Deliverable 3.3

Preliminary Roadmaps in 4 Manufacturing Settings and Preliminary Recommendations

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

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

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1 Executive Summary

The Road4FAME consortium organised a roadmapping workshop with input from 45 participants from industry and academia in Europe. The workshop aims were to:

- Review and prioritise drivers and manufacturing business requirements for ICT in Manufacturing.
- Identify the most important ICT solutions required in manufacturing overall and for each scenario specifically.
- Explore the most important ICT solutions in terms of ICT architecture and services requirements.
- Review and prioritise the research and underlying technologies that will be needed to deliver future ICT solutions.

The workshop took place on 7 October 2014 in London, UK.

The ***top drivers, trends, needs*** and ***business models*** important for ICT in Manufacturing in at least two or more scenarios were the following:

Megatrends

- **Knowledge as key-enabler:** The importance of knowledge is increasing as products, systems and the business environment become more and more complex and technology-intensive. This leads to a trend of perceiving knowledge as capital, with the goal to use and exploit information across traditional boundaries as successfully as possible.

Manufacturing-related trends

- **Demand by customers for individualized/highly configurable products:** Customers increasingly demand highly customized products, ideally at no a higher price than a comparable mass product.
- **Virtualisation and digitisation:** Companies increasingly use simulation, visualisation and virtualisation to understand the product and production behaviour and performance under virtual conditions.
- **Increasing hybrid cross-over products/embedded IT and integrated services:** Transformation opportunities are numerous when companies cross traditional boundaries. Hybrid solutions that help such crossovers are mandatory, and this calls for next generation solutions.

Manufacturing Business Needs

- **Reduction of start-up times, fast scale-up of production:** Shorter start-up and maintenance times improve efficiency as manufacturing assets are used more productively.
- **Increasing flexibility of production environments:** In order to increase their competitiveness, factories will increasingly develop their ability to react to faster-changing markets with regard to production times, products to be manufactured, etc.
- **Identify/anticipate changes in demand:** Being able to anticipate and forecast demand changes and adapt internal operations accordingly.

- **Reduction of effort for integration of new equipment/tools:** Improve the ability to integrate new equipment or tools to the existing company infrastructure.
- **Flexibility in supply chain participation:** Factories should easily be able to join production networks in order to be able to quickly react to market demand changes.
- **Integration of human worker in manufacturing process:** As products and processes become more complex and the half-life of knowledge is decreasing, the human worker threatens to become the bottleneck in achieving the progress and flexibility required to remain competive.
- **Information sharing; operational and strategic**

Business Models

- **Added value potential through new services:** Provision of new (B2B or B2C) services and business models enabled by intelligent products.

The ***top 11 ICT manufacturing Solutions*** identified able to meet these trends, drivers and needs were the following:

Shop floor production

- **Big data analysis and use for quality control:** A solution to develop big data analytics for production to enable full transparency on the shop floor.
- **Flexible production equipment and interconnections:** A solution that enables different types of products to be produced at the same time inside a production plant. It requires configurable systems that have plug and play modularity, tools and equipment that can be changed and reconfigured, robot collaboration and autonomous transportation solutions.

Intra-company

- **Joint Cognitive Systems for decision support:** This is a Decision Support System (DSS), based on multiple criteria that combine machine and human expertise.
- **Engineering Platform for design/operations continuum:** This ICT solution involves product and process monitoring and exchanging engineering and usage data throughout the whole product lifecycle from production stage to its end of life.

Inter-company

- **Customer and demand data gathering for analysis:** A solution that ensures that a product always meets the customer requirements and provides them with exactly what they want.
- **Product and service co-design with customer:** This is forward looking range of ICT solutions in line with current socio-technological trends in manufacturing that foresee an increasing demand for product or service personalisation, individualisation and active customer engagement and co-creation.

Supply Network

- **Supply chain visibility and decision assistance:** This is a decision support system for manufacturing businesses' supply chain network. It helps companies synchronise, co-ordinate and communicate with their supply chain having a flexible, bi-directional information exchange system.

- **Security solutions for collaborative networks:** This ICT solution enables secure data storage and exchange in real-time between different companies. It should provide services for authentication Identification and encryption in secure platforms using robust security standards.

Other

- **Open data and system integration platform for unstructured data environment - including harmonised/standardised interfaces:** This solution is required to enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrateable data sets.
- **Information technology (IT) and operational technology (OT) convergence: integrated architecture of Product Lifecycle Management-Manufacturing Execution Systems-Enterprise Resource Management (PLM-MES-ERP):** The desired vision for this solution is to enable the interoperability and ultimately the convergence of the current major business ICT applications such as ERP, MES and PLR.
- **Problem and context-centric display of only crucial information to the users:** This solution provides personalised information and user centric visualisation within an organisation to aid a range of employees (e.g. supervisors, operators, product managers, etc) in problem solving.

The ***main Research and Resources*** required to deliver these ICT Manufacturing Solutions are:

(Mfg) ICT Services

- Big Data: Data analysis/Data fusion
- Factory knowledge base: virtual representation of manufacturing environments; Factory knowledge base: Data consistency by means of (standardised) semantic models/system descriptions; Stakeholder education (users, decision makers etc.); Human-centric digital age - Knowledge about human behaviour using digital media, etc.
- Knowledge transfer between manufacturing and engineering
- Improved usability: hide complexity from users: not hide but make complexity manageable; Improved usability: multi-modal user interfaces; User-centred design
- Real-time monitoring

(Mfg) ICT Architectures

- Security: Operational safety and reliability
- Horizontal integration and optimisation of value chains
- Managing manufacturing uncertainty in an increasingly complex value chain
- Complexity management

(Mfg) ICT Infrastructures

- Cyber-physical Production Systems

Important ***ICT and other Enablers*** to help the development of these technologies and realization of the solutions are:

- Distributed systems (both function-wise and geographically) and multi-level modelling

- Standardisation and reference architectures

The ***main research recommendations*** put forward by the delegates, necessary for realising these ICT manufacturing solutions, were:

Integration

- Integration approaches for existing ICT systems and information (tackling the “wild garden”)
- Integration of new smart components (e.g. new improved low-cost, miniaturised sensors) for data collection, analysis and visualisation
- Development/promotion of interoperability and standards: note standards exist, e.g. IEC 61499, but industrial uptake is very weak

Data and Information

- Unified engineering exchange of data considering provenance, accuracy, contextual awareness and semantic content of unstructured data
- Big Data capture (live streaming for situational awareness), storage (event-driven databases) and analysis (data mining – ideally in real time)
- Distributed processing algorithms for data and systems in real time supported by resilient “industrial strength” cloud computing for the plant floor
- Visualisation techniques and specifically context-aware responsive visualisation of data
- Decision support systems to reduce operator load

Machine Learning and Adaptive Systems to Enable Flexible and Adaptive Manufacturing

- Environments and infrastructures for machine learning, self-adapting and reconfigurable manufacturing
- Intra- and inter-machine communication standards
- Human-centric adaptive interfaces to enhance usability

Multidisciplinary Modelling

- Modelling of factories, information modelling and work domain modelling of socio-technological systems

Security

- Robust Machine-to-Machine (M2M) security protocols that guarantee operational safety and reliability

Confidentiality

- Affordable security for confidentiality, especially within manufacturing supply networks

Demonstrators & Education

- To convince the conservative manufacturing sector of the cost/benefits of new ICT architectures and services
- Education initiatives and training materials to increase awareness

The preliminary research roadmap for the ICT Solutions in manufacturing is shown in Figure 1 below.

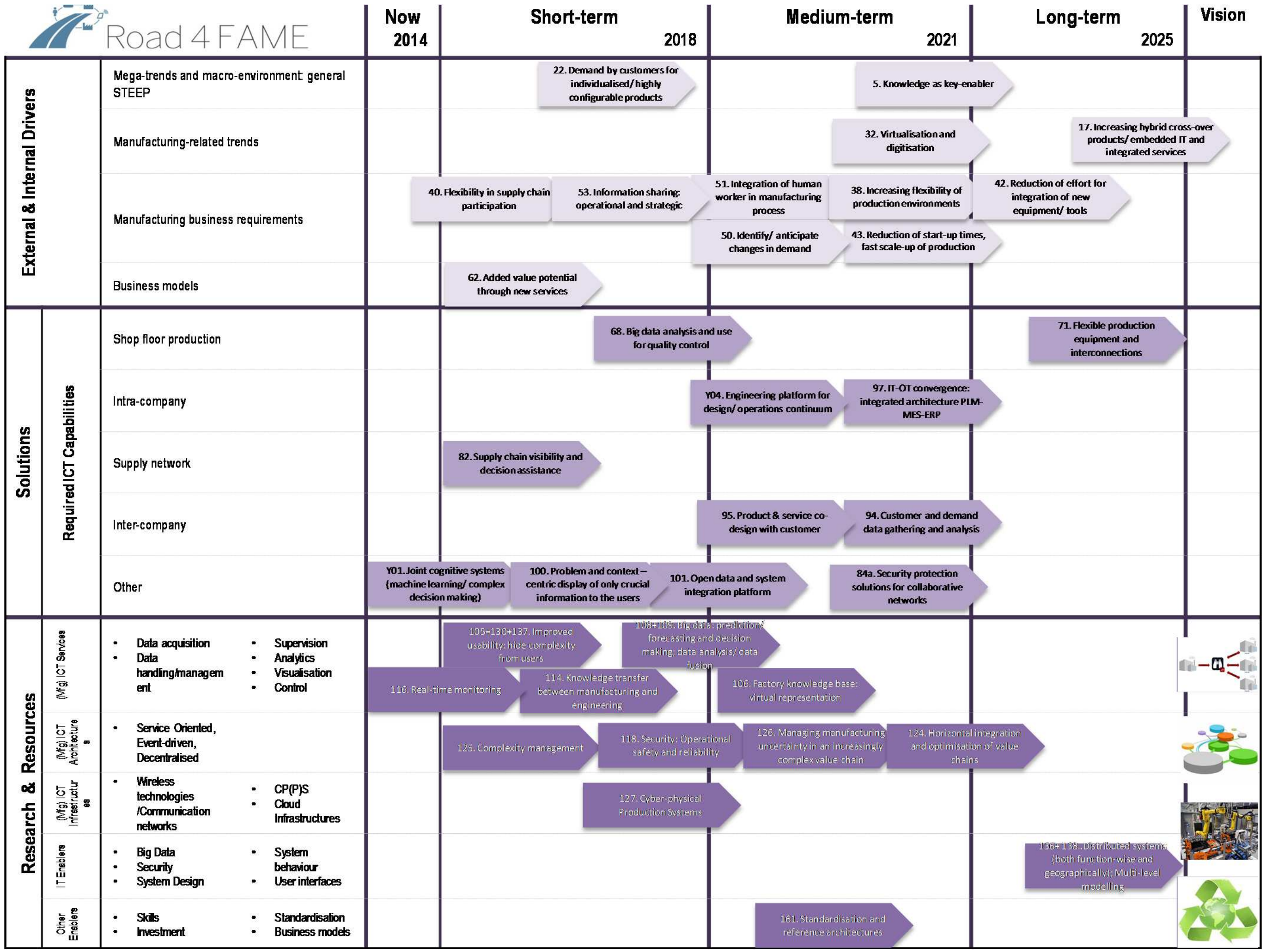

Figure 1: Preliminary research roadmap derived for the Road4FAME project

2 Introduction

European manufacturers face increased pressure in competing in a global economy. Continuous innovation is considered paramount to remain ahead and in particular Information and Communication Technologies (ICT) offer the potential for distinct differentiation.

However, ICT is not yet fully exploited in the manufacturing sector for a variety of reasons such as lack of awareness, resistance to novel ICT paradigms or lack of customisation of competitive ICT solutions to manufacturing.

The Road4FAME project is developing a strategic research and innovation roadmap for IT architectures and services in manufacturing. The project is focussing on architectures and services which facilitate agile and flexible manufacturing processes, ease interoperability in distributed manufacturing environments, support effective collaboration in context-aware enterprises, and provide the foundations for sustainable manufacturing.

The aims of the roadmap are to align future ICT research with the needs of European manufacturing businesses, and to provide European manufacturing businesses with a reference against which they can derive innovation strategies and identify novel business opportunities.

The overall methodology for the creation of the roadmap is summarised by the proposed sequence of workshops in Figure 2: Sequence and number of roadmapping workshops for the Road4FAME project below[3].

This document describes the four main roadmapping workshops run in parallel, which drew upon the outputs from WP1 and WP2 and the initial roadmap with additional input of external experts present at this workshop on 7 October 2014.

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[3] Additional work package specific activities e.g. expert panel meetings, content validation workshops, interviews, etc also take place within the project, but these are described within their specific work package deliverables.

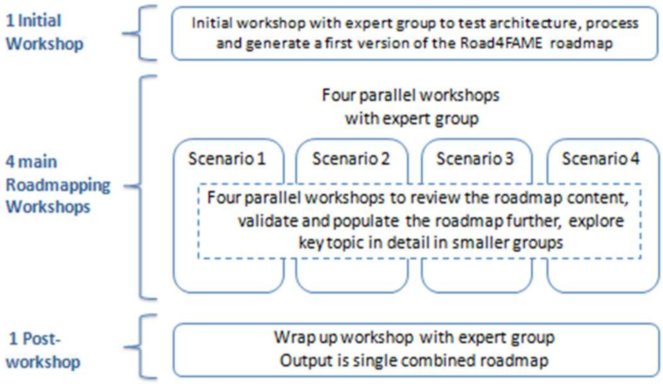


Figure 2: Sequence and number of roadmapping workshops for the Road4FAME project

The Road4FAME project incorporates a series of workshops, and this report summarises the findings from the four main roadmapping workshops that were conducted in parallel involving 45 industrial and academic experts from Europe.

2.1 Objectives of the main Roadmapping workshop on 7 October 2014

The objectives of the main roadmapping workshop for four manufacturing settings were to:

- Review and prioritise drivers and manufacturing business requirements for ICT in Manufacturing
- Identify the most important ICT solutions required in manufacturing overall and for each scenario specifically
- Explore the most important ICT solutions in terms of ICT architecture and services requirements
- Review and prioritise the research and underlying technologies that will be needed to deliver future ICT solutions.

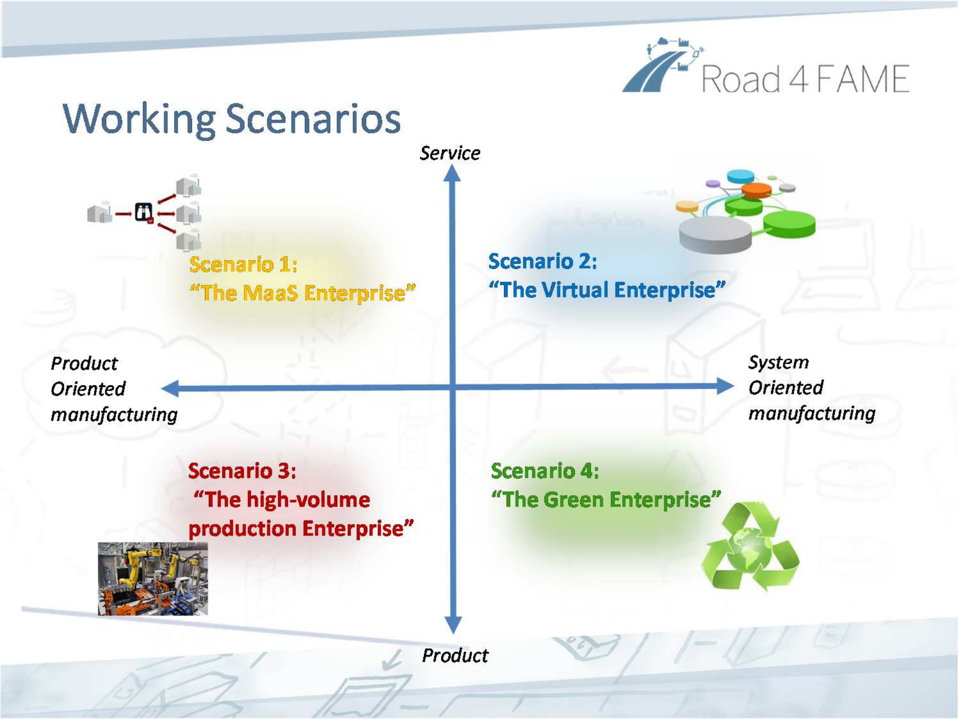
The workshop was designed to explore the four Scenarios in more depth; prioritise the Drivers, ICT and Technology and Resources layers of the roadmap; explore in more detail the ICT solutions that were considered important for most scenarios; generate an action plan and preliminary recommendations from the priority ICT Solutions.

The Scenarios were reviewed and finalised in the initial workshop in Porto, Portugal in May 2014 and are currently:

- **The Manufacturing as a Service Enterprise**: a manufacturing company which does not sell products, but offers manufacturing as a service.
- **The Virtual Enterprise**: an association of manufacturing companies that cooperate to jointly identify and exploit new market opportunities, innovate products and minimise costs.

- **The High-Volume Production Enterprise**: a manufacturing company which produces very high volumes of goods and increasingly faces the challenge of shorter product life-cycles.
- **The Green Enterprise**: a manufacturing company for which environmental awareness is an important part of the company image and objectives.

These reflect possible end points across two roughly independent (orthogonal) axes; the degree that a manufacturing business provides a service or a product to its customers and the level in which a business is addressing the whole life cycle of a product (concerned just with production or each step in the manufacturing cycle from raw material to decommissioning and recycling).



Road 4 FAME

Working Scenarios

Service

Scenario 1:
"The MaaS Enterprise"

Scenario 2:
"The Virtual Enterprise"

Product Oriented manufacturing

System Oriented manufacturing

Scenario 3:
"The high-volume production Enterprise"

Scenario 4:
"The Green Enterprise"

Product

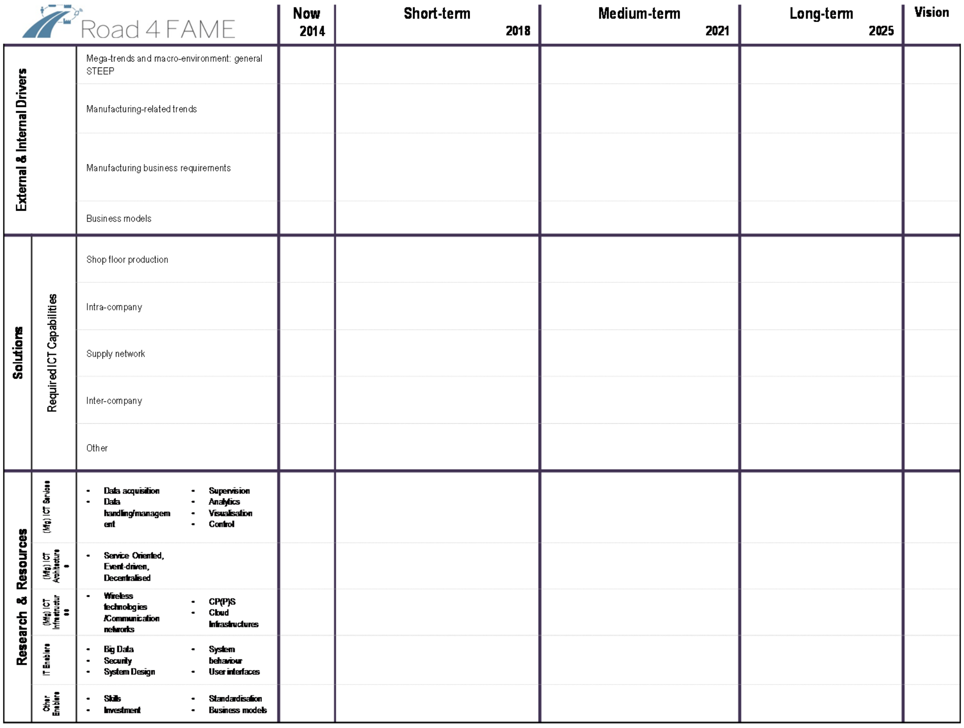
Figure 3: The four working Scenarios for the Road4FAME project

These four Scenarios form the basis for the four perspectives of the initial Road4FAME roadmapping workshop described in this document.

3 Preliminary Road4FAME Roadmap in 4 Manufacturing Settings Methodology

3.1 Architecture

The roadmap architecture has gone through several iterations. After the preliminary roadmapping workshop on 23 May in Porto the following architecture was established as shown in Figure 4 below.



			Now 2014	Short-term 2018	Medium-term 2021	Long-term 2025	Vision
External & Internal Drivers		Mega-trends and macro-environment: general STEEP					
		Manufacturing-related trends					
		Manufacturing business requirements					
		Business models					
Solutions	Required ICT Capabilities	Shop floor production					
		Intra-company					
		Supply network					
		Inter-company					
		Other					
Research & Resources	(Mfg) ICT Services	- Data acquisition - Data handling/management - Supervision - Analytics - Visualisation - Control					
	(Mfg) ICT Architecture	- Service Oriented, Event-driven, Decentralised					
	(Mfg) ICT Infrastructures	- Wireless technologies /Communication networks - CP(P)S - Cloud Infrastructures					
	IT Enablers	- Big Data - Security - System Design - System behaviour - User interfaces					
	Other Enablers	- Skills - Investment - Standardisation - Business models					

Figure 4: Roadmap architecture for the Road4FAME project

Industry and market dimensions have been included at the top, and typically this ‘top third’ of the roadmap would provide external and internal drivers and trends – ‘why’ things are done (Drivers layer).

- **Mega-Trends & Macro-environment** includes generic ‘STEEP’ factors – those macro-environmental sociological, technological, environmental, economic and political factors which are generally applicable.
- **Manufacturing-related trends** – relates more directly to manufacturing industry itself, and looks at trends within the industry.
- **Manufacturing business requirements** – this defines how manufacturing trends and drivers in the layer above translate into needs to manufacturing businesses.
- **Business models** – the routes by which value is delivered by manufacturing businesses.

Solutions dimensions have been included in the central section, and this middle part of the roadmap considers ‘what’ needs to be provided to address the needs, trends and drivers in the ‘why’ section above from the perspective of manufacturing industry. This includes the required ICT capabilities - the functionality required to support the stated manufacturing business requirements now and in the future.

The Solutions layer contains the following sub-layers:

- **Shop floor production** – These are ICT Solutions predominantly affecting operations within the production area.
- **Intra-company** – These are ICT Solutions necessary for the smooth operation of a company as a whole that link different departments or functions together. They may include coordination and business processes for production, finance, sales, dispatch, etc.
- **Supply network** – These are ICT Solutions required for a business to coordinate its activities with its own supply network.
- **Inter-company** – These are ICT Solutions enabling business operations with available suppliers, partners, customers etc.
- **Other**

Research and resources make up the bottom third of the roadmap. This section considers 'how' the 'what' can be achieved to address the 'why'.

- **(Manufacturing) ICT Services** - these provide encapsulated functionality – e.g. a browser enables browsing of the internet by means of defined interfaces.
- **(Manufacturing) ICT Architectures** – these describe the means of organization – i.e. it is a framework of how to integrate/connect services together to create the overall functionality. Often there is a hierarchical architecture in manufacturing e.g. sensors and actors, EPLC level, manufacturing execution system, and then enterprise resource planning (ERP) system.
- **(Manufacturing) ICT Infrastructures** – these are hardware or IT related, which enables use of hardware in some way. It is the underlying 'thing' on which architectures and services are realised, e.g. cloud computing.
- **IT Enablers** – non-ICT technologies that enable ICT developments.
- **Other enablers** – skills, investment (funding required for the developments identified, together with potential sources), standardization and business models.

3.2 Roadmapping Workshop Process

This section describes the methodology followed for the preparations, organization and facilitation of the main roadmapping workshop on 7 October 2014 in London.

The S-Plan process (R. Phaal, 2010) is particularly appropriate for the broad scope of the Road4FAME project. The aim is to identify, prioritize, and explore key issues, research needs, strategic options, and innovation opportunities which lead to decisions and actions. This one-day workshop process involves a group of participants reviewing and populating a large 'landscape' chart in the morning, before identifying points of interest – ***'landmarks'*** – which are investigated in further detail by smaller groups in the afternoon.

An important process step during the exploration of the ***'landmarks'*** would be understanding in detail a range of factors such as existing knowledge gaps, resource and skill limitations, key success factors and barriers. These will form a basis for developing preliminary recommendations that will be analyzed, explored and expanded further in WP5.

The plan was followed successfully and the workshop consolidated the information gathered through desk-based research, explored the medium and longer-term timeframes of the roadmap for the four manufacturing Scenarios in greater depth, and generated additional content.

The two figures below summarise the main steps of the workshop process for the morning and afternoon sessions, respectively:

Road 4 FAME

Scenario 2: "The Green Enterprise"

A company to which environmental awareness is an important part of its image and objectives

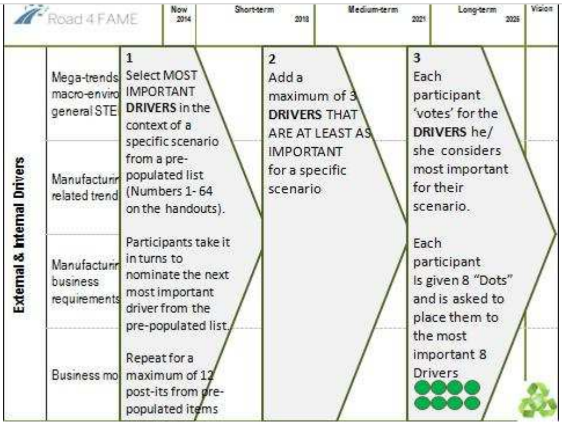
- Availability of real-time information about the footprint of manufacturing processes to steer production towards minimal environmental impact.
- Recycling, product rental and return policies are strategic and are implemented and followed.
- Environmental implications of design, process, and buying decisions are completely transparent.
- *The **main challenge** is to achieve high degree of transparency to its customers and demonstrate clear environmental sustainability.*

Step 1: Explain the specific Scenario to the group of participants

Road 4 FAME

GREEN Scenario – The Green Enterprise	In 2014	In 2025
Who is your most important customer & what are THEIR priorities		
What is your biggest supply chain challenge		
What are your top 3 KPIs / Order-winning criteria		
What is the biggest opportunity?		
What is the greatest threat?		

Step 2: Participants complete this template to help them think about what issues are important in their scenario – Now and in the Future



Road 4 FAME

Now 2014 | Short-term 2018 | Medium-term 2021 | Long-term 2025 | Vision

External & Internal Drivers

Mega-trends macro-enviro general STE

Manufacturin related trend

Manufacturin business requirements

Business mo

1
Select MOST IMPORTANT **DRIVERS** in the context of a specific scenario from a pre-populated list (Numbers 1- 64 on the handouts).

Participants take it in turns to nominate the next most important driver from the pre-populated list.

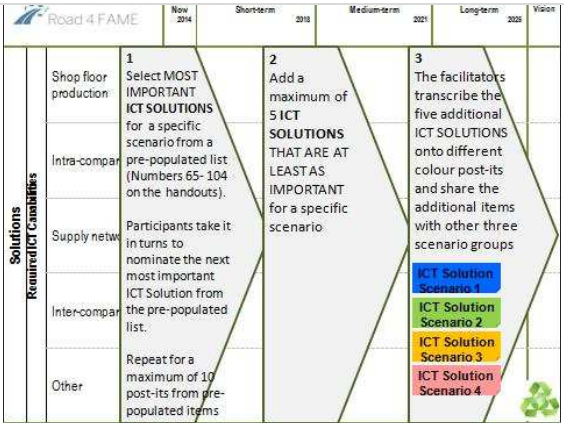
Repeat for a maximum of 12 post-its from pre-populated items

2
Add a maximum of 3 **DRIVERS** THAT ARE AT LEAST AS IMPORTANT for a specific scenario

3
Each participant 'votes' for the **DRIVERS** he/ she considers most important for their scenario.

Each participant Is given 8 "Dots" and is asked to place them to the most important 8 Drivers

Step 3: Participants select from an existing list the most important drivers for their scenario, add three additional and equally important new ones and prioritise them using 8 dots each.



Road 4 FAME

Now 2014 | Short-term 2018 | Medium-term 2021 | Long-term 2025 | Vision

Solutions

Required ICT Capabilities

Shop floor production

Intra-compar

Supply netw

Inter-compar

Other

1
Select MOST IMPORTANT **ICT SOLUTIONS** for a specific scenario from a pre-populated list (Numbers 65- 104 on the handouts).

Participants take it in turns to nominate the next most important ICT Solution from the pre-populated list.

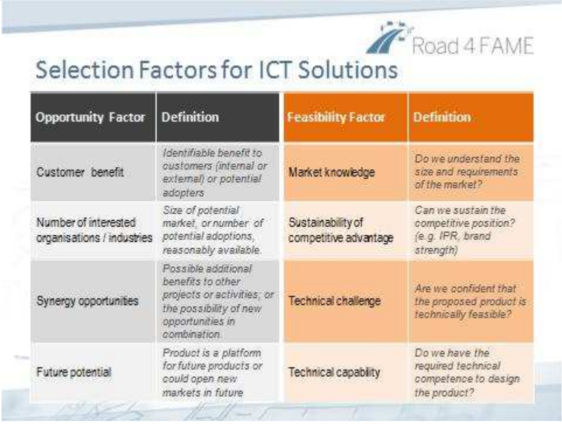
Repeat for a maximum of 10 post-its from pre-populated items

2
Add a maximum of **5 ICT SOLUTIONS** THAT ARE AT LEAST AS IMPORTANT for a specific scenario

3
The facilitators transcribe the five additional ICT SOLUTIONS onto different colour post-its and share the additional items with other three scenario groups

ICT Solution Scenario 1
ICT Solution Scenario 2
ICT Solution Scenario 3
ICT Solution Scenario 4

Step 4: Participants review the prioritized drivers from step 3 and select from the existing list required ICT solutions to address those drivers. They add five additional new solutions. Each facilitator shares the additional ICT solutions with the other three scenario groups.

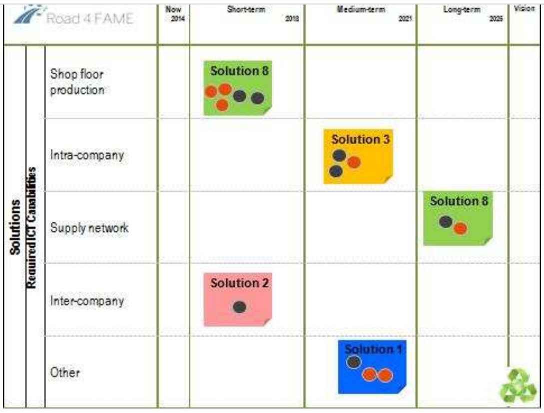


Road 4 FAME

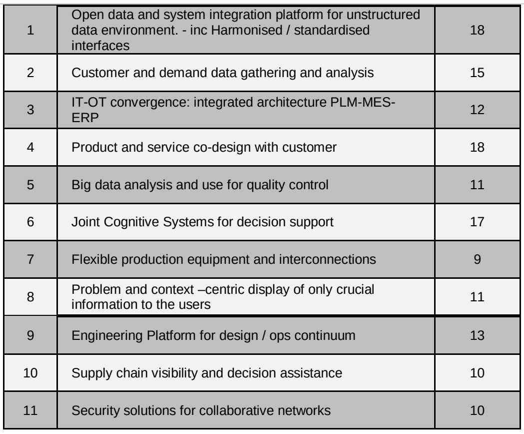
Selection Factors for ICT Solutions

Opportunity Factor	Definition	Feasibility Factor	Definition
Customer benefit	Identifiable benefit to customers (internal or external) or potential adopters	Market knowledge	Do we understand the size and requirements of the market?
Number of interested organisations / industries	Size of potential market, or number of potential adoptions, reasonably available.	Sustainability of competitive advantage	Can we sustain the competitive position? (e.g. IPR, brand strength)
Synergy opportunities	Possible additional benefits to other projects or activities; or the possibility of new opportunities in combination.	Technical challenge	Are we confident that the proposed product is technically feasible?
Future potential	Product is a platform for future products or could open new markets in future	Technical capability	Do we have the required technical competence to design the product?

Step 5: Participants review pre-selected Opportunity and Feasibility criteria that are used to prioritise the 30 ICT Solutions (15 from own scenario and 5 new ones from the other 3 scenarios).

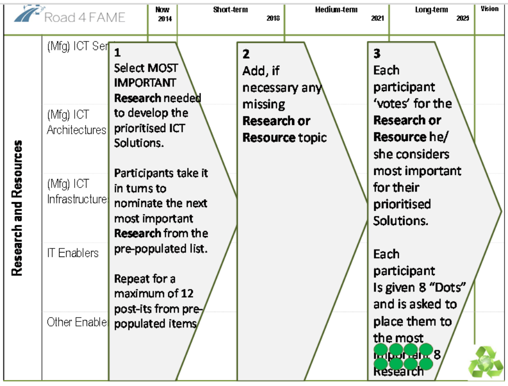


Step 6: Each participant allocates 8 Black "Dots" for How **Attractive** is the Opportunity. Focussing only on Solutions that have black "Dots", each participant allocates 4 Orange "Dots" for How **Feasible** is the Solution.



1	Open data and system integration platform for unstructured data environment. - inc Harmonised / standardised interfaces	18
2	Customer and demand data gathering and analysis	15
3	IT-OT convergence: integrated architecture PLM-MES-ERP	12
4	Product and service co-design with customer	18
5	Big data analysis and use for quality control	11
6	Joint Cognitive Systems for decision support	17
7	Flexible production equipment and interconnections	9
8	Problem and context –centric display of only crucial information to the users	11
9	Engineering Platform for design / ops continuum	13
10	Supply chain visibility and decision assistance	10
11	Security solutions for collaborative networks	10

Step 7: Opportunity and Feasibility votes are consolidated across all scenarios and a list is created of the highest scoring ICT Solutions applicable to more or more scenarios



1
Select MOST IMPORTANT **Research** needed to develop the prioritised ICT Solutions.

Participants take it in turns to nominate the next most important **Research** from the pre-populated list.

Repeat for a maximum of 12 post-its from pre-populated items

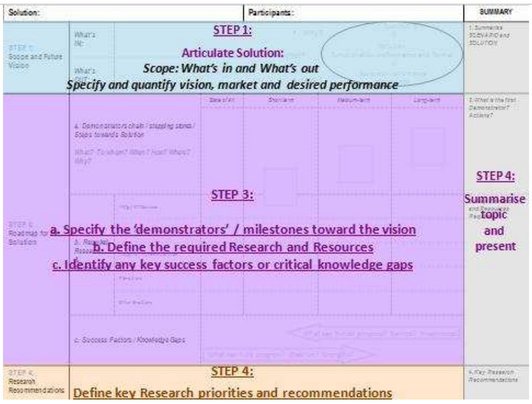
2
Add, if necessary any missing **Research or Resource** topic

3
Each participant 'votes' for the **Research or Resource** he/ she considers most important for their prioritised Solutions.

Each participant Is given 8 "Dots" and is asked to place them to the most important 8 Research

Step 8: Participants review the prioritized ICT Solutions from step 6 and select from the existing list required Research and Resources needed to develop these Solutions. They add Research themes if necessary and prioritise them using 8 dots each.

Figure 5: Workshop process for the four parallel workshops (plenary morning session)



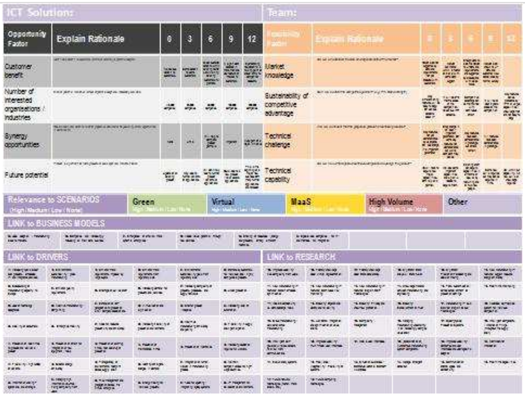
STEP 1:
Articulate Solution:
Scope: What's in and What's out
Specify and quantify vision, market and desired performance

STEP 3:
a. Specify the 'demonstrators' / milestones toward the vision
b. Define the required Research and Resources
c. Identify any key success factors or critical knowledge gaps

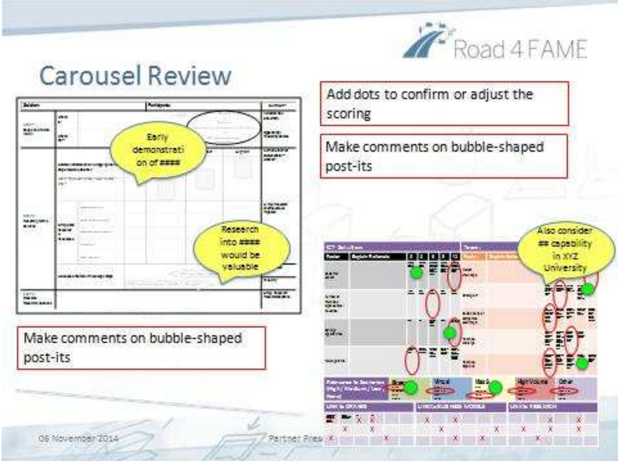
STEP 4:
Summarise topic and present

STEP 4:
Define key Research priorities and recommendations

Step 1: Participants split into groups of 3-4 and explore one of the eleven ICT Solutions in more detail. After completion of step 2, they present their assessment to the other groups.



Step 2: After exploration, the participants score each ICT solution against each specific Opportunity and Feasibility factors, assess its relevance to a specific scenario, and its specific links to manufacturing drivers and needs and ICT architecture and services.



Carousel Review

Add dots to confirm or adjust the scoring

Make comments on bubble-shaped post-its

Make comments on bubble-shaped post-its

Step 3: At the end a Carousel review takes place, where every participant has the opportunity to comment and vote on all other topics.

Figure 6: Workshop process for the group work (afternoon) session

3.2.1 Timing

The agenda for the workshop was as follows:

08.45	Arrival	
09.00	Welcome, Introductions and Project Overview	
09.15	Scenario Introductions – Briefing and Immersion exercise	Scenario Groups
09.45	Review, Add & Prioritise Drivers and Business requirements	Scenario Groups
10.15	Review and Add Required ICT Solutions	Scenario Groups
11.00	Break	
11.15	Prioritise Required ICT Solutions based on different Scenarios	Scenario Groups
11.45	Review, Add & Prioritise Required Research & Resources	Scenario Groups
12.15	Lunch	
13.00	Cross-scenario review of ICT Solutions and define breakout groups	All
13.15	Explore and define the selected Solutions - Template 1	Solution Groups
14.15	Break	
14.30	Characterise selected solutions - Template 2	Solution Groups
15.30	Presentation of “Elevator Pitches” for each ICT Solution	All
16:15	Carousel Review	All
17.00	Wrap up & Close	All

3.2.2 Follow up

In the immediate follow up of the workshop, the outputs on all the sticky notes were transcribed and captured electronically. These were analysed and used for the creation of this deliverable report.

4 Roadmap – overall output from the workshop

For the main roadmapping event, a one-day workshop was planned, with 45 industrial and academic participants from Europe. Industrial participants represented more than 60% of the delegates and were both ICT developers as well as users of ICT from the manufacturing industry. Approximately 20% of the industrial participants were SMEs. A full list of the participants, with a breakdown by EU country and Industry/Academia, is provided in Appendix 4.

The participants, split in four groups (one per scenario), explored and refined the four scenarios, selected, updated and prioritized the information that had been collected previously and selected the most important ICT solutions to explore further in smaller groups.

The four workshops were conducted in parallel to ensure time was used efficiently and maximum benefit is gained for the project by optimizing the time available from the participants and their expertise.

Each Scenario was colour-coded (charts and pre-printed post-it notes) and each participant was assigned to one of the four Scenarios in advance of the workshop taking into account their specific expertise and interests. Each participant was given a colour-coded post-it in accordance to his/her Scenario to provide input as well as votes in the form of colour-coded sticky dots. This way the input and votes from each Scenario could be easily distinguished and compiled for analysis, as well as total input and priorities for the ICT in manufacturing sector.

The following people participated in the each Scenario/group:

Yellow Scenario: **The MaaS Enterprise**	**Blue Scenario:** **The Virtual Enterprise**	**Red Scenario:** **The High-volume production Enterprise**	**Green Scenario:** **The Green Enterprise**
Lina Huertas Martin Kelman Ioannis Kotsiopoulos Andrei Lobov George Pintzos Keith Popplewell Juha Roning Christian Sonntag Haydn Thompson Connor Upton Teles Vasco	Silvia Castellvi Eva Coscia Alexander Demmer Harald Egner Gregory Ella Raik Hartung Artur Krukowski Angelica Nieto Lee Michael Peschl Daniel Stock Bob Young	Christopher Kirsch Thor List Tim Lucas Pierfrancesco Manenti Rafael Michalczuk Robert Mills Pedro Oliveira Ursula Rauschecker Luis Saenz de Santamaria Raquel Ventura Ian Walls Patricia Wolny	Alicia González Rick Greenough Sergio Gusmeroli Mikael Haag Manuel Oliveira Anibal Reñones Diego Esteban Rodríguez Björn Sautter

Table 1: List of Participants for each Scenario for the morning (plenary) discussion

4.1 Vision for each scenario

The participants of each scenario group were asked to consider the manufacturing industry under their scenario now and in 10 years time. This was to create a potential vision of the future industrial landscape and its requirements on ICT. The participants were asked to consider who are the customers and their requirements, how companies can differentiate their position and offerings in the market place, the potential challenges for the companies and their suppliers and any opportunities and threats they need to be aware of under each operating scenario. A summary of the outputs for each scenario is shown below:

YELLOW Scenario – The MaaS Enterprise	In 2014	In 2025
Who is your most important customer & what are THEIR priorities?	• Most are long term customers including OEM • High-margin customers Priorities: • Working with an industry expert • Accessing flexible & large volume capability • Achieving high quality/low-cost customisation trade-off • Able to produce niche – low volume products	Brand-name customers Priorities: • Ability to manufacture small batch quantities • Merging requirements • Customisation & speed for all
What is your biggest supply chain challenge?	• Materials expertise & forecasting • Buying in stock – o Risk management across the board o Cash flow • Visibility • Last minute orders • Managing pre-defined customisation	• Synchronisation fixed - flexibility • Materials expertise & "control" • Mass personalisation • Networks & complexity • Need to understand increasing risk • Customer dependent on your supply expertise – or total directed buy
What are your top 3 KPIs/ Order-winning criteria?	• Speed of response • Price • Quality • Scale up/down	• Variety – rate of successful mutation • Portfolio of abilities • Information sharing – systems interoperability
What is the biggest opportunity?	• Flexibility & "virtual supply chain" • Mass customisation • More flexible leading to more robust & more diverse business • Technological agility • "Manufacturing experts" • Risk management • Additive technology • IP ownership & security	• New business model • Forecasting issues • Setting the right prices • Shorter life cycles & lead time expectation
What is the greatest threat?	• IP ownership & security • Validation & propagation • OEM vertical integration • Brand definition/differentiation • High skill availability • Fast technology changes & integration issues	• Forecasting issues • Setting the right prices • Shorter life cycles & lead time expectation • Reliance on general economic conditions • Capital investment quickly obsolete

BLUE Scenario – The Virtual Enterprise	In 2014	In 2025
Who is your most important customer & what are THEIR priorities?	Customers: 1. SMEs that rapidly adapt to customer needs and are able to track products to share data with partners. Enables them to offer low volume or personalised products 2. Large service operators (adaptation flexibility to changing demands) 3. OEMs (product development department); offering new, high quality products & services at low cost. Enables distributed manufacturing, innovation and flexibility. Priorities: - Respond to customer demand; fast, appropriate quality & price, ecologic manufacture - SMEs that need cheap and fast prototyping. SMEs that require the same product at the same quality worldwide close to the consumer - Large OEMs improved efficiencies information - Always some combination of “better, faster, cheaper” - Government (procurement); Reduce costs	Customers 1. OEMs 2. Consumers Customers are now both companies and end users. Putting customers in the loop with flexible, scalable, secure solutions. Offering fast innovation customisation Devolution of supply chain “driving force” away from OEM towards Tier1, Tier2 Priorities: - Fast adoption of trends keeping the quality requirements of markets and customers - Offering OEMs fast time to market, high quality and pre- and post-sales services - Offering end user – individual features and/or close loop control & innovation
What is your biggest supply chain challenge?	Supply chain challenges: - Flexibility in configuration - Globalisation - Servitisation - Trust - Responsibility - Standardisation, transparency and common standards (information/ data exchange formats - Interoperability - Information flow - Distributed data and information sources - Speed of delivery to customer - Minimising stocks and storage - Minimising transport cost	Supply chain challenges: - Synchronisation of the group of virtual partners - Planning - Balance between central synchronisation and dispatching unit and local units - Flexible building of supply chain related to the actual demand
What are your top 3 KPIs/ Order-winning criteria	Top KPIs: - Partner trust - Effectiveness - Time (ramp-up for production) - Cost (material, personnel) - Flexibility (time related) “How long it takes a company to react to specific demand”	Top KPIs: The same as for 2014
What is the biggest opportunity?	- Product servitisation, innovation and collaboration - Cost reduction and knowledge sharing that “grows” over time	- Transport: land and small deliveries over air - Small runs of customised products - Cloud infrastructure/ services

	• New standards in communication m/c to business ICT • Keep the pool position worldwide	• ICT costs reduction • ICT as a service self-solutions development
What is the greatest threat?	• Lack of flexibility in ICT tools • Lack of standards in ICT • Security & privacy of data • Communication of the virtual partners	• Cost benefit especially for small production runs • ICT Security - increasing in importance & criticality

RED Scenario – The High Volume Production Enterprise	**In 2014**	**In 2025**
Who is your most important customer & what are THEIR priorities?	Customers want to be seen as individuals Priorities: • Better customer experience • Right time to market • Keep up quality	• Personalised products • Engage customers in product design • New products every year • Short period of time from design to market • Small lot sizes
What is your biggest supply chain challenge?	• No visibility throughout the whole chain • Short term “delivery & availability” • Cost of innovation • End user support of complex products • Difficult to achieve high delivery time to assist planning	• Sustaining quality & volume • New types of supplier contracts • Agility in order to adapt • Manufacturing without fixed tooling • Increasing product complexity/ functionality • Customer of choice • Open innovation • Communication between phases
What are your top 3 KPIs/ Order-winning criteria?	• Excellent/Perfect Quality • Agility and speed of delivery • Forecasting • OEE and/or machine failure • Production downtime due to supply shortage • Sustained volume to schedule • Flexibility • Quantity sold • Quantity return	• Products end-of-life • Order lead times
What is the biggest opportunity?	• Emerging markets • Globalisation • Predict customers’ needs	• Local production close to market • Globally available resources • 3D printing • Engaging consumer
What is the greatest threat?	• Losing touch with customers • Missing market trends • Too broad diversity • Failing to understand the flow of the business variables to the bottom line	• Supply chain disruption • Quality control of full supply chain • Raw material cost increasing • 3D printing of similar designs & functionality • Miss system-integration, stick to traditional branch boundaries • Unfair labour • Cheaper solutions for SMEs • IP

GREEN Scenario – The Green Enterprise	In 2014	In 2025
Who is your most important customer & what are THEIR priorities?	• OEM with green reputation, e.g. Patagonia • Companies building "green"/ image • Consumer who shares green values • Governments • More "Market push"	• Longevity will be more important • Products last longer (services) • Society is green minded so more consumers demand green • Low life-cycle impact • Life-cycle awareness • Companies from countries with problems of resources • More "Market pull"
What is your biggest supply chain challenge?	• New business models along supply chain • Carbon footprint vs. globalisation	• Consumers of healthy products • Information transparency and traceability • Green certification in supply chain
What are your top 3 KPIs/ Order-winning criteria	• Cost in order to become green • Total cost of ownership including including purchasing, operations etc. • Customer satisfaction wellbeing	• Satisfaction & consumer • Information overload for customer • Single label?
What is the biggest opportunity?	• Being green means being efficient and profitable • Knowledge & training • Produce green for non-developed countries consumers	• Reuse waste material as new material for additive manufacturing • Close 100% recycling and energy independency
What is the greatest threat?	• Lack of resource for manufacturing • Lack of KPI and standards on green • Increasing cost of energy • Wellbeing unbalance among countries • Society consumer education • Different global timing in change • How to recover the investment • How to get revenues	• Climate change affecting supply chain • Geopolitical unrest (resource wars)

There is commonality of issues between the different scenarios with customers requiring more product customisation, innovation and traceability while maintaining quality and reducing costs. This puts pressure to the manufacturers and their supply chains for more flexibility and faster delivery, better planning and forecasting. There are opportunities for companies to embrace ICT-enabled innovation and new manufacturing methods (i.e. 3D printing), access to global markets, and adopt new business models including greater servitisation. The potential threats relate mainly to the global competition and exposure to global financial problems, increasing complexity of products and commercial networks, potential ICT security issues, skill shortages and realising the cost benefits of the investments and new business models.

4.2 Trends & Drivers

Exploration of the trends and drivers took place initially with group discussion. Sixty-four trends, drivers, needs and business models derived from Deliverable 2.3 and prioritized in the initial workshop in Porto were pre-printed in post-it notes and provided to each scenario team. Each team member was asked to review the list and select one he/she considered most important for their scenario. The participants took turns to select and add post-its to their roadmap and approximately

10-15 of trends and drivers were selected by each scenario group. They were also asked to add three additional and equally important new ones (or select three more from the existing list).

The groups added the following scenario-specific trends, drivers and needs:

Scenario	Swimlane	New Driver, Trend, Need, Business Model
MaaS enterprise	Manufacturing-related trends	Ever increasing complexity of manufacturing environment
	Manufacturing Business Needs	Portfolio of manufacturing capability
Virtual enterprise	Megatrends	Servitisation
High Volume enterprise	Manufacturing Business Needs	Engagement with consumers/ co-operation
Green enterprise	Manufacturing Business Needs	Society education
	Manufacturing Business Needs	Green labels for factories
	Business Models	Remanufacturing

Table 2: Additional trends, drivers and needs added by each scenario group

Finally, the participants were provided with eight sticky dots each, were asked to review the selected 13 -15 trends and drivers on their roadmap and affix the dots to the trends and drivers they considered the most important overall for their scenario.

The results of the voting per Scenario and overall were as follows:

Number	Swimlane 1	Text	Timeline	Votes
50	Manufacturing Business Needs	Identify/anticipate changes in demand	L	10
61	Business Models	Emergence of smaller, more dynamic enterprises	M	7
38	Manufacturing Business Needs	Increasing flexibility of production environments	S	6
43	Manufacturing Business Needs	Reduction of start-up times, fast scale-up of production	Now	6
53	Manufacturing Business Needs	Information sharing; operational and strategic	S	6
33	Manufacturing-related trends	Shorter product lifecycles	Now	5
55	Manufacturing Business Needs	Risk management and propagation across the virtual enterprise	M	5
41	Manufacturing Business Needs	Reduction of lead times to produce and deliver a product	S	5
5	Megatrends	Knowledge as key-enabler	M	3
13	Megatrends	Increasing rate of knowledge and technological change	S	3
17	Manufacturing-related trends	Increasing hybrid cross-over products / embedded IT and integrated services	L	3
NEW	Manufacturing-related trends	Ever increasing complexity of manufacturing environment	M	3
42	Manufacturing Business Needs	Reduction of effort for integration of new equipment / tools	Now	3
58	Manufacturing Business Needs	IP management for collaborative environments	S	3
62	Business Models	Added value potential through new services	S	3
22	Manufacturing-related trends	Demand by customers for individualized / highly configurable products	M	2
31	Manufacturing-related trends	Extension of ICT perspective to production site / company associations	M	2
51	Manufacturing Business Needs	Integration of human worker in manufacturing process	M	2
64	Business Models	Specialised companies for IT and methods for integration of advanced ICT solutions	S	2
6	Megatrends	Resource stress and scarcity, rising energy costs, raw material prices	S-L	1
23	Manufacturing-related trends	Backsourcing of manufacturing capacity to Europe	M	1
NEW	Manufacturing Business Needs	Portfolio of manufacturing capability	L	1

Table 3: Voting on trends and drivers by Scenario 1 (YELLOW)- The MaaS Enterprise

Number	Swimlane 1	Text	Timeline	Votes
5	Megatrends	Knowledge as key-enabler	Now	8
40	Manufacturing Business Needs	Flexibility in supply chain participation	S	6
32	Manufacturing-related trends	Virtualisation and digitisation	S-M	5
51	Manufacturing Business Needs	Integration of human worker in manufacturing process	M	5
53	Manufacturing Business Needs	Information sharing; operational and strategic	S-M	5
63	Business Models	Sharing of resources (energy and products) among different factories	S	5
22	Manufacturing-related trends	Demand by customers for individualized / highly configurable products	M	4
23	Manufacturing-related trends	Backsourcing of manufacturing capacity to Europe	M	4
25	Manufacturing-related trends	Shortage of skilled staff	S	4
27	Manufacturing-related trends	Increasing complexity of products, processes, and supply networks	S	4
50	Manufacturing Business Needs	Identify/anticipate changes in demand	M	4
29	Manufacturing-related trends	Lack of technology acceptance	Now	3
41	Manufacturing Business Needs	Reduction of lead times to produce and deliver a product	S	3
43	Manufacturing Business Needs	Reduction of start-up times, fast scale-up of production	Now	3
30	Manufacturing-related trends	Additive manufacturing / 3D-printing	L	2
1	Megatrends	Demographic change	S	1
18	Manufacturing-related trends	Stricter/more requirements imposed by large buyers	M	1
20	Manufacturing-related trends	Environmental sustainability goals from regulatory side	S	1
31	Manufacturing-related trends	Extension of ICT perspective to production site / company associations	Now-S	1
48	Manufacturing Business Needs	Greater energy efficiency	M	1

Table 4: Voting on trends and drivers by Scenario 2 (BLUE) - The Virtual Enterprise

Number	Swimlane 1	Text	Timeline	Votes
38	Manufacturing Business Needs	Increasing flexibility of production environments	M	10
42	Manufacturing Business Needs	Reduction of effort for integration of new equipment / tools	M	10
43	Manufacturing Business Needs	Reduction of start-up times, fast scale-up of production	M	10
5	Megatrends	Knowledge as key-enabler	M	7
40	Manufacturing Business Needs	Flexibility in supply chain participation	S	6
10	Megatrends	Rise of the individual	S	5
22	Manufacturing-related trends	Demand by customers for individualized / highly configurable products	S	5
17	Manufacturing-related trends	Increasing hybrid cross-over products / embedded IT and integrated services	L	5
32	Manufacturing-related trends	Virtualisation and digitisation	M	4
51	Manufacturing Business Needs	Integration of human worker in manufacturing process	M	4
30	Manufacturing-related trends	Additive manufacturing / 3D-printing	L	3
58	Manufacturing Business Needs	IP management for collaborative environments	L	3
59	Business Models	Local adaption / manufacturing close to markets	S	3
4	Megatrends	Accelerating innovation and new technologies	S	2
16	Megatrends	Changes in economic purchasing power of customers and populations	S	2
24	Manufacturing-related trends	Stricter quality requirements	S	2
46	Manufacturing Business Needs	Increasing education required for workers	S	1
49	Manufacturing Business Needs	Transparency of environmental footprint across supply chain	S	1
62	Business Models	Added value potential through new services	M-L	1
NEW	Manufacturing Business Needs	Engagement with consumers/co-operation	L	1

Table 5: Voting on trends and drivers by Scenario 3 (RED)- The high-volume production Enterprise

Number	Swimlane 1	Text	Timeline	Votes
49	Manufacturing Business Needs	Transparency of environmental footprint across supply chain	M	5
62	Business Models	Added value potential through new services	S	5
6	Megatrends	Resource stress and scarcity, rising energy costs, raw material prices	S-L	4
22	Manufacturing-related trends	Demand by customers for individualized / highly configurable products	S-L	4
28	Manufacturing-related trends	Urban production	M	4
3	Megatrends	Urbanisation	M	3
NEW	Manufacturing Business Needs	Society education	S-M	3
11	Megatrends	Climate Change	S	2
36	Manufacturing-related trends	Enterprise mobility	Now	2
46	Manufacturing Business Needs	Increasing education required for workers	Now	2
9	Megatrends	Rise of environmental consciousness	Now	1
16	Megatrends	Changes in economic purchasing power of customers and populations	S	1
54	Manufacturing Business Needs	Managing high information volumes / hiding complexity from users	M-L	1
63	Business Models	Sharing of resources (energy and products) among different factories	S	1
NEW	Business Models	Remanufacturing	S	1

Table 6: Voting on trends and drivers by Scenario 4 (GREEN) - The Green Enterprise

Number	Swimlane 1	Text	Timeline	Votes	Votes	Votes	Votes	Total Votes
43	Manufacturing Business Needs	Reduction of start-up times, fast scale-up of production	S-M	6	3	10		19
5	Megatrends	Knowledge as key-enabler	M	3	8	7		18
38	Manufacturing Business Needs	Increasing flexibility of production environments	S-M	6		10		16
22	Manufacturing-related trends	Demand by customers for individualized / highly configurable products	S-M	2	4	5	4	15
50	Manufacturing Business Needs	Identify/anticipate changes in demand	M-L	10	4			14
42	Manufacturing Business Needs	Reduction of effort for integration of new equipment / tools	Now	3		10		13
40	Manufacturing Business Needs	Flexibility in supply chain participation	S		6	6		12
51	Manufacturing Business Needs	Integration of human worker in manufacturing process	M	2	5	4		11
53	Manufacturing Business Needs	Information sharing; operational and strategic	S-L	6	5			11
32	Manufacturing-related trends	Virtualisation and digitisation	S-M		5	4		9
62	Business Models	Added value potential through new services	S-L	3		1	5	9
17	Manufacturing-related trends	Increasing hybrid cross-over products / embedded IT and integrated services	L	3		5		8
61	Business Models	Emergence of smaller, more dynamic enterprises	M	7				7
49	Manufacturing Business Needs	Transparency of environmental footprint across supply chain	M			1	5	6
58	Manufacturing Business Needs	IP management for collaborative environments	L	3		3		6
63	Business Models	Sharing of resources (energy and products) among different factories	S		5		1	6
6	Megatrends	Resource stress and scarcity, rising energy costs, raw material prices	S-L	1			4	5
10	Megatrends	Rise of the individual	S			5		5
23	Manufacturing-related trends	Backsourcing of manufacturing capacity to Europe	M	1	4			5
30	Manufacturing-related trends	Additive manufacturing / 3D-printing	L		2	3		5
33	Manufacturing-related trends	Shorter product lifecycles	Now	5				5
55	Manufacturing Business Needs	Risk management and propagation across the virtual enterprise	M	5				5
25	Manufacturing-related trends	Shortage of skilled staff	S		4			4
27	Manufacturing-related trends	Increasing complexity of products, processes, and supply networks	S		4			4
28	Manufacturing-related trends	Urban production	M				4	4
3	Megatrends	Urbanisation	M				3	3
13	Megatrends	Increasing rate of knowledge and technological change	S	3				3
16	Megatrends	Changes in economic purchasing power of customers and populations	S			2	1	3
29	Manufacturing-related trends	Lack of technology acceptance	Now		3			3
31	Manufacturing-related trends	Extension of ICT perspective to production site / company associations	Now-S	2	1			3
41	Manufacturing Business Needs	Reduction of lead times to produce and deliver a product	Now-S		3			3
46	Manufacturing Business Needs	Increasing education required for workers	S			1	2	3
NEW	Manufacturing Business Needs	Society education	S-M				3	3
59	Business Models	Local adaption / manufacturing close to markets	S			3		3
NEW	Manufacturing-related trends	Ever increasing complexity of manufacturing environment	M	3				3

4	Megatrends	Accelerating innovation and new technologies	S			2		2
11	Megatrends	Climate Change	S				2	2
24	Manufacturing-related trends	Stricter quality requirements	S			2		2
36	Manufacturing-related trends	Enterprise mobility	Now				2	2
64	Business Models	Specialised companies for IT and methods for integration of / migration to advanced ICT solutions	S	2				2
1	Megatrends	Demographic change	S		1			1
9	Megatrends	Rise of environmental consciousness	Now				1	1
18	Manufacturing-related trends	Stricter/more requirements imposed by large buyers	M		1			1
20	Manufacturing-related trends	Environmental sustainability goals from regulatory side	S		1			1
48	Manufacturing Business Needs	Greater energy efficiency	M		1			1
54	Manufacturing Business Needs	Managing high information volumes / hiding complexity from users	M-L				1	1
NEW	Business Models	Remanufacturing	S				1	1
NEW	Manufacturing Business Needs	Portfolio of manufacturing capability	L	1				1
NEW	Manufacturing Business Needs	Engagement with consumers/ co-operation	L			1		1

Table 7: Voting on trends and drivers across all Scenarios

The ***drivers, trends, needs*** and ***business models*** important to more than one scenario were:

Megatrends

- **Knowledge as key-enabler:** The importance of knowledge is increasing as products, systems and business environment become more and more complex and technology-intensive. This leads to a trend of perceiving knowledge as capital, with the goal to use and exploit information across traditional boundaries as successfully as possible.
- **Resource stress and scarcity, rising energy costs, raw material prices:** The combined pressures of population growth, economic growth and climate change will put increased stress on essential natural resources (including water, food, arable land and energy).
- **Changes in economic purchasing power of customers and populations:** Disposable income as a proportion of income is rising at various levels, changing the buying patterns of populations and forcing companies to respond.

Manufacturing-related trends

- **Demand by customers for individualized / highly configurable products:** Customers increasingly demand highly customized products, ideally at no higher price than a comparable mass product.
- **Virtualisation and digitisation:** Companies increasingly use simulation, visualisation, and virtualisation to understand the product and production behaviour and performance under virtual conditions.
- **Increasing hybrid cross-over products / embedded IT and integrated services:** Transformation opportunities are numerous when companies cross traditional boundaries. Hybrid solutions that help such crossovers are mandatory, and this calls for next generation solutions.
- **Back-sourcing of manufacturing capacity to Europe:** Backsourcing is the process of bringing manufacturing capacity (previously moved or outsourced to low-wage counties) back to Europe.
- **Additive manufacturing / 3D-printing:** Additive manufacturing enables fast manufacturing of specific products by means of small and flexible production facilities.
- **Extension of ICT perspective to production site / company associations:** Employing ICT technologies to consider not only one's own production site when executing planning and optimisation tasks.

Manufacturing Business Needs

- **Reduction of start-up times, fast scale-up of production:** Start-up and maintenance times decrease overall inefficiency because manufacturing assets are not used productively.
- **Increasing flexibility of production environments:** In order to increase their competitiveness, factories will increasingly develop their ability to react to faster changing markets with regard to production times, products to be manufactured, etc.
- **Identify/anticipate changes in demand**
- **Reduction of effort for integration of new equipment / tools**
- **Flexibility in supply chain participation:** Factories should easily be able to join production networks in order to be able to quickly react on market demand changes.
- **Integration of human worker in manufacturing process:** As products and processes become more complex and the half-life of knowledge is decreasing, the human worker threatens to

become the bottleneck in achieving the progress and flexibility required to remain competive.

- **Information sharing; operational and strategic**
- **Transparency of environmental footprint across supply chain:** To realize green manufacturing; for environemental sustainability to became an available optimization parameter.
- **IP management for collaborative environments**
- **Increasing education required for workers:** Due to an increasing complexity of products and processes, workers require ever more knowledge and skills.

Business Models

- **Added value potential through new services:** Provision of new (B2B or B2C) services and business models enabled by intelligent products.
- **Sharing of resources (energy and products) among different factories**

The ***drivers, trends, needs*** and ***business models*** that were important for a specific scenario only were the following:

Megatrends	🟨	Increasing rate of knowledge and technological change
	🟦	Demographic change
	🟥	Rise of the individual
	🟥	Accelerating innovation and new technologies
	🟩	Urbanisation
	🟩	Climate Change
	🟩	Rise of environmental consciousness
Manufacturing-related trends	🟨	Shorter product lifecycles
	🟨	Ever increasing complexity of manufacturing environment
	🟦	Shortage of skilled staff
	🟦	Increasing complexity of products, processes, and supply networks
	🟦	Lack of technology acceptance
	🟦	Stricter/more requirements imposed by large buyers
	🟦	Environmental sustainability goals from regulatory side
	🟥	Stricter quality requirements
	🟩	Urban production
	🟩	Enterprise mobility
Manufacturing Business Needs	🟨	Risk management and propagation across the virtual enterprise
	🟨	Portfolio of manufacturing capability
	🟦	Reduction of lead times to produce and deliver a product
	🟦	Greater energy efficiency
	🟥	Engagement with consumers/ co-operation
	🟩	Society education
	🟩	Managing high information volumes / hiding complexity from users

Business Models	🟨	Emergence of smaller, more dynamic enterprises
	🟨	Specialised companies for IT and methods for integration of / migration to advanced ICT solutions
	🟥	Local adaption / manufacturing close to markets
	🟩	Remanufacturing

Table 8: Scenario-specific trends, drivers, needs and business models

The most important trends, drivers, needs and business models are overall different for the different scenarios. The two scenarios with possibly the most commonality are the Manufacturing as a Service enterprise and the High Volume/High Value enterprise. Overall the scenarios themselves represent largely discrete and demarcated manufacturing situations with different priorities. The most distinct is the Green enterprise probably because is currently driven by legislation rather than market forces. It was therefore anticipated that the needs of manufacturing businesses for ICT architectures and services will vary accordingly.

Some of the trends, drivers, needs and business models that are important in more than one scenario appear in different timeframes for each of them. These are highlighted in the table below.

Number	Text	Timeline	Timeline	Timeline	Timeline
5	Knowledge as key-enabler		S	M	
6	Resource stress and scarcity, rising energy costs, raw material prices	M			S
16	Changes in economic purchasing power of customers and populations			S	M
17	Increasing hybrid cross-over products / embedded IT and integrated services	L		L	S
22	Demand by customers for individualized / highly configurable products	M	L		S
23	Back-sourcing of manufacturing capacity to Europe	S	M		
30	Additive manufacturing / 3D-printing		L	L	
31	Extension of ICT perspective to production site / company associations	M	S		
32	Virtualisation and digitisation		M	M	
33	Shorter product lifecycles	S			
38	Increasing flexibility of production environments	M		M	
40	Flexibility in supply chain participation		S	S	
42	Reduction of effort for integration of new equipment / tools	S		M	
43	Reduction of start-up times, fast scale-up of production	S	S	M	
49	Transparency of environmental footprint across supply chain			S	M
50	Identify/anticipate changes in demand	L	M		
51	Integration of human worker in manufacturing process	M	M	M	
53	Information sharing; operational and strategic	S	M		
58	IP management for collaborative environments	S		L	
62	Added value potential through new services	S		L	S
63	Sharing of resources (energy and products) among different factories		S		S

Table 9: Different timeframes for the trends, drivers, needs and business models important to more than one scenario

4.3 ICT Solutions

Thirty-nine ICT solutions had been collected from public sources, expert interviews and workshops prior to the roadmapping workshop were pre-printed in post-its. The participants were asked – still in their Scenario groups – to review the priority trends, drivers and needs that had emerged from the previous step and select the ICT Solutions that could best address these would address these needs.

The participants took turns to select and discuss the most appropriate ICT solutions and add the post-its to their roadmap. Participants were asked to note on each post-its the number of trend or driver that specific solution was addressing. In total approximately 10-15 Solutions were selected from the existing ones and five new ICT solutions were added by each scenario group onto their map. These new Solutions were then copied and added to the other three scenario groups making the total number of solutions for each scenario approximately 35 (15 Solutions from the pre-existing list, 20 new Solutions – five from each scenario).

The new ICT Solutions proposed by each scenario group are shown in the table below.

Number	Roadmap sub-layer	Description	Timeline
Y01	Intra company	Joint cognitive systems (machine learning/complex decision making)	M
Y02	Supply Network	Manufacturing project/system management	M
Y03	Inter-company	Complete methodologies for understanding risk	L
Y04	Intra-company	Engineering platforms for design/operations continuum	M
Y05	Other/Inter-company	Big data analysis for market information - portfolio (price)	S
B01	Inter-company	Virtual assets management	S
R01	Other/Inter-company	Consumer/usage data acquisition	S
R02	Inter-company	CAVE visualisation through supply value chain - consumer	M
R03	Shop floor production	Robotic & human cooperation for flexible batch of one	L
R04	Shop floor production	3D printing/zero tooling approaches	M
R05	Intra-company	Collaboration tool and ways of working inter company in supply network	L
R06	Inter-company	Consumer visualisation for engagement in design	S
R07	Inter-company	Quality control systems in production and in NPI process (moving to simulation and predictive)	S
G01	Shop floor production	Real-time waste & emissions monitoring	S
G02	Shop floor production	Weather based scheduling	M
G03	Intra-company	Simulation, e.g. for energy feedback loops (not just production but also business). Feedback loops for lifecycle data to real time e.g. Engineering to process control	M
G04	Other	Standard green measure	Now
G05	Inter-company	Energy (Exergy) cascading	M-L
G06	Other	Personalised contextualised training	Now

Table 10: Additional ICT Solutions added by each scenario group

Participants were then asked to prioritise the ICT solutions using two different and roughly separate considerations; Opportunity and Feasibility. Opportunity was defined as the magnitude of the potential for advancement plausibly available to an organisation. Feasibility was defined as how well-prepared the organisation is to grasp the opportunity.

Prior to the workshop, the consortium partners and the EU project officer had reviewed a list of possible factors and selected those shown in the figures below that supported the EU's strategic objectives:

Opportunity Factor	Definition	Feasibility Factor	Definition
Customer benefit	*Identifiable benefit to customers (internal or external) or potential adopters*	**Market knowledge**	*Do we understand the size and requirements of the market?*
Number of interested organisations/industries	*Size of potential market, or number of potential adoptions, reasonably available.*	**Sustainability of competitive advantage**	*Can we sustain the competitive position? (e.g. IPR, brand strength)*
Synergy opportunities	*Possible additional benefits to other projects or activities; or the possibility of new opportunities in combination.*	**Technical challenge**	*Are we confident that the proposed product is technically feasible?*
Future potential	*Product is a platform for future products or could open new markets in future*	**Technical capability**	*Do we have the required technical competence to design the product?*

Figure 7: Opportunity and Feasibility factors used to assess the various ICT Solutions

There were two steps to the assessment process. Firstly, each participant was given eight black sticky dots, asked to review the ICT Solutions, independently select four to eight based on the five Opportunity factors and place their black sticky dots on their selected Solutions.

Then the participants were asked to consider only solutions that had already been received votes for opportunity factors. Each participant was given four orange sticky dots and asked to independently select four solutions based on the three Feasibility factors. Consequently, some solutions received only Opportunity but not Feasibility votes.

Between 16 and 25 Solutions were prioritized by each Scenario group. These are shown in the tables and figures below.

Number	Roadmap sub-layer	Description	Timeline	O Votes	F Votes	Total O+F
94	Inter-company	Customer and demand data gathering and analysis	L	7	6	13
66	Shop floor production	Predictive maintenance	S	5	6	11
68	Shop floor production	Big data analysis and use for quality control	L	5	6	11
97	Other	IT-OT convergence: integrated architecture PLM-MES-ERP	L	5	6	11
71	Shop floor production	Flexible production equipment and interconnections	S	4	6	10
101	Other	Open data and system integration platform (for unstructured data environment.)	L	8	2	10
95	Inter-company	Product and service co-design with customer	M	6	3	9
R3	Shop floor production	Robotic & human cooperation for flexible batch of one	L	5	3	8
82	Supply Network	Supply chain visibility and decision assistance	S	4	4	8
Y01	Intra company	Joint cognitive systems (machine learning/complex decision making)	M	4	3	7
86	Supply Network	Harmonised / standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information	S	5	1	6
75	Shop floor production	Knowledge management tools	Now	4	1	5
Y03	Inter-company	Complete methodologies for understanding risk	L	4	1	5
80	Supply Network	Total product tracking	L	3		3
84	Supply Network	Security and IP protection solutions for collaborative networks	M	3		3
91	Inter-company	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S	3		3
103	Other/inter-company/supply	Advanced decision making considering multiple objectives and uncertainties in information source	S	3		3
G01	Shop floor production	Real-time waste & emissions monitoring	S	2		2
R01	Inter-company	Consumer/usage data acquisition	S	2		2
G03	Intra-company	Simulation, e.g. for energy feedback loops	M	1		1
Y02	Supply/Intra-company/shop floor	Manufacturing project/system management	M	1		1
Y04	Intra-company	Engineering platforms for design/operations continuum	M	1		1
R02	Inter-company	Consumer visualisation for engagement in design	M	1		1
G04	Other	Standard green measure	Now	1		1
Y05	Other/inter-company	Big data analysis for market information - portfolio (price)	M	1		1

Table 11: Manufacturing ICT Solutions identified by the Yellow Scenario team: The MaaS Enterprise

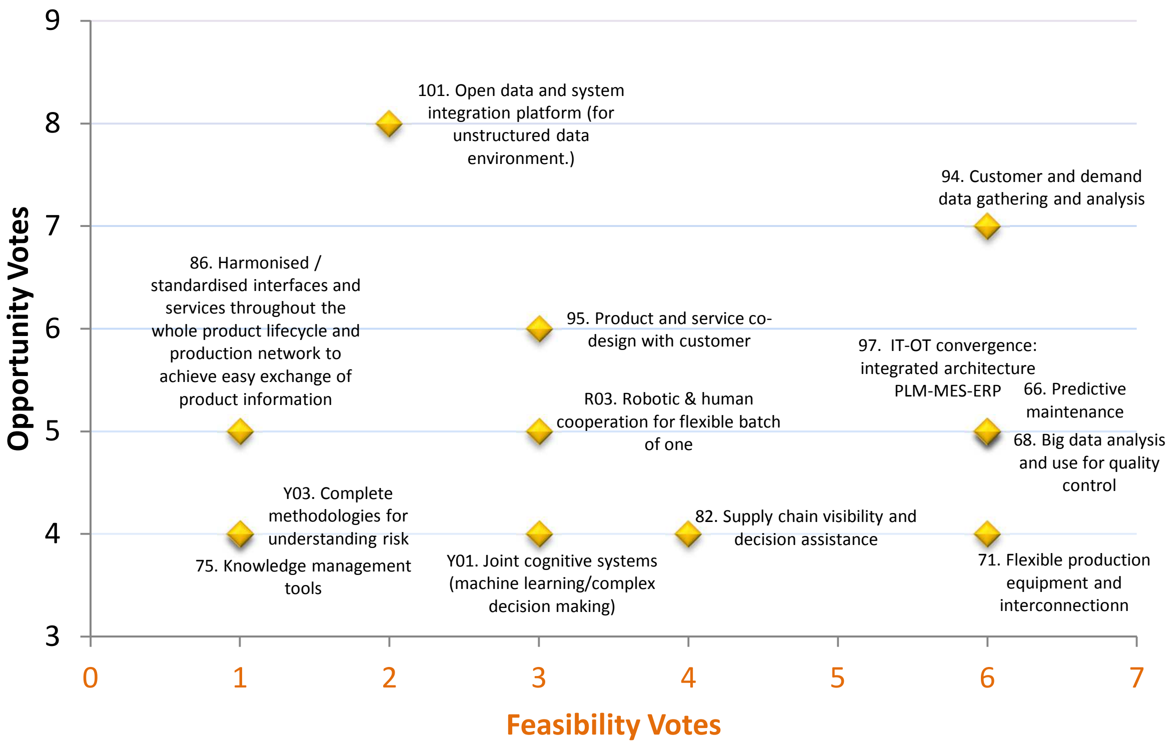


Figure 8: Highest scoring ICT Solutions prioritised by the Yellow Scenario team: The MaaS Enterprise

Number	Roadmap sub-layer	Description	Timeline	O Votes	F Votes	Total O+F
86 & 87 & 99	Supply Network	86. Harmonised / standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information; 87. Interoperability solutions; 99. Collaborative, easy-to-use, customised, plug-and-play user interfaces	S	8	8	16
89	Inter-company	Multi-level heterogeneous modelling of virtual enterprises	S	7	6	13
67	Shop floor production	Production monitoring / data acquisition in real time (to achieve transparency, support data analytics for optimisation etc.)	S	5	7	12
84	Supply Network	Security and IP protection solutions for collaborative networks	M	5	5	10
101	Other	Open data and system integration platform (for unstructured data environment.)	S	5	5	10
Y05	Other/inter-company	Big data analysis for market information - portfolio (price)	M	4	5	9
94	Inter-company	Customer and demand data gathering and analysis	L	5	3	8
Y04	Intra-company	Engineering platforms for design/operations continuum	M	5	2	7
100&102	Other	102. Filtering mechanisms to provide only relevant information / avoid data deluge; 100. Problem and context-centric display of only crucial information to the users	M	5	2	7
83	Supply Network	Resilience mechanisms for collaborative production networks	M	4	2	6
95	Inter-company	Product and service co-design with customer	M	5		5
69	Shop floor production	Simulating tools for new process design	L	3		3
Y01	Intra company	Joint cognitive systems (machine learning/complex decision making)	M	3		3
79	Supply Network	Evolution and emergent behaviour of production networks	S	3		3
82	Supply Network	Supply chain visibility and decision assistance	S	3		3
R01	Inter-company	Consumer/usage data acquisition	S	3		3

80	Supply Network	Total product tracking	S	2		2
96	Inter-company	PLM Solutions for collaborative designs	L	2		2
104	Other	Training, e.g. supported by e-learning, for efficient knowledge transfer to / among workers	Now	2		2
G01	Shop floor production	Real-time waste & emissions monitoring	S	1		1
R04	Shop floor production	3D printing/zero tooling approaches	L	1		1
R02	Inter-company	Consumer visualisation for engagement in design	S	1		1
G05	Inter-company	Energy (Exergy) cascading	M	1		1

Table 12: Manufacturing ICT Solutions prioritised by the Blue Scenario team: The Virtual Enterprise

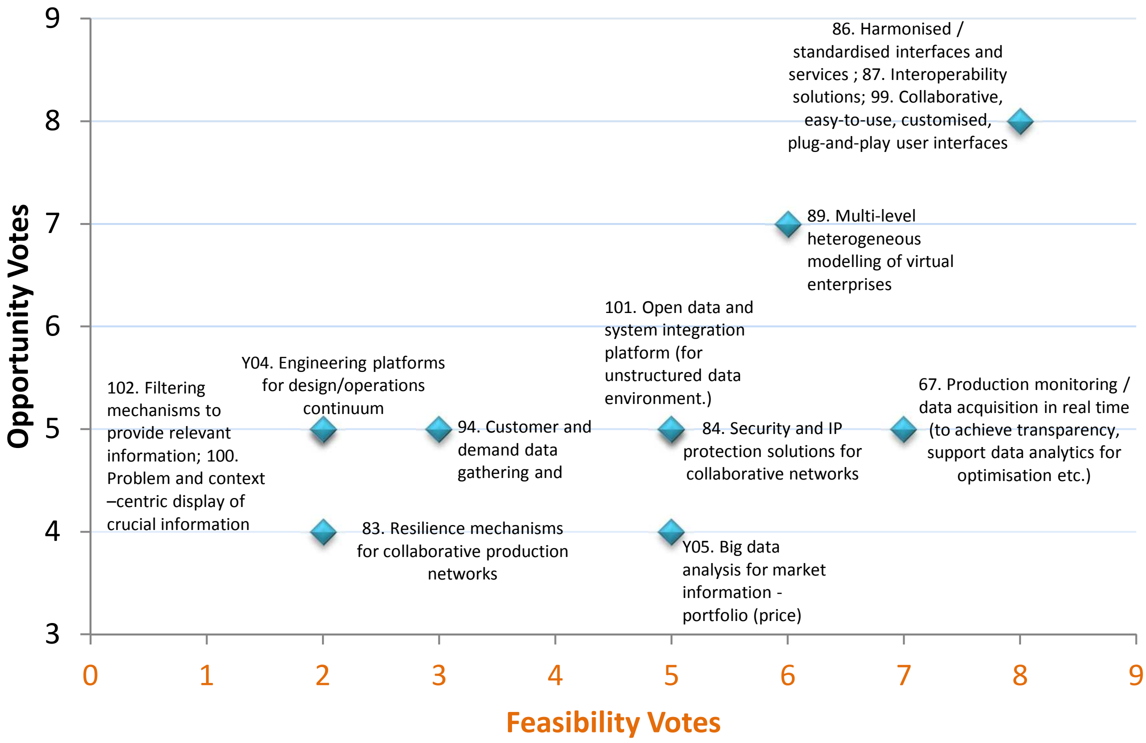


Figure 9: Highest scoring ICT Solutions prioritised by the Blue Scenario team: The Virtual Enterprise

Number	Roadmap sub-layer	Description	Timeline	O Votes	F Votes	Total O+F
68 & 74	Shop floor production	68. Big data analysis and use for quality control; 74. Closed-loop of manufacturing analysis and control including consumer usage	S	6	7	13
103 &Y01	Other/inter-company/supply	103. Advanced decision making considering multiple objectives and uncertainties in information source; Y01. Joint cognitive systems (machine learning/complex decision making)	Now	9	4	13
97 & Y04	Other	97. IT-OT convergence: integrated architecture PLM-MES-ERP; Y04. Engineering platforms for design/operations continuum	M	6	6	12
71& 78	Shop floor production	71. Flexible production equipment and interconnections; 78. Separated production stations rather than fixed production lines; automated transportation systems serving the stations.	L	5	5	10
69	Shop floor production	Simulating tools for new process design	L	4	3	7
82	Supply Network	Supply chain visibility and decision assistance	S	3	3	6
85	Supply Network	Algorithms to determine / optimise routes, material grouping, (re) ordering of components etc. for shortest set-up cycles	S	3	3	6
Y05& G03& R01	Other/inter-company	Y05. Big data analysis for market information - portfolio (price); G03.Simulation, e.g. for energy feedback loops; R01. Consumer/usage data acquisition	S	3	2	5
75	Shop floor production	Knowledge management tools	Now-S	3	1	4
84	Supply Network	Security and IP protection solutions for collaborative networks	M	2	2	4
94	Inter-company	Customer and demand data gathering and analysis	M	3	1	4
86	Supply Network	Harmonised / standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information	Now	1	1	2
73	Shop floor production	Material arrival predictions	S	2		2
R03	Shop floor production	Robotic & human cooperation for flexible batch of one	M	2		2
R04	Shop floor production	3D printing/zero tooling approaches	M	2		2
80	Supply Network	Total product tracking	M	2		2
91	Inter-company	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S	2		2
95 & R02	Inter-company	95. Product and service co-design with customer; R02. CAVE visualisation through supply value chain - consumer	M	2		2
Y02	Supply/Intra-company/shop floor	Manufacturing project/system management	L	1		1
Y03	Inter-company	Complete methodologies for understanding risk	L	1		1
100	Other	Problem and context –centric display of only crucial information to the users	S	1		1
104	Other	Training, e.g. supported by e-learning, for efficient knowledge transfer to / among workers	S	1		1

Table 13: Manufacturing ICT Solutions prioritised by the Red Scenario team: The high-volume production Enterprise

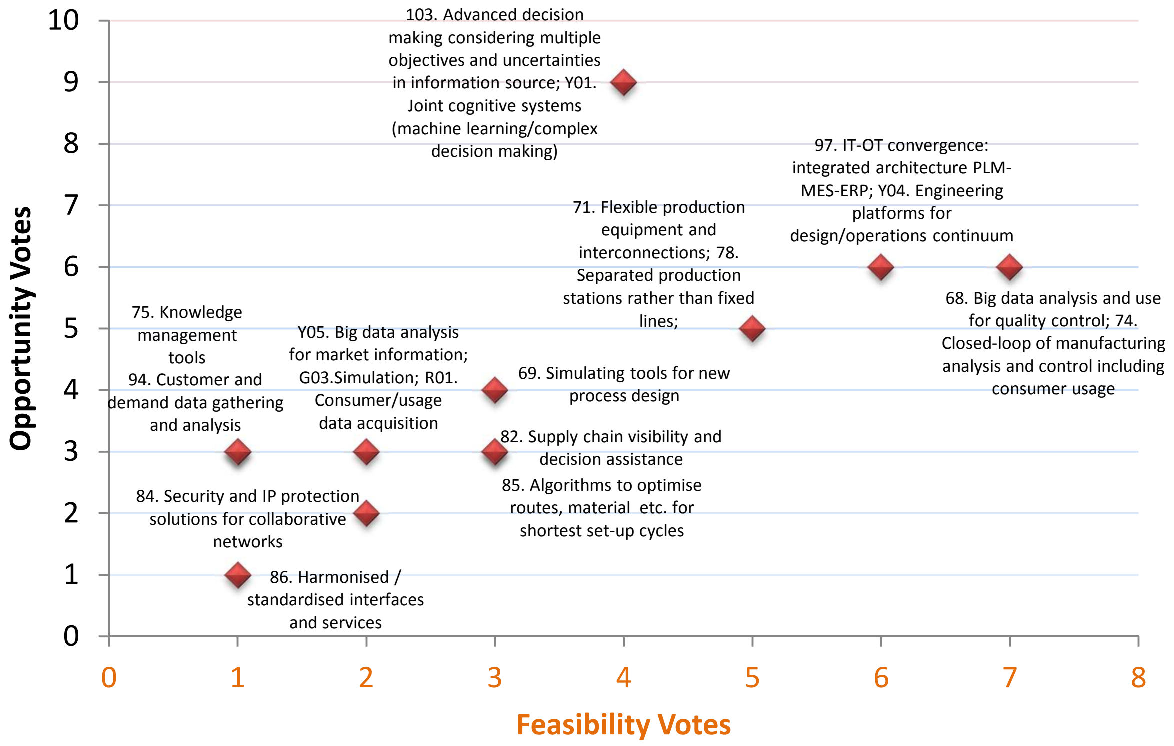


Figure 10: Highest scoring ICT Solutions prioritised by the Red Scenario team: The High Volume Enterprise

Number	Roadmap sub-layer	Description	Timeline	O Votes	F Votes	Total O+F
76	Shop floor production	Analytics and optimisation of equipment energy consumption	S	4	6	10
G03	Intra-company	Simulation, e.g. for energy feedback loops (not just production but also business). Feedback loops for lifecycle data to real time e.g. Engineering to process control	M	5	5	10
80 & 93	Supply Network	80. Total product tracking, 93. Sustainability tracing into products (energy, raw materials, social, recursive)	S	5	5	10
95& R01&R02&Y05	Inter-company	95. Product and service co-design with customer; R01. Consumer / user data acquisition; R02. Consumer Visualisation for engagement in design; Y05. Big data analysis for market information - portfolio (price)	M	6	4	10
104	Other	Training, e.g. supported by e-learning, for efficient knowledge transfer to / among workers; Personalised contextual training	Now	3	6	9
65	Shop floor production	Condition monitoring; Performance Optimisation	S-L	3	4	7
G01	Shop floor production	Real-time waste & emissions monitoring	S	3	3	6
66	Shop floor production	Predictive maintenance; Contributing to energy efficient production	S-L	2	3	5
G02	Shop floor production	Weather based scheduling	M	2	2	4
Y03	Inter-company	Complete methodologies for understanding risk	L	3	1	4
97	Other	IT-OT convergence: integrated architecture PLM-MES-ERP	L	1	2	3
R03	Shop floor production	Robotic & human cooperation for flexible batch of one	L	1	1	2
G04	Other	Standard green measure	Now	1	1	2
R04	Shop floor production	3D printing/zero tooling approaches	L	1		1
Y01	Intra company	Joint cognitive systems (machine learning/complex decision making)	M	1		1
G05	Inter-company	Energy (Exergy) cascading	M-L	1		1

Table 14: Manufacturing ICT Solutions prioritised by the Green Scenario team: The Green Enterprise

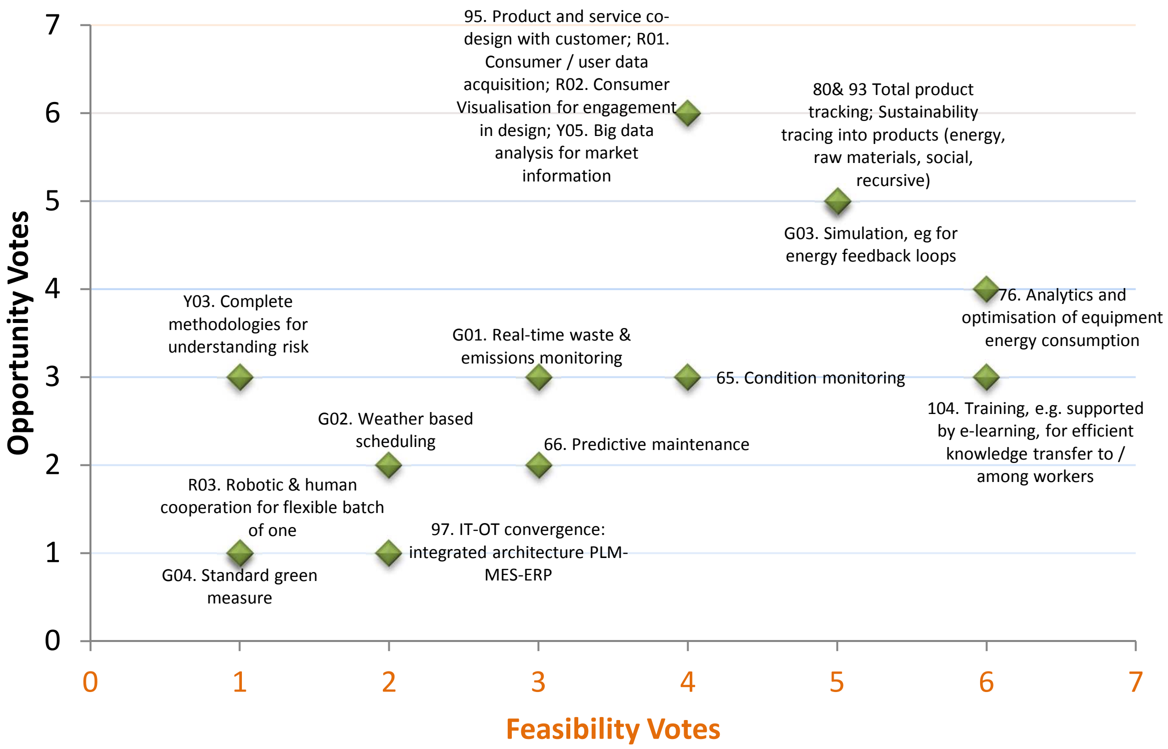


Figure 11: Highest scoring ICT Solutions prioritised by the Green Scenario team: The Green Enterprise

A new list of 47 ICT Solutions (shown below) was derived from all scenarios and considered further during the workshop. This list contained solutions for every sub-layer of the roadmap (i.e. shop-floor production, supply network etc).

#	Swimlane 1	Text	Timeline	O	F	O	F	O	F	O	F	Total O	Total F	Total O+F
65	Shop floor production	Condition monitoring	S-L							3	4	3	4	7
66	Shop floor production	Predictive maintenance	S-L	5	6					2	3	7	9	16
67	Shop floor production	Production monitoring / data acquisition in real time	S			5	7					5	7	12
68	Shop floor production	Big data analysis and use for quality control	L	5	6			5	7			10	13	23
69	Shop floor production	Simulating tools for new process design	L			3		4	3			7	3	10
71	Shop floor production	Flexible production equipment and interconnections	S	4	6			5	5			9	11	20
73	Shop floor production	Material arrival predictions						2				2	0	2
74	Shop floor production	Closed-loop of manufacturing analysis and control	Now					1				1	0	1
75	Shop floor production	Knowledge management tools	Now	4	1			3	1			7	2	9

76	Shop floor production	Analytics and optimisation of equipment energy consumption	S							4	6	4	6	10
78	Shop floor production	Separated production stations rather than fixed production lines; automated transportation systems serving the stations.	S					5	5			5	5	10
79	Supply Network	Evolution and emergent behaviour of production networks	S			3						3	0	3
80	Supply Network	Total product tracking	S	3		2		2		3	2	10	2	12
82	Supply Network	Supply chain visibility and decision assistance	S	4	4	3		3	3			10	7	17
83	Supply Network	Resilience mechanisms for collaborative production networks	M			4	2					4	2	6
84	Supply Network	Security and IP protection solutions for collaborative networks	M	3		5	5	2	2			10	7	17
85	Supply Network	Algorithms to determine / optimise routes, material grouping, (re) ordering of components etc. for shortest set-up cycles	Now					3	3			3	3	6
86	Supply Network	Harmonised / standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information	S	5	1	8	8	1	1			14	10	24
89	Inter-company	Multi-level heterogeneous modelling of virtual enterprises	S			7	6					7	6	13
91	Inter-company	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S	3				2				5	0	5
93	Inter-company	Sustainability tracing into products (energy, raw materials, social, recursive)	S							2	3	2	3	5
94	Inter-company	Customer and demand data gathering and analysis	L	7	6	5	3	3	1			15	10	25
95	Inter-company	Product and service co-design with customer	M	6	3	5		2		6	4	19	7	26
96	Inter-company	PLM Solutions for collaborative designs	L			2						2	0	2
97	Other	IT-OT convergence: integrated architecture PLM-MES-ERP	L	5	6			6	6	1	2	12	14	26
100	Other	Problem and context – centric display of only crucial information to the users	S-M					1				1	0	1
101	Other	Open data and system integration platform (for unstructured data environment.)	M	8	2	5	5					13	7	20

102	Other	Filtering mechanisms to provide only relevant information / avoid data deluge	M			5	2					5	2	7
103	Other/inter-company/supply	Advanced decision making considering multiple objectives and uncertainties in information source	Now	3				9	4			12	4	16
104	Other	Training, e.g. supported by e-learning, for efficient knowledge transfer to / among workers	Now			2		1		3	6	6	6	12
G01	Shop floor production	Real-time waste & emissions monitoring	S	2		1				3	3	6	3	9
G02	Shop floor production	Weather based scheduling	M							2	2	2	2	4
G03	Intra-company	Simulation, e.g. for energy feedback loops	M	1				3	2	5	5	9	7	16
G04	Other	Standard green measure	Now	1						1	1	2	1	3
G05	Inter-company	Energy (Exergy) cascading	M-L							1		1	0	1
Y01	Intra company	Joint cognitive systems (machine learning/complex decision making)	M	4	3	3		9	4	1		17	7	24
Y02	Supply/Intra-company/shop floor	Manufacturing project/system management	M	1				1				2	0	2
Y03	Inter-company	Complete methodologies for understanding risk	L	4	1			1		3	1	8	2	10
Y04	Intra-company	Engineering platforms for design/operations continuum	M	1		5	2	6	6			12	8	20
Y05	Other/inter-company	Big data analysis for market information - portfolio (price)	S	1		4	5	3	2			8	7	15
R02	Inter-company	CAVE visualisation through supply value chain - consumer	M					2				2	0	2
R01	Inter-company	Consumer/usage data acquisition	S	2		3		3	2			8	2	10
R06	Inter-company	Consumer visualisation for engagement in design	S	1		1						2	0	2
R03	Shop floor production	Robotic & human cooperation for flexible batch of one	L					2		1	1	3	1	4
R04	Shop floor production	3D printing/zero tooling approaches				1		2		1		4	0	4

Table 15: All selected and prioritised manufacturing ICT Solutions

4.4 Research and Resources - ICT capabilities

The final step of the plenary session was to identify the necessary ICT services, architectures and infrastructures that would be required to realize the prioritized ICT solutions. A similar process was followed as in previous steps, i.e. the participants focused on the highest scoring ICT Solutions, took turns to review and suggest the most appropriate ICT services, architectures and infrastructures required by these solutions from the pre-existing list, select the post-its and add to their scenario roadmap. Additional research and resources were added if they were missing from the original list.

Participants were asked to note on each post-it the number of ICT solution that specific research or resource contributed to. In total approximately 20-30 research and resources were selected from the existing list and some new ones were added by some scenario groups. The new Research and Capabilities proposed by each scenario group are shown in the table below.

Number	Roadmap sub-layer	Description	Timeline
Y06	(Mfg) ICT Infrastructures	Low cost sensor systems	M
Y07	(Mfg) ICT Services	Human centric interfaces (for complex information)	M-L
Y08	(Mfg) ICT Architectures	Real time data stream processing	L
Y09	Other enablers	Specialised transfer strategies academia - industry	S
B02	IT enablers	Systems engineering approach to the design of manufacturing systems	M
G07	(Mfg) ICT services	Cloud-IoT architecture for real time data analytics (fog computing)	M
G08	(Mfg) ICT infrastructures	Smart "green" object platforms enable people to create new products	L
G09	Other enablers	Green specific nanotechnology for improving product recycling e.g. material	M

Table 16: Additional Research and Resources added by each scenario group

A few technologies were deemed similar and were grouped by the participants. Each participant was then given eight sticky dots to select the most important Research and Resources topics for their scenarios. The chosen and the prioritized (the ones that received votes) Research and Resources by each scenario group are shown in the tables below.

Number	Roadmap sub-layer	Description	Timeline	Votes
Y08	(Mfg) ICT Architectures	Real time data stream processing	L	9
Y07	(Mfg) ICT Services	Human centric interfaces (for complex information)	M-L	8
109	(Mfg) ICT Services	Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global	S	7
120	(Mfg) ICT Architectures & Services	Security: Establishment of trust	L	6
121	(Mfg) ICT Architectures & Services	Manufacturing IT as a Service: Exploit Cloud Technologies	M-L	6
126	(Mfg) ICT Architectures & Services	Managing manufacturing uncertainty in an increasingly complex value chain	M	6
137	ICT Enablers (& Architectures, Infrastructures and Services)	User-centred design	S	6
Y09	Other enablers	Specialised transfer strategies academia - industry	S	6

107	(Mfg) ICT Services	Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions	M	5
161	Other enablers	Standardisation and reference architectures	M	5
116	(Mfg) ICT Services	Real-time monitoring	S	4
125	(Mfg) ICT Architectures & Services	Complexity management	S	4
Y06	(Mfg) ICT Infrastructures	Low cost sensor systems	M	4
114	(Mfg) ICT Services	Knowledge transfer between manufacturing and engineering	S	2
138	ICT Enablers (& Architectures, Infrastructures and Services)	Multi-level modelling	S	2
127	(Mfg) ICT Infrastructures & Services	Cyber-physical Production Systems	M	1
141	ICT Enablers (& Architectures, Infrastructures and Services)	Evolutionary systems	S	1

Table 17: Selected and prioritised Research and Resources by the Yellow Scenario team: The MaaS Enterprise

Number	Roadmap sub-layer	Description	Timeline	Votes
119+118 +120	(Mfg) ICT Architectures & Services	119. Security: Privacy and know-how protection; 118. Security: Operational safety and reliability; 120. Security: Establishment of trust	M	8
124	(Mfg) ICT Architectures & Services	Horizontal integration and optimisation of value chains	M-L	8
161	Other enablers	Standardisation and reference architectures	M	6
108	(Mfg) ICT Services	Big Data: Data analysis / Data fusion	S-M	5
114	(Mfg) ICT Services	Knowledge transfer between manufacturing and engineering	S	5
154	Other enablers	Demonstrations / Best practice examples	M	5
117	(Mfg) ICT Architectures & Services	Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)	S	4
128+129	(Mfg) ICT Infrastructures & Services	128. Intelligent components / Internet of Things (throughout the supply chain); 129. Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	M	4
106+107+ 155+156	(Mfg) ICT Services	106. Factory knowledge base: virtual representation of manufacturing environments; 107. Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions; 155. Stakeholder education (users, decision makers etc.); 156. Human-centric digital age - Knowledge about human behaviour using digital media etc.	M	3
136 +138	ICT Enablers (& Architectures, Infrastructures and Services)	136. Distributed systems (both function-wise and geographically); 138. Multi-level modelling	S	3
142	ICT Enablers (& Architectures, Infrastructures and Services)	Resilience / Adaptability / Flexibility of systems	S	3
147	ICT Enablers (& Architectures, Infrastructures and Services)	Future network technologies (faster, more stable, etc.)	M	3
151	Other enablers	Regulatory measures / Legal framework for collaboration in federated manufacturing environments	M	3
153	Other enablers	New business models	M	3
B02	IT enablers	Systems engineering approach to the design of manufacturing systems	M	3
110	(Mfg) ICT Services	New Manufacturing IT features: support resource energy efficiency	L	2
122	(Mfg) ICT Architectures & Services	Advanced self-service system for individual composition of services for manufacturing	S	2
141+150	ICT Enablers (& Architectures, Infrastructures and Services)	141. Evolutionary systems; 150. Migration strategies towards next generation factories / production environments	S	2
149	Other enablers	Additive Manufacturing / 3D-print 3D-scanning / rapid prototyping technologies etc.	L	2

Table 18: Selected and prioritised Research and Resources by the Blue Scenario team: The Virtual Enterprise

Number	Roadmap sub-layer	Description	Timeline	Votes
108+109	(Mfg) ICT Services	108. Big Data: Data analysis / Data fusion; 109. Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global	S-M	9
105+130 +137	(Mfg) ICT Services	105. Improved usability: hide complexity from users: not hide but make complexity manageable; 130. Improved usability: multi-modal user interfaces; 137. User-centred design	Now	5
114	(Mfg) ICT Services	Knowledge transfer between manufacturing and engineering	M	5
125	(Mfg) ICT Architectures & Services	Complexity management	S	5
134	(Mfg) ICT Infrastructures & Services	Man-Machine-Interaction: increase ergonomics while ensuring human safety	M	5
150	Other enablers	Migration strategies towards next generation factories / production environments	M-L	5
107	(Mfg) ICT Services	Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions	L	4
126	(Mfg) ICT Architectures & Services	Managing manufacturing uncertainty in an increasingly complex value chain	M	4
127	(Mfg) ICT Infrastructures & Services	Cyber-physical Production Systems	S	4
111	(Mfg) ICT Services	New Manufacturing IT features: Condition-based optimisation of production (schedules etc.)	M	3
128	(Mfg) ICT Infrastructures & Services	Intelligent components / Internet of Things (throughout the supply chain)	S	3
132	(Mfg) ICT Infrastructures & Services	(Coordination of) Autonomous manufacturing system components	S	3
138	ICT Enablers (& Architectures, Infrastructures and Services)	Multi-level modelling	L	3
142	ICT Enablers (& Architectures, Infrastructures and Services)	Resilience / Adaptability / Flexibility of systems	S	3
143	ICT Enablers (& Architectures, Infrastructures and Services)	Situation awareness / Contextualisation & Context-Awareness	S	3
135	ICT Enablers (& Architectures, Infrastructures and Services)	Agent-oriented computing	S	2
124	(Mfg) ICT Architectures & Services	Horizontal integration and optimisation of value chains	L	1
116	(Mfg) ICT Services	Real-time monitoring	Now	
156	Other enablers	Human-centric digital age - Knowledge about human behaviour using digital media etc.	M	

Table 19: Selected and prioritised Research and Resources by the Red Scenario team: The High Volume Enterprise

Number	Roadmap sub-layer	Description	Timeline	Votes
110	(Mfg) ICT Services	New Manufacturing IT features: support resource energy efficiency	M	5
116	(Mfg) ICT Services	Real-time monitoring	Now	5
140	ICT Enablers (& Architectures, Infrastructures and Services)	Technologies for better teaching and learning	S	5
127	(Mfg) ICT Infrastructures & Services	Cyber-physical Production Systems	S	4
114	(Mfg) ICT Services	Knowledge transfer between manufacturing and engineering	S	3
120	(Mfg) ICT Architectures & Services	Security: Establishment of trust	S	3
106	(Mfg) ICT Services	Factory knowledge base: virtual representation of manufacturing environments	M	2
112	(Mfg) ICT Services	New Manufacturing IT features: Continuous risk monitoring and mitigation	M	2
118	(Mfg) ICT Architectures & Services	Security: Operational safety and reliability	S-M	2
155	Other enablers	Stakeholder education (users, decision makers etc.)	S	2
G07	(Mfg) ICT services	Cloud-IoT architecture for real time data analytics (fog computing)	M	2
105	(Mfg) ICT Services	Improved usability: hide complexity from users: not hide but make complexity manageable	S	1
109	(Mfg) ICT Services	Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global	S	1
129	(Mfg) ICT Infrastructures & Services	Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	S	1
138	ICT Enablers (& Architectures, Infrastructures and Services)	Multi-level modelling	S	1

146	ICT Enablers (& Architectures, Infrastructures and Services)	Real-time capabilities	S	1
151	Other enablers	Regulatory measures / Legal framework for collaboration in federated manufacturing environments	M	1
154	Other enablers	Demonstrations / Best practice examples	S	1
157	Other enablers	Web Entrepreneurship	S	1
160	Other enablers	Digital gaming / gamification technologies	S	1
161	Other enablers	Standardisation and reference architectures	M	1
123	(Mfg) ICT Architectures & Services	Cloud manufacturing / service-oriented manufacturing	M-L	
130	(Mfg) ICT Infrastructures & Services	Improved usability: multi-modal user interfaces	S-M	
133	(Mfg) ICT Infrastructures & Services	Improved usability: context-aware user interfaces and user-specific adaption	S	
139	ICT Enablers (& Architectures, Infrastructures and Services)	Prototyping of systems / seamless integration and testing with productive environments	S	
149	Other enablers	Additive Manufacturing / 3D-print 3D-scanning / rapid prototyping technologies etc.	S	
153	Other enablers	New business models	M	
G08	(Mfg) ICT infrastructures	Smart "green" object platforms enable people to create new products	L	
G09	Other enablers	Green specific nanotechnology for improving product recycling e.g. material	M	

Table 20: Selected and prioritised Research and Resources by the Green Scenario team: The Green Enterprise

Overall 18 Research and Resources were voted as important by two or more scenarios. These are shown below.

Number	Roadmap sub-layer	Description	Timeline	Votes	Votes	Votes	Votes	Total Votes
108+109	(Mfg) ICT Services	Big Data: Data analysis / Data fusion	S-M	7	5	9	1	22
118+119+120	(Mfg) ICT Architectures & Services	Security: Operational safety and reliability	S-M	6	8		5	19
106+107+155+156	(Mfg) ICT Services	106. Factory knowledge base: virtual representation of manufacturing environments; 107. Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions; 155. Stakeholder education (users, decision makers etc.); 156. Human-centric digital age - Knowledge about human behaviour using digital media etc.	M	5	3	5	4	17
114	(Mfg) ICT Services	Knowledge transfer between manufacturing and engineering	S	2	5	5	3	15
105+130+137	(Mfg) ICT Services	105. Improved usability: hide complexity from users: not hide but make complexity manageable; 130. Improved usability: multi-modal user interfaces; 137. User-centred design	S	6		5	1	12
161	Other enablers	Standardisation and reference architectures	M	5	6		1	12
116	(Mfg) ICT Services	Real-time monitoring	Now	4		1	5	10
124	(Mfg) ICT Architectures & Services	Horizontal integration and optimisation of value chains	M		8	2		10
126	(Mfg) ICT Architectures & Services	Managing manufacturing uncertainty in an increasingly complex value chain	M	6		4		10
125	(Mfg) ICT Architectures & Services	Complexity management	S	4		5		9
127	(Mfg) ICT Infrastructures & Services	Cyber-physical Production Systems	S	1		4	4	9
136+138	ICT Enablers (&	136. Distributed systems (both function-	S	2	3	3	1	9

	Architectures, Infrastructures and Services)	wise and geographically); 138. Multi-level modelling						
128+129	(Mfg) ICT Infrastructures & Services	128. Intelligent components / Internet of Things (throughout the supply chain); 129. Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	S		4	3	1	8
141+150	ICT Enablers (& Architectures, Infrastructures and Services)	141. Evolutionary systems; 150. Migration strategies towards next generation factories / production environments	S	1	2	5		8
110	(Mfg) ICT Services	New Manufacturing IT features: support resource energy efficiency	M		2		5	7
142	ICT Enablers (& Architectures, Infrastructures and Services)	Resilience / Adaptability / Flexibility of systems	M		3	3		6
154	Other enablers	Demonstrations / Best practice examples	S		5		1	6
151	Other enablers	Regulatory measures / Legal framework for collaboration in federated manufacturing environments	M		3		1	4

Table 21: Research and Resources important to more than one scenario

An additional of 22 Research and Resources were voted as important for a specific scenario. These are shown below.

Number	Roadmap sub-layer	Description	Timeline	Votes	Votes	Votes	Votes	Total Votes
Y08	(Mfg) ICT Architectures	Real time data stream processing	L	9				9
Y07	(Mfg) ICT Services	Human centric interfaces (for complex information)	M-L	8				8
121	(Mfg) ICT Architectures & Services	Manufacturing IT as a Service: Exploit Cloud Technologies	M-L	6				6
Y09	Other enablers	Specialised transfer strategies academia - industry	S	6				6
Y06	(Mfg) ICT Infrastructures	Low cost sensor systems	M	4				4
117	(Mfg) ICT Architectures & Services	Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)	S		4			4
147	ICT Enablers (& Architectures, Infrastructures and Services)	Future network technologies (faster, more stable, etc.)	M		3			3
153	Other enablers	New business models	M		3			3
B02	IT enablers	Systems engineering approach to the design of manufacturing systems	M		3			3
122	(Mfg) ICT Architectures & Services	Advanced self-service system for individual composition of services for manufacturing	S		2			2
149	Other enablers	Additive Manufacturing / 3D-print 3D-scanning / rapid prototyping technologies etc.	S		2			2
134	(Mfg) ICT Infrastructures & Services	Man-Machine-Interaction: increase ergonomics while ensuring human safety	M			5		5
111	(Mfg) ICT Services	New Manufacturing IT features: Condition-based optimisation of production (schedules etc.)	M			4		4

132	(Mfg) ICT Infrastructures & Services	(Coordination of) Autonomous manufacturing system components	S			3		3
135	ICT Enablers (& Architectures, Infrastructures and Services)	Agent-oriented computing	S			3		3
143	ICT Enablers (& Architectures, Infrastructures and Services)	Situation awareness / Contextualisation & Context-Awareness	S			3		3
140	ICT Enablers (& Architectures, Infrastructures and Services)	Technologies for better teaching and learning	S				5	5
112	(Mfg) ICT Services	New Manufacturing IT features: Continuous risk monitoring and mitigation	M				2	2
G06	(Mfg) ICT services	Cloud-IoT architecture for real time data analytics (fog computing)	M				2	2
146	ICT Enablers (& Architectures, Infrastructures and Services)	Real-time capabilities	S				1	1
157	Other enablers	Web Entrepreneurship	S				1	1
160	Other enablers	Digital gaming / gamification technologies	S				1	1

Table 22: Research and Resources important to one scenario only

The summary roadmaps for each Scenario are laid out as shown in the figures below. For the top and bottom layers (External & Internal Drivers and Research & Resources respectively) only the items that received 3 votes or more are included. In the Solutions layer only ICT Solutions that received both Opportunity and Feasibility votes are included. The roadmap is not designed to be read from a report-sized document in this format and is shown here as illustration only – the information itself is best taken from the Tables in the sections above.

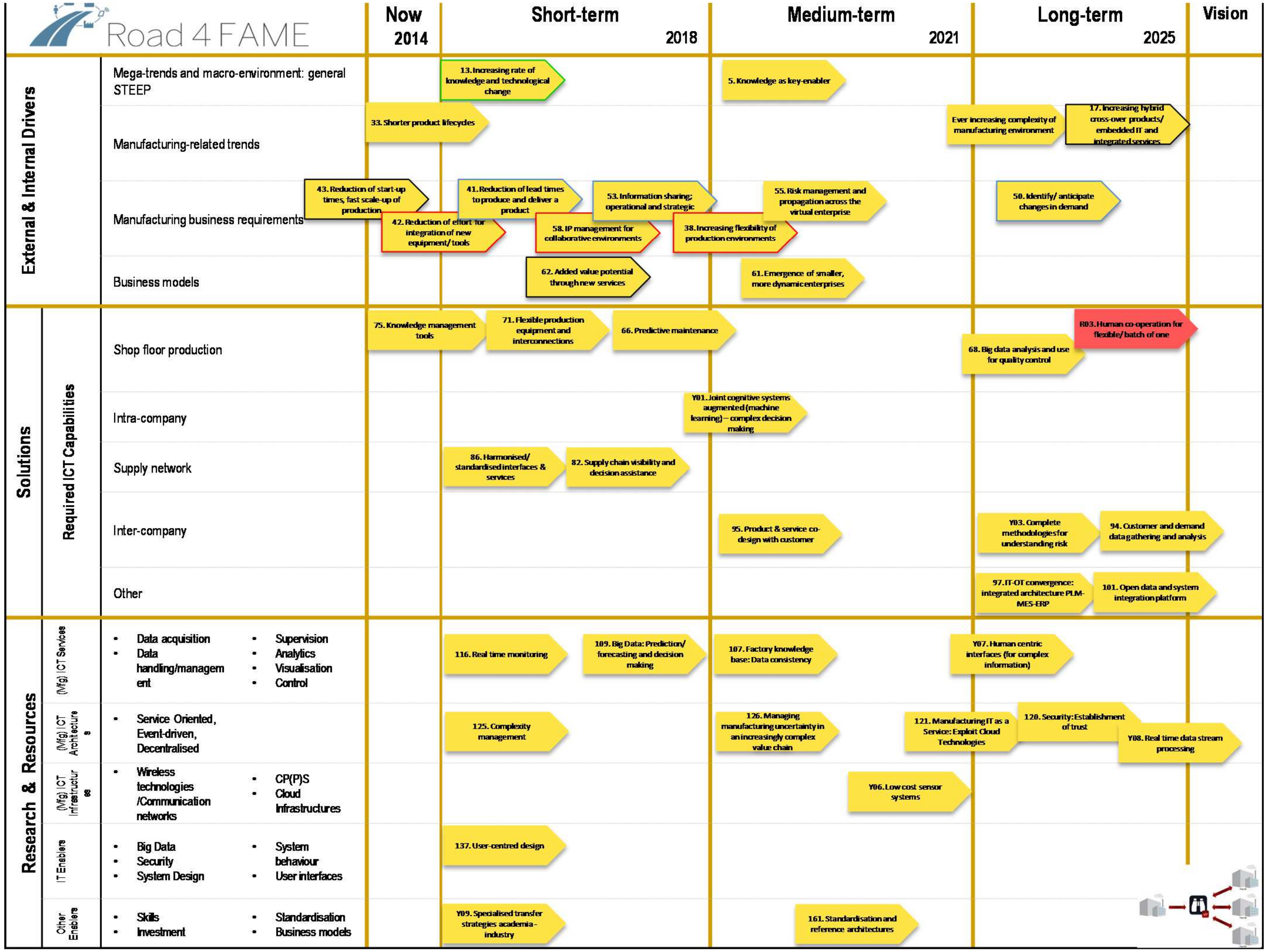


Figure 12: Summary roadmap for the Yellow Scenario: The MaaS Enterprise

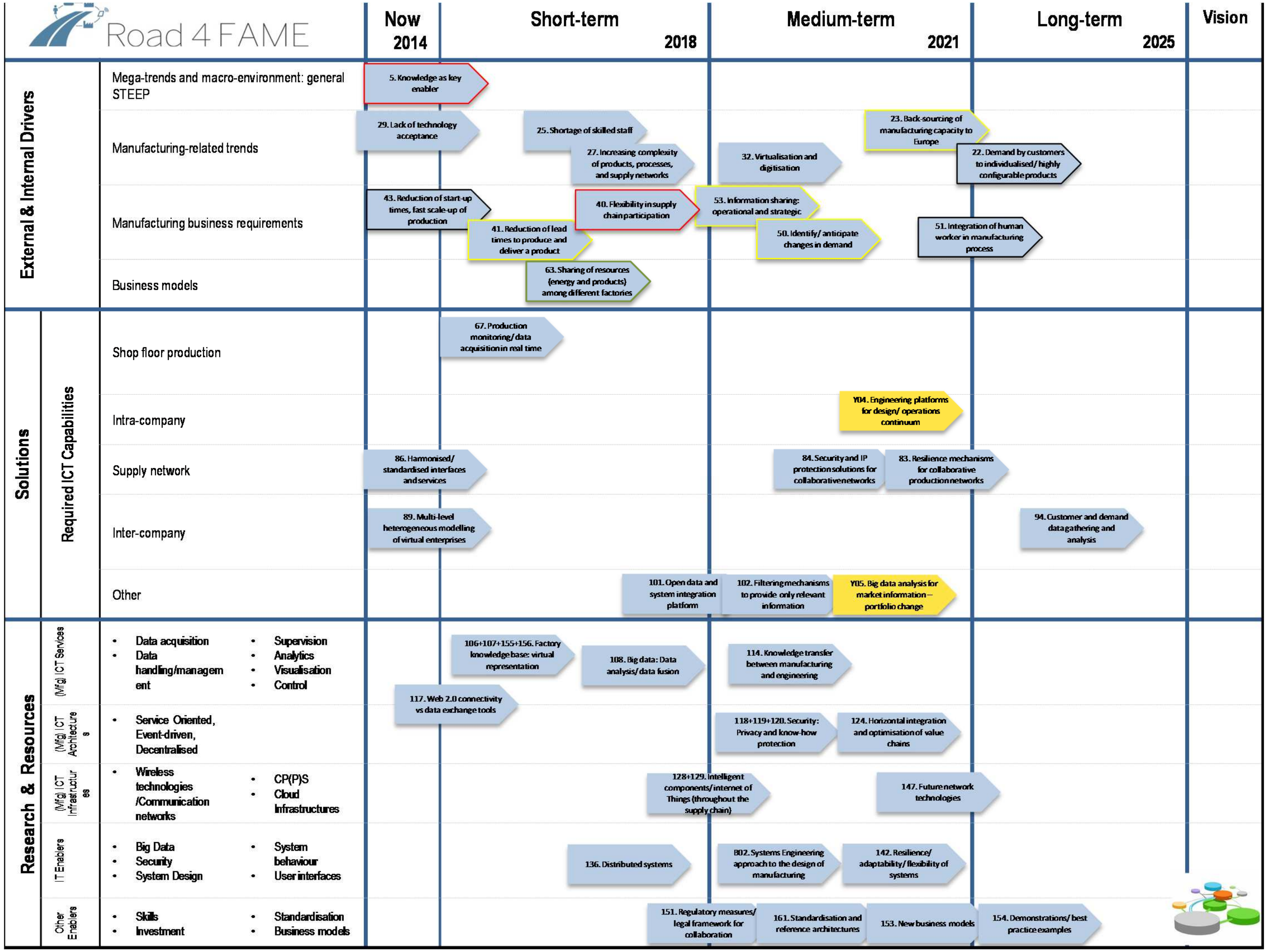


Figure 13: Summary roadmap for the Blue Scenario: The Virtual Enterprise

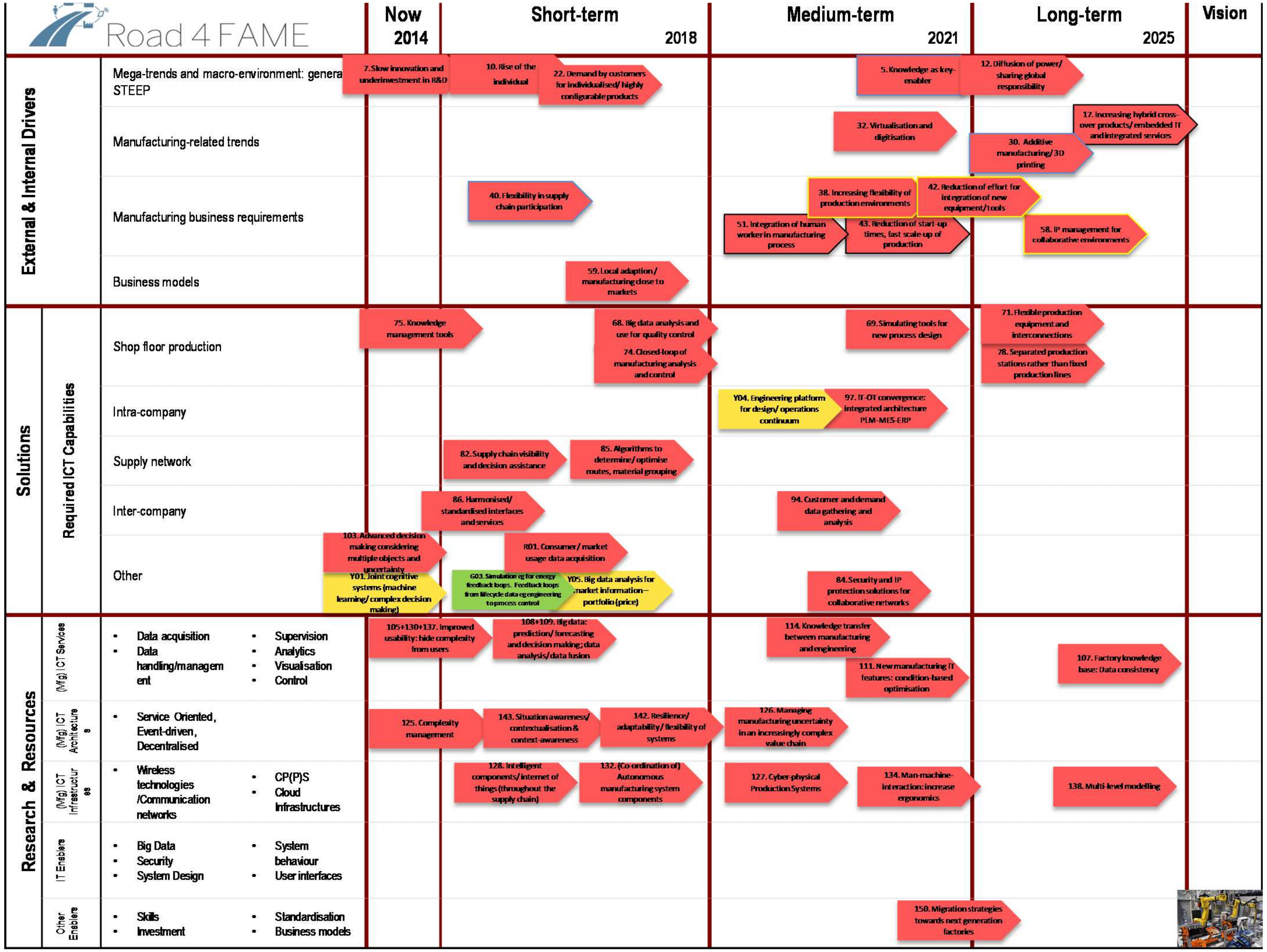


Figure 14: Summary roadmap for the Red Scenario: The High-Volume Production Enterprise

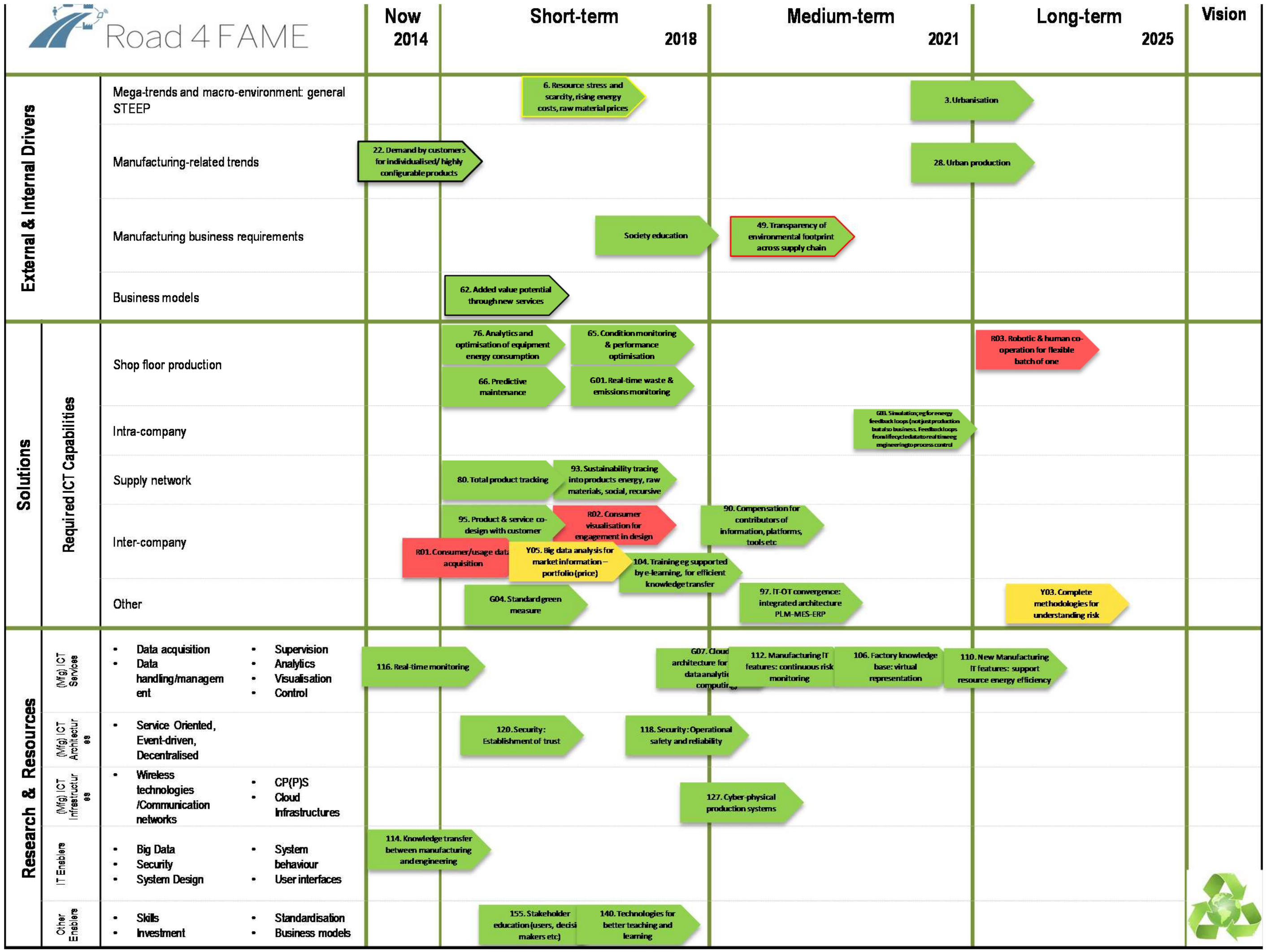


Figure 15: Summary roadmap for the Green Scenario: The Green Enterprise

4.5 Selection and Exploration of ICT Solutions

At the end of the plenary session, the ICT Solution that had received votes from each scenario group were collected and compared across the different scenarios. This was done in a small group involving the EU project officer and the project consortium partners with consultation with a few of the participants.

A review of the shortlisted ICT Solutions was made as follows:

- Solution 86 *"Harmonised/standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information"* and 101 *"Open data and system integration platform (for unstructured data environment)"* were considered very similar so only 101 was selected for further consideration.
- Solution Y05 *"Big data analysis for market information - portfolio (price)"* was also considered very similar to the Solution *94 "Customer and demand data gathering and analysis*", so the former was not taken forward.
- Solution 84 *"Security and IP protection solutions for collaborative networks"* was split into two different ones, 84a *"Security solutions for collaborative networks"* and 84b *"IP protection solutions for collaborative networks"* as it was felt that they were distinctly different and had different research requirements. Eventually, Solution 84b *"IP protection solutions for collaborative networks"* was dropped very early on the exploration process as it became evident that although a very important issue for the manufacturing industry, it had very few or no ICT research requirements.

Several aspects were considered before deciding which solution to select for more detailed exploration during the afternoon session. The first criterion was the Opportunity and Feasibility scores each solution received by each scenario group. The second was if a particular solution was deemed important (had received high Opportunity and Feasibility scores) in more than one scenarios. For this the total Opportunity and Feasibility scores received for this particular solution from all scenarios was calculated. A third criterion was the timeline for the solution as a good balance of short, medium and long term prospects was preferred. Finally, the team checked that solutions from all different sub-layers of the roadmap (i.e. shop-floor production, inter-company, etc) had been selected to ensure that the solutions can address a wide range of a manufacturing business's needs.

The short list of the 12 ICT solutions taken forward after the end of the plenary session is shown in the table below.

	Number	Swimlane	Description	Timeline	O	F	O	F	O	F	O	F	All O	All F	All O+F
1	101	Other	Open data and system integration platform for unstructured data environment.	M	8	2	10	7					18	9	27

			- inc Harmonised / standardised interfaces												
2	94	Inter-company	Customer and demand data gathering and analysis	L	7	6	5	3	3	2			15	11	26
3	97	Other	IT-OT convergence: integrated architecture PLM-MES-ERP	L	5	6			6	6	1	2	12	14	26
4	95	Inter-company	Product and service co-design with customer	M	6	3	5		1		6	4	18	7	25
5	68	Shop floor production	Big data analysis and use for quality control	L	5	6			6	7			11	13	24
6	Y01	Intra company	Joint Cognitive Systems for decision support		4	3	3		9	4	1		17	7	24
7	71	Shop floor production	Flexible production equipment and interconnections	S	4	6			5	6			9	12	21
8	100	Other	Problem and context – centric display of only crucial information to the users	S-M			10	7	1				11	7	18
9	Y04	Intra-company	Engineering Platform for design / ops continuum		2		5	2	6	6			13	8	21
10	82	Supply Network	Supply chain visibility and decision assistance	S	4	4	3		3	3			10	7	17
11	84 a	Supply Network	Security solutions for collaborative networks	M	3		5	5	2	2			10	7	17
12	84 b	Supply Network	IP protection solutions for collaborative networks	M	3		5	5	2	2			10	7	17

Table 23: ICT priority Solutions relevant to two scenarios or more

It was also decided that these Solutions would not be examined in the same groups using the lens of Scenarios, as earlier, but rather by using the specific expertise and interests of the participants.

During the afternoon session, the participants rearranged themselves according to their interest in exploring the one of the 11 Solutions selected at the end of the morning session. The new groups are shown in the table below.

#	ICT Solution	Participants				
1	Open data and system integration platform for unstructured data environment. - inc Harmonised / standardised interfaces	Christian Sonntag	Andrei Lobov	Bob Young		
2	Customer and demand data gathering and analysis	Rafael Michalczuk	Raquel Ventura	Anibal Reñones		
3	IT-OT convergence: integrated architecture PLM-MES-ERP	Pedro Oliveira	Michael Peschl	Alexander Demmer	Ian Walls	Pierfrances Manenti
4	Product and service co-design with customer	Tim Lucas	Sergio Gusmeroli	Rick Greenough	Manuel Oliveira	
5	Big data analysis and use for quality control	Raik Hartung	Ioannis Kotsiopoulos	Alicia González		
6	Joint Cognitive Systems for decision support	Connor Upton	Bob Mills	Keith Popplewell	Patricia Wolny	
7	Flexible production equipment and interconnections	Mikael Haag	Christopher Kirsch	Vaso Teles		
8	Problem and context –centric	Angelica	Silvia	Thor List		

	display of only crucial information to the users	Nieto Lee	Castellvi			
9	Engineering Platform for design / ops continuum	Eva Coscia	George Pintzos	Gregory Ella		
10	Supply chain visibility and decision assistance	Artur Krakowski	Bjorn Sautter	Martin Kelman	Luis Saenz de Santamaria	Lina Huertas
11	Security solutions for collaborative networks	Juha Roning	Michael Peschl	Diego Esteban	Harald Egner	Daniel Stock

Table 24: Delegates per ICT Solution group

These new groups were given two custom-designed roadmapping templates (as shown in Figure 6 in section 3.2) to provoke discussion and asked to complete them in preparation for presentation back to the workshop in plenary at the end of the day.

4.5.1 Solution Scope and key Milestones

Each group was asked to define the desired ICT Solution and its specific boundaries as well as any performance characteristics that were important for its successful implementation. These were as follows, for each solution:

1. Open data and system integration platform

This solution should enable the progression from dealing with “unstructured” data to self-descriptive to eventually dynamically integrateable data sets. It includes (formal) semantics on data/information, methodologies for data semantic enrichment, open standards and flexible solutions for change management. It is envisaged that such a platform will provide distinct benefits to the manufacturing sector such as:

- Improved decision-making (time, quality)
- One-click integration viability
- Common/standard of knowledge representation projects
- Fewer errors due to manual format/language transformation and reduction of engineering efforts
- Consistency & context management also allowing inter-context management
- Creation and availability of sustainable knowledge models
- Tools with user-acceptance focus

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Legacy systems integration “DB→KB”	Open plant/factory floor data aggregators Contextualisation of data	Dynamic integration based on changing system needs Context-based integration,	One-click integration for manufacturing systems Comprehensive site-wide

	sources	basic consistency management	consistency

2. Customer and demand data gathering and analysis

This solution's major aim was to ensure that a product always meets the customer requirements and provides them with exactly what they want. Ultimately, this solution should enable individual customer-led personalised product designs. The solution includes existing and new products especially targeted for retailers. It excludes internal (company) customers and the organisation's supply chain.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Customer feedback loop on how the product was received. JD Powell & 24hr on-line & warranty data • Desires; customer clinics • Market/fashion Design/ gadget magazines • Inspired rather than informed	Draw in data from social networks Use Apple model	Context-aware customer service Existing prod New prod	Individual customer-led personalised design

3. IT-OT convergence: integrated architecture PLM-MES-ERP

The desired vision for this solution is to enable the interoperability and ultimately the convergence of the current major business ICT applications such as ERP, MES and PLR. The convergence should be applicable throughout a product's life cycle and involve the entire supply chain. The solution needs to enable information flow from a variety of cyber physical systems. The anticipated benefits for organisations would be:

- Reducing time to market for products
- Reducing the cost of innovation and change
- Improving an organisation's agility to market demands

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Information and organisation silos Duplication of BOM and routing	Breaking silos in both the organisation and information	Unifying data models, e.g. BOM	Seamless information flow at zero cost

4. Product and service co-design with customer

This is forward looking range of ICT solutions in line with current socio-technological trends in manufacturing that foresee an increasing demand for product or service personalisation, individualisation and active customer engagement and co-creation. The co-creation involves the entire value chain throughout a product's or service's lifecycle and requires an alignment of a product and service (process view) in order to support a product over its whole lifecycle. It ultimately requires the creation of urban factories in close proximity to customers.

The product/service value will need to be defined for each partner in the supply chain to make the ICT solution viable and implementable. This innovative ICT solution defies current manufacturing practices which are mainly a "push" model of product to the market, have predominantly a cost reduction focus and are based on simulation and process optimisation.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Upstream niche OEM & supplies Quirky	Scale: Quirky Pan-European product/ service innovation ecosystem	Urban living labs	Urban factories

5. Big data analysis and use for quality control

This solution seeks to develop big data analytics for production to enable full transparency on the shop floor. This is considered very important for improving product quality, by spotting performance gaps and detecting problems thus improving the overall production efficiency and reducing costs. The solution encompasses new architectures, analytics and visualisation as well as data transmission, collection, storage and security

This ICT solution is applicable to data from many operations within an organisation such as product design and production, process, logistics and equipment monitoring but excludes any data from external sources as well as the required hardware necessary.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
• Isolated data • Partial visualisation of data • Semantic content of semi-structured data • Expanded storage (cloud)	Data-aided operation Shorten the gap between analytics and control on the shop floor	Intuition and data-driven decision environment	• Data-driven enterprise • Close the gap between analytics and control • Data-driven decision support • Maintenance optimisation

6. Joint Cognitive Systems for decision support (DSS)

This is a Decision Support System (DSS), based on multiple criteria that combine machine and human expertise. In its core is a human-centric machine learning system that enables learning and evolution and is able to model tacit knowledge to improve various business processes. It goes beyond classical ergonomics and close-loop automation, instead is based on socio-technical systems engineering.

Reasoning, UX of mathematical modelling, semantic ontologies and mainly visual languages and visualisation are important aspects needed for the design and implementation of such a system. Especially visualisation of 3D simulation environments, virtual and augmented reality, is critical for assessing process and information flow, mapping of concepts, resources and expert knowledge, configuration of rules and assessing causality and uncertainty.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Separation of model building versus application (e.g. conventional export systems) Static decision cycles so far Based on single knowledge paradigms Lack of "social / human" approaches Lack of trust in automation Visual interactive rules composition integrated with flexible machine learning system Applied to two diverse modelling problems	Collect exemplars of socio-technical systems (USA cases) More accessible models through visual languages for statistical/ stochastic modelling Taxonomy of applications susceptible to joint cog DSS Identification of flexible automated solutions suitable for inclusion	Integration of flexible automated solutions Problem space representation Evolving DSS Interaction with visual domain specific languages	Highly flexible infinitely evolving DSS Grey box automation

7. Flexible production equipment and interconnections

This solution will enable different types of products to be produced at the same time inside of the production plant. It requires configurable systems that have plug and play modularity, tools and equipment that can be changed and reconfigured and also includes robot collaboration and autonomous transportation solutions (for example, AGVs with dynamic mapping and navigation or changeable conveyor systems). The latest production techniques such as 3D printing are also compatible with this solution.

Such a solution can significantly increase the response time of a business to market demand and the higher degree of automation can improve productivity.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Specialised production and logistics machines (re-programming needed)	Service Robotics that are capable of dealing with different tasks (manipulate, transport etc) Flexible and adaptable production cell	Human – Robot - Collaborate Modularity Examples → possibility to use different grippers →possibility to transport a pallet or a box	Autonomous devices Self-learning machines Self-configuration

8. Problem and context –centric display of only crucial information to the users

This solution aims to provide personalised information and user centric visualisation within an organisation to aid a range of employees (e.g. supervisors, operators, product managers, etc) in problem solving. The implementation of the solution is enabled by the use of consumer electronic, multimodal devices throughout the business.

The solution assumes that different types of data (e.g. historical, real time, context, etc) are available from different business areas (e.g. supply chain, scheduling, production, etc). These are used as a baseline for performing context-aware analysis of the information and simulation processes to assist decision-making.

The benefits from such a system are multiple, especially around cost reduction, increasing safety and improving the performance of the operators.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Currently available only monolithic control rooms and distributed & heterogeneous systems Proof of concept: a prototype for mobile devices that has adaptive interfaces Raw data displays with static interfaces	Reasoning engine and algorithms for hierarchical decisions provided by built-in intelligence Integration of smart components for big data collection analysis and visualisation Structured report formats Training new employees	KPIs as a service (individual definition and consultancy) Multi user devices	Prediction (maintenance, production)

9. Engineering Platform for design / ops continuum

This ICT solution involves product and process monitoring and exchanging engineering and usage data. Apart of the initial phase of product conceptualisation, the aim of this system is to provide engineering information throughout the whole product lifecycle from production stage to its end of life.

Using a common language, the system helps to aggregate different views about the product, the various processes and the resources used. This is presented in a virtualised product/production format that also allows enhanced meta-information to be captured. This can evolve during the product lifecycle and assist with future product reconfigurations improving communication between different lifecycle phases.

This solution is designed on an open-source platform for exchanging engineering and usage data. It is focused on products, production and services (maintenance, recycling, suggestions on usage, etc) and it is an important enabler of concurrent engineering facilitating the development of low cost configurable solutions. For its implementation, the availability of low cost sensors, tracking systems (passive RFID, QR codes) or embedded systems (IoT) is essential.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
PDM, PLM platforms ERP, MES systems (non-integrated)	High level integration systems. Eng data exchange Existing technologies coupled with inter-communication modules. End: intelligent product with recorded history from design-through-disposal/ reuse	Integration at all levels ERP ↑ PLC Extension of interconnected lifecycle phases AS-designed AS-produced AS-maintained of product instances Info sharing to track modifications	Remanufacturing paradigm Controlled/ tracked reuse of component Repaid, overhaul

10. Supply chain visibility and decision assistance

This is a decision support system for manufacturing businesses' supply chain network. It helps companies synchronise, co-ordinate and communicate with their supply chain having a flexible, bi-directional information exchange system.

With this solution internal decisions can be based on supply chain info taken into account interoperability capability (time, AV, cost, quality), IP, available resources and capacity.

The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Paper-based Manual collection of information Web portals/email/files “Phone call” decision making No visibility	Improvement of internal processes Understanding and representation of internal resources & capacity to enable decision making Demonstration of information exchange for two business models: 1. High volume 2. High complexity Capability (time, quality, etc) Understanding constraints	Common data format Information exchange Product tracking/hidden info	Fully automated/ “real” time data collection, exchange & decision making Customer driven

11. Security solutions for collaborative networks

This ICT solution should enable secure data storage and exchange in real-time between different companies. It should provide services for authentication Identification and encryption in secure platforms using robust security standards.

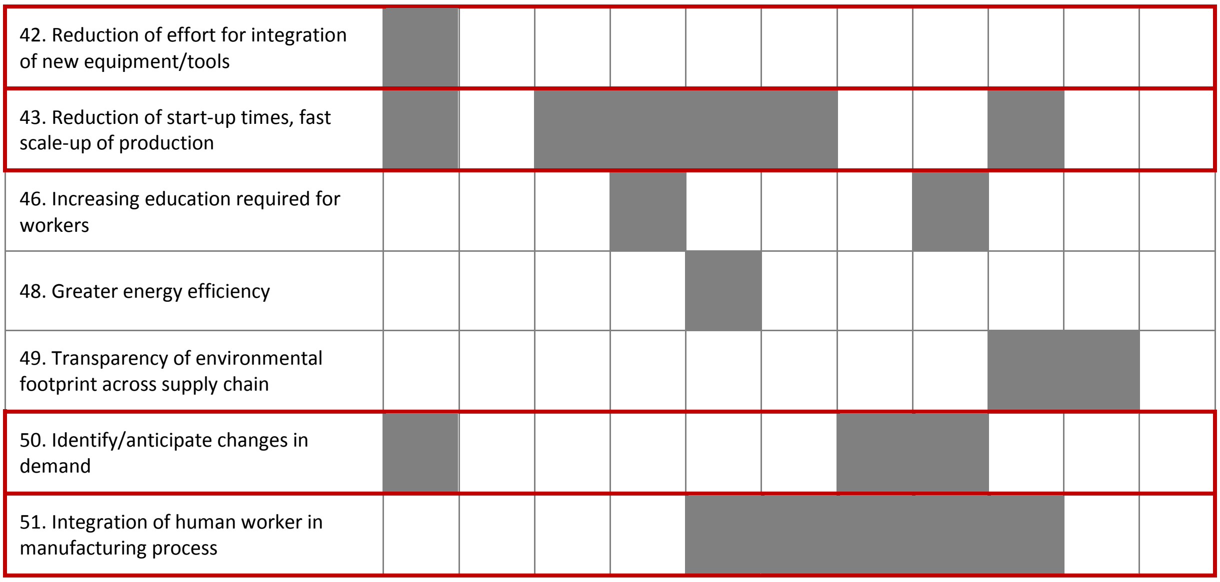
The current state-of-the-art and key development milestones required to deliver this solution are shown below.

State of the Art	***Short-term***	***Medium-term***	***Long-term***
Information in data silos	Information exchange with companies – not interruptible	Partly available information (in the cloud	Full access of data (in the cloud)

4.5.2 Links of Solutions to manufacturing Trends, Needs and Business Models

At the end of group work, each group was asked to assess which manufacturing trends and needs were addressed by each Solution. After the workshop, any trends or needs written onto the actual solution post-its were checked and included for completeness. The table below shows the links (in grey) between the eleven Solutions and the manufacturing trends and needs. For comparison, the red outline indicates the trends and needs that were prioritised as important across all the different scenarios at the plenary session at the beginning of the workshop.

Manufacturing Trend or Need	1. Open data and system integration platform	2. Customer and demand data gathering and analysis	3. IT-OT Convergence	4. Product & service co-design with customer	5. Big data for production	6. Joint cognitive systems for decision support (DSS)	7. Flexible production equipment and interconnections	8. Problem and context –centric display of only crucial information to the users	9. Engineering platform for design/ ops continuum	10. Supply chain visibility & decision assistance	11. Security solutions for collaborative networks
17. Increasing hybrid cross-over products/embedded IT and integrated services	■							■	■		
18. Stricter/more requirements imposed by large buyers					■				■	■	
20. Stricter/more requirements imposed by large buyers									■		
22. Demand by customers for individualized/highly configurable products	■	■	■	■		■	■	■	■		
24. Stricter quality requirements					■			■		■	
25. Shortage of skilled staff			■								
27. Increasing complexity of products, processes, and supply networks	■		■			■		■	■	■	
28. Urban production				■							
29. Lack of technology acceptance	■					■		■			
30. Additive manufacturing/3D-printing				■			■				
31. Extension of ICT perspective to production site/company associations			■			■		■	■	■	
32. Virtualisation and digitisation			■	■					■		■
33. Shorter product lifecycles	■	■	■		■		■				
36. Enterprise mobility								■	■		
38. Increasing flexibility of production environments			■	■	■	■	■			■	
40. Flexibility in supply chain participation			■		■					■	
41. Reduction of lead times to produce and deliver a product	■	■	■				■				

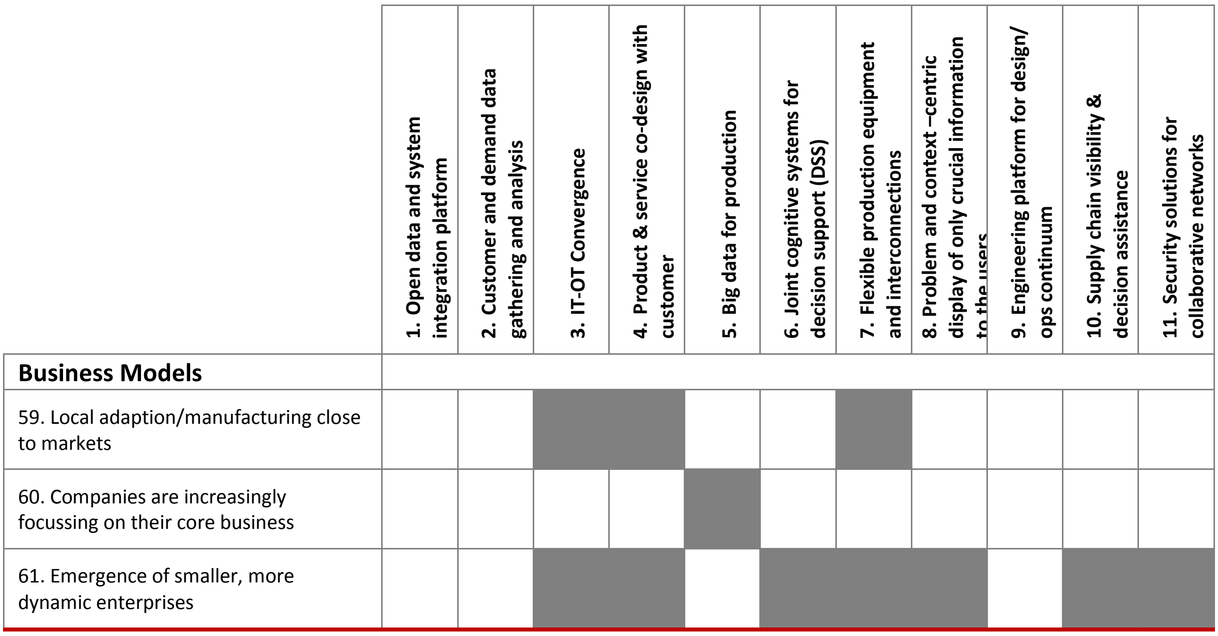


42. Reduction of effort for integration of new equipment/tools	■										
43. Reduction of start-up times, fast scale-up of production	■		■	■	■	■			■		
46. Increasing education required for workers				■				■			
48. Greater energy efficiency					■						
49. Transparency of environmental footprint across supply chain									■	■	
50. Identify/anticipate changes in demand	■						■	■			
51. Integration of human worker in manufacturing process					■	■	■	■	■		

Figure 16: Links between the 11 priority ICT Manufacturing Solutions and the most important manufacturing trends and needs

All important manufacturing trends and needs are addressed well by the 11 priority ICT Solutions. One important manufacturing need that is weakly addressed is Solution 42 *“Reduction of effort for integration of new equipment / tools”.*

Also each group was asked to assess the business models that are relevant to each ICT solution. The links between the two are shown below. For comparison, the red outline indicates one business model, 62 “Added value potential through new services” that was important across all the different scenarios at the plenary session of the workshop.



	1. Open data and system integration platform	2. Customer and demand data gathering and analysis	3. IT-OT Convergence	4. Product & service co-design with customer	5. Big data for production	6. Joint cognitive systems for decision support (DSS)	7. Flexible production equipment and interconnections	8. Problem and context –centric display of only crucial information to the users	9. Engineering platform for design/ ops continuum	10. Supply chain visibility & decision assistance	11. Security solutions for collaborative networks
Business Models											
59. Local adaption/manufacturing close to markets			■	■			■				
60. Companies are increasingly focussing on their core business					■						
61. Emergence of smaller, more dynamic enterprises			■	■		■	■	■		■	■

62. Added value potential through new services	■	■		■				■	■		■
63. Sharing of resources (energy and products) among different factories	■								■	■	■
64. Specialised companies for IT and methods for integration of/migration to advanced ICT solutions	■		■		■	■	■	■		■	■

Figure 17: Links between the 11 priority ICT Manufacturing Solutions and possible business models

The 11 ICT solutions can enable or promote a range of different business models including the servitisation of manufacturing.

4.5.3 Links of Solutions to key Technologies and Enablers

Several research topics and technologies were deemed necessary by the delegates to enable the realization of the ICT manufacturing Solutions. The table below shows the links (in grey) between the 11 Solutions and the Research and Resources required to deliver these solutions as derived from group work. It also incorporates any links written onto the actual Research and Resource post-its by the delegates during the plenary session.

The red outline indicates the Research and Resources that were prioritised as important across all the different scenarios at the plenary session at the beginning of the workshop.

	1. Open data and system integration platform	**2. Customer and demand data gathering and analysis**	**3. IT-OT Convergence**	**4. Product & service co-design with customer**	**5. Big data for production**	**6. Joint cognitive systems for decision support (DSS)**	**7. Flexible production equipment and interconnections**	**8. Problem and context –centric display of only crucial information to the users**	**9. Engineering platform for design/ ops continuum**	**10. Supply chain visibility & decision assistance**	**11. Security solutions for collaborative networks**
Research and Resources											
105. Improved usability: hide complexity from users: not hide but make complexity manageable; 130. Improved usability: multi-modal user interfaces; 137. User-centred design	■	■		■		■		■		■	
106. Factory knowledge base: virtual representation of manufacturing environments; 107. Factory knowledge base: Data consistency by means of (standardised) semantic models/system descriptions; 155. Stakeholder education (users, decision makers etc.); 156. Human-centric digital age - Knowledge about human behaviour	■		■	■	■		■	■	■	■	

using digital media etc.	■		■	■	■		■	■	■	■	
108. Big Data: Data analysis/Data fusion; 109. Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global	■	■			■	■	■	■	■	■	
110. New Manufacturing IT features: support resource energy efficiency					■					■	
114. Knowledge transfer between manufacturing and engineering	■		■	■	■			■	■	■	
115. Total customisation/ad-hoc establishment of production settings	■						■	■		■	
116. Real-time monitoring; 146. Real-time capabilities			■		■		■	■		■	
117. Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)			■				■				■
118. Security: Operational safety and reliability; 119.Security: Privacy and know-how protection; 120. Security: Establishment of trust	■	■	■	■	■				■		■
121. Manufacturing IT as a Service: Exploit Cloud Technologies	■		■		■					■	■
123. Cloud manufacturing/service-oriented manufacturing	■		■	■					■		■
124. Horizontal integration and optimisation of value chains	■		■							■	■
125. Complexity management		■	■		■	■	■	■	■	■	
126. Managing manufacturing uncertainty in an increasingly complex value chain			■	■			■			■	
127. Cyber-physical Production Systems							■				
128. Intelligent components/Internet of Things (throughout the supply chain); 129. Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.	■	■		■	■		■	■	■	■	
130. Improved usability: multi-modal user interfaces	■			■				■			
132. (Coordination of) Autonomous manufacturing system components	■					■	■	■	■	■	
133. Improved usability: context-aware user interfaces and user-specific adaption	■			■	■			■			
134. Man-Machine-Interaction: increase ergonomics while ensuring human safety						■	■	■			

Table 25: List of priority Research and Resources required to realise the ICT Manufacturing Solutions

When these 11 Solutions were cross linked, eight top Research and Resources were highlighted as having three or more connections with the top solutions. These are shown below. Looking at the Top eight Research & Resources, a pattern of support for the Top 11 Solutions emerges.

	1. Open data and system integration platform	**2. Customer and demand data gathering and analysis**	**3. IT-OT Convergence**	**4. Product & service co-design with customer**	**5. Big data for production**	**6. Joint cognitive systems for decision support (DSS)**	**7. Flexible production equipment and interconnections**	**8. Problem and context –centric display of only crucial information to the users**	**9. Engineering platform for design/ ops continuum**	**10. Supply chain visibility & decision assistance**	**11. Security solutions for collaborative networks**
ICT and Other Enablers											
136. Distributed systems (both function-wise and geographically); 138. Multi-level modelling											
141. Evolutionary systems; 150. Migration strategies towards next generation factories / production environments	■	■				■					
142. Resilience / Adaptability / Flexibility of systems			■			■	■				■
143. Situation awareness / Contextualisation & Context-Awareness		■			■	■		■		■	
145. Communication channel speed and connectivity		■	■						■		
155. Stakeholder education (users, decision makers etc.); 156. Human-centric digital age - Knowledge about human behaviour using digital media etc.								■	■		
161. Standardisation and reference architectures	■		■								

Table 26: List of priority ICT and Other Enablers required to realise the ICT Manufacturing Solutions

4.5.4 Links of Solutions to manufacturing Scenarios

Each group was asked to assess to what extent their solution was relevant to each of the four manufacturing scenarios (by ticking a None/Low/Medium/High box in the group template). This was to ensure that the proposed solutions, after they were explored and defined in more detail, were still relevant for different potential manufacturing settings. The table below indicates that this is the case, with the MaaS scenario represented the best by all of the 11 solutions. This also agrees with the previous finding that servitisation has become more important in the manufacturing sector. Although the solutions also apply to Green manufacturing, this scenario is addressed less than the other three. This is also consistent with the current manufacturing industry status where Green manufacturing is mainly legislation- rather than market-driven.

Relevance to SCENARIOS

None	Low	Medium	High
	░	▒	▓

ICT Solution	**Scenarios** MaaS	Virtual	High Volume	Green
1. Open data and system integration platform	▒	▒		
2. Customer and demand data gathering and analysis	▓	░	▓	░
3. IT-OT convergence: integrated architecture PLM-MES-ERP	▓	▓	▓	▒
4. Product and service co-design with customer	▓	▒	░	▓
5. Big data analysis and use for quality control	▓	░	▓	▒
6. Joint Cognitive Systems for decision support (DSS)	▓	▓	▓	
7. Flexible production equipment and interconnections	▓	▒		▒
8. Problem and context –centric display of only crucial information to the users	▓		▓	▒
9. Engineering Platform for design / ops continuum	▓	▓	▒	▒
10. Supply chain visibility and decision assistance	▓	▓	▓	▓
11. Security solutions for collaborative networks	▓	▓	▒	

Table 27: Relevance of the 11 priority ICT Solutions to the four manufacturing scenarios

After the detailed exploration of each solution, the participants of each group were asked to score the solution using the four specific Opportunity and Feasibility criteria detailed in Section 4.3. The scoring range was from 0-12 for each criterion and specific scaling statements were provided for each criterion to facilitate objective scoring within and across solutions. Participants were encouraged to add comments and their rational for their scores. The scaling statements are shown below.

Opportunity Factor	Explain Rationale	0	3	6	9	12
Customer benefit	*Identifiable benefit to customers (internal or external) or potential adopters*	No obvious benefit to customers	Some benefit to some customers	Clear customer benefits within existing norms; work visiting existing customers to promote	A significant advance in more than one key feature of interest to customers	Eye-catching new benefits; a talking point at shows; entry to competitor accounts
Number of interested organisations/industries	*Size of potential market, or number of potential adoptions, reasonably available.*	< 5,000 companies	25,000 companies	50,000 companies	100,000 companies	200,000 companies
Synergy opportunities	*Possible additional benefits to other projects or activities; or the possibility of new opportunities in combination.*	None	Little	Will help to complete product portfolio	Important	A key part of a major initiative
Future potential	*Product is a platform for future products or could open new markets in future*	Update of an existing product	May lead to further variants of applications	Will definitely lead to further product variants or applications	Could lead to a new product line or several applications	This is the beginning of a major new business OR many further applications are foreseen

Feasibility Factor	Explain Rationale	0	3	6	9	12
Market knowledge	*Do we understand the size and requirements of the market?*	Market size not supported by data and requirements not yet checked with customers	Market estimated within a factor of 2 or 3 with some data support	Enough data to size the market to +/-50% and requirements are supported by discussions with sales force	Market size known to +/-20% and customer view established by formal survey	
Sustainability of competitive advantage	*Can we sustain the competitive position? (e.g. IPR, brand strength)*	Key differentiating features will be easy to copy. Or serious concerns about IP	It will be 6-12 months ahead of the competition. No serious IPR concerns.	Competitive advantage can be maintained with continuous effort	It will be at least 2 years ahead of the competition	Key features can be protected by IPR or unique capabilities / knowledge that are not easy to copy

Technical challenge	*Are we confident that the proposed product is technically feasible?*	Key features not yet demonstrated by us anyone. Or >3x change in a important parameter	Step change in at least 1 important parameter. OR some key features not demonstrated but we're confident they can be	Key features have been demonstrated in prototype, but others remain	All features have been demonstrated in prototype	
Technical capability	*Do we have the required technical competence to design the product?*	We will have to acquire new major capabilities, OR rely on a partner	We lack some important capabilities and a plan is needed to acquire them	Existing staff can acquire capabilities in 3 months or less, or by recruiting one or two new people	Some new skills required but they can be acquired in time	Well within our capability. No new skills or knowledge required

Table 28: Opportunity and Feasibility scaling statements and associated scores used to assess each of the 11 ICT Solutions after the exploration step

The new scores received for each of the 11 ICT solutions is shown in the figure below.

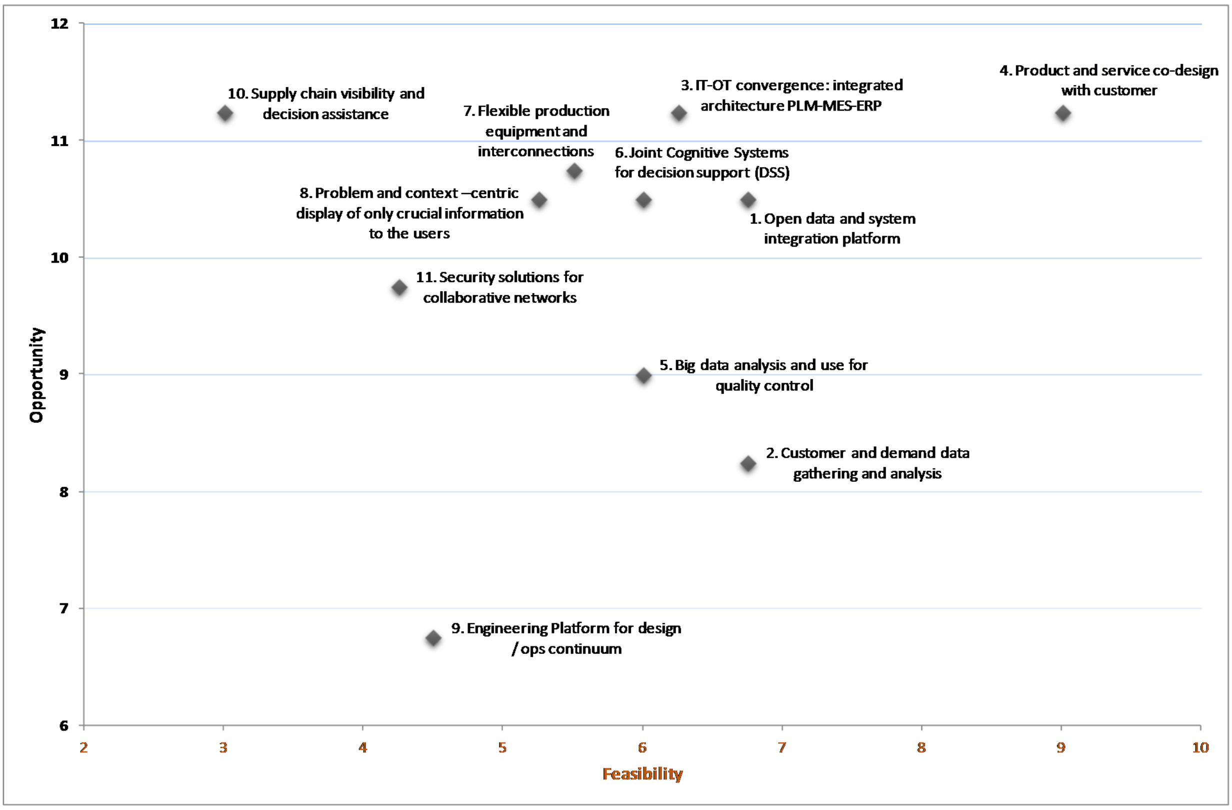


Figure 18: Opportunity and Feasibility scores for each of the eleven ICT Solutions after the exploration step

There are variations in the scores received after detailed exploration, which is to be expected. The ICT Solution 4 "Product and service co-design with customer" was considered more feasible after exploration while Solution 10 “Supply chain visibility and decision assistance” was considered to be harder than originally thought although it had a much higher opportunity score. Solution 5 “Big data analysis and use for quality control” and Solution 9 “Engineering Platform for design/ops continuum” were considered harder with a somewhat lower opportunity potential. Solution “No significant change” was observed on the other ICT solutions.

4.5.5 Success Factors and Knowledge gaps

In the final step of the exploration the key success factors or critical knowledge gaps as well as recommended research priorities were identified. These are summarised in the table below for the 11 Solutions:

Solution	Success factors	Knowledge gaps	Research Recommendations
1. Open data and system integration platform	• Demonstrators with compelling business cases • Core infrastructure & training materials	• Serious security challenges for an “open platform” • Serious IP challenges for an “open platform” • “Big player” dictating not always “the best” solution • Loss of faith in fast-changing many standard	• Core infrastructure & training materials • Data quality is likely to be a major issue (complete? still relevant? connect?) • Tools for consistency verification/ propagation/generation
2. Customer and demand data gathering and analysis	• Translation of emotions into digital data • Customer aware customised services	• Privacy • New business models development	• Driven by customers • Data mining • Decision making • Business engineering
3. IT-OT convergence: integrated architecture PLM-MES-ERP	• Having sponsors and clear vision • Awareness of opportunity of convergence • Willingness of large players to really co-operate	• Lack of trust (along the supply chain) • Change management • Complexity of IT	• Make cloud resilient for the plant floor - FI-oriented architecture cloud is often not adequate or enough • Interoperability
4. Product and service co-design with customer	• Idea of 3D printing made manufacturing cool • Culture of creativity • Generation Z and social networking • Decentralisation & power shift	• Austerity • Scale • IP • Poor trust • Culture differences • Manufacturing education & awareness • Cultural risk aversions	• Education initiatives to increase awareness • (games, teaching, factory, gamification, competitions, simulations & VR) • Pan-European product/service innovation ecosystem • ICT to support alignment of processes on product/services across value chain
5. Big data analysis and use for quality control	• Consider balance between central/ decentralised systems	• Economic conditions (recessions etc) • Trust/security	• Semantic content of unstructured data • Information integration

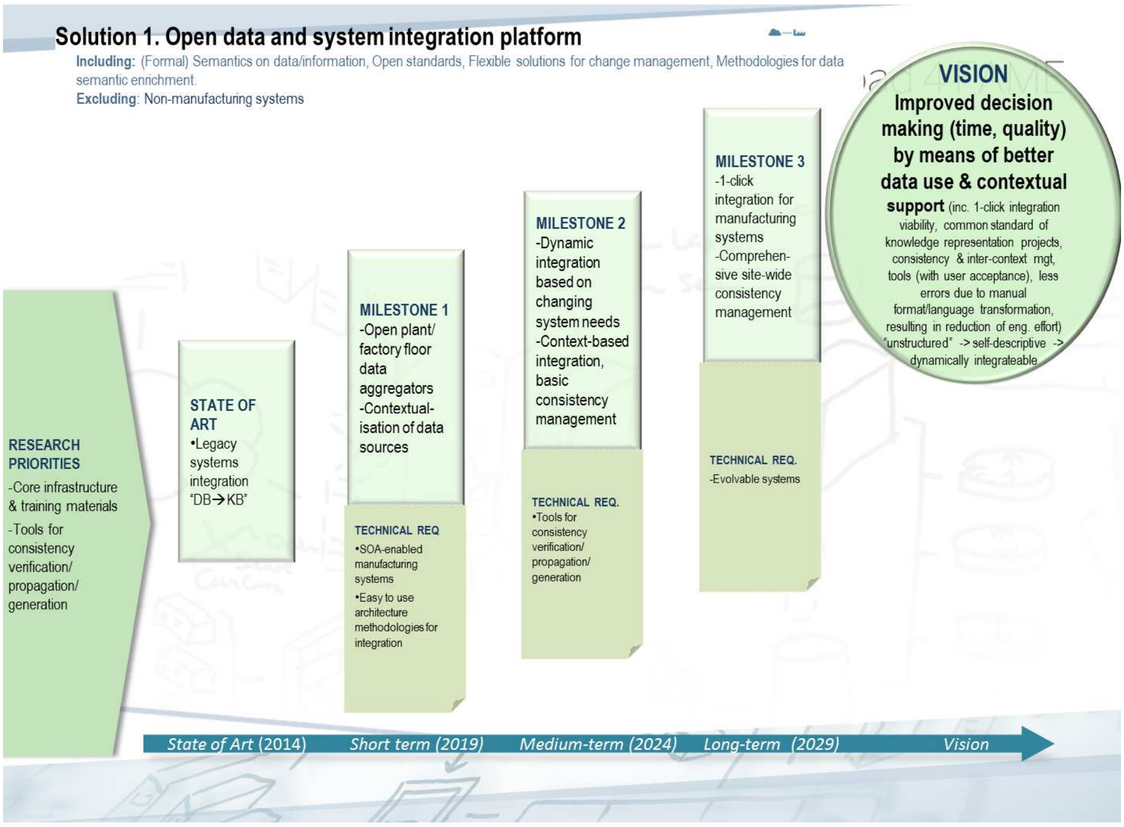
	• Advances in hardware • Transfer of knowhow from other sectors • Investment climate		• New types of algorithms for distributed processing/ systems • M2M security protocols • Context-aware responsive visualisation of data • Fusion of systems • DB and streams • Event driven DB/ systems • Real-time data mining • New architectures (hybrid system) • New distributed algorithms
6. Joint Cognitive Systems for decision support (DSS)	• Common ground representations for multidisciplinary research • Flexible Integration • Long term perspective • Quantifiable results/ impact, Evaluation?	• Technology acceptance/ assessment (research)	• Applied research (Industry collaboration essential) Needs large scale collaboration approach – no one entity could bring all necessary skills • Multidisciplinary research • Psychology • Visual design • ICT • Machine learning • Mix of specific tech research & research into integration of multiple paradigms • Work domain modelling of socio-tech systems & visual encoding & AI algorithm development
7. Flexible production equipment and interconnections	• Market (consumers) demand “technology push” • Manufacturing companies demand for ICT solutions • Automation development platforms by major actors (Google, Microsoft etc)	• Central MES synchronisation unit/ de-central MES “embedded” functionality • Proprietary standards and polarisation of actors • Complexity • New) economic downturn	• Short term • Standardisation of intra-and inter-machine communication • Medium term • Information modelling • Self-learning, self-adapting and reconfigurable manufacturing environment • Standardisation - Standards are also there, e.g. IEC 61499. But again industrial uptake is very weak • Information modelling • Self-adapting production
8. Problem and context-centric display of only crucial information to the users	• Usability - Encourage deployment • Multidisciplinary collaboration • Mobile devices developments (customer electronic devices) • Scalable, also SME-orientated solutions- to be accessible for SMEs • More open innovation		• Integration of smart components for big data collection, analysis & visualisation • Contextual awareness in manufacturing • Standardisation interfaces & communication - should self-service configuration be an option? • Human-centric adaptive interfaces - usability • Research in new modalities for interaction

	acceptance – change of mindset		• Holistic top-down approach in developing the solution! • Research on context awareness, human-centric information
9. Engineering Platform for design /ops continuum	• Standardisation of product – process – resource – service description • Low cost, high performance, low energy consuming sensors	• Resistance to remove/ substitute existing systems • Vulnerability of production systems • Privacy of data (from end – users	• Standardisation of product – process – service description • New or improved low cost sensors • Unified engineering exchange of data • Big data analysis and categorisation • New business model exploration for convincing existing companies. • Added value for current competitors • Secure cloud platform, standards with universal acceptance • Miniaturisation of smart, lower cost sensors • Big data analytics →Production and usage Different stakeholders
10. Supply chain visibility and decision assistance	• Standards, open protocols, advanced supply chain intelligence demonstrators	• Lack of collaboration between application providers • Adoption by business, lack of engagement	• Two different business models: high volume – low complexity/ low volume – high complexity • Demonstrators/ validated solutions • Standards/ information models • Business models • Data analytics
11. Security solutions for collaborative networks	• Increasing processing power • Emerging technology • Common Standards (look out existing high standards)	• No real world experience • Acceptance and trust • No verification standards	• Common Standards derived from existing industry specific standards • Security: cost/ benefit? • Security strategy for companies • Investigate all common standards

Table 29: Summary of the key milestones, success factors, knowledge gaps and research recommendations for the 11 ICT manufacturing Solutions explored during the main roadmapping workshop

4.5.6 Solution roadmaps

The 11 summary roadmaps derived for each of the ICT manufacturing Solutions explored during the roadmapping workshop are shown below.



Solution 1. Open data and system integration platform

Including: (Formal) Semantics on data/information, Open standards, Flexible solutions for change management, Methodologies for data semantic enrichment.

Excluding: Non-manufacturing systems

RESEARCH PRIORITIES

-Core infrastructure & training materials

-Tools for consistency verification/ propagation/ generation

STATE OF ART

- Legacy systems integration "DB→KB"

MILESTONE 1

-Open plant/ factory floor data aggregators

-Contextual-isation of data sources

TECHNICAL REQ

- SOA-enabled manufacturing systems
- Easy to use architecture methodologies for integration

MILESTONE 2

-Dynamic integration based on changing system needs

-Context-based integration, basic consistency management

TECHNICAL REQ.

- Tools for consistency verification/ propagation/ generation

MILESTONE 3

-1-click integration for manufacturing systems

-Comprehen-sive site-wide consistency management

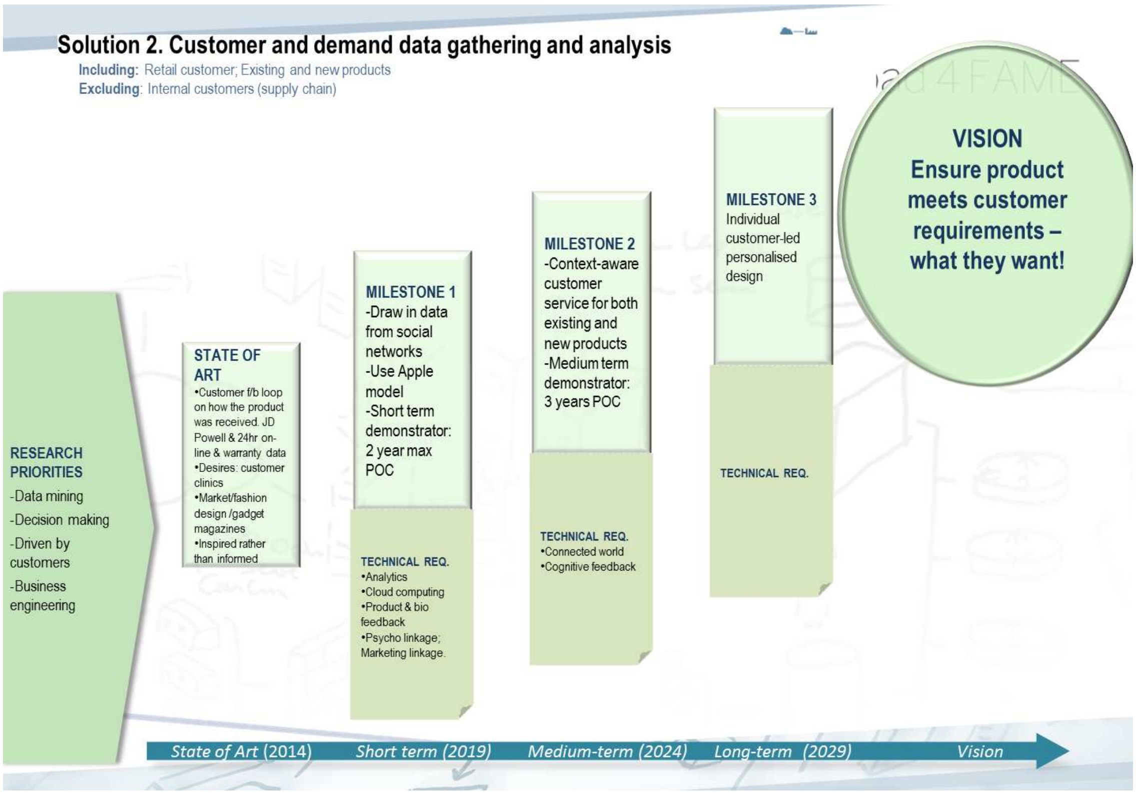
TECHNICAL REQ.

-Evolvable systems

VISION

Improved decision making (time, quality) by means of better data use & contextual support (inc. 1-click integration viability, common standard of knowledge representation projects, consistency & inter-context mgt, tools (with user acceptance), less errors due to manual format/language transformation, resulting in reduction of eng. effort) "unstructured" -> self-descriptive -> dynamically integrateable

Figure 19: Roadmap and Summary for the Solution 1: Open data and system Integration platform



Solution 2. Customer and demand data gathering and analysis

Including: Retail customer; Existing and new products
Excluding: Internal customers (supply chain)

RESEARCH PRIORITIES
-Data mining
-Decision making
-Driven by customers
-Business engineering

STATE OF ART
•Customer f/b loop on how the product was received. JD Powell & 24hr on-line & warranty data
•Desires: customer clinics
•Market/fashion design /gadget magazines
•Inspired rather than informed

MILESTONE 1
-Draw in data from social networks
-Use Apple model
-Short term demonstrator: 2 year max POC

TECHNICAL REQ.
•Analytics
•Cloud computing
•Product & bio feedback
•Psycho linkage; Marketing linkage.

MILESTONE 2
-Context-aware customer service for both existing and new products
-Medium term demonstrator: 3 years POC

TECHNICAL REQ.
•Connected world
•Cognitive feedback

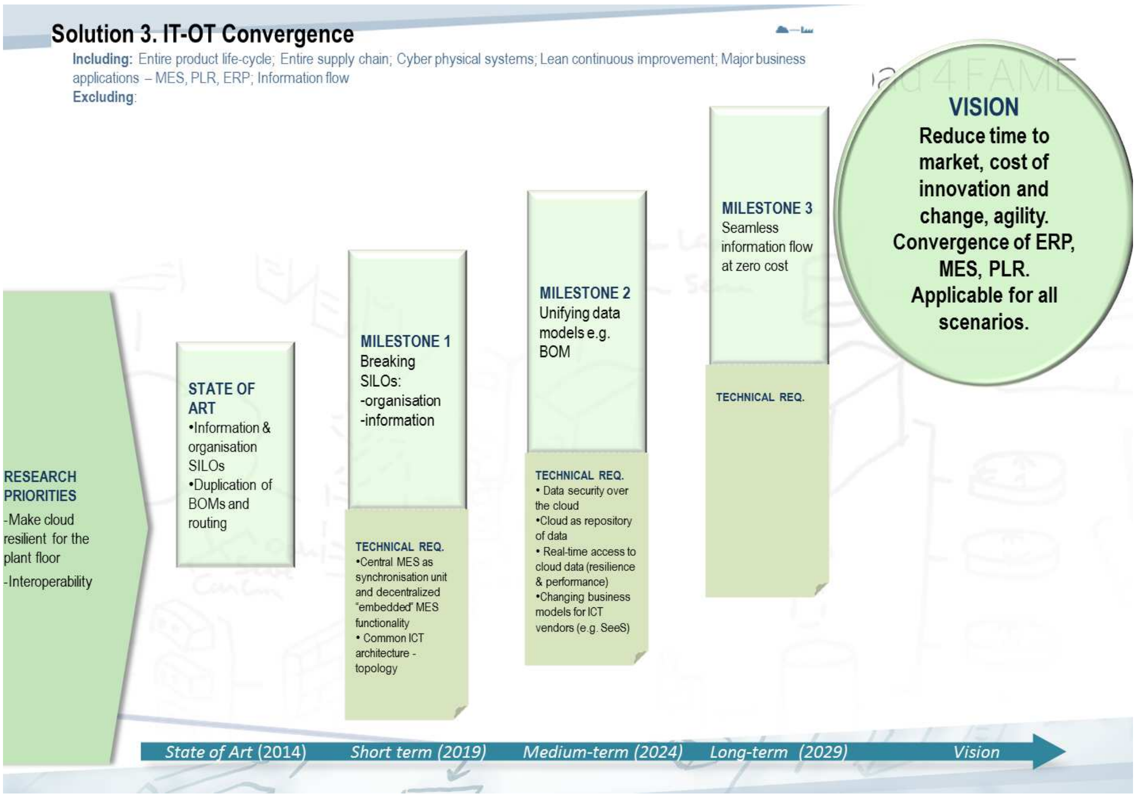
MILESTONE 3
Individual customer-led personalised design

TECHNICAL REQ.

VISION
Ensure product meets customer requirements – what they want!

State of Art (2014) | Short term (2019) | Medium-term (2024) | Long-term (2029) | Vision

Figure 20: Roadmap and Summary for the Solution 2: Customer and demand data gathering and analysis



Solution 3. IT-OT Convergence

Including: Entire product life-cycle; Entire supply chain; Cyber physical systems; Lean continuous improvement; Major business applications – MES, PLR, ERP; Information flow
Excluding:

RESEARCH PRIORITIES
-Make cloud resilient for the plant floor
-Interoperability

STATE OF ART
•Information & organisation SILOs
•Duplication of BOMs and routing

MILESTONE 1
Breaking SILOs:
-organisation
-information

TECHNICAL REQ.
•Central MES as synchronisation unit and decentralized "embedded" MES functionality
• Common ICT architecture - topology

MILESTONE 2
Unifying data models e.g. BOM

TECHNICAL REQ.
• Data security over the cloud
•Cloud as repository of data
• Real-time access to cloud data (resilience & performance)
•Changing business models for ICT vendors (e.g. SeeS)

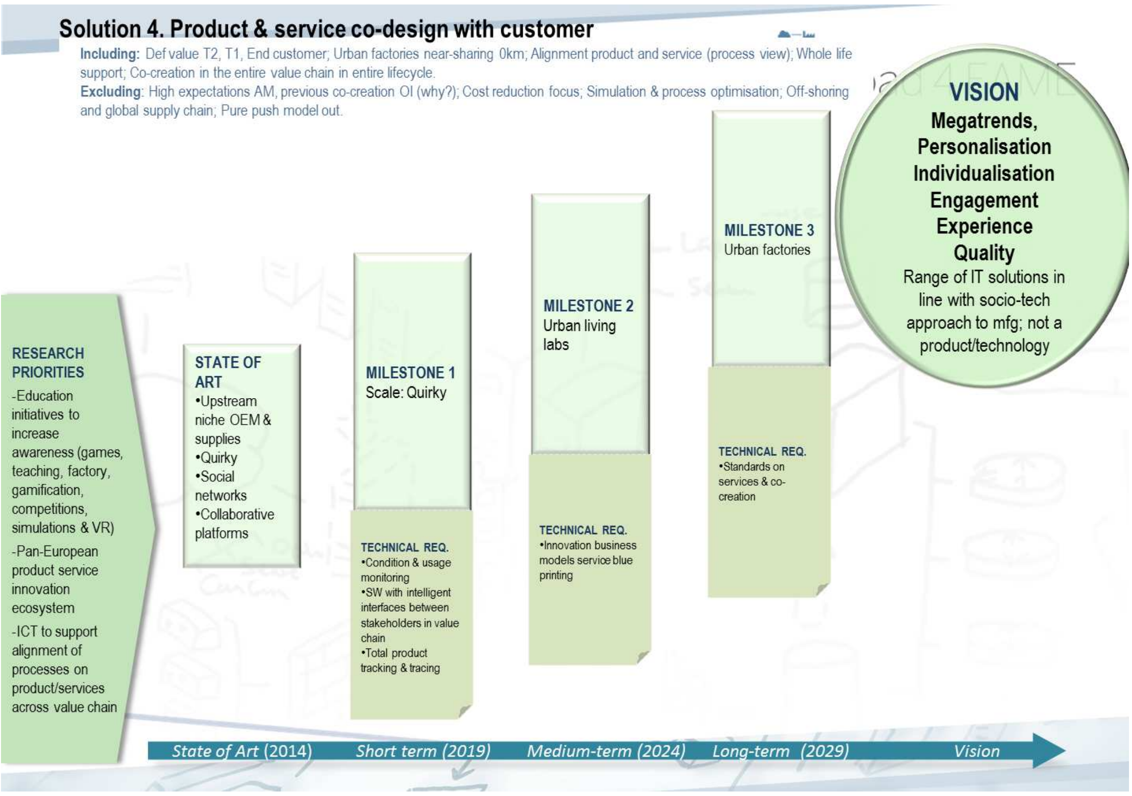
MILESTONE 3
Seamless information flow at zero cost

TECHNICAL REQ.

VISION
Reduce time to market, cost of innovation and change, agility. Convergence of ERP, MES, PLR. Applicable for all scenarios.

State of Art (2014) | Short term (2019) | Medium-term (2024) | Long-term (2029) | Vision

Figure 21: Roadmap and Summary for the Solution 3: IT-OT Convergence



Solution 4. Product & service co-design with customer

Including: Def value T2, T1, End customer; Urban factories near-sharing 0km; Alignment product and service (process view); Whole life support; Co-creation in the entire value chain in entire lifecycle.
Excluding: High expectations AM, previous co-creation OI (why?); Cost reduction focus; Simulation & process optimisation; Off-shoring and global supply chain; Pure push model out.

RESEARCH PRIORITIES
-Education initiatives to increase awareness (games, teaching, factory, gamification, competitions, simulations & VR)
-Pan-European product service innovation ecosystem
-ICT to support alignment of processes on product/services across value chain

STATE OF ART
- Upstream niche OEM & supplies
- Quirky
- Social networks
- Collaborative platforms

MILESTONE 1
Scale: Quirky

TECHNICAL REQ.
- Condition & usage monitoring
- SW with intelligent interfaces between stakeholders in value chain
- Total product tracking & tracing

MILESTONE 2
Urban living labs

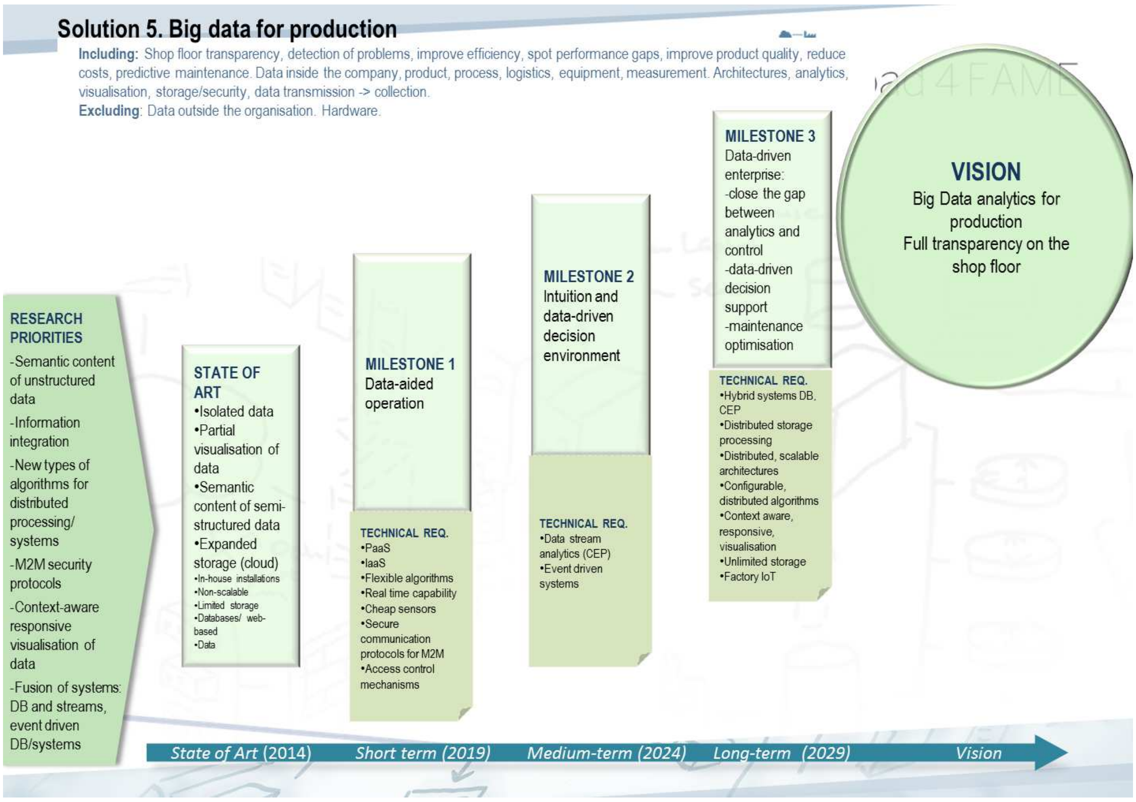
TECHNICAL REQ.
- Innovation business models service blue printing

MILESTONE 3
Urban factories

TECHNICAL REQ.
- Standards on services & co-creation

VISION
Megatrends, Personalisation Individualisation Engagement Experience Quality
Range of IT solutions in line with socio-tech approach to mfg; not a product/technology

Figure 22: Roadmap and Summary for the Solution 4: Product & service co-design with customer



Solution 5. Big data for production

Including: Shop floor transparency, detection of problems, improve efficiency, spot performance gaps, improve product quality, reduce costs, predictive maintenance. Data inside the company, product, process, logistics, equipment, measurement. Architectures, analytics, visualisation, storage/security, data transmission -> collection.
Excluding: Data outside the organisation. Hardware.

RESEARCH PRIORITIES
-Semantic content of unstructured data
-Information integration
-New types of algorithms for distributed processing/ systems
-M2M security protocols
-Context-aware responsive visualisation of data
-Fusion of systems: DB and streams, event driven DB/systems

STATE OF ART
- Isolated data
- Partial visualisation of data
- Semantic content of semi-structured data
- Expanded storage (cloud)
- In-house installations
- Non-scalable
- Limited storage
- Databases/ web-based
- Data

MILESTONE 1
Data-aided operation

TECHNICAL REQ.
- PaaS
- IaaS
- Flexible algorithms
- Real time capability
- Cheap sensors
- Secure communication protocols for M2M
- Access control mechanisms

MILESTONE 2
Intuition and data-driven decision environment

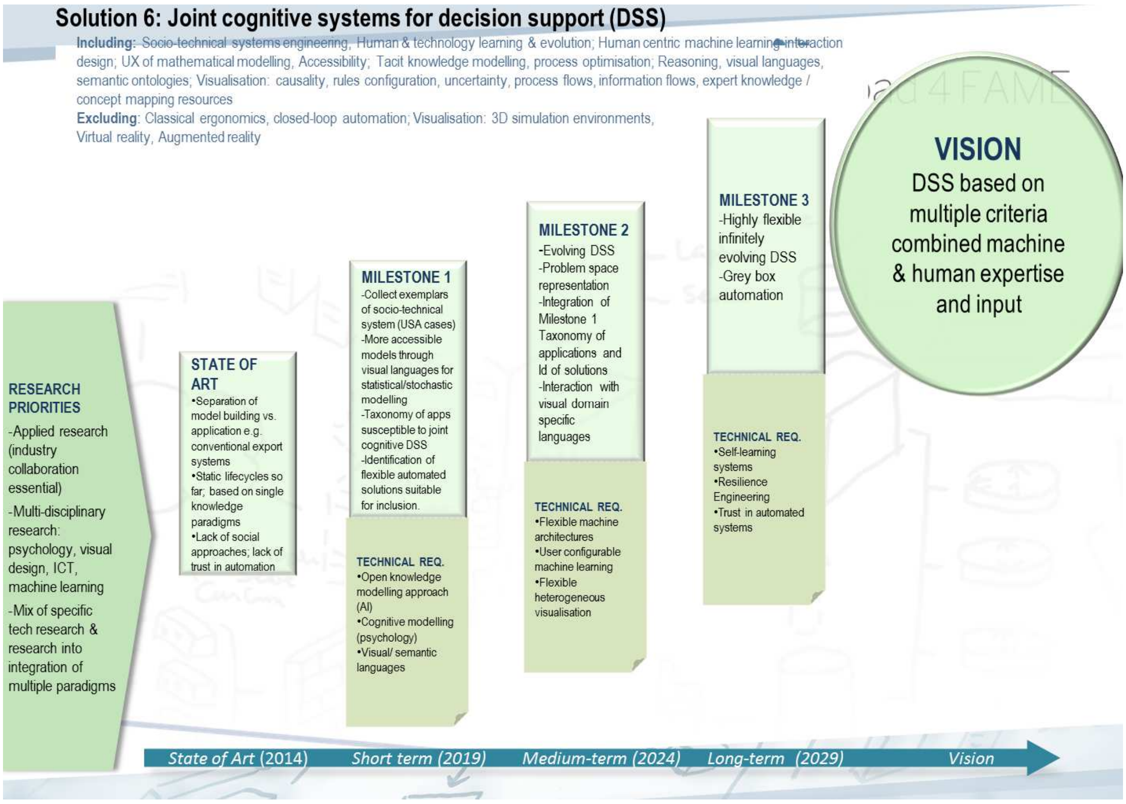
TECHNICAL REQ.
- Data stream analytics (CEP)
- Event driven systems

MILESTONE 3
Data-driven enterprise:
-close the gap between analytics and control
-data-driven decision support
-maintenance optimisation

TECHNICAL REQ.
- Hybrid systems DB, CEP
- Distributed storage processing
- Distributed, scalable architectures
- Configurable, distributed algorithms
- Context aware, responsive, visualisation
- Unlimited storage
- Factory IoT

VISION
Big Data analytics for production
Full transparency on the shop floor

Figure 23: Roadmap and Summary for the Solution 5: Big data for production



Solution 6: Joint cognitive systems for decision support (DSS)

Including: Socio-technical systems engineering, Human & technology learning & evolution; Human centric machine learning-interaction design; UX of mathematical modelling, Accessibility; Tacit knowledge modelling, process optimisation; Reasoning, visual languages, semantic ontologies; Visualisation: causality, rules configuration, uncertainty, process flows, information flows, expert knowledge / concept mapping resources

Excluding: Classical ergonomics, closed-loop automation; Visualisation: 3D simulation environments, Virtual reality, Augmented reality

RESEARCH PRIORITIES
-Applied research (industry collaboration essential)
-Multi-disciplinary research: psychology, visual design, ICT, machine learning
-Mix of specific tech research & research into integration of multiple paradigms

STATE OF ART
•Separation of model building vs. application e.g. conventional export systems
•Static lifecycles so far; based on single knowledge paradigms
•Lack of social approaches; lack of trust in automation

MILESTONE 1
-Collect exemplars of socio-technical system (USA cases)
-More accessible models through visual languages for statistical/stochastic modelling
-Taxonomy of apps susceptible to joint cognitive DSS
-Identification of flexible automated solutions suitable for inclusion.

TECHNICAL REQ.
•Open knowledge modelling approach (AI)
•Cognitive modelling (psychology)
•Visual/ semantic languages

MILESTONE 2
-Evolving DSS
-Problem space representation
-Integration of Milestone 1 Taxonomy of applications and Id of solutions
-Interaction with visual domain specific languages

TECHNICAL REQ.
•Flexible machine architectures
•User configurable machine learning
•Flexible heterogeneous visualisation

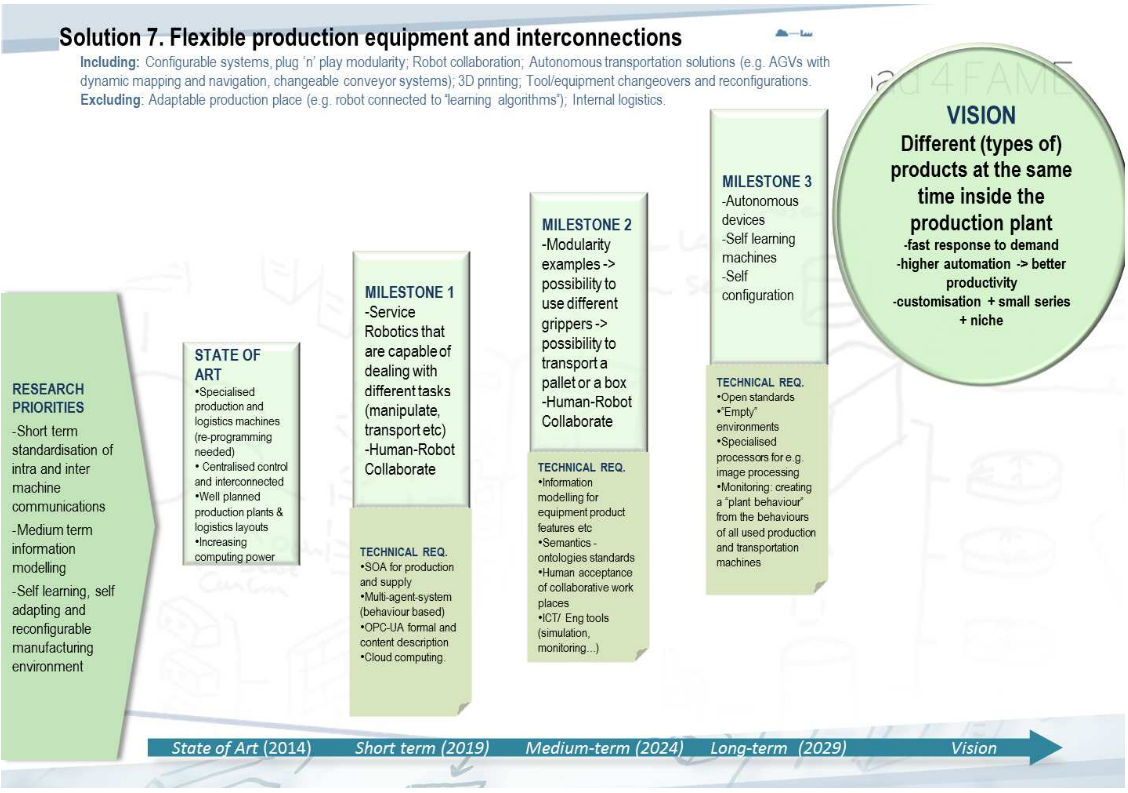
MILESTONE 3
-Highly flexible infinitely evolving DSS
-Grey box automation

TECHNICAL REQ.
•Self-learning systems
•Resilience Engineering
•Trust in automated systems

VISION
DSS based on multiple criteria combined machine & human expertise and input

State of Art (2014) *Short term (2019)* *Medium-term (2024)* *Long-term (2029)* *Vision*

Figure 24: Roadmap and Summary for the Solution 6: Joint cognitive systems for decision support (DSS)



Solution 7. Flexible production equipment and interconnections

Including: Configurable systems, plug 'n' play modularity; Robot collaboration; Autonomous transportation solutions (e.g. AGVs with dynamic mapping and navigation, changeable conveyor systems); 3D printing; Tool/equipment changeovers and reconfigurations.

Excluding: Adaptable production place (e.g. robot connected to "learning algorithms"); Internal logistics.

RESEARCH PRIORITIES
-Short term standardisation of intra and inter machine communications
-Medium term information modelling
-Self learning, self adapting and reconfigurable manufacturing environment

STATE OF ART
•Specialised production and logistics machines (re-programming needed)
• Centralised control and interconnected
•Well planned production plants & logistics layouts
•Increasing computing power

MILESTONE 1
-Service Robotics that are capable of dealing with different tasks (manipulate, transport etc)
-Human-Robot Collaborate

TECHNICAL REQ.
•SOA for production and supply
•Multi-agent-system (behaviour based)
•OPC-UA formal and content description
•Cloud computing.

MILESTONE 2
-Modularity examples -> possibility to use different grippers -> possibility to transport a pallet or a box
-Human-Robot Collaborate

TECHNICAL REQ.
•Information modelling for equipment product features etc
•Semantics - ontologies standards
•Human acceptance of collaborative work places
•ICT/ Eng tools (simulation, monitoring...)

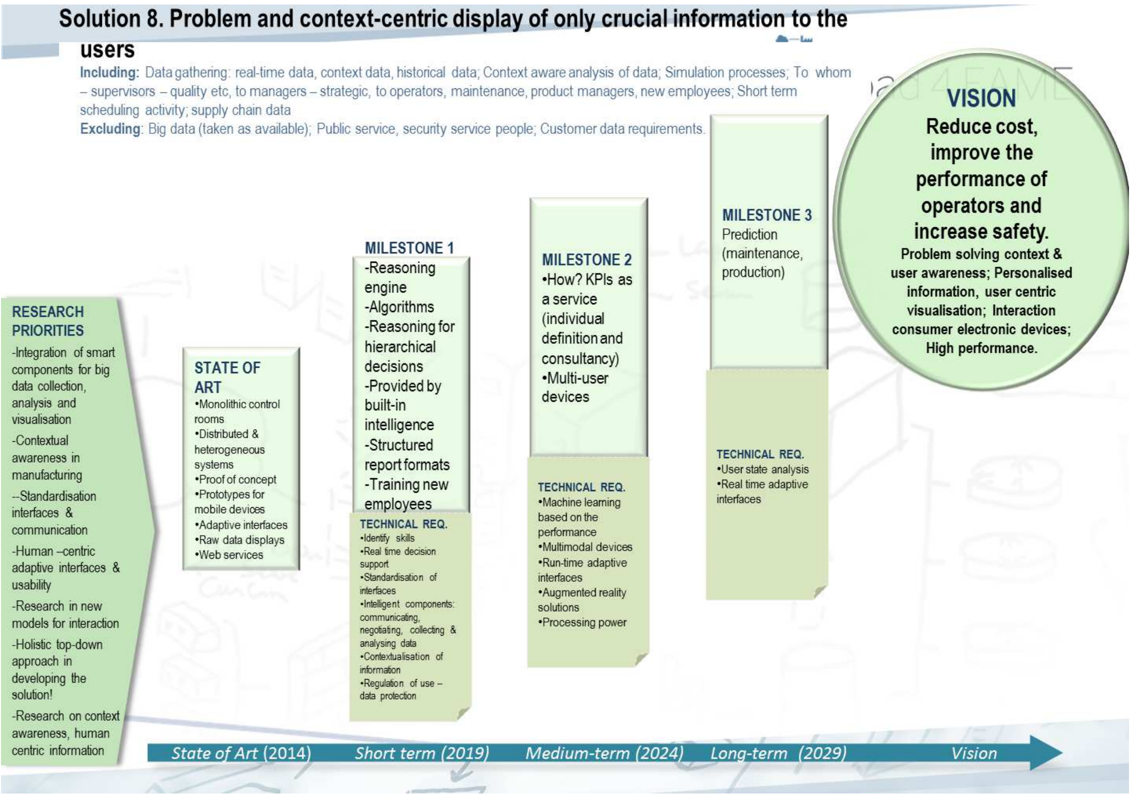
MILESTONE 3
-Autonomous devices
-Self learning machines
-Self configuration

TECHNICAL REQ.
•Open standards
•"Empty" environments
•Specialised processors for e.g. image processing
•Monitoring: creating a "plant behaviour" from the behaviours of all used production and transportation machines

VISION
Different (types of) products at the same time inside the production plant
-fast response to demand
-higher automation -> better productivity
-customisation + small series + niche

State of Art (2014) *Short term (2019)* *Medium-term (2024)* *Long-term (2029)* *Vision*

Figure 25: Roadmap and Summary for the Solution 7: Flexible production equipment and interconnections



Solution 8. Problem and context-centric display of only crucial information to the users

Including: Data gathering: real-time data, context data, historical data; Context aware analysis of data; Simulation processes; To whom – supervisors – quality etc, to managers – strategic, to operators, maintenance, product managers, new employees; Short term scheduling activity; supply chain data

Excluding: Big data (taken as available); Public service, security service people; Customer data requirements.

RESEARCH PRIORITIES

-Integration of smart components for big data collection, analysis and visualisation

-Contextual awareness in manufacturing

--Standardisation interfaces & communication

-Human –centric adaptive interfaces & usability

-Research in new models for interaction

-Holistic top-down approach in developing the solution!

-Research on context awareness, human centric information

STATE OF ART

- Monolithic control rooms
- Distributed & heterogeneous systems
- Proof of concept
- Prototypes for mobile devices
- Adaptive interfaces
- Raw data displays
- Web services

MILESTONE 1

-Reasoning engine

-Algorithms

-Reasoning for hierarchical decisions

-Provided by built-in intelligence

-Structured report formats

-Training new employees

TECHNICAL REQ.

- Identify skills
- Real time decision support
- Standardisation of interfaces
- Intelligent components: communicating, negotiating, collecting & analysing data
- Contextualisation of information
- Regulation of use – data protection

MILESTONE 2

- How? KPIs as a service (individual definition and consultancy)
- Multi-user devices

TECHNICAL REQ.

- Machine learning based on the performance
- Multimodal devices
- Run-time adaptive interfaces
- Augmented reality solutions
- Processing power

MILESTONE 3

Prediction (maintenance, production)

TECHNICAL REQ.

- User state analysis
- Real time adaptive interfaces

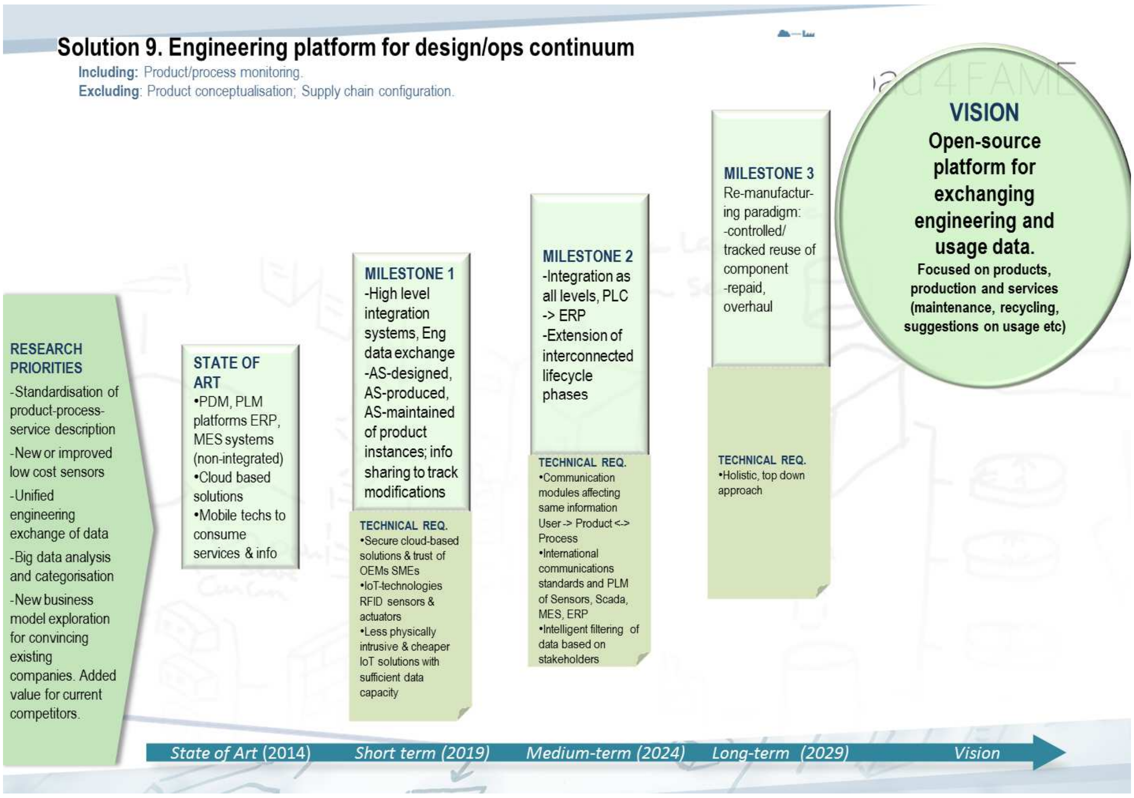
VISION

Reduce cost, improve the performance of operators and increase safety.

Problem solving context & user awareness; Personalised information, user centric visualisation; Interaction consumer electronic devices; High performance.

State of Art (2014) *Short term (2019)* *Medium-term (2024)* *Long-term (2029)* *Vision*

Figure 26: Roadmap and Summary for the Solution 8: Problem and context-centric display of only crucial information to the users



Solution 9. Engineering platform for design/ops continuum

Including: Product/process monitoring.

Excluding: Product conceptualisation; Supply chain configuration.

RESEARCH PRIORITIES

-Standardisation of product-process-service description

-New or improved low cost sensors

-Unified engineering exchange of data

-Big data analysis and categorisation

-New business model exploration for convincing existing companies. Added value for current competitors.

STATE OF ART

- PDM, PLM platforms ERP, MES systems (non-integrated)
- Cloud based solutions
- Mobile techs to consume services & info

MILESTONE 1

-High level integration systems, Eng data exchange

-AS-designed, AS-produced, AS-maintained of product instances; info sharing to track modifications

TECHNICAL REQ.

- Secure cloud-based solutions & trust of OEMs SMEs
- IoT-technologies RFID sensors & actuators
- Less physically intrusive & cheaper IoT solutions with sufficient data capacity

MILESTONE 2

-Integration as all levels, PLC -> ERP

-Extension of interconnected lifecycle phases

TECHNICAL REQ.

- Communication modules affecting same information User -> Product <-> Process
- International communications standards and PLM of Sensors, Scada, MES, ERP
- Intelligent filtering of data based on stakeholders

MILESTONE 3

Re-manufacturing paradigm:

-controlled/ tracked reuse of component

-repaid, overhaul

TECHNICAL REQ.

- Holistic, top down approach

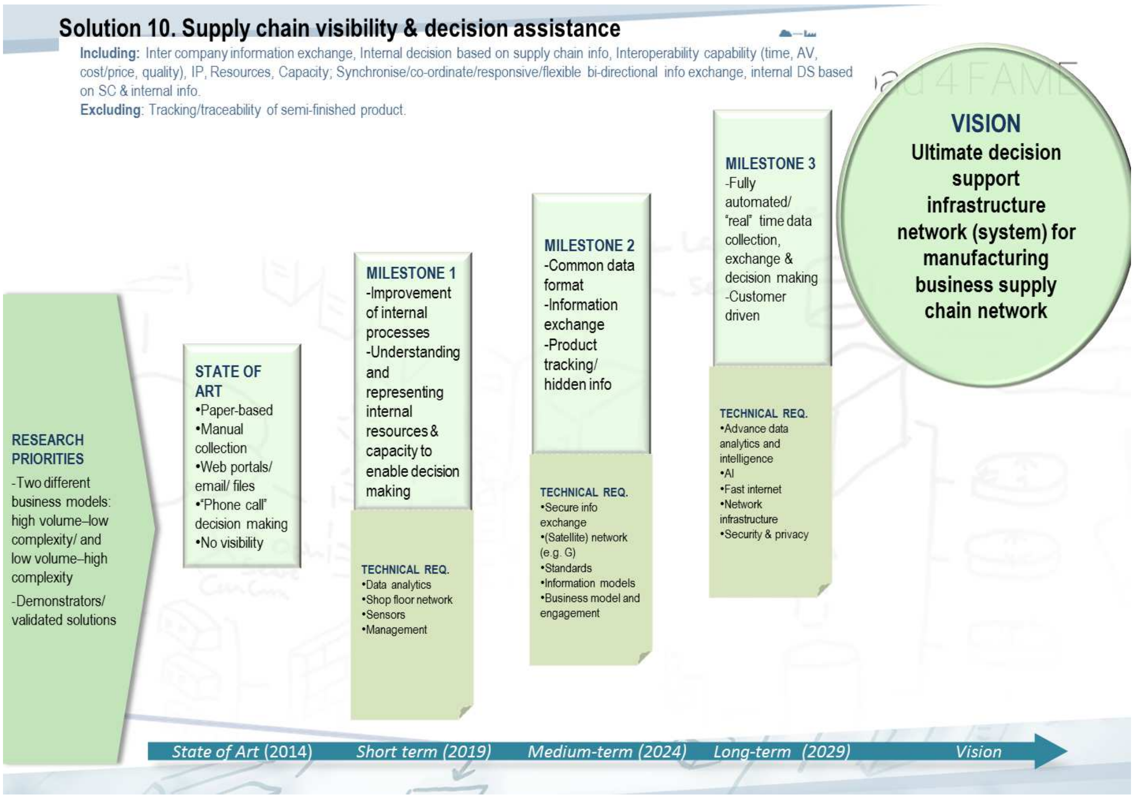
VISION

Open-source platform for exchanging engineering and usage data.

Focused on products, production and services (maintenance, recycling, suggestions on usage etc)

State of Art (2014) *Short term (2019)* *Medium-term (2024)* *Long-term (2029)* *Vision*

Figure 27: Roadmap and Summary for the Solution 9: Engineering platform for design/ops continuum



Solution 10. Supply chain visibility & decision assistance

Including: Inter company information exchange, Internal decision based on supply chain info, Interoperability capability (time, AV, cost/price, quality), IP, Resources, Capacity; Synchronise/co-ordinate/responsive/flexible bi-directional info exchange, internal DS based on SC & internal info.

Excluding: Tracking/traceability of semi-finished product.

RESEARCH PRIORITIES
-Two different business models: high volume–low complexity/ and low volume–high complexity
-Demonstrators/ validated solutions

STATE OF ART
•Paper-based
•Manual collection
•Web portals/ email/ files
•"Phone call" decision making
•No visibility

MILESTONE 1
-Improvement of internal processes
-Understanding and representing internal resources & capacity to enable decision making

TECHNICAL REQ.
•Data analytics
•Shop floor network
•Sensors
•Management

MILESTONE 2
-Common data format
-Information exchange
-Product tracking/ hidden info

TECHNICAL REQ.
•Secure info exchange
•(Satellite) network (e.g. G)
•Standards
•Information models
•Business model and engagement

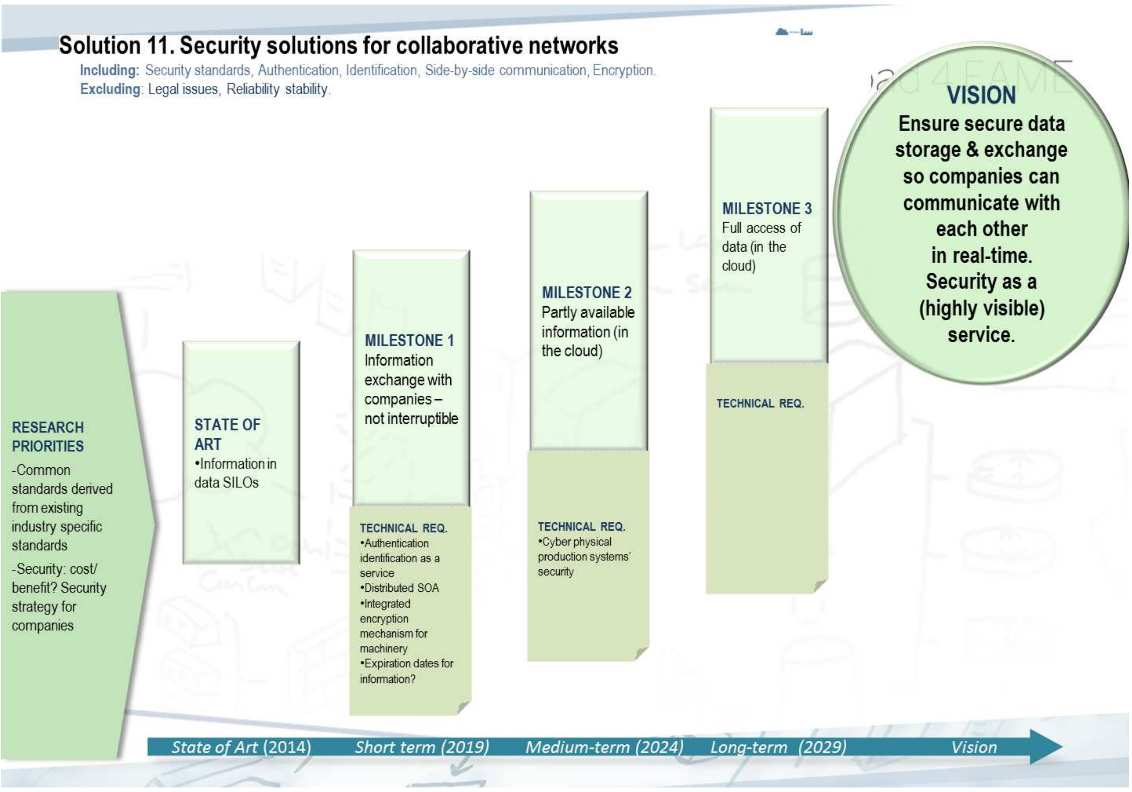
MILESTONE 3
-Fully automated/ "real" time data collection, exchange & decision making
-Customer driven

TECHNICAL REQ.
•Advance data analytics and intelligence
•AI
•Fast internet
•Network infrastructure
•Security & privacy

VISION
Ultimate decision support infrastructure network (system) for manufacturing business supply chain network

State of Art (2014) Short term (2019) Medium-term (2024) Long-term (2029) Vision

Figure 28: Roadmap and Summary for the Solution 10: Supply chain visibility & decision assistance



Solution 11. Security solutions for collaborative networks

Including: Security standards, Authentication, Identification, Side-by-side communication, Encryption.

Excluding: Legal issues, Reliability stability.

RESEARCH PRIORITIES
-Common standards derived from existing industry specific standards
-Security: cost/ benefit? Security strategy for companies

STATE OF ART
•Information in data SILOs

MILESTONE 1
Information exchange with companies – not interruptible

TECHNICAL REQ.
•Authentication identification as a service
•Distributed SOA
•Integrated encryption mechanism for machinery
•Expiration dates for information?

MILESTONE 2
Partly available information (in the cloud)

TECHNICAL REQ.
•Cyber physical production systems' security

MILESTONE 3
Full access of data (in the cloud)

TECHNICAL REQ.

VISION
Ensure secure data storage & exchange so companies can communicate with each other in real-time. Security as a (highly visible) service.

State of Art (2014) Short term (2019) Medium-term (2024) Long-term (2029) Vision

Figure 29: Roadmap and Summary for the Solution 11: Security solutions for collaborative networks

5 Overall Recommendations

At the end of the workshop each group was asked to comment on what they considered to be the most important research priorities relevant to their Solution. Any issues identified during the group work such as required research and technologies, enablers, barriers, risks, decision points and knowledge gaps were summarized and consolidated by the delegates and they put forward some initial recommendations for future research priorities in Europe relevant to academia, IT companies and manufacturing businesses. The following research recommendations were put forward:

	Updated Recommendations	**Recommendations from Initial Roadmapping workshop (Deliverable 3.2)**
Architectures and Services	**System and Information Integration Architectures** New ICT Architectures are required that enable seamless integration and low-effort configuration of systems with appropriate IT architectures. Preconditions for this are innovative ICT architectures, beyond current concepts like standard web services, cloud computing, etc, which enable interoperability with regards to connectivity, protocols, data formats, data semantics, and system functionalities/capabilities. These features have to be provided by all manufacturing system components, starting from intelligent equipment components up to overall factory control systems or related IT services, and managed by means of appropriate infrastructures. Some aspects to be covered by new ICT Architectures would be: • The application of standardised product–process–service descriptions and their alignment across value chain in order to enable seamless integration and management of production processes throughout production networks, as well as seamless system integration/information exchange throughout the whole product life cycle (e.g. transfer of product specification to production, reuse of manufacturing and operation data for product design). • Scalable Cyber-Physical Production System (CPPS) architectures that integrate the real-time information from sensor-actuators devices in manufacturing process, the Machine-to-Machine (M2M) communications and cognitive control systems with power of computing systems such as modelling, planning and prediction. • Hybrid architectures that combine the service-oriented architectures and semantic technologies.	Future internet architectures

	New Business Models also need to be considered for convincing existing companies to adopt these innovations, especially SME facilitating IT-services that require lower implementation costs and are less complex. New business models could include servitisation, decision support, supply chain collaboration and visibility amongst others.	
	Data Capture, Storage and Analysis New ICT Services are likely to require the capture, storage and analysis of large amount of data of varying quality and CPPS could be the major source collector and distributor of data. These need to enable event-driven databases and streams as well as contextual awareness. Research on a number of issues will be required to make new ICT services viable, such as: • Data mining, ideally in real-time • Semantic content and context of (unstructured) data • Big data analysis and categorisation • Unified engineering exchange of data • Big data analytics, especially on production Additionally, new tools will need to be developed or (existing tools reconfigured) to enable big data to be checked for consistency and verification determination of data quality (reliability, accuracy, etc). Finally, integration of smart components for data collection, analysis and visualisation will be necessary and this is an important enabler for new ICT services in manufacturing, facilitating manufacturing enterprises to take advantage of the large amounts of data their systems generate.	Decision support tools
	Data and Information Visualisation (for decision making) Supporting the previous recommendation is the required research in data and information visualisation and specifically context-aware responsive visualisation of data and prescriptive analytics, which is a major pre-condition for efficient decision support systems. The data provenance needs also to be maintained to assure IP and knowledge protection. Visual design and visual encoding are also important parameters as well as human-centric adaptive interfaces to enhance usability.	Visualisation tools contextual awareness
	Security Security is an important issue for the manufacturing sector and new ICT Architectures need to ensure protection, especially within	ICT security and Solutions for security on distributed/cloud

	manufacturing networks at a reasonable cost. Research needs to cover different aspects of digital security and cyber-security. Security protocols for M2M and other forms of interactions of manufacturing equipment and related components or network nodes need to be robust and guarantee operational safety and reliability. Finally, research in security strategy for companies and standards would be necessary to ensure balance between security cost and benefits to an organisation.	systems
	Confidentiality In addition to security, confidentiality and know-how protection is essential for the acceptance and application, of new ICT architectures and services in manufacturing. This has to be ensured by the implementation of appropriate authentication and authorisation mechanisms, which could range from straight-forward role based access rights to more complex solutions reflecting individual needs (also for machines accessing respective information).	
Infrastructures	**Flexible and adaptable manufacturing** New ICT Infrastructures should be researched that promote self-adapting, resilient and reconfigurable manufacturing environments. These need to be facilitated by standardisation of intra-and inter-machine communication, but also need to reflect production process aspects. New networking protocols and mechanisms will have to improve the linking of various equipment as actuators, and (wireless)sensors, RFID devices, etc, significantly contributing to efficiency improvements of the (re-)configuration and ramp-up of manufacturing environments . Additionally, appropriate context awareness and self-learning (e.g. for production configuration) mechanisms have to be developed based on continuous real-time monitoring of logistics, material flow and resource utilization.	
	New Algorithms New types of algorithms for distributed processing of data and systems in close-to-real time would be necessary in order to improve and accelerate applications of big data processing, etc, for manufacturing, and so making them applicable for the production domain, also on intra-factory control system layers. The development of ready to use algorithms for analysis, real time prediction, etc, will need to meet the needs of every manufacturing	Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results; manufacturing data-orientated search engine

	enterprise, without organisations, especially SMEs, having to spend additional time and resources on the definition and development of those algorithms. Furthermore, those algorithms should be able to run on limited processing / power capacity to ensure their applicability in manufacturing environments, considering that cloud connections are not appropriate or available for all locations and applications. New algorithms also can incorporate knowledge from other domains that could be beneficial to manufacturing (e.g. game theory, artificial intelligence, simulations, etc).	
	Modelling Modelling and in particular information modelling and work domain modelling of socio-technological systems would be beneficial in manufacturing. Simulations, virtual reality, tacit knowledge modelling and UX of mathematical modelling can be important for enabling better problem solving and decision support and rapid prototyping. The development of smarter and better models can provide not only design details but also greater predictive capacity in order to reduce physical prototyping needs or construction of pilot plants.	Multilevel architecture models and model management including stochastic/human modelling and model integration i.e. ontology-based information modelling
ICT Enablers	**Demonstrators** Demonstrators are important for convincing the generally conservative manufacturing sector on the benefits of new ICT architectures and services, as well as the cost/benefit of new ICT adoptions. It would beneficial to encourage the development of a pan-European product/service innovation ecosystem where validated solutions are demonstrated. A large scale collaboration approach is necessary for developing demonstrators which are representing “industrial strength”.	

	Interoperability and Standards According to aforementioned recommendations/examples, standardised product – process – service descriptions are required to enable seamless information exchange along value chains and throughout production systems. Besides widely applied standards like IEC 61131, OPC UA, etc, some relevant innovative standards exist, e.g. IEC 61499 but industrial uptake is very weak. Reference ICT architectures are key for standards definition and adoption. On the other hand, many of the existing standards are quite industry-specific (e.g. SEMI, SiLA, etc.) The lack of standardisation and harmonisation of many interfaces and communication is normally a barrier with self-service configuration be a potential alternative.	Collaboration model definition: protocols and regulations
Other enablers	• Education initiatives to increase awareness and training materials • Applied, multidisciplinary research with large scale industrial collaboration – no one entity could bring all necessary skills • Incorporation of psychology into ICT research • New or improved low-cost, miniaturised smart sensors	Development of lower power electronics and communication protocols Development of very low cost sensors and their physical integration into smart systems and distributed controllers

6 Conclusions

A preliminary roadmap for ICT in Manufacturing was produced through literature research, expert panel meetings, interviews, and two one-day workshops; the first involving 17 participants from the Core and Expert Groups and the second involving 45 participants from the Core and Expert Groups as well as external participants from Europe. The participants validated the information already gathered, added additional content to the roadmap, prioritised all content and helped highlight the research required for ICT development in manufacturing.

Eleven priority ICT manufacturing Solutions were selected and explored in detail during the second workshop, as follows:

- **Big data analysis and use for quality control**
- **Flexible production equipment and interconnections**
- **Joint Cognitive Systems for decision support**
- **Engineering Platform for design/operations continuum**
- **Customer and demand data gathering for analysis**
- **Product and service co-design with customer**
- **Supply chain visibility and decision assistance**
- **Security solutions for collaborative networks**
- **Open data and system integration platform for unstructured data environment - including harmonised / standardised interfaces**
- **IT-OT convergence: integrated architecture PLM-MES-ERP**
- **Problem and context-centric display of only crucial information to the users**

The ***main research recommendations*** put forward by the delegates, necessary for realising these ICT manufacturing Solutions, were clustered around the main themes of:

- **Integration:** Integration for both existing ICT systems and new smart components (e.g. new improved low cost, miniaturised sensors) for data collection, analysis and visualisation.

- **Data and Information:** Unification of engineering exchange of data, Big Data capture (live streaming for situational awareness), storage (event driven databases) and analysis (data mining – ideally in real time), distributed processing algorithms for data and systems in real time, visualisation techniques and decision support systems to reduce operator load. This should include standardisation and reference ICT architectures as well as interoperability and harmonization of different interfaces.

- **Machine Learning and Adaptive Systems to Enable Flexible and Adaptive Manufacturing:** Environments and infrastructures for machine learning, self-adapting and reconfigurable manufacturing including intra-and inter- machine communication standards and human-centric adaptive interfaces.

- **Multidisciplinary Modelling:** Modelling of factories, information modelling and work domain modelling of socio-technological systems.

- **Security:** Robust Machine-to-Machine (M2M) security protocols that guarantee operational safety and reliability.

- **Confidentiality:** Affordable security for confidentiality, especially within manufacturing supply networks.

- **Demonstrators & Education:** Demonstrators are required to convince the conservative manufacturing sector of the cost/benefits of new ICT architectures and services. Education initiatives and training materials are needed to increase awareness in the manufacturing sector.

Further work is planned within the project to enhance and refine these recommendations.

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Appendix 1: List of Trends and Drivers

Megatrends

1. Demographic change

Higher life expectancy and falling birth rates are increasing the proportion of elderly people across the world, challenging the solvency of social welfare systems, including pensions and healthcare.
Timeline: **Now-L**

2. Globalisation / Economic interconnectedness

The interconnected global economy will see a continued increase in the volume of international trade and capital flow, but unless international conventions can be strengthened, progress and optimum economic benefits may not be realised.
Timeline: **Now-L**

3. Urbanisation

Urbanisation is creating significant opportunities for social and economic development and more sustainable living, but is also exerting pressure on infrastructure and resources, particularly energy.
Timeline: **M-L**

4. Accelerating innovation and new technologies

A new wave of technological advances is now creating novel opportunities, while testing governments' ability to harness their benefits and provide prudent oversight.
Timeline: **S-L**

5. Knowledge as key-enabler

The importance of knowledge is increasing as products, systems and business environment become more and more complex and technology-intensive. This leads to a trend of perceiving knowledge as capital, with the goal to use and exploit information across traditional boundaries as successfully as possible.
Timeline: **Now-L**

6. Resource stress and scarcity, rising energy costs, raw material prices

The combined pressures of population growth, economic growth and climate change will put increased stress on essential natural resources (including water, food, arable land and energy).
Timeline: **S-L**

7. Slow innovation and underinvestment in R&D

Innovation still takes considerable time to be put into practice – from laboratory prototype to full-scale production – giving competitors a chance to overtake European enterprises through speed.
Timeline: **Now-L**

8. Language barriers and cultural differences

Language barriers and cultural differences result in communication issues and may thus decrease

efficiency or introduce quality issues in global manufacturing networks.
Timeline: **Now-L**

9. Rise of environmental consciousness
Environmental consciousness throughout society, and herewith also the production domain, will lead to lower energy consumption and less waste.
–Timeline: **10. Rise of the individual**
Individual empowerment will accelerate owing to poverty reduction, growth of the global middle class, greater educational attainment, widespread use of new communications and manufacturing technologies and healthcare advances.
Timeline: **M-L**

11. Climate Change
Rising greenhouse gas emissions (GHGs) are causing climate change and driving a complex mix of unpredictable changes to the environment while further taxing the resilience of natural and built systems.
Timeline: **Now-L**

12. Diffusion of power/Sharing global responsibility
Power will shift to networks and coalitions in a multipolar world. The trend contains aspects like shift to global cooperation, growing power of NGOs, increasing philanthropy, etc.
Timeline: **M-L**

13. Increasing rate of knowledge and technological change
In certain fields, the rate of human knowledge acquisition will soon be exceeded by the rate at which such knowledge becomes irrelevant.
Timeline: **S-L**

14. Increasing importance of work-life balance
Assistance systems, learning tools, etc. which support to maintain work-life balance could help to enable and support better alignment of work, private life, personal and professional advancement.
Timeline: **M-L**

15. Sustainability for societal and economic issues
In a certain markets, environmental sustainability is becoming a relevant parameter for the company's competitiveness.
Timeline: **S-L**

16. Changes in economic purchasing power of customers and populations
Disposable income as a proportion of income is rising at various levels, changing the buying patterns of populations and forcing companies to respond.
Timeline: **S**

Manufacturing-related Trends

17. Increasing hybrid cross-over products/embedded IT and integrated services

Transformation opportunities are numerous when companies cross traditional boundaries. Hybrid solutions that help such crossovers are mandatory, and this calls for next generation solutions.
Timeline: **Now-L**

18. Environmental sustainability/green manufacturing

Timeline: **S-L**

19. Stricter/more requirements imposed by large buyers

Timeline: **M-L**

20. Stricter/more requirements from regulatory side

In some industries, increasingly strict requirements are imposed from the regulatory side, such as the requirement for full traceability.
Timeline: **M-L**

21. Environmental sustainability goals from regulatory side

Timeline: **S-L**

22. Demand by customers for individualized/highly configurable products

Customers increasingly demand highly customized products, ideally at no higher price than a comparable mass product.
Timeline: **S-L**

23. Backsourcing of manufacturing capacity to Europe

Backsourcing is the process of bringing manufacturing capacity (previously moved or outsourced to low wage counties) back to Europe.
Timeline: **M-L**

24. Stricter quality requirements

Ever higher quality is expected by customers. When strict quality requirements are combined with a high number of variants, assuring such high quality is a particular challenge.
Timeline: **S-L**

25. Shortage of skilled staff

A shortage of sufficiently skilled staff especially occurs in economically strong regions.
Timeline: **Now-L**

26. Increasing demand for products and services

With population projected to grow 20% over the next 20 years, to more than 8 billion people by 2030, demand will be generated by more than onw billion additional, increasingly wealthy customers.
Timeline: **Now-L**

27. Increasing complexity of products, processes, and supply networks
These changes require adequate action and infrastructures in order to maintain and optimise efficiency.
Timeline: **Now-L**

28. Urban production
The trend to relocate manufacturing facilities to cities in order to shorten commuting times, etc.
Timeline: **S-L**

29. Lack of technology acceptance
In an industrial environment, a certain resistance to change and scepticism towards new technologies can be observed. As a consequence, new technological developments are not sufficiently exploited.
Timeline: **Now-L**

30. Additive manufacturing/3D-printing
Additive manufacturing enables fast manufacturing of specific products by means of small and flexible production facilities.
Timeline: **M-L**

31. Extension of ICT perspective to production site/company associations
Employing ICT technologies to consider not only one's own production site when executing planning and optimisation tasks.
Timeline: **M-L**

32. Virtualisation and digitisation
Companies increasingly use simulation, visualisation, and virtualisation to understand the product and production behaviour and performance under virtual conditions.
Timeline: **S-L**

33. Shorter product lifecycles
Affluence and purchasing power are increasing the pace of change in many industrial sectors; products are replaced faster than before. This causes an increasing need for shorter time-to-market for innovative products but also for total product lifecycle management.
Timeline: **Now-L**

34. Increasing level of automation
Timeline: **S-L**

35. Mobility of consumers
Timeline: **S-L**

36. Enterprise mobility
Timeline: **S-L**

Manufacturing Business Needs

37. Need for resource productivity and efficiency

The need to use resources, including water and energy, in a less wasteful way to achieve the target output.

Timeline: **S-L**

38. Increasing flexibility of production environments

In order to increase their competitiveness, factories will increasingly develop their ability to react to faster changing markets with regard to production times, products to be manufactured, etc.

Timeline: **Now-L**

39. Maximise manufacturing efficiency and quality

Promising contributions are expected from new IT-tools, logistic concepts, product design methods, quality management methods, scheduling mechanisms, etc.

Timeline: **Now-L**

40. Flexibility in supply chain participation

Factories should easily be able to join production networks in order to be able to quickly react on market demand changes.

Timeline: **S-L**

41. Reduction of lead times to produce and deliver a product

In order to reduce inventories and to increase customer satisfaction, companies seek to continuously reduce lead times.

Timeline: **Now-L**

42. Reduction of effort for integration of new equipment/tools

Timeline: **Now-L**

43. Reduction of start-up times, fast scale-up of production

Start-up and maintenance times decrease overall inefficiency because manufacturing assets are not used productively.

Timeline: **Now-L**

44. Reduction of maintenance times

Timeline: **Now-L**

45. Reduction of inventories

Inventories equate to tied-up capital, which must be considered unproductively employed capital.

Timeline: **Now-L**

46. Increasing education required for workers

Due to an increasing complexity of products and processes, workers require ever more knowledge and skills.

Timeline: **M-L**

47. Flexibility/high number of variants

The capability of producing different parts without major retooling resulting a) in the ability of a manufacturing company to offer a wide variety of products to its customers; or b) in the ability to efficiently produce highly customized or even unique products.

Timeline: **S-L**

48. Greater energy efficiency

Timeline: **S-L**

49. Transparency of environmental footprint across supply chain

To realize green manufacturing; for environemental sustainability to became an available optimization parameter.

Timeline: **S-L**

50. Identify/anticipate changes in demand

Timeline: **S-L**

51. Integration of human worker in manufacturing process

As products and processes become more complex and the half-life of knowledge is decreasing, the human worker threatens to become the bottle neck in achieving the progress and flexibility required to remain competive.

Timeline: **M-L**

52. Maintain competitiveness for high-wage countries

Since labour costs are high in Europe, it is necessary to maintain and optimise competiveness e.g. by improvement of efficiency, optimisation of added value processes, quality standards, product innovation, outsourcing and collaboration, etc.

Timeline: **Now-L**

53. Information sharing – operational and strategic

Timeline: **S-L**

54. Managing high information volumes / hiding complexity from users

Timeline: **M-L**

55. Risk management and propagation across the virtual enterprise

Timeline: **Now-L**

56. Energy tracing for individual products

Timeline: **Now-L**

57. Need for updating/integrating legacy systems

Timeline: **S**

58. IP management for collaborative environments

Timeline: **S**

Business Models

59. Local adaption/manufacturing close to markets

Large centralised manufacturing units have now given way to networks of smaller modular factories, which are closer to centres of demand.

Timeline: **S-L**

60. Companies are increasingly focusing on their core business

Under global cost pressures many companies focus on their core business and optimise their comparative advantage to remain competitive.

Timeline: **Now-L**

61. Emergence of smaller, more dynamic enterprises

The need to be innovative is an increasing necessity in more and more markets, putting pressure on large European enterprises, once market leaders in their own domains, but now losing out to smaller and more agile companies.

Timeline: **Now-L**

62. Added value potential through new services

Provision of new (B2B or B2C) services and business models enabled by intelligent products.

Timeline: **M-L**

63. Sharing of resources (energy and products) among different factories

Timeline: **S**

64. Specialised companies for IT and methods for integration of/migration to advanced ICT solutions

Timeline: **S**

Appendix 2: List of Solutions

Shop floor production

65. Condition monitoring

Condition monitoring is the process of monitoring a parameter of condition in machinery (vibration, temperature, etc). It is a major component of predictive maintenance but does also provide the grounds for process optimization (e.g. resource consumption).

Timeline: **S-L**

66. Predictive maintenance

Predictive maintenance is about the early detection of deficiencies which allows appropriate maintenance measures to be taken before actual damage to the equipment occurs. Thus, maintenance cost can be drastically reduced, minimal energy consumption of the equipment can be ensured, and downtime can be minimized resulting in high system availability and high productivity.

Timeline: **S-L**

67. Production monitoring/data acquisition in real time (to achieve transparency, support data analytics for optimisation, etc)

Timeline: **S**

68. Big data analysis and use for quality control

Timeline: **L**

69. Simulating tools for new process design

Timeline: **L**

70. Decision making based on measured resource utilisation

Timeline: **S**

71. Flexible production equipment and interconnections

Timeline: **S**

72. Real time dispatching capabilities

Timeline: **Now**

73. Material arrival predictions

Timeline: **S**

74. Closed-loop of manufacturing analysis and control

Timeline: **Now**

75. Knowledge management tools

Timeline: **Now**

76. Analytics and optimisation of equipment energy consumption
Timeline: **S**

77. Quality measurement and management per process and equipment
Timeline: **S**

78. Separated production stations rather than fixed production lines; automated transportation systems serving the stations
Timeline: **S**

Supply network

79. Evolution and emergent behaviour of production networks

Production networks have increasingly to deal with unexpected events and react to them in an optimal way since overall markets are becoming more agile, customer demands are changing faster, collaborations can be established and dissolved faster, etc.

Timeline: **S-L**

80. Total product tracking

Product tracking becomes increasingly necessary either in the context of mass customization, to manage product recycling, fulfil regulations, or to exploit the full potential of planning and optimisation mechanisms.

Timeline: **Now-L**

81. Supply chain performance data (well defined KPIs)

Timeline: **S**

82. Supply chain visibility and decision assistance

Timeline: **S**

83. Resilience mechanisms for collaborative production networks

Timeline: **S**

84. Security and IP protection solutions for collaborative networks

Timeline: **M**

85. Algorithms to determine/optimise routes, material grouping, (re-)ordering of components, etc. for shortest set-up cycles

Timeline: **Now**

86. Harmonised/standardised interfaces and services throughout the whole product lifecycle and production network to achieve easy exchange of product information

Timeline: **S**

Inter-company

87. Interoperability solutions
Timeline: **S**

88. Novel risk analysis algorithms embedded in software services accessible to non-expert users
Timeline: **M-L**

89. Multi-level heterogeneous modelling of virtual enterprises
Timeline: **S**

90. Compensation for contributors of information, platforms, tools, etc
Timeline: **S**

91. Addressing agile methodologies in products/services (design & software for dynamic and modular design of supply network)
Timeline: **S**

92. New virtual enterprise-wide coordination methods for partly autonomous systems
Timeline: **M**

93. Sustainability tracing into products (energy, raw materials, social, recursive)
Timeline: **S**

94. Customer and demand data gathering and analysis
Timeline: **L**

95. Product and service co-design with customer
Timeline: **M**

96. PLM Solutions for collaborative designs
Timeline: **L**

Other

97. IT-OT convergence: integrated architecture PLM-MES-ERP
Timeline: **L**

98. Advanced support services & platforms for collaborative working
Timeline: **S**

99. Collaborative, easy-to-use, customised, plug-and-play user interfaces
Timeline: **S-M**

100. Problem and context-centric display of only crucial information to the users
Timeline: **S-M**

101. Open data and system integration platform for unstructured data environment
Timeline: **S-M**

102. Filtering mechanisms to provide only relevant information/avoid data deluge
Timeline: **M**

103. Advanced decision making considering multiple objectives and uncertainties in information source
Timeline: **Now**

104. Training, e.g. supported by e-learning, for efficient knowledge transfer to/among workers
Timeline: **Now**

Appendix 3: List of Research and Resources

Manufacturing ICT Services

105. Improved usability: hide complexity from users
Timeline: **S-L**

106. Factory knowledge base: virtual representation of manufacturing environments
For modelling/simulation purposes.
Timeline: **Now-M**

107. Factory knowledge base: Data consistency by means of (standardised) semantic models/system descriptions
E.g. to collect and store data gathered throughout the manufacturing environment in order to make it available for further analysis and optimisation tasks throughout system boundaries.
Timeline: **S-L**

108. Big Data: Data analysis/Data fusion
Extract higher-level information from available data (gathered from sensors, IT systems, etc.)
Timeline: **S-M**

109. Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global
Timeline: **S-M**

110. New Manufacturing IT features: support resource energy efficiency
Timeline: **M**

111. New Manufacturing IT features: Condition-based optimisation of production (schedules, etc.)
Timeline: **M**

112. New Manufacturing IT features: Continuous risk monitoring and mitigaton
Timeline: **M**

113. New Manufacturing IT features: Exploit CEP (Complex Event Processing) Technologies
Timeline: **M**

114. Knowedge transfer between manufacturing and engineering
Information about manufacturability available during design; seamless transfer of product specification to process control systems.
Timeline: **M**

115. Total customisation/ad-hoc establishment of production settings
Connection of design tools to customers in the manufacturing environment.
Timeline: **M**

116. Real-time monitoring

Providing ad-hoc information (KPIs, etc).

Timeline: **S**

Manufacturing ICT Architectures (& Services)

117. Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)

Information integration rather than system integration.
Timeline: **S**

118. Security: Operational safety and reliability

Timeline: **S-M**

119. Security: Privacy and know-how protection

Especially in federated manufacturing environments.
Timeline: **M**

120. Security: Establishment of trust

Timeline: **M-L**

121. Manufacturing IT as a Service: Exploit Cloud Technologies

Cost models, security, privacy, trust, etc. are important topics.
Timeline: **M-L**

122. Advanced self-service system for individual composition of services for manufacturing

This could be considered part of cloud manufacturing concepts.
Timeline: **S**

123. Cloud manufaturing/service-oriented manufacturing

Implement appropriate management infrastructures for virtual enterprises.
Timeline: **S-L**

124. Horizontal integration and optimisation of value chains

Inter- and Intra-Company interoperability of heterogeneous systems / multi-system integration.
Timeline: **M-L**

125. Complexity management

Appropriate scalable system architectures using services for managing modularity, flexibility, service composition, etc.
Timeline: **S**

126. Managing manufacturing uncertainty in an increasingly complex value chain

Timeline: **M**

Manufacturing ICT Infrastructures (& Services)

127. Cyber-physical Production Systems

Making manufacturing environments more intelligent and flexible by integrating additional sensors, acutators, and software to machines, enable easy integration of equipment to production environments, etc.

Timeline: **S-L**

128. Intelligent components/Internet of Things (throughout the supply chain)

Smart products, carriers etc. which provide intelligence by means of integrated sensors, actuators, and software. Security/access rights when intelligent components move/are tracked throughout the supply chain have to be considered.

Timeline: **S-L**

129. Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs, etc

Timeline: **S**

130. Improved usability: multi-modal user interfaces

Multimodal interfaces aim at more efficient and natural ways of delivering answers to users' queries especially in unexpected and/or difficult circumstances by means of cognitive features (computer visions) for sensing, monitoring, reacting, etc.

Timeline: **M**

131. Mobile user interfaces

e.g. for instant KPIs on the shop floor.

Timeline: **S**

132. (Coordination of) Autonomous manufacturing system components

Implementation of agent-based concepts, and cooperation and self-organisation concepts in production systems. The objective of implementing autonomous manufacturing system components such as products, carriers, machines, robots, or transport systems in manufacturing environments.

Timeline: **S-L**

133. Improved usability: context-aware user interfaces and user-specific adaption

User interfaces recognising users and their characteristics, preferences, etc.; Situational awareness and respective adaption of user interaction.

Timeline: **L**

134. Man-Machine-Interaction: increase ergonomics while ensuring human safety

Timeline: **M**

ICT Enablers (& Architectures, Infrastructures and Services)

135. Agent-oriented computing

One approach to implement autonomous systems.

Timeline: **S**

136. Distributed systems (both function-wise and geographically)

Timeline: **S**

137. User-centred design

Consider user requirements during the design phase of systems.

Timeline: **S**

138. Multi-level modelling

Comprehensive methods and tools beyond static modeling, considering multi-disciplinary domains, iterative approaches, etc.

Timeline: **S**

139. Prototyping of systems / seamless integration and testing with productive environments

Timeline: **S**

140. Technologies for better teaching and learning

Timeline: **S**

141. Evolutionary systems

Continuous/seamless exploration of/migration to new ICT architectures.

Timeline: **S**

142. Resilience/Adaptability/Flexibility of systems

Easy adaption of systems to changing environment conditions, disruptions, etc.

Timeline: **S**

143. Situation awareness/Contextualisaton & Context-Awareness

Awareness of systems/components about their environment (e.g. by means of sensor integration and intelligence).

Timeline: **S**

144. Manage emergent behaviour

Deal with (unforeseen) system properties arising from service composition.

Timeline: **S**

145. Communication channel speed and connectivity

Connectivity, especially for distributed CP(P)S.

Timeline: **S**

146. Real-time capabilities
Information available and processed "meeting the deadline".
Timeline: **S**

147. Future network technologies (faster, more stable, etc.)
Beyond the internet?
Timeline: **M**

148. Future computing technologies
Cloud computing is going to be exploited now; what comes next?
Timeline: **M-L**

Other Enablers

149. Additive Manufacturing/3D-print 3D-scanning/rapid prototyping technologies etc.
Timeline: **S**

150. Migration strategies towards next generation factories/production environments
Timeline: **M-L**

151. Regulatory measures/Legal framework for collaboration in federated manufacturing environments
Timeline: **M**

152. Governance modes/structures
Conditions for centralised/decentralised control/decision making; how to ensure fairness in distributed systems, etc.
Timeline: **S**

153. New business models
Timeline: **M-L**

154. Demonstrations/Best practice examples
Timeline: **M-L**

155. Stakeholder education (users, decision makers, etc)
Timeline: **S**

156. Human-centric digital age - Knowledge about human behaviour using digital media, etc.
Timeline: **S**

157. Web Entrepreneurship
Web entrepreneurship aims at efficiently launching and scaling up new operations, creating exposure to new financing opportunities, linking potential entrepreneurs with key actors, etc.
Timeline: **S**

158. Thin, Organic, and Large Area Electronics (TOLAE)
Timeline: **M**

159. Cracking the language barrier
Overcome cultural and language differences by means of appropriate IT tools.
Timeline: **S**

160. Digital gaming/gamification technologies
Game technologies applied in non-leisure contexts, e.g. for education & training, better integration of targeted excluded groups to society, etc.
Timeline: **S**

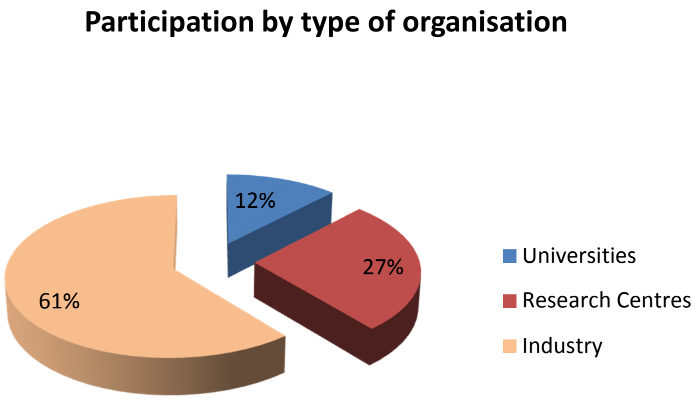
161. Standardisation and reference architectures
to enable interoperability among systems (syntax & semantics for interface definitions), functional descriptions and basic system architectures.
Timeline: **M**

162. Performance assessment for future ICT applications in manufacturing
Methods and tools to get statements about efficiency of new developments (e.g. simulation-based).
Timeline: **M**

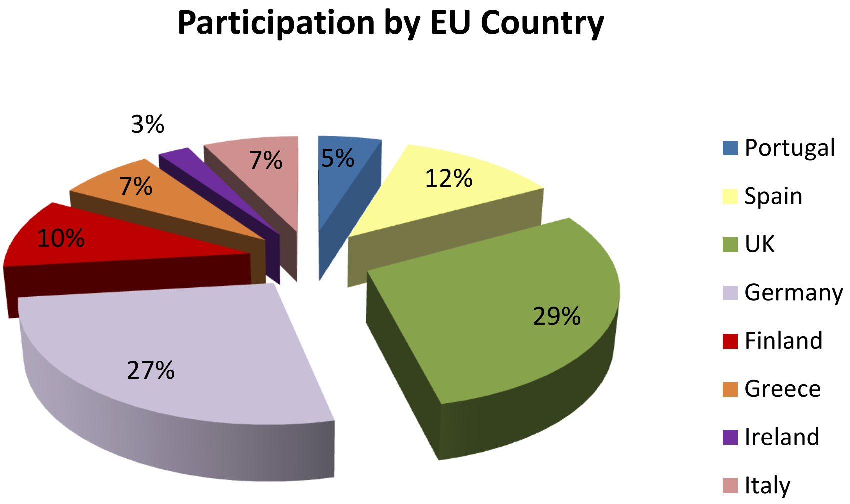
Appendix 4: List of Participants

Name	Organisation
Athanassopoulou Nicky	IfM Cambridge
Castellvi Silvia	Atos Spain
Coscia Eva	Holonix s.r.l.
Demmer Alexander	MES Consult
Egner Harald	The Manufacturing Technology Centre
Gregory Ella	ATS Applied Tech Systems Ltd.
González Alicia	Innovalia Association
Greenough Rick	De Montfort University Leicester
Gusmeroli Sergio	TxT Solutions
Haag Mikael	VTT (Technical Research Centres of Finland)
Hartung Raik	SAP SE
Huertas Lina	The MTC
Hughes Jonathan	IfM Cambridge
Kelman Martin	ATS Applied Tech Systems Ltd.
Kirsch Christopher	Fraunhofer IML
Kotsiopoulos Ioannis	EUROPEAN DYNAMICS S.A.
Krukowski Artur	Intracom S. A. Telecom Solutions
Krull Elisabeth	PhD student Auckland, NZ
Levakos Sotirios	IfM PhD student
List Thor	CMLabs /Communicative Machines
Lobov Andrei	Tampere University of Technology
Lucas Tim	adidas AG
Manenti Pierfrancesco	SCM World
Michalczuk Rafael	EVOLARIS NEXT LEVEL GMBH
Mills Bob	Jaguar Land Rover
Mortimer Sarah	Steinbeis-Europa-Zentrum
Nieto Lee Angelica	Tampere University of Technology
Oliveira Manuel	SINTEF
Oliveira Pedro	Critical Manufacturing
Oughton Dominic	IfM Cambridge
Peschl Michael	Harms & Wende GmbH & Co KG
Pintzos George	University of Patras
Popplewell Keith	Coventry University
Rauschecker Ursula	Fraunhofer IPA
Reimann Meike	Steinbeis-Europa-Zentrum
Reñones Aníbal	CARTIF
Riemenschneider Rolf	European Commission
Rodríguez Diego Esteban	Atos Spain
Roning Juha	University of Oulu
Saenz de Santamaria Luis	AERnnova Aerospace S.A.
Salter Liz	IfM Cambridge

Sautter Björn	Steinbeis-Europa-Zentrum
Sonntag Christian	euTeXoo/TU Dortmund
Stock Daniel	Fraunhofer IPA
Thompson Haydn	THHINK Wireless Ltd.
Upton Connor	Intel Corporation
Teles Vasco	INESC Porto
Ventura Raquel	Ascamm Technology Centre
Walls Ian	Siemens
Wolny Patricia	Steinbeis-Europa-Zentrum
Bob Young	Loughborough University



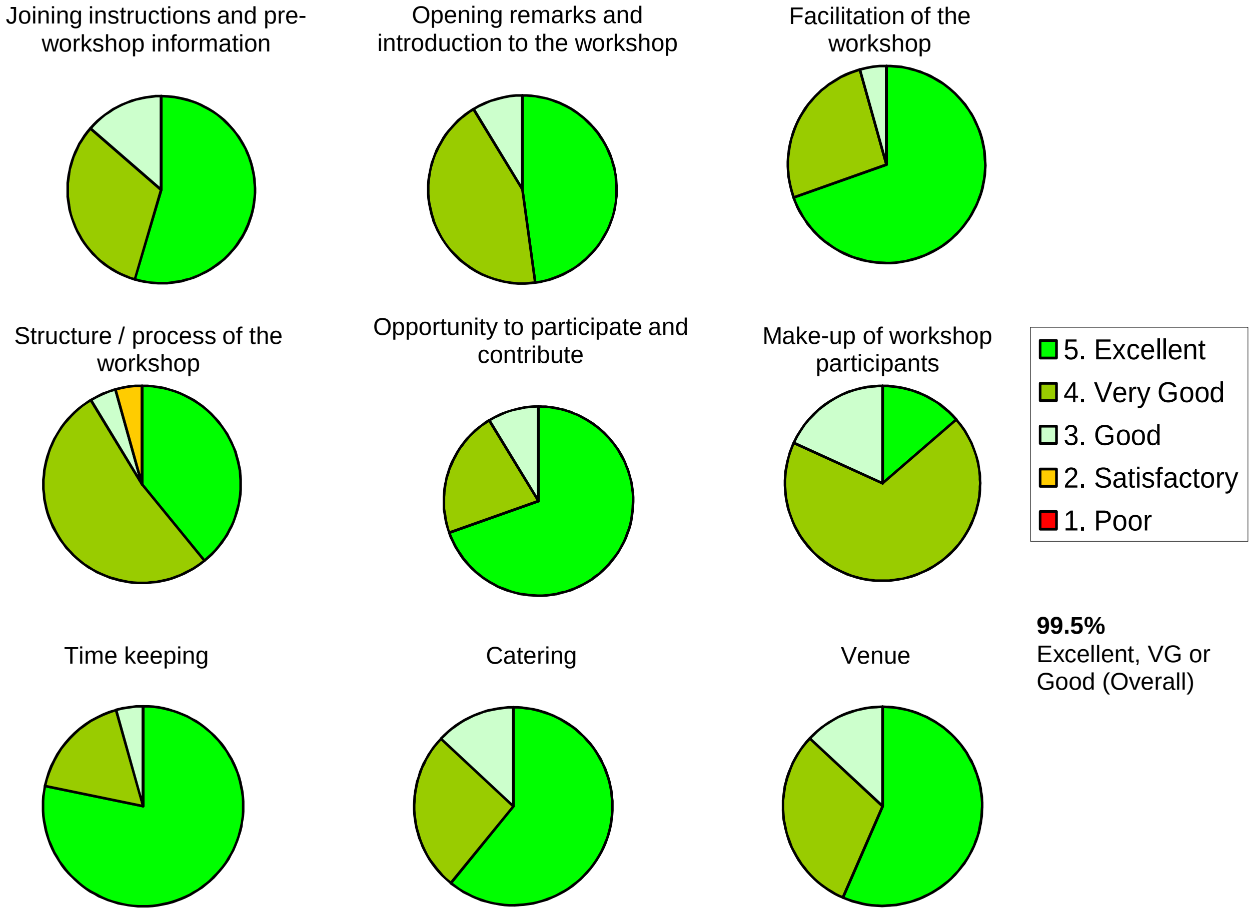
Participation by type of organisation



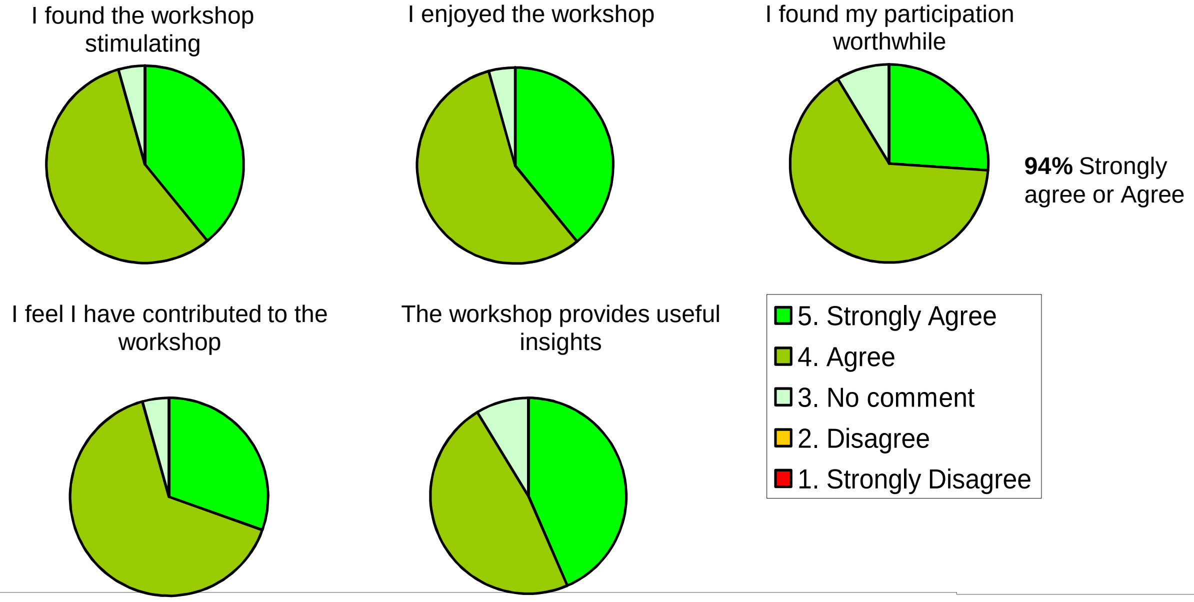
Participation by EU Country

Appendix 5: Participants Feedback

Feedback was received from 23 participants at the end of the workshop. Three participants did not stay till the end of the day and therefore did not complete the feedback forms.



99.5% Excellent, VG or Good (Overall)



94% Strongly agree or Agree