g. for monitoring energy consumption

or creating commands for certain actions). In Business Intelligence applications time constraints are set much wider and timing requirements are significantly less strict

- For data analysis in production, data mining and herewith finding new interdependencies in processes etc. plays a major role, too. In this regards, methods like pattern recognition, adapted to manufacturing-specific information structures, and interpretation mechanisms e.g. based on semantic technologies, are highly relevant. Also, efficient ways to analyse Big Data are required.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to data analysis for manufacturing:

- Develop big-data intelligence and signal-processing solutions featuring self-adjustment and correction capabilities, and covering a wide field of sensing and detection systems integrated / considered during respective analysis.
- Exploit Complex Event processing technologies in production
- Modelling for complexity management, i.e. usage of models to represent and analyse interdependencies and behaviour of system behaviour not only during engineering phases, but also / especially during operating stages. Therefore, appropriate data gathering and automated modelling, methods and tools for analysis, etc. are necessary.
- Artificial vision systems for advanced data gathering and analysis

Timeline: mid-term

3.1.6 Decision making / Factory optimisation / Emergent behaviour

Many approaches for factory optimisation are based on simulation. Since this is in the scope of the Pathfinder project[5], they are not considered here.

Objective / Purpose of development: Optimise manufacturing environments, i.e. finding an optimum throughout all involved components (products, equipment, etc.) and processes (engineering, production, sales, etc.) by means of intelligent decision making. Decisions have to be made according to strategic factory objectives and current situations which means that appropriate actions also have to be taken in case of unexpected events.

Innovative aspects in current projects:

- Interdependencies among available data: Knowledge about how available information has to be analysed to extract specific KPIs, and how those KPIs (which have to be aligned with strategic objectives of a factory) can be influenced by the production system. This goes in close cooperation with appropriate data analyses and their implementation.

[5] http://www.pathfinderproject.eu/

- Knowledge-based systems which could be self-learning from existing manufacturing settings and configurations, and feedback e.g. from customers, in order to suggest and establish new settings as fast as possible.
- Safe decision-making: Since decisions cause actions within the manufacturing environment, systems have to ensure that these actions do not cause a decrease in efficiency or other strategic KPIs of a factory, or even cause damages to the overall system or humans. To do so, the impact of decisions has to be known to the system.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to decision making and factory optimisation:

- Development of condition-prediction reference models to support decisions which should be integrated to software environments and translated to appropriate algorithms.

Timeline: mid-term

3.1.7 User Interfaces / Improved Usability

Objective / Purpose of development: To hide the complexity of manufacturing IT systems from users, i.e. production engineers and workers. Additionally, intuitive usage of the systems should be enabled. This topic is relevant for manufacturing companies in order to optimise their process and IT systems interactions. However, it is more important for manufacturing IT providers in order to strengthen their market positions.

Innovative aspects in current projects:

- In order to hide complexity from users, a major aspect is to hide accessibility of functionalities from the user which are not relevant at the given moment or in the given context. To do so, it is essential to implement appropriate modular architectures which enable user-specific, situation-specific, and context-specific feature / service provision. Furthermore, user interfaces have to be migrated from "IT expert views" to "user views", since many user interfaces show information and feature structures etc. in the form they are represented in the IT system and not in the way the user would expect. Data population should take place user- or role-specific which has to be enabled by a respectively well-structured knowledge warehouse
- Augmented reality also can contribute to usability since it is able to integrate user interfaces seamlessly to workflows and extends the visualisation options in production environments.
- The introduction of mobile applications to manufacturing environments is an approach to make user interfaces available where they are needed, providing ways to interact with stationary equipment in a mobile way. Especially in existing manufacturing environments they also can help to replace intelligent equipment and components since they enable ad-

hoc user actions to gather and monitor data (e.g. from simple measurements up to complex KPIs) and execute commands.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to user interfaces:

- Development of standardised user-interface libraries which incorporate easy-to-access symbols and bottoms for older workers and are also easy to incorporate in production systems.
- Overhaul legacy systems by decoupling user interfaces from main systems logic and incorporating modular approaches which can be extended based on new advances in user-interface layouts and languages
- Develop a feedback mechanism to capture user interactions and improve iteratively future versions of the user interfaces and related systems
- One-stop-shop for mobile manufacturing apps to deploy use-case-specific factory-performance management apps
- Enhanced visualisation of complex manufacturing and production data, i.e. reduction of complexity of high volume data through appropriate data clustering and visualisation techniques, human-data interaction methods including means for multi-cultural interactions, visualisation sharing using hosted social collaboration platforms which enable workers and decision makers to discuss and brainstorm factory issues and process improvement strategies, etc.
- New ICT-facilitated initiatives to engage younger generations in manufacturing, e.g. by related ICT-based games, right awareness channels exploring social networks to get in touch with the young generations, appropriate physical demonstrators, metrics and feedback mechanisms to understand the impact on young generations, etc.
- Adaptive learning mechanisms to fit in as much as possible with the daily practice of workers
- Crowdsourcing of inter- and inter-company experts for industrial learning
- Modelling and representation of human behaviour in terms of intentions, reactions, difficulties and uncertainties in ICT middleware and related analysis of observation sources such as HMIs, workflow tracking etc. in order to enable fast reorganisation, adaption and optimisation of workflows, task distribution, etc.

Timeline: mid-term

3.1.8 Man-Machine Interaction

Objective / Purpose of development: In order to increase ergonomics for workers, man-machine interaction intends to take loads or environmental risks from workers during the execution of tasks for which other human skills are needed, e.g. due to positioning precision required, process knowledge, etc.

Innovative aspects in current projects:

- The most critical aspect of this research topic is the safety of workers which as to guaranteed at any time when workers are closely cooperating with robots. For this reason, the safety and security mechanisms of the systems have to be implemented in a redundant way and able to react in real time, since robots applied in industrial contexts usually have much power which could cause considerable damages to the humans in case of system failures.
- In case the robots only take over the load from the humans, and are guided by the human who moves the product the robot holds, the implementation of associated movement control algorithms is a challenge, since forces caused by the heavy products themselves are much higher than the forces caused by the operator movements.
- In addition to direct interaction, robots can also be used for virtual interaction in critical environments. This means that the operators are guiding a virtual representative of the robot while the real one is executing tasks in a critical or non-ergonomic environment.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to professional service robots and multimodal human-machine-robot collaboration:

- Highly advanced perception and situation analysis capabilities to plan automatically or interactively in the context of incomplete information about tasks and scene
- Semantics, reasoning, self-learning and decision-making capabilities for smart and autonomous robots interacting with other robots, machinery and human workers. This item also concerns item 3.1.4, 3.1.5, and 3.1.6 (topics related to data gathering, storage, analysis, and related decision making).
- Novel multimodal interfaces among machines, robots, and human operators in order to improve worker interaction with factory machinery and enterprise systems. This includes embedded cognitive functions for supporting the use of machinery and robot systems in changing or less/partly structured shop floor environments

Timeline: long-term

3.1.9 Manufacturing-IT as a Service

Objective / Purpose of development: Since manufacturing IT systems are usually quite expensive and require administration efforts which especially SMEs cannot afford, Manufacturing-IT as a Service concepts focus on providing respective systems via new business models and cloud-like infrastructures. Especially the initial costs for the application of manufacturing IT systems are eliminated, e.g. by the provision of pay per use (e.g. tracked products) or time period (monthly) billing options.

Innovative aspects in current projects:

- In order to provide services via marketplace-like platforms, the services have to be made available via appropriate service registries. There, they should be categorised in order to simplify service search for potential applicants, etc.
- Since services provided via such platforms are usually focussing on specific functionalities such as tracking, certain analyses, workflow man, etc. it should be able to orchestrate them in order to create higher level functionalities or services which are e.g. providing holistic MES features to a user.
- In case the IT services used on-demand and running on cloud infrastructures do not only provide features covered by encapsulated software, but also functionalities which require integration of / communication with equipment, appropriate interfaces have to be provided, too, together with well-defined access control and other security mechanisms.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to manufacturing-IT as a Service:

- Control of machines / equipment from cloud environments. Therefore, real time communication capabilities, the technological basis for such services would have to be developed first.
- High-performance computing leveraging the cloud to deal with the execution of additional analyses based on large amounts of data and related real-time reactivity which would not be possible on standard IT infrastructures within factories.
- Provision of a one-stop manufacturing IT app store

Timeline: long-term

3.1.10 New factory level manufacturing IT features

Objective / Purpose of development: The purpose depends on the respective feature developed. Examples are environmental foot print calculation for production environments, or automatically finding optimum production settings during reconfigurations based on historical data. Manufacturing IT providers intend to strengthen their market position or to extend their product portfolio by means of such developments.

Innovative aspects in current projects:

- Development of flexible, intelligent, and self-organising production planning and execution services. The challenge here is to deal with ad-hoc requirements, e.g. resulting from product changes or specific orders, in order to initiate production system reconfigurations and appropriate production process execution.

- Self-diagnosis systems for manufacturing equipment in order to make components self-aware and support self-healing production environments.
- Development of sustainability or energy efficiency monitoring and optimisation methodologies. An objective could for example be to calculate environmental footprints for products during their manufacturing. Therefore, not only resource usage of machines has to be considered, but also the consumption caused by the whole production environment such as buildings and transport units.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to new manufacturing IT services:

- Dynamic manufacturing execution environments for smarter integration of new evolving features and smarter integration into dynamic and agile factories
- Complex event processing (CEP) and data-stream analysis for generating rea-time production performance indicators
- Condition-based optimisation of production schedules in real time based on implementation and adaption of self-learning approaches to MES
- Services for continuous evaluation and mitigation of manufacturing risks. This includes tools to identify and monitor specific key risk indicators, analytical algorithms able to suggest recovery or mitigation strategies, support to decision making processes, and visualisation of data about identified risks for different stakeholders, dynamic rendering of key risk indicators, etc.

Timeline: mid-term

3.1.11 Knowledge transfer between manufacturing and engineering

Objective / Purpose of development: In order to enable short time to market, it is necessary to transfer product designs seamlessly to production environments with a minimum effort for specific adaption of manufacturing equipment, e.g. in terms of configuration and programming.

Besides this, product design would in most cases benefit from manufacturing knowledge in order to address overall company objectives.

Innovative aspects in current projects: To achieve automated transfer of knowledge from product design to manufacturing and vice versa, research is executed on

- Product specifications already including all information necessary to adapt related production processes, since nowadays much of this knowledge is brought into the process by production engineers.

- Information has to be gathered during manufacturing and usage of products. Therefore, appropriate integration of (additional) data sources is necessary. The data gathered have to be mapped to respective product design related aspects.
- Cooperation mechanisms, to reinforce the exchange of information and the sharing of knowledge among the actors involved in all the phases of the product conception and realisation.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to knowledge transfer between manufacturing and engineering:

- Manufacturing intelligence for informed product design, based on the topics already under research, the following aspects should be developed additionally: This includes semantic technologies, analysis and data filtering for process knowledge management as a tool for designers do evaluate the relevance of feedback from manufacturing phases; Automatic extraction of generalised parametric models from existing examples of product models and process routings; Effective implementation within existing PLM tools for bi-directional alerting and for faster searches of existing designs that can be reused.
- Conception stage integration of multi-disciplinary and synergetic technologies such as new machine architectures, redundant feed-drives, active machine elements, innovative structural concepts in order to enable advanced equipment with maximised throughput and minimised total lifecycle environmental and economic costs.

Timeline: mid-term

3.2 Production network related results and concepts

3.2.1 Cloud manufacturing

Two definitions exists around Cloud manufacturing: a) Using cloud computing for manufacturing, and b) the transfer of cloud computing concepts (Anything-as-a-Service – XaaS) to the manufacturing domain and implementation of the Manufacturing-as-a-Service (MaaS) paradigm. Here, we are focussing on the second aspect, since the first is already covered to a large extent by section 3.1.9.

Objective / Purpose of development: To make production networks more flexible, i.e. implement appropriate IT platforms to realise Virtual Enterprise concepts. To do so, manufacturing facilities have to be integrated on demand, which also requires ad-hoc integration of the participants' manufacturing IT infrastructures in order to be able to easily communicate factory capacities and capabilities, orders, production status etc.

There are some industry settings, from which interest in such a concept is stated such as associations of SMEs who intend to jointly provide customisable products, or industry clusters who would like to make their members' abilities easily available (searchable and usable) for other members.

Innovative aspects in current projects:

- In order to be able to manage distributed manufacturing facilities according to the needs of a virtual enterprise, these facilities have to be integrated and described on the respective cloud manufacturing platform. Therefore, usually concepts to virtualise manufacturing resources are used which intend to generally describe the resources, their capabilities and capacities, and which give information about how to access / communicate with them in order to enable on-demand order execution.
- Especially when manufacturing clouds are not restricted to well-defined associations of manufacturers, alignment and joint execution of manufacturing processes and the related capacity planning might become a challenge since priorities of the involved partners likely will differ. The challenge is to dispatch and execute incoming manufacturing orders in a way that end-user requirements are fulfilled as well as prioritisation of individual production partners are considered.
- Furthermore, exchange of production level information throughout the virtual enterprise requires well-defined handling of the related data in order to make sure that no unauthorised party is able to access respective information. An example therefore could be that within a value chain, one manufacturer delivers detailed measurement data to the following process executor while all other participants are only allowed to know that the sub-product delivered has sufficient quality. However, data access also concerns availability of associated secure business and IT infrastructures.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to collaborative manufacturing concepts:

- Unified resource-naming schemes which could be extended to abstract and physical entities within the supply network
- Service delivery framework for easy deployment and consumption of manufacturing services, enabled e.g. by service visibility, discovery, composition, mash-up environment and metering capabilities
- End-of-life applications in a network of remanufacturing stakeholders, including standardised product data models for remanufacturing information, unified product tracking and mapping schemes, distributed data storage persistency for product data across enterprise systems, etc.
- Connected objects for assets and enterprises in supply networks, i.e. open and interoperable Internet-of-Things on-demand platforms for mass configuration, modelling and interfacing co-operating objects with backend business systems as well as other Internet-of-Things platforms; discovery, scalable look-up and monitoring of IoT resources based on ID, location,

type, services and subscription topics; effective and efficient security and privacy mechanisms throughout the related infrastructure, etc.

- Digital-rights management of products and code in supply networks and multi-enterprise role-based access control

Timeline: short-term

3.2.2 Total Customisation / Ad-hoc establishment of production settings

Objective / Purpose of development: Individualisation is one of the major socio-economic trends identified within D2.1. In order to address it and enable total customisation of products, appropriate IT infrastructures and tools have to be implemented which are able to manage and analyse product specifications, select manufacturing facilities accordingly, and dispatch and track respective orders. Potential applications of such systems focus on high-value products for which added value by means of individualisation is provided, e.g. high-value design consumer products.

Innovative aspects in current projects:

- Appropriate creation tools and analysis mechanisms (for the mapping from specification to production needs) of customer-specific product specifications is the basis for product design executable by customers and automated transfer of so created specifications to the production environment. To achieve this, mainly solutions which are combining CAD and knowledge-based system capabilities are considered to be relevant. However, this topic is not considered in Road4FAME since this is a topic related to PLM and herewith in the focus of the Pathfinder project.
- Manufacturers have to provide their capabilities and possible customisation options to associated platforms, e.g. by means of appropriate digital resource / capability descriptions. The information provided has to be extracted from real equipment capabilities, i.e. not specified as pre-defined options in order to enable full customisation.
- When a product specification is analysed, appropriate production partners have to be searched and selected. This applies for suppliers of sub-products as well as assembly tasks etc. To do so, e.g. semantic technologies can be used, together with rule engines etc. to find partners who can execute the needed processes in combination with the required process parameters. Also costs and available capacities for specific manufacturers should be considered during set up of the ad-hoc supply chains.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to product customisation and ad-hoc establishment of production environments:

- Collaborative design environments for SME involvement, including search functions to find experts in the community who could contribute, interoperable and open interfaces to connect systems across competence centres and companies, appropriate digital rights management and user interfaces for seamless collaboration.

- ICT- and market based costing and manufacturability assessment, including predictive costing models, searchable ontologies for mapping company experience, expertise and capability to deliver products according to new designs, predictive customer-requirements modelling based on social technologies and data mining of sales records and customer feedback, correlation of financial and production KPIs to capture holistic overviews, etc.

Timeline: mid-term

3.2.3 Horizontal integration and optimisation of value chains

Objective / Purpose of development: The objective of activities focusing on this topic are mainly faster and more flexible reaction to changing markets, reduction of search efforts, failure consequential costs, production downtimes, inventories, high-effort tracking in case of quality issues as well as lead times, and the improvement of product quality, throughput, etc. While addressing these objectives, it has to be considered that none of the stakeholders is fleeced by achieving global optima.

Even if there exist already some tools for process and supply chain optimisation, there is huge optimisation potential remaining, for long-term production networks which are based on strategic co-operations which intend to jointly improve their processes, as well as for companies which frequently change suppliers in order to react to changing market demands, etc.

Innovative aspects in current projects: Current research on optimisation of production environments considers the following topics:

- Gathering higher amounts of data which can be used for optimisation tasks, e.g. from production, business, or logistic processes. This can e.g. take place by means of CP(P)S, but also be enhancing existing IT systems with additional intelligence. The exchange of process relevant data has to take place in a standardised way to ensure fast integration and a common understanding between various manufacturing facilities. Furthermore, respective information has to be available in time (i.e. minimum in parallel to the material flow) to control and optimise value chains in a decentralised network.
- Assisting systems which are able to compare planning and real data with each other and suggest actions in case of differences.
- Improved demand forecasting, performance assessment, and other planning and data analysis tools. Therefore both aspects have to be considered: the algorithms which are used to execute analysis and planning, and the amount and quality of data integrated to those systems.
- Data mining and analysis systems which are able to detect additional interdependencies and optimisation potentials throughout production networks.

- Decision making technologies considering the needs of several network participants while aiming at global optima. The latter have to be specified e.g. by aligning strategic objectives of core production network partners.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to horizontal integration and optimisation of value chains:

- Complex Event Processing for state detection and analysis in supply networks, i.e. CEP algorithms, formulation of predicates for detection and ways to filter, aggregate and correlate results from multiple predicates, query optimisation techniques, persistency, subscription and brokerage of events within a network of IoT resources, etc.
- Collaborative demand-and-supply planning, traceability and execution, including full tracking of product genealogy, uniform quality management, correlating KPIs, global optimisation, fast replanning and forecasting while considering manufacturing, sales, and logistics information at the same time.
- Data collection and anonymity during product use using advanced sensors and IoT advances to transfer product-specific data to monitoring services hosted in clouds, applying CEP algorithms to detect predicates and conditions on monitored use patterns in order to exploit the so generated knowledge for future product and service provision. Data security and privacy plays an important role for this topic.
- System-oriented quality control strategies in multi-stage manufacturing, supported by tools to prevent the generation of defects at single stage level and to prevent the propagation of defects throughout the system stages.

Timeline: mid- to long-term

3.3 Other results and concepts

3.3.1 Migration strategies towards next generation factories

Objective / Purpose of development: In existing factories, usually various legacy systems are in place in which relevant historical data is stored, etc. Furthermore, the slogan "never change a running system" is widely applied in industrial production environments, that is in order to not jeopardise robustness of production systems by integrating new features which might not necessarily be needed. To overcome these issues while introducing new IT concepts to factories, appropriate migration strategies are necessary.

Innovative aspects in current projects: While developing appropriate migration strategies towards next generation ICT systems in manufacturing, the following topics are to be considered:

- Definition of appropriate rules for decision making processes in production IT projects (e.g. for alignment of stakeholders with differing planning horizons and objectives), i.e. in networked systems with decentralised intelligence.
- New networked and flexible organisation structures for future intelligent factories.
- Real-time visualisation and calculation of possible decision options to increase planning reliability
- Development of specific project management support tools designed for the specific needs of manufacturing IT system projects.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to migration strategies towards next generation factories:

- n.a.

Timeline: n.a.

3.3.2 Performance assessment for future ICT applications in manufacturing

Objective / Purpose of development: In order to make sure that new ICT applications in manufacturing really fit the production environment to which they should be integrated, it is necessary to assess their performance as soon as possible, ideally before integration decisions are made. Appropriate applications would be highly relevant for industry since they make companies able to judge on ICT applications within their production environments without expert knowledge.

Innovative aspects in current projects: To assess the performance of future ICT applications in manufacturing without having them in place in a certain setting, it is necessary to

- Get fast and cheap statements about efficiency of certain technologies and production strategies specifically for the settings applicable for a certain company. Knowledge-based systems using information from previous analyses can contribute to this.
- Simulation-based approval of certain decisions / virtual try-out of specific IT components. To do so, the production environment and IT system behavior have to be modeled appropriately.

Future research recommendations: While current research projects focus on the topics described above, none of the projects provides fully developed or holistic solutions. For this reason, the topics listed there will also apply in the future. Besides this, additional research recommendations were identified with regard to performance assessment for future ICT applications in manufacturing:

- n.a.

Timeline: n.a.

3.3.3 Standardisation and reference architectures

Objective / Purpose of development: In order to establish manufacturing IT architectures which are integrable with other systems (e.g. of value chain partners), flexible in order to adapt to future needs, etc., it is necessary to establish a common understanding of basic system descriptions, interfaces, logical and infrastructure layers, etc.

Innovative aspects in current activities: In current projects, existing standards are used, further developed, new aspects are discussed, etc. New architectures are implemented prototypically. However, impact of these activities is most often restricted to the boundaries of the related projects.

Recommendations:

- Standardisation of collaboration and exchangeable information among systems (from small CPS to value chain level).
- Harmonisation / extension / simplification of existing standards for information exchange in production as appropriate for generalised applications.
- Definition of a reference architecture, i.e. a technological description and implementation of standard definitions, related logical and infrastructural layers, etc. in order to establish a common understanding of future manufacturing architectures and services.
- Open standards, operational systems, engineering tools, (communication) infrastructures which prevent access restrictions to future production IT system exploitations should be driven forward / used in respective projects.

Timeline: mid-term

3.3.4 Security, Privacy & legal aspects

Objective / Purpose of development: One of the main concerns related to future manufacturing IT systems is about security and privacy of such systems, since operational safety and confidential data of manufacturing environments may be affected.

Innovative aspects in current activities: In current projects, mainly existing security standards, technologies and methodologies are used, further developed, new aspects are discussed, etc. However, impact of such activities is most often restricted to the boundaries of the related projects. They often only consider certain security aspects, not the whole picture.

Recommendations:

- Establishment of security by design principles for manufacturing IT systems
- Development of IT security concepts, architectures, and standards which are able to establish trust, integrity and availability in open, heterogeneous system networks
- Unique and secure identities and appropriate validation mechanisms for products, processes, machines, etc.
- User-friendly security solutions

- Cost-efficient security solutions
- Guidelines and frameworks for IP, confidential data, liabilities within collaboration networks, etc.
- Establishment of certifications for parties (companies, IT-components, equipment, etc.) participating in future IT architectures and services for manufacturing

Timeline: mid-term

3.3.5 Business models and demonstrations

Objective / Purpose of the development: In order to achieve industrial acceptance of new developments for future manufacturing IT solutions, architectures and services, it is necessary to demonstrate their benefit along the underlying business model.

Innovative aspects in current activities: In current projects, focus is mainly on technological developments, even if projects are dealing with new business models. The industrial relevance of such business models is often not evaluated sufficiently.

Recommendations:

- Development of new business models exploiting new manufacturing IT architectures and services. To do so, two kinds of business models have to be considered: the implementation of superior value to existing business models, e.g. by providing additional information about existing products, the other is the provision of additional services, e.g. hosting of platforms or additional IT services based on new manufacturing IT paradigms.
- Establishment of demonstrator systems which not only show technological developments but especially the business models behind in order to enable evaluation of the benefits which are provided by the associated developments.

Timeline: mid- to long-term

3.3.6 Stakeholder education

Objective / Purpose of the development: Since a lack of knowledge is often restricting the willingness of stakeholders to support or participate in future manufacturing IT architectures and services, transferring knowledge about technical background, business models and benefits, etc. to them is a key enabler for future application and exploitation of respective solutions.

Innovative aspects in current activities: Current projects rather deal with teaching new production techniques by means of new technologies than teaching new technologies. Knowledge transfer mainly takes place via standard dissemination activities.

Recommendations:

- Communication of future manufacturing IT concepts with special focus on aspects like security and privacy, robustness, etc. which are related to main concerns of stakeholders

Timeline: short-term

4 Conclusion and Outlook

In order to establish a sound basis for the roadmapping process of the Road4FAME project, the analysis of current concepts and results from research initiatives / projects reported in D1.1 has been extended by comparing the results with research challenges focusing on manufacturing IT extracted from strategic documents from relevant initiatives and institutions. To do so, the consortium extracted numerous research challenges from strategic documents, analysed them, and clustered them into *research themes*. The descriptions of these research themes have been adjusted in this document to comprise recent and current research (T1.1), as well as future research challenges (T1.2).

Even though the strategic documents selected for analysis originated from independent sources, the contained research challenges overlapped considerably. This indicates that, for an initial overview of future research challenges, the set of strategic documents considered was already a sufficient sample.

In order to complete the work in WP1, this document will be updated with an overview of IT topics gathered from roadmaps, research agendas, and similar strategy documents which do *not* have an explicit manufacturing orientation but could cross-fertilize manufacturing IT (established in Task 1.3). These are referred to as *IT enablers*. Originally, it has been planned to identify IT enablers based on an extension of the project search described in Deliverable 1.1. However, this approach would have yielded only an overview of current and recent IT topics, whereas an overview of potential future IT enablers is more desirable for the purposes of Road4FAME.

The results of WP1 will be validated by means of the following activities:

A full-day expert workshop will be conducted on March 6, 2014. It includes the validation of the identified research challenges focusing on manufacturing IT. The approach here is to gather research challenges for manufacturing IT from experts independently from the results listed in this report, clustering according to the production system hierarchy (subchapters in section 3), and validation by evaluating overlaps. The collection of IT enablers is also foreseen as part of the workshop, again to validate and complement the findings of the Road4FAME consortium.

To furthermore verify that the established overview of future research challenges is exhaustive, the list of strategic documents considered by the ActionPlanT project will be revisited. Any of these documents which have been updated since, will be reconsidered. Documents which have not been updated since are considered to be covered already by our transfer of topics from the ActionPlanT strategic research agenda.