Deliverable 2.2

4 Reports on Needs and Requirements in Selected Manufacturing Business Settings

DISSEMINATION LEVEL		
PU	Public	**X**
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)	

COVER AND CONTROL PAGE OF DOCUMENT	
Project Acronym:	Road4FAME
Project Full Name:	Development of a Strategic Research and Innovation Roadmap for Future Architectures and Services for Manufacturing in Europe and Derivation of Business Opportunities
Grant Agreement No.:	609167
Programme	ICT – Challenge 7: ICT for the Enterprise and Manufacturing
Instrument:	Coordination Action
Start date of project:	01.06.2013
Duration:	29 months
Deliverable No.:	D 2.2
Document name:	4 Reports on Needs and Requirements in Selected Manufacturing Business Settings
Work Package	WP2
Associated Task	T2.2
Nature [1]	R
Dissemination Level [2]	PU
Version:	1.0
Actual Submission Date:	2014-07-03
Contractual Submission Date	2014-06-30
Editor: Institution: E-mail:	Christian Albrecht Steinbeis-Europa-Zentrum (SEZ) albrecht@steinbeis-europa.de

The Road4FAME project is co-funded by the European Community's Seventh Framework Programme under grant agreement n° 609167.

[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

Document History

Version	Date	Change History	Author(s)	Organization
0.1	2014-04-02	Document structure	Christian Albrecht	SEZ
0.2	2014-05-05	Summary of aspects from face-to-face interviews	Christian Albrecht	SEZ
0.3	2014-06-08	Summary of aspects from telephone interviews	Christian Albrecht	SEZ
0.4	2014-06-09	Summary of aspects from Brussels workshop and Porto workshop	Christian Albrecht	SEZ
0.5	2014-06-10	Description texts for challenges and needs	Christian Albrecht	SEZ
0.6	2014-06-13	Update with comments received from THHINK, ATOS; introductory sections added	Christian Albrecht	SEZ
0.7	2014-06-16	Update with comments received from CMF, ATOS	Christian Albrecht	SEZ
0.8	2014-06-22	Update of document with comments received from members of the Road4FAME Experts Group	Christian Albrecht	SEZ
0.9	2014-06-29	Finalization of document	Christian Albrecht	SEZ
1.0	2014-07-03	Final revision of document for submission	Christian Albrecht	SEZ

List of Contributions

Date	**Organization(s)**	**Person(s)**	**Contribution**
2014-06-13	THHINK	Prof. Haydn Thompson	Refinements to needs descriptions, description of IT requirements (sections 4.1, 4.2)
2014-06-13	ATOS	Silvia Castellvi, Diego Esteban	Refinements to needs descriptions, description of IT requirements (sections 4.1, 4.2)
2014-06-16	ATOS	Silvia Castellvi, Diego Esteban	description of IT requirements (section 4.3)
2014-06-13	CMF	Pedro Gama	Refinements to needs descriptions, description of IT requirements (sections 4.1, 4.2)
2014-06-20	SAP AG	Raik Hartung	Comments on section 4
2014-06-24	Technische Universität Dresden	Prof. Dr.-Ing. Martin Wollschlaeger	Comments on section 4
2014-06-24	HP Enterprise Services AG	Michael Mey	Comments on section 4
2014-06-24	XETICS GmbH	Dr.-Ing. Philipp Dreiss	Comments on section 4

Table of Contents

1 Executive Summary

Context and content of this document

The work documented in this deliverable is an important building block in the roadmap development process. It contributes to establishing the *pull perspective* which describes the *required* innovation by the manufacturing domain. To establish this pull perspective, we conducted a series of interviews with representatives of manufacturing businesses and manufacturing IT solution providers to learn about the *challenges* they are facing and the *business needs* which follow from these challenges.

This document presents the *challenges and needs* which were described in the conducted interviews. These are challenges and needs which either hold in one of the four manufacturing scenarios examined in Road4FAME (the Virtual Enterprise, the Green Enterprise, the Manufacturing-as-a-Service Enterprise, the High-Volume Production Enterprise, see section 4.3), are relevant across these scenarios, or are of general relevance to the manufacturing domain (see section 4.1 and 4.2). For the most widely relevant challenges and needs we present some considerations on the implications for *IT requirements* so to respond adequately to these needs with future manufacturing IT solutions. This is what makes this document a *report on needs and requirements*: A description of the needs of manufacturing businesses, and their translation into requirements for future manufacturing IT systems.

Relevance of this document

The knowledge about the needs of manufacturing businesses is very important to take into account in the Road4FAME roadmapping process because, ultimately, this ensures that the roadmap and recommendations are in alignment with the actual needs of manufacturing companies in Europe.

Approach

In a multi-step process, 37 representatives of manufacturing businesses and manufacturing IT solution providers were involved in face-to-face interviews and telephone interviews of 20-40 minute duration. Input from two workshops with the Road4FAME Experts Group contributes to this document as well. The preparation of this document involved manufacturing experts within the Road4FAME consortium and selected members of the Road4FAME Experts Group. (Please see section 3 for details on the approach.)

Important general observations

The following observations from the interviews are neither positive nor negative – they just have to be kept in mind to drive manufacturing IT innovation successfully.

I. **Manufacturing IT innovation – push or pull driven?** The interviews suggest that innovation pull for manufacturing IT innovation is slightly weaker than innovation push, i.e. manufacturing IT innovation seems to be mainly driven by IT solution providers and less strongly demanded by manufacturing companies. In manufacturing companies, decision makers seem to tend to only ascribe to manufacturing IT a supporting role, but not one which determines competitiveness. The impression arises that the potential of manufacturing IT innovation to drive competitiveness is underestimated and thus, IT innovation is not as strongly demanded by manufacturing companies as one might expect. In manufacturing companies, IT is seen as a tool to accomplish a given task. But its potential to enable entirely new capabilities may be underestimated. Among the reasons may be that, in many manufacturing businesses today, there is usually no role or function defined with specific responsibility for manufacturing IT or industrial automation so there is no person specifically looking at this topic who would drive manufacturing IT innovation. In many cases, manufacturing IT innovation has to be driven by C-level management, since none of the functions or departments below are specifically concerned with manufacturing IT. Thus, awareness for the potential of IT innovation in manufacturing must be achieved among C-level management to drive manufacturing IT innovation.

II. **What drives manufacturing IT innovation in manufacturing companies?** Due to globalized markets and the increasing competitive pressure, manufacturing companies seek to optimize where possible. Frequently, this creates also the need to innovate with regards to their manufacturing IT. But IT innovation at manufacturing companies is not only driven by competitive pressure. For many manufacturing companies, the driving force for IT innovation are ever stricter requirements imposed by large buyers. To these companies, *affordable* manufacturing IT solutions to meet the imposed requirements are crucial. A third driver for manufacturing IT innovation besides competitive pressure and stricter requirements are new standards and regulations.

III. **Sources of manufacturing IT innovation – where does innovative IT originate?** Frequently, IT innovation originates outside the field of manufacturing IT. In the past, manufacturing IT has benefitted e.g. from IT technologies from consumer markets, an example being the Ethernet technology. Thus, in search for future manufacturing IT innovation, consumer IT markets are worth watching. One can think of consumer IT markets as fulfilling something like a *sandbox function* for future manufacturing IT. Because of comparatively low requirements and the much greater market pull and volume on consumer markets, very advanced technologies can be seen at work very early here.

IV. **Manufacturing IT landscapes today – a wild garden.** Over the last decades, many companies have been implementing point-solutions, each bringing a specific feature or fixing a specific issue. Resulting from this approach is usually a highly heterogeneous manufacturing IT landscape which one interviewee likened to a “wild garden”. While these IT landscapes are already costly to administer, further addition of capabilities becomes even more costly because they have to be fitted into the “wild garden” already existing. This is a main reason why manufacturing companies are usually well behind the latest manufacturing IT technology. Without approaches to overcome this situation, or lessen the impact of it, manufacturing IT innovation will always be doomed to happen slowly. As we observed strongly, it is not the *unavailability* of technology that poses a bottle-neck for IT innovation in manufacturing companies, but the fact that the latest manufacturing IT technologies are in effect out of reach for most manufacturing companies, especially SMEs, due to the very high implementation costs.

V. **Security and privacy as a key imperatives.** More than ever, manufacturing is *based* on IT and thus IT security becomes increasingly important as well. There are many well publicized cases of big IT systems failing and costing a lot of money. Today, as many interviewees point out, concerns about security and privacy are the number one show-stopper for manufacturing IT innovation, an issue just as urgent as the high-implementation-cost-problem described above.

Most important challenges and needs

I. **Flexible manufacturing:** Arguably the most important need for manufacturing businesses is flexibility. The need for flexibility is driven by the trend to shorter product life-cycles which, in turn, is caused by increased competition due to global markets. Another important driver for the need for flexibility is the increasing demand for customized products which can be observed on many markets. Several interviewees described flexibility as the need which has most strongly increased in importance over the past decade, a trend, which they anticipate to sustain. Ironically, with manufacturing IT landscapes as they are today (see discussion of the “wild garden” above), flexibility is precisely what is very hard to achieve.

II. **Supply-chain flexibility:** Since parts of the value-chain lie outside plant or company boundaries, to attain highest levels of flexibility at the plant level, the upstream supply chain must be flexible as well. But the need for a flexible supply chain goes beyond realizing flexible manufacturing. It is also important to manage risk. The nuclear incident in Japan has shown, e.g. in the automotive sector, how vulnerable supply chains can be.

III. **Traceability:** A requirement in process industries already, traceability is increasingly desired in the manufacturing domain as well. Traceability comprises two aspects which are referred to as product tracking and product tracing. *Product tracking* describes the capability to follow the path of each single unit of a product throughout the supply chain. There is an increasing interest to not only track a product along the supply-chain but also throughout its entire life-cycle, enabling cradle-to-grave management of products with true re-cycling and re-manufacturing. As opposed to product tracking, *product tracing* describes the capability to identify the origin of a particular unit of a product by reference to records held upstream in the supply chain. Products are traced for purposes such as quality management, tracing of failures, product recall and investigating complaints. In coming years, manufacturing companies expect to increasingly face the requirement for traceability, often imposed by large buyers, e.g. OEMs who will not accept to take the financial responsibility for damage caused by product recall resulting from the failure of a low-price component.

IVa. **Monitoring and optimisation of resource efficiency** is becoming a goal of increasing importance, for several reasons. Firstly, in many industries, used resources constitute major expenditures and it is increasingly being realized that profitability is not only driven by output – it is also driven by resource-efficiency. A second reason for the increased need to monitor resource efficiency are regulations or tax incentives and a third reason are self-imposed targets to build and maintain an image of environmental sustainability. Increasingly, corporations provide sustainability information in their annual reports and appoint a responsible at management level to gather related data and implement improvements. Driven by such corporations, suppliers, in turn, are increasingly facing the requirement to provide resource efficiency information and to meet imposed targets. Accordingly, suppliers have to equip themselves with such resource monitoring capabilities to stay competitive.

IVb. Monitoring and Decision Making for Performance Optimisation: More efficient production requires more detailed knowledge about the production process. Today, in many industries measurements are taken already at numerous locations already. But data are acquired by a multitude of separate systems and are often not joined or correlated. Manufacturing companies already have lots of data available acquired at the shop floor but struggle to derive information from it, i.e. to correlate/interrelate it properly and derive decisions from it.

IVc. Condition Monitoring and Predictive Maintenance: The frequency and duration of machinery downtime drastically affects profitability. Seeking to use manufacturing assets to an optimal extent, to a near 100% uptime, there is a strong need for predictive maintenance, referring to the capability of estimating the health status of manufacturing assets during their operation and to repair even before actual damage occurs. Such capability reduces downtime due to unexpected failure, reduces maintenance costs by avoiding damage to the equipment and the time required to restore operating condition.

V. More intuitive system interaction / mobile devices: Driven by the proliferation of mobile devices in the consumer sector, manufacturing companies increasingly desire to apply mobile devices in a manufacturing context. A production manager who will be able to see manufacturing data in real-time on his smartphone or tablet is only one of the less interesting use cases. Mobile devices will become most powerful once they constitute a new form of human machine interface, enabling the worker to operate not just a single machine but interact with the entire production equipment, get context information and correlated information from multiple sources, receive maintenance instructions, interact with big-data-based decision support tools and adjust processes based on real-time information. Mobile devices in manufacturing are a move away from the central decisions made in a control room, rather, an order or a warning would be sent directly to the right person who can then take action. In the future, the need for mobile devices as human machine interfaces is expected to increase for they enable human beings to interact easily even with complex systems, and support informed decision based on real-time information. Such devices are what integrate the human being in an Internet of Things and allow him to interact with it.

Please refer to sections 4.1 and 4.2 for a more complete description of the challenges and needs, including also considerations on the IT implications following from these needs. Please referee to section 4.3 for challenges and needs which are specific to one of the manufacturing scenarios considered in Road4FAME.

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

The work documented in this deliverable is one important building block in phase 1, highlighted in figure 1. It contributes to establishing the *pull perspective* which describes the *required* innovation by the manufacturing domain.

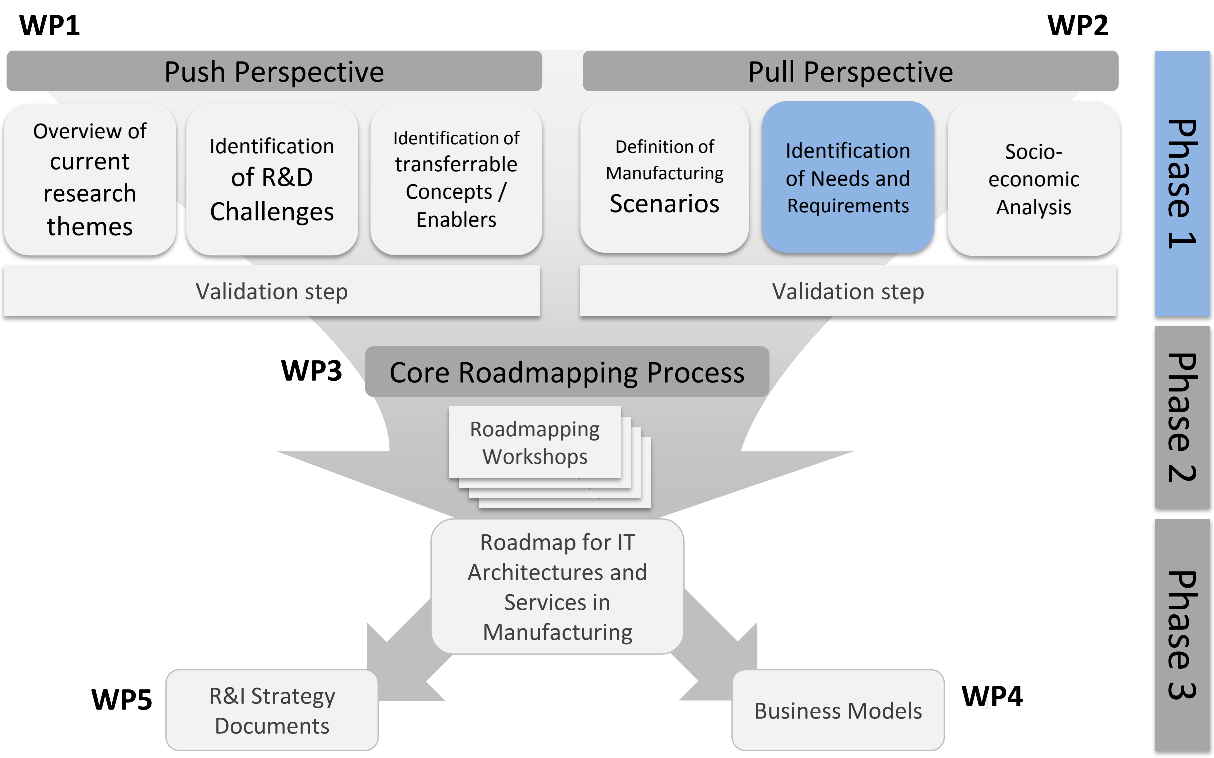

Figure 1: Road4FAME roadmapping process

Content of this document

To establish this pull perspective, a series of interviews was conducted with representatives of manufacturing businesses to learn about the *challenges* they are facing (new challenges as well as ongoing challenges) and the *business needs* which follow from these challenges. The challenges can be understood as arising from *external trends or conditions* which these manufacturing businesses are facing and to which they must respond successfully to remain competitive.

Report on needs and requirements in 4 manufacturing business settings

In Road4FAME, four manufacturing scenarios or "manufacturing business settings" are considered. Considering such scenarios is motivated by the assumption that, while certain *challenges and needs* are common to the entire manufacturing domain, other challenges and needs may be very specific to the particular stetting a manufacturing company is embedded in. The four manufacturing scenarios considered in Road4FAME – the Virtual Enterprise, the Green Enterprise, the Manufacturing-as-a-Service Enterprise, the High-Volume Production Enterprise – represent four interesting settings which were constructed for examination.

This document presents the challenges and needs identified *in all four scenarios* in a combined way. Sections 4.1 and 4.2 present challenges and needs which are of relevance across several scenarios *or* which seem to be of general relevance to the manufacturing domain as a whole. Section 4.3 presents challenges and needs which are relevant only to one of the scenarios (but may not be as relevant in other scenarios or in general).

For the challenges and needs which were found to be relevant across several scenarios or even to the manufacturing domain as a whole, we present considerations on the *IT requirements* which follow from these needs, i.e. what future manufacturing IT solutions will have to look like to adequately respond to the challenges and needs of manufacturing companies. This is what makes this document a *report on needs and requirements*: A description of the needs of manufacturing businesses, and their translation into requirements for manufacturing IT systems.

Relevance of this document

This knowledge about the needs of manufacturing businesses is very important to take into account in the Road4FAME roadmapping process because, ultimately, this ensures that the roadmap is in alignment with the needs of manufacturing companies in Europe. In turn, this ensures that the recommendations derived from the roadmap are also in alignment with the needs of manufacturing companies in Europe. And ultimately, this ensures that any action following these recommendations – e.g. European research activities – will deliver just the results that manufacturing companies in Europe need.

3 Approach and Scope

As has been described in the previous section, the objective was to establish knowledge on the *challenges* that manufacturing companies are facing (new challenges as well as ongoing challenges) and the *business needs* which follow from these challenges. Secondly, the objective was to translate these needs into *requirements for manufacturing IT.*

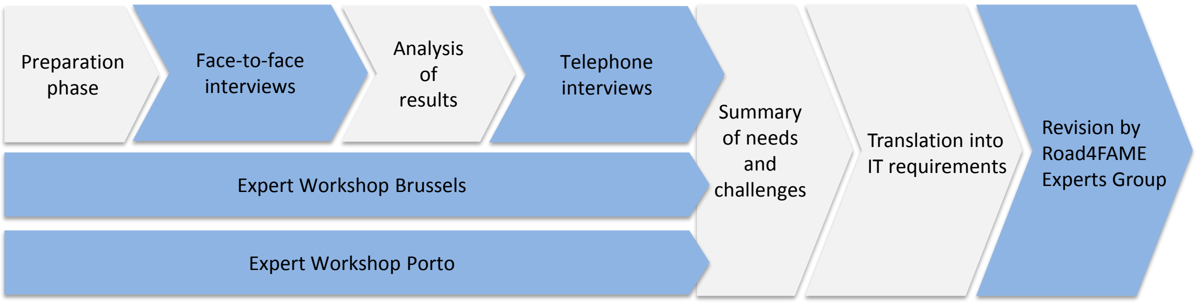

Figure 2: Approach for establishing challenges, needs, and IT requirements

Followed approach

Figure 2 shows the approach which was followed. (Grey colour indicates work primarily within the Road4FAME consortium; blue colour indicates information gathering from almost exclusively external sources.)

In a **preparation phase** prior to the interview phase, an interviewer guideline was elaborated by the Road4FAME consortium comprising a set questions to allow a well-structured, yet flexible, face-to-face interview (the interviewer guideline can be found in the annex). The questions were deliberately phrased openly, so to not lead the interviewee in a specific direction. Each interview comprised four parts: i) context and introduction to the interview, ii) brief information on the interviewee and company, iii) a set of general questions on challenges and needs, iv) a set of questions on challenges and needs, specific to one of the four Road4FAME scenarios, v) close of interview and outlook. The interviewer guideline was finalized in a personal meeting with members of the SmartFactory Initiative at DFKI in Kaiserslautern, Germany.

The **face-to-face interviews** were conducted at the Industrial Automation Fair in Hannover, during the days April 9-11. Overall, 26 face-to-face interviews were conducted (see Annex I for a list of companies interviewed) of 20-40 minutes duration each. The target group comprised representatives of manufacturing companies with direct contact to manufacturing operations as well as representatives of manufacturing IT solution providers. (In many cases, representatives of manufacturing IT solution providers were best capable of articulating the challenges and needs of manufacturing companies, based on their experience with their customers, i.e. manufacturing companies)

Following this face-to-face interview phase, a **first analysis** of these results was performed. Based on this analysis, **telephone interviews** were conducted to elaborate on key issues, to put observations in context and discuss possible interpretations. Overall, 11 telephone interviews were conducted with members of the Road4FAME Experts Group.

In parallel to the interview phase, **two Road4FAME Expert Workshops**, one in Brussels on March 6, and a second workshop in Porto on May 23 have also been used to discuss challenges and needs.[3]

All information gathered at face-to-face interviews and workshops, refined in telephone interviews, was subsequently **summarized**. Based in this summary of challenges and needs, Road4FAME consortium members discussed the resulting **requirements for manufacturing IT**.

In a final step, selected members of the Road4FAME Experts Group verified the described challenges, needs and the derived IT requirements and enhanced existing content. The result of all this is documented in section 4 of this document.

Design decisions

The following discusses some design decisions implicit to the approach described above.

- **Interviews over questionnaire-based survey:** Since it was the objective to receive an unbiased and broad overview of challenges and needs of manufacturing companies, interviews were the tool of choice. Although they involve significantly more effort to conduct than using a questionnaire, they allow to go beyond the closed questions of a questionnaire and capture responses to rather broadly posed questions, to follow-up on responses, and to get into discussion. With each question and response, the interviewer gains new knowledge which he can immediately apply to steer the ongoing interview in an interesting direction. While a questionnaire-based survey would be much quicker to conduct, it lacks such flexibility.
- **2-step interview phase:** A 2-step interview phase brings a number of benefits over a single-step phase. The first step allows capturing a variety of responses to the same set of questions. But at a certain point, the responses will converge, i.e. less and less often will new aspects be mentioned by interviewees. Having reached this point, it is much more interesting to transition to a second step where certain results from the previous interviews would be presented to other interviewees for discussion. The benefits of this second step are: Instead of getting repeated answers to the same set of questions, i) interviewees help to reflect on the responses from the first step and ii) further detail is added to the key issues identified in the first step.
- **Inclusion of manufacturing IT solution providers in the target group:** Instead of interviewing only representatives of manufacturing companies, as originally planned, it was decided to also interview representatives of manufacturing IT solutions providers. As was quickly realized, they usually have very good knowledge of the needs of their customers, i.e. manufacturing companies. Furthermore, they were often better capable than manufacturing companies themselves in articulating these needs.
- **Involvement of manufacturing scenarios in interviews:** In Road4FAME, the establishment of the pull perspective is based on the understanding that challenges and needs are strongly dependent on the setting a manufacturing company is embedded in. Thus, four manufacturing

[3] The discussion of challenges and needs was only a part of these workshops.

scenarios have been defined as a tool to elicit challenges and requirements. In the interviews, these scenarios were applied as well. In a first part of the interview, challenges and needs were discussed in abstraction from a specific manufacturing scenario. In a second part, challenges and needs were discussed with reference to one of the manufacturing scenarios.

Remark:

- In each interview, interviewees were asked to respond from their personal point of view, not to provide an official company statement. Thus, in each interview, one can expect to capture a perspective which is influenced by a personal point of view and the point of view of the company the interviewee represents.

4 Summary and analysis of interviews

In this section, we are presenting the most important *challenges and needs* of manufacturing companies as they were articulated in the interviews conducted with representatives of manufacturing companies and manufacturing IT solution providers.

To begin, section 4.1 presents some important general observations from the interviews. The subsequent section 4.2 presents the challenges and needs which were found to be relevant across the four manufacturing scenarios considered in Road4FAME *or* which seem to be of general relevance for the manufacturing domain entirely. For each of these needs, we are elaborating on their implications on manufacturing IT, that is: What will manufacturing IT systems have to look like to respond to the respective need of manufacturing companies; what requirements describe these manufacturing IT systems, and what can be said about their architecture.

Finally, section 4.3 presents challenges and needs which were found to be of specific relevance in one the four manufacturing scenarios (but of subordinate relevance in other scenarios or the manufacturing domain in general).

4.1 General observations

The following observations are neither positive nor negative – they just have to be kept in mind to drive manufacturing IT innovation successfully. Where applicable, considerations are presented on implications for future manufacturing IT solutions.

I. Manufacturing IT innovation – push or pull driven?

The idea behind conducting interviews was to establish the (innovation) pull perspective in Road4FAME, i.e. to learn about the *challenges and needs of manufacturing businesses from a business perspective* and then use this as a basis to elaborate on required *manufacturing IT capabilities* and other *implications for manufacturing IT*. This constitutes an innovation pull approach, i.e. the notion that innovation is demanded or required by the application side, i.e. manufacturing companies. (Slightly earlier in Road4FAME, the complementing *push perspective* had been established, i.e. an overview of research fields which may be the cradle for future innovation in manufacturing IT.) Interestingly, the interviews suggest that innovation pull is slightly weaker than innovation push, i.e. manufacturing IT innovation seems to be mainly driven by IT solution providers and not so strongly demanded by manufacturing companies.

Surely, manufacturing companies today employ automation technology and manufacturing IT solutions to various degrees, but when asked for the key ingredients for their company's competitiveness, production managers would name aspects like a "good product", a "well defined product development process", "well defined, smart processes", or an "intelligently designed product i.e. to be manufactured efficiently". Manufacturing IT, however, is often only ascribed a supporting role, but not one which determines competitiveness. Thus, from the interviews conducted the impression arises that the innovation potential of manufacturing IT, more specifically its potential for driving competitiveness is underestimated and thus, IT innovation is not as strongly demanded by manufacturing companies as one might expect. In manufacturing companies, IT is seen as a tool to accomplish a given task. But its potential to enable entirely new capabilities seems to be underestimated.

Lack of awareness of how IT and integration of IT systems could support is accompanied by a well-known resistance to change. Given that the manufacturing operation is running fine, which is usually the case, no strong need is felt to change this running system. While this perspective is to be respected, it lacks strategic view and may entail risks in the medium and long term.

Another reason for a weak innovation pull may be that, in manufacturing businesses today, there is usually no role or function defined with specific responsibility for manufacturing IT or industrial automation so there is no person specifically looking at this topic who would drive manufacturing IT innovation. In principal, the optimization of manufacturing falls under the responsibility of production managers or lean managers. But their role is primarily to achieve a defined target productivity and quality and manufacturing IT is not top of the list of readily accessible optimization parameters. Similarly, an IT department may fulfil a service role in maintaining deployed manufacturing IT systems, but they are usually not industrial automation technology experts and many times the IT department is not even considered a core part of the business but ascribed a service role, not appreciating the fact that manufacturing IT is closely tied to cash flow and thus of much greater criticality than other IT applications. An IT department within production management may be more adequate, as is indeed increasingly introduced in manufacturing companies.

As a result, today, in many cases, manufacturing IT innovation has to be driven by C-level management, since none of the functions or departments below are specifically concerned with manufacturing IT. Thus, awareness for the potential of IT innovation in manufacturing must be achieved among C-level management to drive manufacturing IT innovation.

II. What drives manufacturing IT innovation in manufacturing companies?

Due to globalized markets and the increasing competitive pressure, manufacturing companies seek to optimize where possible. Frequently, this creates also the need to innovate with regards to their manufacturing IT.

But IT innovation at manufacturing companies is not only driven by competitive pressure. For many manufacturing companies, the driving force for IT innovation are ever stricter requirements imposed by large buyers. Especially in medium-sized and smaller manufacturing enterprises, manufacturing IT innovation is thus driven by ever stricter requirements, e.g. for traceability. In this example, a manufacturing company may be required to supply with the product a detailed protocol, certifying that all machinery has run without errors, that manufactured raw material has fulfilled quality requirements, measurement tolerance intervals, etc. Especially for medium-sized and smaller manufacturing enterprises, the investment related to keeping up with imposed requirements can be considerable. Thus, to these companies, *affordable* manufacturing IT solutions to meet the imposed requirements are crucial.

A third driver for manufacturing IT innovation besides competitive pressure and stricter requirements are new standards and regulations. Examples are the Eco-Reinforcement standard, the increasing introduction of eco labels, FDA CFR 21 Part 11 in medical sectors, or GMP for the automotive sector.

Implications/requirements for future manufacturing IT solutions:

- To manufacturing companies, especially to smaller ones, *affordable* manufacturing IT solutions are crucial to keep their competitive position. While the required manufacturing IT solutions as such are usually available today, they are not available at a moderate cost and thus frequently beyond reach of smaller companies who are struggling to keep up with the imposed requirements.
- Solutions need to come at low setup cost, and must be easy to integrate with the existing IT landscape. These must not interfere with already running processes so seamless (and low risk) integration is required. New models of renting software and cloud based approaches may be opportunities here, e.g. pay for use type models.

Implications/requirements for IT architectures:

- A flexible IT architecture is required which allows integration with and alongside existing systems (we are adding to an already operating factory in the majority of cases).
- The complexity of the system needs to be hidden from the owner as they are just interested in the information or service it provides. Opportunity here is for service providers to provide a pay for use service. The infrastructure used – e.g. cloud, may not actually be on site or owned by the factory. This is a far more cost effective approach for SME's who may be producing for larger companies.

III. Sources of manufacturing IT innovation – where does innovative IT originate?

Frequently, IT innovation originates outside the field of manufacturing IT. In the past, manufacturing IT has benefitted e.g. from IT technologies from consumer markets, an example being the Ethernet technology. Technologies from consumer markets were then adapted to meet the requirements in the manufacturing domain. Since industrial application usually entails much stricter requirements in comparison to consumer markets, the necessary efforts to adapt such technology must not be underestimated. While there is a well-known resistance to change in the manufacturing domain, part of this rightfully results from concerns about technologies from consumer markets which may not yet by ready to meet all industrial requirements.

In any regard, in search for future manufacturing IT innovation, consumer IT markets are worth watching. One can think of consumer IT markets as fulfilling something like a *sandbox function* for future manufacturing IT. Because of comparatively low requirements and the much greater market pull and volume on consumer markets, very advanced technologies can be seen at work very early here.

Looking at the consumer IT domain then, a number of promising observations can be made. As the manufacturing domain still struggles with high integration costs, hardware and software heterogeneity, the *industrialization of IT* has already progressed much further in the consumer domain, where we see much more homogeneity in the deployed hardware, strict hardware abstraction layers, and highly modular software.

IVa. Manufacturing IT landscapes today – a wild garden

In the interviews, we were also looking to get an idea of how sophisticated deployed manufacturing IT systems are today. As expected, today's deployed manufacturing IT was described as being far behind of what would be technologically possible. Especially in medium-sized enterprises and, needless to say, in smaller ones, the automation pyramid was often described as incompletely populated. But most importantly, the manufacturing IT landscape was often described as old and heterogeneous. Over the last decades, many companies have implemented point-solutions, each bringing a specific feature or fixing a specific issue. Resulting from this approach is a highly heterogeneous manufacturing IT landscape which one interviewee likened to a "wild garden". Into this IT landscape, ever more systems are added, each time tied to high integration effort because they have to be fitted into the "wild garden" already existing. As becomes obvious, while these IT landscapes are already costly to administer, further addition of capabilities becomes even more costly which is precisely why manufacturing companies are usually well behind the latest technology. So, in short: Manufacturing IT systems are heterogeneous because they have developed iteratively from a number of point-solutions, and they are usually far behind of what would be technologically possible because any change within the established landscape is costly.

IVb. Implementation costs are *the* barrier for manufacturing IT innovation

Across industries, few manufacturing companies are today equipped with state-of-the-art manufacturing IT systems. As mentioned above, this demonstrates clearly the bottle-neck for manufacturing IT innovation: it is usually not the un-availability of IT solutions but their immense implementation cost that prevents manufacturing IT companies from leveraging the latest manufacturing IT technologies. As main reason, the existing "wild garden" has been discussed above. While IT research is certainly necessary to push the boundary of manufacturing IT capabilities, the need to decrease implementation/integration costs seems to be of paramount importance. In the interviews conducted, few representatives of manufacturing companies pointed to a need for entirely new IT capabilities. Instead, new approaches to decrease implementation costs are required or else manufacturing companies will always be hindered to leverage the latest manufacturing IT innovation.

Implications/requirements for future manufacturing IT solutions:

The aspects described above may well be one of the main issues preventing IT innovation in the manufacturing domain. What must future manufacturing IT be like to avoid the issues described above?

- Strongly decreased implementation costs: Future manufacturing IT solutions must not only be able to provide certain functionality – first and foremost they need to do so at a low implementation cost. If future manufacturing IT solutions are not plug-and-play, i.e. to integrate with low effort, IT innovation in manufacturing companies will be costly and thus happen too slowly. This is especially important if SMEs are to benefit from the power of manufacturing IT solutions the same way large manufacturers do, to which high implementation costs are less a barrier. Especially for SMEs it is important that IT solutions are available at low integration effort and without any lock-in effect.
- External IT infrastructure / cloud services: To decrease implementation costs, external provision of novel IT capabilities can be an interesting option, such as the use of cloud services additionally to the local IT infrastructure. This realizes low implementation/integration costs by not investing in infrastructure, i.e. just buying in cloud services and letting someone else invest in this. Similar arguments can be made for software which could be pay-for-use as well. An advantage of this model is that when it comes to upgrading, this is done by the supplier so it is largely invisible to the manufacturer. A requirement to manufacturing IT software components, then, is that they have to be deployable as SaaS to realize an easy entry model for SMEs.
- Migration strategies: Since future manufacturing IT solutions will seldom be implemented in a green-field-scenario but into an existing "wild garden" this means that any manufacturing IT revolution must happen by-evolution, i.e. step by step. It must build on existing infrastructure for two reasons: a) Capital investment reason: The smaller the investment, the more likely that manufacturers will take an innovation step with their manufacturing IT; b) political reason: a CIO who has just invested considerably in a manufacturing IT landscape will be unwilling to switch e.g. to the cloud, which would make the previous investment seem useless. In any case, future manufacturing IT systems need to allow a smooth migration strategy, e.g. in a first step just supplementing the existing IT landscape, then step-by-step becoming more encompassing in the functionality provided and the processes covered.
- Dealing with heterogeneity: In order to swiftly advance deployed manufacturing IT, approaches are required to deal with the existing heterogeneity. As developments in consumer IT markets continue to spill over to manufacturing IT, there is hope that manufacturing IT will benefit from the increasing homogeneity on consumer markets. Looking

at data buses, there were about a dozen competing standards in the late 1990's and nowadays there are far fewer with Ethernet being dominant at the higher levels. Future manufacturing IT solutions need to abstract from the heterogeneity of the existing IT landscape allowing low implementation costs and easily interchangeable components.

- Interoperability solutions: Approaches to ease interoperability among different manufacturing components play an important role in reducing costs for integration. While standards would greatly ease interoperability, novel approaches are required (e.g. semantic interoperability) to cope with a reality which is characterized not by a lack of standards but a by multitude of standards.

- Modular software / apps: As systems are becoming complex, modularity has to be the solution so that new functionality can be incorporated *if*, *when* and *as* needed. It may be that functionality is only needed for specific product runs so there is no point in investing in it permanently. Modular software is a powerful approach to enable users to plug-in capabilities without significant integration costs. The provision of manufacturing apps via a standard platform may be promising but it is unclear who would ideally operate such an app store. Business models are required to incentivize app development. As an example, apps could be offered for free and additional services or functionality would be charged for.

  A tendency in other fields is to offer open solutions, most of them could be further adaptable to the new requirements. In the manufacturing domain this is still a bit far; companies try to get an exclusive way for manufacturing specific products. If open apps are the solution, modularity is mandatory. Solutions should be adaptive to new requirements avoiding this way to go obsolete. Offer these apps free and offer additional services (customer pay for them, for example support) would be the solution.

- Plug-and-play capability: As mentioned above, a plug-and-play capability could decrease integration costs significantly. This refers to the plug-and-play capability of physical manufacturing components, from a sensor up to any kind of component, as well as the plug-and-play capability of software components. The difficulty is that the manufacturing equipment is usually tailor-made for a very specific purpose and often the amount of machines of the same type is very small. Most of the machines are not mass products and the development of standard interfaces does not seem to be worth the effort. However, like in every communication, a machine can accept certain orders and report status information. The communication protocols and message formats need to be open and standardized, and the well-defined set of messages a machine can deal with should always be exposed. Such a machine interface description can create a foundation for integration into an IT landscape. First steps are made, however convenient functionality like auto discovery as we know e.g. from home entertainment systems is rarely available at the shop floor.

- Limitation of programming effort to specialised software: The main costs of a new IT system are no longer tied to hardware but related with integration and tailored software programming. To reduce such costs, ideally the IT needs to work out of the box with little or no tailoring. If anything, software should only have to be configured – but no programming should be necessary to make it fit. Surely, not all functionality required can be covered with off-the-shelf solutions as there will always be specific solutions required to the individual problems of a given manufacturing company. But the goal would be to provide at least the most commonly required functionality out-of-the-box so the programming efforts will be limited to only pieces of software which have non-standard, very specific functionalities.

Implications/requirements for IT architectures:

- IT architectures offer a huge potential to reduce implementation costs. The right architecture is one that is flexible to change. Technology and software are rapidly evolving so if the system is rigorously fixed it will become obsolete very quickly. Manufacturers are struggling with a range of obsolete and incompatible systems that have evolved over time and current system architectures can be an impediment to introducing new manufacturing IT functionality.
- The architecture should also be open in the sense that it should be able to download and incorporate new software/functionality easily. This requires well defined interfaces and the ability to access data from the plant/systems.
- The architecture should be able to handle existing heterogeneity and prevent it from driving up integration costs for added functionality. It could do so by introducing an abstraction layer to shield the complexity of the existing IT landscape and provide interoperability among heterogeneous systems, and to enable the application of solutions from multiple suppliers. Thus, an important role of an architecture is its capability to integrate services and components and to reduce the complexity of the overall system.

V. Security and privacy as a key imperatives

Manufacturing automation and the dispersion of IT systems in manufacturing at all levels of the automation pyramid has been increasing, observable also in industries in which automation was traditionally not strong. More than ever, manufacturing is *based* on IT. As manufacturing operations are increasingly based on IT systems, and especially as these IT systems become increasingly networked and remotely accessible, IT security becomes increasingly important as well. There are many well publicized cases of big IT systems failing and costing a lot of money. There is thus a perception of risk and strong awareness for the impact a security breach may have on the business. So security of IT systems becomes an increasing concern because a security breach could not only result in downtime of the system but could entail a drain of intellectual property (process information and manufacturing know-how).

Today, as many interviewees point out, concerns about security and privacy are the number one show-stopper for manufacturing IT innovation, an issue just as urgent as the high-implementation-cost-problem described above.

As mentioned above, externally provided manufacturing IT infrastructure offers potential for reducing implementation costs and promises additional IT capabilities for manufacturers. But such technologies require trust. Despite the functionality and convenience of e.g. cloud services, there are substantial concerns about where sensitive data is held, a company's intellectual property and the lack of control over this IT infrastructure (e.g. scheduling of updates, planning of downtime, etc.).

Implications/requirements for future manufacturing IT solutions:

- Alignment of security mechanisms with data not with systems: With business mobility and cloud computing eroding the concept of defined physical location, a new approach to dealing with IT security is required. The increased portability of data brings the increased risk of unintended exposure, misuse and loss or alienation. Because of the potentially transient nature of the devices, applications and users that access any given data, security mechanisms have to be aligned to the data itself. Security must be built on the assumption that anyone or any device may get access to the data, but that only authorized users should be able to use it. New algorithms (encryption, split, etc.) for storing data are required which make the data unreadable to any unauthorized person.
- No storage on physical devices: With an increasing amount of mobile devices in manufacturing, local storage of information on the devices should be avoided, mindful of the fact that these devices may leave company boundaries or may get lost.
- Security solutions for off-the-shelf components: As has been discussed above, modular software and off-the-shelf components may greatly reduce implementation costs and provide manufacturers with easy access to new capabilities. Also, companies are much more likely to overcome their resistance to change of a proven piece of software is to be integrated. But it must be noted that the security risks with standard software may in fact be greater. While tailor-made software is usually much less thoroughly tested than software components with a large user community, the vulnerability of standard components is arguably greater because a successful hack would have far-reaching consequences for the entire user base. Thus, the use of off-the-shelf components introduces a particular need for security.

- Fail-safe capability: Software and physical manufacturing equipment should be designed to fail safe, so that even if someone is successful in getting into the system no serious consequences for the safety of workers are entailed.
- Ability to detect attacks and security breaches: Well-known companies experience attacks continuously from foreign states or competitors. Often the resulting security breaches are detected late or not at all. The ability to detect an attack or security breach is very important, to reduce such any unknown vulnerability to a minimum or avoid it entirely.
- Need to be able to upgrade security immediately across the whole factory if required – i.e. in response to new threat.

Remark: Beyond the IT requirements mentioned above, it is considered important to rationalize the discussion of security and privacy topics among manufacturers. While a manufacturer needs to be aware that there will never be a system that can guarantee absolute security, neither in the cloud and nor on premise, a sense of control over data needs to be established. IT solutions need to ideally be available as a cloud-option and a on-premise option so that customers can chose. Migration to an own data center should always be possible to build trust. With cloud infrastructures in particular, it is important to not push a technology but to show benefits by means of demonstration.

Implications/requirements for IT architectures:

- Security by design: This is possible but it also limits what can be achieved. The easiest way to provide security is by not connecting a system or piece of machinery to a system that has a connection to the outside world.
- An architecture would ideally be designed to guarantee availability of the system even in the presence of attack.
- The architecture should provide full transparency about what is stored where and when was it accessed by whom.

4.2 Challenges and needs of manufacturing businesses

This section describes the challenges and needs of manufacturing companies from a business perspective, i.e. what they need to stay competitive today or to technologically advance their manufacturing facilities.

For each described challenge and need, non-exhaustive considerations are presented on implications for IT requirements.

I. Flexible manufacturing

Arguably the most important need for manufacturing businesses is flexibility. Flexibility can be defined as the capability to produce multiple products on a single line, or multiple variants of one product. Flexibility is the antithesis of mass production, where fixed assets are tied together to produce one product. The need for flexibility is driven by the trend to shorter product life-cycles which, in turn, is caused by increased competition which, in turn, is driven by globalization due to the fact that global markets or multi-national markets equate to a higher number of competitors. In global competition, fast reaction to changing market requirements is key to remain competitive.

Another important driver for the need for flexibility is the increasing demand for customized products which can be observed on many markets. A manufacturing company, as one interviewee illustrates, would ideally like to sell millions of instances of the same product whereas the customer desires the polar opposite, namely a perfectly individual product, ideally at the price of a mass product. Thus, the challenge for manufacturing companies arises to realize many variants of the same product on a given production line. (Some interviewees commented that producing a high number of variants on a single production line, in itself, may not be the actual challenge – but to achieve the same level of process security, i.e. quality, is a challenge.)

Several interviewees described flexibility as the need which has most strongly increased in importance over the past decade, a trend, which they anticipate to sustain. Ironically, with manufacturing IT landscapes as they are today (see section 4.1), flexibility is precisely what is very hard to achieve. Furthermore, the manufacturing IT systems which would be required to deliver such flexibility are usually very costly.

Interestingly, beyond the drivers for flexibility described above, the high investment tied to manufacturing IT is driving the need for flexibility as well: Manufacturing companies know that they need to increase automation levels. But they would like to avoid an investment in automation technology which is too rigid and would require major re-investment soon, once changes in product occur. Thus flexible systems are demanded. So, the rise of demand for flexibility is also driven by a higher automation in general, and the need of a sustainable investment in manufacturing IT.

<u>Implications/requirements for future manufacturing IT solutions:</u>

- <u>Support for reconfigurablity:</u> Although flexible manufacturing is by far not just an IT challenge, IT plays an important role in supporting configurability of a production line. A quite fundamental condition for flexible manufacturing is connectivity between the machines of a production line. Semantic technologies and self-learning capabilities can play an important role in supporting reconfigurability.

- Product model: A comprehensive model of the product is needed that has all the manufacturing data for all possible customizations. Standard data exchange formats are required to describe aspects of a product and how it should be machined. More flexible master data models and designs are needed that can handle mass customization and flexible management of hundreds of product attributes.

Implications/requirements for IT architectures:

- Moving intelligence from central to local: Architecture that enables fast line reconfiguration, with more intelligence at the machine level so machines can negotiate reconfiguration and setup
- Scalability: In order to increase both the data and applications available in the system.

II. Supply-chain flexibility

Realizing a high degree of flexibility is not only a challenge at plant level. Since parts of the value-chain lie outside plant or company boundaries, to attain highest levels of flexibility at the plant level, the upstream supply chain must be flexible as well.

But the need for a flexible supply chain goes beyond realizing flexible manufacturing. It is also important to manage risk. The nuclear incident in Japan has shown, e.g. in the automotive sector, how vulnerable supply chains can be. It took manufacturers around the world weeks to adapt accordingly. The ability of the supply chain to adapt and reconfigure is therefore crucial to shield a manufacturing company from such risk.

In general, a major aspect in a supply chain is trust, i.e. each supplier has to be trusted that they deliver what they committed themselves to delivering. To support such trust, visibility is desired at the plant level, i.e. visibility/tracing of what is going on inside factories. Ideally, manufacturers would want to have visibility of all the components being manufactured across the supply chain that are going to be assembled into a product. They would want visibility across the whole supply chain and would want to know about any risks that could cause delays or non-conformance.

Implications/requirements for future manufacturing IT solutions:

- Communication: Fast, efficient, secure and reliable communications and networking between suppliers to guarantee quick adaptation to the new customization of the product. Such communication between different factories will likely rely on internet technologies. There may be issues on security and privacy with respect to data which need to be handled.
- Data quantity: Communication platforms need to be able to handle the amount of data exchanged between enterprises, the volume of which could be quite significant.
- Integration: Collaboration and integration capabilities need to be established through existing MES and ERP modules.
- Role-based information disclosure: Sharing of detailed information across supply chain but with role-based access to information, i.e. each party has only access to the information

necessary. Intellectual property is only disclosed partially but never completely to any of the supply chain members.

- Capacity balancing capability between suppliers in supply chain: Having available supply chain real-time information for being able to decide on optimal solution each time: select by price, by location, by volume, by rating, etc. Supply chain processes need to be monitored in order to guarantee the process is not interrupted in any case.

Implications/requirements for IT architectures:

- Establishment of communication across manufacturing enterprises
- Scalability: In order to increase both the data and applications available in the system.
- Security by design: Security issues at platform level must never be able to propagate down to the participating entities.

III. Traceability

A requirement in process industries already, traceability is increasingly desired in the manufacturing domain as well. Traceability comprises two aspects which are referred to as product tracking and product tracing. *Product tracking* describes the capability to follow the path of each single unit of a product throughout the supply chain. Products may be tracked for obsolescence, inventory management and logistical purposes. There is an increasing interest to not only track a product along the supply-chain but also throughout its entire life-cycle, enabling cradle-to-grave management of products with true re-cycling and re-manufacturing.

As opposed to product tracking, *product tracing* describes the capability to identify the origin of a particular unit of a product by reference to records held upstream in the supply chain. Products are traced for purposes such as quality management, tracing of failures, product recall and investigating complaints. As more and more safety critical parts are originating in low-wage countries, and counterfeits could result in severe consequences, tracing is becoming increasingly necessary.

In coming years, manufacturing companies will increasingly face the requirement for traceability. Either they are imposing the requirement on themselves, e.g. to be able to demonstrate ethical sourcing to the customer or the traceability requirement is imposed by large buyers, e.g. OEMs who will not accept to take the financial responsibility for damage caused by product recall resulting from the failure of a low-price component.

Ensuring traceability usually involves substantial IT support and companies struggle to implement this. But manufacturing companies need to fulfil this requirement in order to be considered as a supplier. (Interestingly, this traceability requirement puts limits to outsourcing to low-wage countries and is reportedly already resulting in back-sourcing because traceability requirements are not always met by manufacturers in low-wage countries.)

Implications/requirements for future manufacturing IT solutions:

- Data collection and storage: The capability to collect data from sensors at all stages of production and across supply-chain is required to track and trace components. (At a hardware level, there is a need for self-powered wireless sensors for retrofitting through factory to monitor stages of process, which may be storing information on time at temperature, etc. and a need robust RFID technology for tagging components.) Furthermore, the information from these sensors needs to be recorded and semantically stored. Large volumes of data will have to be stored, since the information is to be maintained over the life of the product (e.g. automotive 10 years for millions of cars).
- Open platform and access rights: An open platform for product tracking and tracing will be necessary where every supply chain participant can upload tracking/tracing data. Tracking/tracing data will need to be available to a number of different parties with different access rights.
- Unified product model and ID: A unified product model is required as well as a unique product ID.
- Traceability for low automation levels: Approaches are required to feasibly provide tracking/tracing capabilities even for manufacturers which do not manufacture at a high level of automation.
- Decision making: To make use of tracking/tracing information, it has to be integrated with decision making tools.

Implications/requirements for IT architectures:

- The architecture must allow establishing connectivity with a very large number of sensors and tracking/tracing systems across supply chain and throughout the product life cycle.
- The architecture needs to be able to gather and correlate a large amount of data and reference this to a product. This database needs to be maintained for many years. The provenance of data also needs to be guaranteed. Must consider the need of being able to access archived data after long time (assure retro-compatibility).
- Scalability: In order to increase both the data and applications available in the system.
- Security by design: Security issues at platform level must never be able to propagate down to the participating entities.

IVa. Monitoring and optimisation of resource efficiency

Monitoring and optimisation of resource efficiency is becoming a goal of increasing importance, for several reasons. Firstly, in many industries, used resources (e.g. energy or materials) constitute major expenditures and it is increasingly being realized that profitability is not only driven by output – it is also driven by resource-efficiency. Lean management as such is not considered sufficient anymore and resource efficiency is introduced as an additional target. The pressure for resource efficient manufacturing is likely to increase over time, since resource scarcity will aggravate and prices can be expected to increase.

A second reason for the increased need to monitor resource efficiency are regulations or tax incentives. In such cases, to be eligible, an energy monitoring and management system must be in place and adhering successfully to limits in e.g. CO2 emission can be rewarded with tax breaks.

A third reason for the increased importance of resource-efficiency in the manufacturing domain are self-imposed targets to build and maintain an image of environmental sustainability. Increasingly, corporations provide sustainability information in their annual reports and appoint a responsible at management level to gather related data and implement improvements. Driven by such corporations, suppliers, in turn, are increasingly facing the requirement to provide resource efficiency information and to meet imposed targets. Accordingly, suppliers have to equip themselves with such resource monitoring capabilities to stay competitive.

Resource efficiency targets entail the need to measure and monitor resource consumption as a basis to improve resource efficiency, i.e. to reduce energy consumption, cut the use of raw materials and minimize waste. The ability to identify precisely what resources are consumed and how much is also important to assess the business risk entailed by price fluctuations, i.e. the exposure of the manufacturing business to such volatilities on source markets.

In the future, the environmental footprint of products may become a parameter of the product driving buying decisions (at least in certain segments). Thus, the environmental footprint information may influence buying decisions (among two otherwise similar products, the buyer will choose the environmentally more favourable one, for a good conscience), and may thus influence competitiveness. But environmental sustainability must be achieved without a premium price (organic products are hugely successful; in part because they are not significantly more expensive than non-organic products).

IVb. Monitoring and Decision Making for Performance Optimisation

More efficient production requires more detailed knowledge about the production process. As a basis for the optimization of the manufacturing process, detailed monitoring along a production line is required. Correlating all data acquired in different systems allows steering the process toward an optimum regarding resource utilization (see above), output volume and output quality.

Today, in many industries, data is acquired at numerous locations already. But data is acquired by a multitude of separate systems and is often not joined or correlated, so, while manufacturing companies already have lots of data available from the shop floor they struggle to derive information from it, i.e. to correlate/interrelate it properly and derive decisions from it. Even in the semiconductor industry, known to be one of the most highly automated manufacturing industries, there is still great potential in real-time monitoring, to make immediate decisions and interact with the process on-the-fly.

IVc. Condition Monitoring and Predictive Maintenance

The frequency and duration of machinery downtime drastically affects profitability. Seeking to use manufacturing assets to an optimal extent, to a near 100% uptime, there is a strong need for predictive maintenance, referring to the capability of estimating the health status of manufacturing assets during their operation and to repair even before actual damage occurs. Such capability reduces downtime due to unexpected failure, reduces maintenance costs by avoiding damage to the equipment and the time required to restore operating condition.

Condition monitoring capabilities enable predictive maintenance by providing the data from which can be inferred to the health status of manufacturing assets, e.g. by analysing a vibration frequency spectrum or alerting in case of higher-than-normal energy use.

Implications/requirements for future manufacturing IT solutions:

- Addition of parameters: Traditionally, *Enterprise Resource Planning* systems cover material and people as the only *resources* and will have to be extended to cover further resources, e.g. energy or emissions. These parameters have to be added to the usual optimization goals like speed, throughput, quality, and utilization.
- Detailed metering: Need to introduce much finer grain monitoring of energy, water and materials usage, but also generated scrap. This requires metering and collection of information.
- Data acquisition: Acquisition and storage of large amounts of data from several sources (e.g. RFID, sensors networks) and applications (ERP, MES, and SCADA between others) needs to be achieved. An important requirement here is to provide flexible interfaces for equipment and component integration to get the data at the right time and the right place.
- Monitoring infrastructure: At the hardware level, a sensor network throughout manufacturing plant is required and (wireless) connectivity to a very large number of endpoints needs to be established. Furthermore, since most legacy equipment may not be equipped with monitoring capabilities, a low-cost retrofitting approach is required to equip legacy equipment with monitoring capabilities (e.g. low cost self-powered wireless sensors).
- Requirements for predictive maintenance: Note there may be a range of requirements dependent on the piece of machinery that is being monitored - you may need to catch the failure very quickly. i.e. within minutes, you may be able to leave it running for hours/days before maintenance.
- Integration with decision making applications: Optimization at the shop floor is always a multi-dimensional problem. With further optimization parameters (such as energy consumption or emissions) being introduced, it becomes even more likely that there will not exist a single global optimum but instead a number of local optima. Thus, the result of this optimization

problem will need to be presented to a human being (e.g. via mobile devices) for a final decision to be made.

- Data reduction/fusion: Since many sensors will transmit acquired data wirelessly, data reduction will be required or else the available frequency spectrum will quickly be exhausted. Data fusion also plays an important role in avoiding large quantities of data but also assess the reliability of data coming several sensors.
- Data processing capacity**:** Due to the large amount of data which is continuously acquired, efficient ways of handling the volume and velocity of data are required. In the case of predictive maintenance data, efficient algorithms for local processing of e.g. vibration data are required. In any case, big data capabilities are also required to handle and analyse the acquired amount of data efficiently.

Implications/requirements for IT architectures:

- Connectivity: The architecture must allow establishing connectivity with a very large number of sensors, gather data from them and store them in a database (which may be on-site, off-site, distributed, etc.). The architecture needs to guarantee fast transmission of data and real time decision making for it to be effectively used in a feedback mechanism to improve performance or schedule maintenance.
- Data processing: The architecture should be able to efficiently process a large amount of data coming from all sensors. Depending on how closely the monitoring is to be coupled with decision making, real-time capability may be a requirement.
- Data collection and storage: The capability to collect data from sensors at all stages of production and across supply-chain is required to track and trace components. (At a hardware level, there is a need for self-powered wireless sensors for retrofitting through factory to monitor stages of process, which may be storing information on time at temperature, etc. and a need robust RFID technology for tagging components.) Furthermore, the information from these sensors needs to be recorded and semantically stored. Large volumes of data will have to be stored, since the information is to be maintained over the life of the product (e.g. automotive 10 years for millions of cars).
- Scalability: Both the platform which acquires the data from sensors as well as the algorithms running on this data need to be highly scalable.
- Distribution: Data acquisition, storage, and algorithms running on this data should be ready to run distributedly.
- Security: The architecture must inherently offer minimal possibilities of unauthorized access to the system.

V. More intuitive system interaction / mobile devices

Driven by the proliferation of mobile devices in the consumer sector, manufacturing companies increasingly desire to apply mobile devices in a manufacturing context. A production manager who will be able to see manufacturing data in real-time on his smartphone or tablet is only one of the less interesting use cases. But mobile devices will become a most powerful tool once they constitute a new form of human machine interface, enabling the worker to operate not just a single machine but interact with the entire production equipment, get context information and correlated information from multiple sources, receive maintenance instructions, interact with big-data-based decision support tools and adjust processes based on real-time information. Mobile devices in manufacturing are a move away from the central decisions made in a control room, rather, an order or a warning would be sent directly to the right person who can then take action. Certainly, we are only just at the beginning of what can be done, considering e.g. augmented reality solutions.

Interestingly, despite the advantages of this technology on the shop floor, interviews do not reveal a strong *business* need for this application of mobile devices in a manufacturing context. Despite this, the demand for mobile solutions is reported by interviewees to be strongly increasing. Frequently, it seems that manufacturing companies are looking to implement mobile solutions primarily for image reasons. But in in the future, an actual need for mobile devices as human machine interfaces is expected to arise as they enable human beings to interact easily with ever more complex systems, and support informed decisions based on real-time information. Such devices are what integrate the human being in an Internet of Things and allow him to interact with it.

Discussion of resulting challenges for manufacturing IT

- Robust wireless communication: Considering that interaction with manufacturing equipment is to happen in real-time, a stable and low-latency communication infrastructure must be in place.
- Readiness for Bring-Your-Own-Device (BYOD): As intelligent mobile devices are becoming more common each day, one of the possibilities would be that personal mobile devices from employees are able to interact with company systems. Encoding mechanisms needed in order to preserve the information in case of losing the device. Furthermore, interaction of private devices with the IT infrastructure needs to be possible without any security compromises.
- Access control / rights management is required to guarantee that only the authorized persons have access to the corresponding information. Access control protocols and permission management is needed.
- Context awareness: Providing the right data to the right person at the right time, i.e. the need to provide different views to different people dependent on their role (manager, production line, maintenance etc.) and what they are currently doing.
- Presentation of information – not data: There will be a lot of data available and this may swamp people. The large amount of data should be analysed in order to present only the relevant information.

Implications/requirements for IT architectures:

- Offline capability: The architecture is to ensure stable operation of manufacturing equipment, even if devices which act as HMI to the equipment go offline. Complementary to this, on the device side, it needs to be ensured that continued interaction of possible even in offline-times and intelligent synchronization occurs when going online again.
- Shielding: Any failure of the mobile device must not propagate beyond the device itself. The IT infrastructure must be accessible while ensuring that device failure can in no case have effects on the IT infrastructure.
- Security: Especially in a BYOD scenario, the communication infrastructure must be designed to effectively impede the propagation of security issues beyond the device level.
- M2M communications within factory environment: The mobile devices need to access information from equipment and from IT systems. There is relatively limited processing on a mobile phone/tablet so it is likely that the user will set tasks running remotely on other more powerful systems and just receive results.

4.3 Challenges and needs in selected manufacturing scenarios

In Road4FAME, four manufacturing scenarios are considered. Considering such scenarios is motivated by the assumption that, while certain *challenges and needs* are common to the entire manufacturing domain, certain challenges and needs are very specific to particular the situation a manufacturing company is facing. The four scenarios considered in Road4FAME represent four interesting settings.

Challenges and needs which seem to affect the entire manufacturing domain are reported in section 4.2. In addition, section 4.2 reports challenges and needs which appeared across several manufacturing scenarios.

In the following, we describe the challenges and needs which are specific to each one of the scenarios (but may not be as relevant in other scenarios or even in general).

4.3.1 Scenario: The Virtual Enterprise

The virtual enterprise is an association of companies that cooperate ad-hoc to react to market opportunities, to do research together, innovate products and to minimize costs and risks for approaching new markets with new products. The involved companies have to join forces effectively to really form one business out of many.

For the fulfilment of each order, a subset of members with the needed capabilities and capacities is selected to execute the order. As capabilities might replicate capacity in multiple partners, they will need to bid internally for selection. The virtual enterprise would be established ad-hoc around a short term request and dissolve after the satisfaction of the request.

A virtual enterprise consisting e.g. of SMEs would enable them to complement each other's strengths or to attain the capacities of large enterprises. A virtual enterprise consisting of both large and small companies enables to combine strengths, i.e. the large companies bring in their capacity, and the small companies bring in their flexibility and innovation power. Also, the virtual enterprise enables a much broader product and service portfolio than any individual company could provider alone.

<u>Challenges and needs specific to this scenario:</u>

- <u>Bidding mechanism:</u> Since production capacities may be replicated in several manufacturing companies within the virtual enterprise, there will have to be an internal bidding process based on price, quality, delivery performance to allocate demand for production capacity to supply.
- <u>Compensation mechanism:</u> Even if the economic value created by the virtual enterprise is positive in total, it may be *negative* for some companies within the virtual enterprise, as they may have to make sacrifices for the success of the virtual enterprise as a whole. Compensation mechanisms must be in place so companies have an interest to participate in the virtual enterprise, and are fine with making sub-optimal decisions at the level of the individual organisation for the good of the virtual enterprise as a whole.
- <u>Efficient pooling and seamless usage of resources</u>: For the time of existence of the virtual enterprise, organisations in a virtual enterprise must be able to pool and share virtual and physical resources seamlessly, as if they were a single organization.

- Rapid design of manufacturing processes: When a virtual enterprise forms, the processes to jointly produce the ultimate product must be established very quickly. Since these processes span across manufacturing companies in the virtual enterprise, with each manufacturing company taking over a sub-task of the virtual enterprise, this is a challenge. The quicker these inter-company processes can be fixed, the quicker the virtual enterprise is ready to produce and react to the market opportunity because of which it was formed in the first place.
- Knowledge-sharing about mutual capabilities and available capacity: In order to join together for a virtual enterprise, information must be available on each company which describes its manufacturing capabilities, as well as current availability / current load. In effect, systems like SCM, CRM, ERP, etc. need to extent across the entire virtual enterprise for coordinated action during the time of its existence.
- Mapping of manufacturing capacities to market opportunities: A virtual enterprise forms to react to market opportunities. But to the individual manufacturing company it may not be straightforward to discern the market opportunities to which it could react, being part of a virtual enterprise. Thus, a mapping mechanism must be in place to suggest allocations of companies to given market opportunities or demand and offer this information to manufacturing companies. Upon this information, the manufacturing companies can then decide to actually form a virtual enterprise and jointly seize the market opportunity.
- Seamless scalability at runtime: Mechanisms are required which allow the virtual enterprise to scale manufacturing capacity seamlessly, i.e. allocate additional manufacturing jobs to manufacturing capacity (maybe resulting new manufacturing companies joining the virtual enterprise). This involves also the capability to swiftly re-allocate capacity if a manufacturer leaves the virtual enterprise or is not able to perform as required.
- Protocols for information exchange in the virtual enterprise: Secure and standardized information exchange along the entire life-cycle of the virtual enterprise (establishment of virtual enterprise, operation of virtual enterprise, disbanding of virtual enterprise, etc.) is needed. Mechanisms are required which enable collaboration while securing the intellectual property of the individual organisations in the virtual enterprise.
- Trusted collaboration: In order for manufacturing businesses to collaborate in a virtual enterprise, trust is an important prerequisite. Approaches to help build such trust are required (consider e.g. the simple eBay rating system which serves to create trust between unknown users, and makes it rational for both buyer and seller to comply).

4.3.2 Scenario: The Green Enterprise

This scenario describes a company to which environmental awareness is an important part of the company image. But the company's goal is to go beyond a mere "green washing" of its image and products to really introducing environmental sustainability as a key parameter in all steps of the product life-cycle, including sourcing and recycling. Based on the consideration of data from a large number of sources, real-time information about the footprint of manufacturing processes is available to steer production towards minimal environmental impact.

Keeping record of the origin and history of raw materials as additional aspect of environmental awareness is used as a marketing advantage. Buyback of products for recycling or product rental and return to recycle policies are strategic, increasing sustainability on sourcing and creating stronger bonds with customer.

The environmental footprint of ordered, customized products is available to customers in the customization step, so the footprint generated along the value-chain is transparent to the customer and environmentally aware buying decisions can be made. To the manufacturer and the customer, the environmental footprint is available and can be taken into account as an actual decision parameter. The environmental implications of design decisions, process decisions, and buying decisions become completely transparent.

With a certain customer segment increasingly demanding such transparency, the competitiveness of the company increasingly depends on the degree of transparency it is able to provide, and the level of environmental sustainability it can demonstrate. Thus, its capability to be "green" translates into tangible economic value.

<u>Challenges and needs specific to this scenario:</u>

- (Many challenges and needs relevant for this scenario, such as the need for the monitoring of resource consumption or tracking and tracing capabilities have been described in section 4.2 already, since they are increasingly relevant for companies even outside the green manufacturing scenario.)
- <u>Environmental footprint information across entire supply chain</u>: Using a unique ID for each product, its footprint needs to be recorded throughout the supply chain: energy consumption, emissions produced, history of processing, etc.
- <u>Environmental footprint information across entire life-cycle</u>: Further to the above, in order for manufacturing to become truly green, the handling of products in late life-cycle stages needs to be considered and taken into account in the calculation of any environmental footprint information. Upon re-manufacturing or re-cycling, the product would also need to include information on its previous life.
- <u>Remanufacturing over recycling</u>: Buy-back, recycling-based business models: Not sell but rent product to customer and recycle or re-manufacture towards end of life-cycle, then rent again.
- <u>Transparency of footprint information to customer</u>: For environmental sustainability to become an actual parameter driving consumer demand, adequate signalling has to be

provided to the customer. A customer needs availability of footprint information to make buying decisions which are not only based on price and quality.

4.3.3 Scenario: The Manufacturing-as-a-Service Enterprise

The MaaS enterprise does not sell products, but offers manufacturing as a service. The manufactured goods are complex and fully customized. It frequently faces short-notice requests of high volume. The considered MaaS needs to be able to quickly reconfigure and scale up its production, to establish close information exchange with customers, i.e. integrate with other businesses and enter into business agreements, and cooperate with the new partners in order to fulfil new orders appropriately.

The range of offered services goes beyond pure manufacturing process, extending over all the value chain e.g.: product design, after sales support, product maintenance.

The company offers its services globally and is strongly dependant on an efficient mechanism for service provision. The company's strategic plan is to be able to anticipate changes in demand from the customers, keeping the pace of technological progress in the sector and to improve the companies' ability to take orders ad-hoc. Predicting trends on demand will require using data mining on a variety of data coming from many sources e.g. social networks.

Remarks:

- In certain industries, like the highly automated semiconductor industry, MaaS is a well-established business model already whereas other industries perceive this still as rather challenging.
- As manufacturing is becoming more technology-intensive and thus manufacturing equipment becomes more expensive, the MaaS concept is likely to gain relevance in the future. Instead of investing in costly manufacturing equipment, the manufacturing capacity would be bought as a service.
- A MaaS can also be a part of a virtual enterprise, in the role of a provider of manufacturing capacity or even taking over a coordinating role for the virtual enterprise.

Challenges and needs specific to this scenario:

- (All challenges and needs which have been identified for this scenario have been reported previously in this document: Those challenges and needs which are of general relevance in the manufacturing domain, have been presented in section 4.2, most notably among them the needs for flexibility and traceability. Other challenges and needs are sufficiently similar to those reported in section 4.3.1 for the virtual enterprise scenario, such as the need to know about available manufacturing capacity.)

4.3.4 Scenario: The High-Volume Production Enterprise

Description of scenario:

This scenario describes a company which produces very-high volumes of goods and increasingly faces the challenge of shorter product life-cycles. To remain competitive, it also needs to be capable of offering an increasing degree of customization, despite the high volumes produced (mass customization). The supply network the company is embedded in comprises some long-term cooperation but also ad-hoc cooperation.

The level of automation is high in the plant, and the customisation of production requires short reconfiguration cycles, including tests / experimental production, fast re-programming of machines and frequent updates of information to the workers who need to be skilled and also frequently re-trained, as well as short ramp-up and scale-up cycles. To do so, context-awareness of production facilities is helpful in order to adapt production to current product specifications, react to and schedule order execution appropriately, also according to specific customer relations.

The fact that a company has to react to an increasingly dynamic market entails also that the individual worker has to keep this pace, by acquiring relevant knowledge fast enough. With the half-life of relevant knowledge decreasing, the rate of human knowledge acquisition threatens to become the limiting factor for companies to keep pace with technological progress. Appropriate IT support has to be provided to the human who is embedded in the digital factory, in the form of context-relevant information and on-the-fly knowledge provision supported by, e.g., knowledge based decision support systems or self-learning systems supported by cooperation between humans, machine and data.

Challenges/needs:

- (Most challenges and needs which have been identified for this scenario have been reported previously in this document. Of the challenges reported in section 4.2, the aspect about future human machine interaction is especially relevant for this scenario.)
- Forecasting capabilities to anticipate customer demand: Since high-volume manufacturing capacity is expensive, there is a strong need to anticipate changes in demand early to initiate change in equipment.

5 Concluding remarks

Convergence to a small number of top needs

The challenges which manufacturing companies face today are certainly numerous. Interestingly though, the series of interviews showed a strong convergence to a rather limited number of needs, i.e. the interviewed representatives of manufacturing companies or manufacturing IT solution providers rather unanimously named the same or similar needs. A reason for why a greater spread was not observed may be that needs are only reported as such if there is a clear business case behind which drives a need. Topics which may sound interesting from an IT point of view, say, M2M communication across the supply chain so machines can take issues in the upstream supply chain into account, are of course useful, but they are unlikely to be reported as a need because the benefit to the business is not great enough.

So, from the face-to-face interviews conducted, and the follow-up telephone interviews, we are rather confident that the needs presented in section 4.2 are likely to describe some of the most important needs felt in the manufacturing domain. According to interviewees, these needs are not only urgent today, but are expected to increase in relevance in the future. Thus, they are of high relevance to our further roadmapping process and recommendations for research activities must be given mindful of these needs.

Important observations from the interviews

Interestingly, while we conducted the series of interviews to find out about the challenges and needs of manufacturing companies (as they are presented in section 4.2), the general observations reported in section 4.1 may in retrospect be the actual key part of this document. While these observations do not describe specific needs of manufacturing businesses they are probably some of the most important levers to be aware of in order to make manufacturing IT innovation happen *at all*. As we observed strongly, it is usually not the *unavailability* of technology that poses a bottle-neck for IT innovation in manufacturing companies, but the fact that the latest manufacturing IT technologies are in effect out of reach for most manufacturing companies, especially SMEs, due to the very high implementation costs. It seems that, if no approaches are becoming available to circumvent or solve this issue, manufacturing IT innovation will always be doomed to happen slowly, i.e. manufacturing companies will always be hindered to leverage the latest manufacturing IT innovation. Thus, while the needs reported in this document are important to be addressed, it is not only about "*WHAT technologies do we need?* "but maybe more importantly, about "*HOW is the technology provided and made accessible?".* For Road4FAME, building a manufacturing IT roadmap with an architecture focus, this observation stresses the importance to identify future architectures which could contribute to alleviating such issues, making manufacturing IT innovation more accessible.

Annex I: Interview partners

The following provides an overview of interviewed experts. Due to confidentiality reasons, the name of the interview partner is not provided.

Face-to-face interviews:

Represented Company	Role of interviewee in company
Provertha GmbH	Product manager
ABB AG	Sales, new applications, discrete automation and motion
Microsoft Deutschland GmbH	Industry Market Development Manager, Manufacturing Discrete
Beckoff Automation GmbH	Product manager field bus systems and control systems
M+W Process Automation GmbH / IBM	Head of manufacturing and business integration
Wittenstein motion control GmbH	Executive committee Cyber Physical Systems
Tele Radio GmbH	Managing director
SKS Kontakttechnik GmbH	Head of development
B&R Industrie-Elektronik GmbH	Head of sales, process automation
WAGO Kontakttechnik GmbH & Co. KG	Manager business development, automation
SEAR GmbH	Sales MES
FORCAM GmbH	CEO
M+W Process Automation GmbH / IBM	Head of marketing and communication
InQu Informatics GmbG	Sales
Weidmüller Interface GmbH & Co. KG	Technology development
Harting IT System Integration GmbH & Co. KG	Systems integrator
Lapp Group	Technical support
Hewlett-Packard GmbH	Business development manager
Hewlett-Packard GmbH	Senior consultant manufacturing EMEA
Phoenix Contact Electronics GmbH	Director, R&D control systems
Parametric Technology GmbH	Principal application specialist

ThingWorx	Senior sales engineer
camLine	Key Account Manager
Industrie Informatik GmbH & Co. KG	(Unknown role)
gbo datacomp	(Unknown role)
Delta Industrial Automation	(Unknown role)

Telephone interviews:

Represented Company	**Role of interviewee in company**
Infineon Technologies AG	Director of Factory Integration Strategy
Iconics Germany GmbH	Managing director central Europe
euTeXoo GmbH / TU Dortmund	Managing director
Metasonic AG	Senior Research Engineer
Harms & Wende GmbH & Co KG	Branch manager
Jaguar Land Rover Automotive PLC	Cost management tools lead for new model programmes
Fratelli Piacenza Spa	Chief Research Manager
European Dynamics SA	Manager of R&D
Aernova	Vice president technology development
AIDIMA Instituto Tecnológico del Mueble, Madera, Embalaje y Afines	Head of IT department
Centro Ricerche Fiat S.C.p.A.	Department Responsible

Annex II: Interviewer Guidelines

I. Brief description of context (of Road4FAME, of interview):

We develop a manufacturing IT roadmap to determine future research priorities which will be recommended to the European Commission. These research priorities need to be in alignment with the specific challenges and needs on manufacturing businesses. In this context, we would like to get an idea of the most important challenges and needs from your perspective / from your company's perspective!

II. Interviewee profile

- Name of company
- Size of organization (no. of employees)
- Industry branch
- Type of product / brief description of product portfolio

III. Scenario-unspecific part

III.1 How have the challenges for manufacturing companies changed over the last decade?

III.2 How do you expect the challenges to change in the coming decades?

III.3 What is the most important trend affecting you as a manufacturing business?

III.4 What are the challenges today in reacting to this trend?

If we are interviewing an IT person: III.5 Reacting to this trend, what are the most urgently required functionalities of future manufacturing IT systems?

If we are interviewing a business person: III.5 Reacting to this trend, what are the implications you see regarding business processes or business models?

IV. Scenario specific part

In Road4FAME, certain manufacturing scenarios are examined in detail. Among them:

- The virtual enterprise
- The green enterprise
- The MaaS enterprise
- The high-volume production enterprise

[Select suitable scenario or ask interviewee for preference.]

[Read scenario description to interviewee.]

IV.1 What is the most important challenge that a manufacturing business faces in such a scenario?

IV.2 What makes this a challenge today?

If we are interviewing an IT person: IV.3 What functionalities of future IT systems are needed to respond to this challenge?

If we are interviewing a business person: IV.4 What are the implications do you see regarding business processes or business models in order to meet this challenge?

V. Close of interview and follow-up

- Record contact information, get business card
- Available for follow-up call?
- If interviewed person can be considered an expert: Interested to join Road4FAME Experts Group?