Road 4 FAME

Deliverable 3.2

Initial Roadmaps in 4 Manufacturing Settings

DISSEMINATION LEVEL		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
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[1] **R**=Report, **P**=Prototype, **D**=Demonstrator, **O**=Other

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Organization(s)	Person(s)	Contribution
IfM	Clare Farrukh Jonathan Hughes Nicky Athanassopoulou	References, roadmapping background, review, writing and drafting Writing, drafting and editing Writing , drafting and final editing
IPA	Ursula Rauschecker	Review
SEZ	Meike Reimann	Review
SEZ	Christian Albrecht	Review
CMF	Pedro Gama	Review

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1 Executive Summary

The Road4FAME consortium organised an initial roadmapping workshop with input from 17 participants from industry and academia in Europe. The workshop aims were to:

- Review, expand and prioritise drivers and needs for ICT in Manufacturing;
- Discuss and refine different potential "end points" (Scenarios) in manufacturing;
- Identify most important ICT Solutions required in manufacturing overall and for each Scenario specifically;
- Review and prioritise the capabilities and underlying technologies that will be needed to deliver future ICT Solutions.

The workshop took place on 23 May 2014 in Porto, Portugal.

The ***top four drivers and trends*** important for ICT in Manufacturing were the following:

- **Optimisation and decision making**
  Real-time decisions for faster reaction to exceptions, higher planning reliability, optimised processes throughout production networks etc. to help increase competitiveness.
- **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.
- **Maximise manufacturing efficiency and quality**
  Promising contributions are expected from new IT-tools, logistic concepts, product design methods, quality management methods, scheduling mechanisms, etc.
- **Increasing complexity of products, processes, and supply networks**
  These changes require adequate action and infrastructures in order to maintain and optimise efficiency.

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

- **Real time data acquisition and analysis**
  This includes advanced MES systems, production monitoring in real time, distributed ICT systems for collecting resource utilization on individual machines, open data and system integration platform for unstructured data environment and capability for big data analysis and use especially for quality control.
- **ICT platform for advanced supply chain decision support**
  This includes advanced support services and platforms for collaborative working and supply chain visibility and performance data to assist decision.
- **Interoperability and standards**
  This includes interoperability Solutions, united interfaces and model formats for transferring digital models, standards for exchange of manufacturing information and eventually IT-OT convergence.
- **Modelling of virtual Enterprise**

This includes multi-level heterogeneous modelling of virtual enterprises, novel risk analysis algorithms embedded in software services accessible to non-expert users and simulating tools for new process design.

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

- Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results; manufacturing data-orientated search engine
- Visualisation tools contextual awareness
- Decision support tools
- Collaboration model definition: protocols and regulations
- Future internet architectures
- ICT security and Solutions for security & IP protection on distributed/cloud systems
- Multilevel architecture models and model management including stochastic/human modelling and model integration i.e. ontology-based information modelling
- Development of lower power electronics and communication protocols
- Development of very low cost sensors and their physical integration into smart systems and distributed controllers

The initial roadmap for the ICT Solutions in manufacturing is shown in section 4.

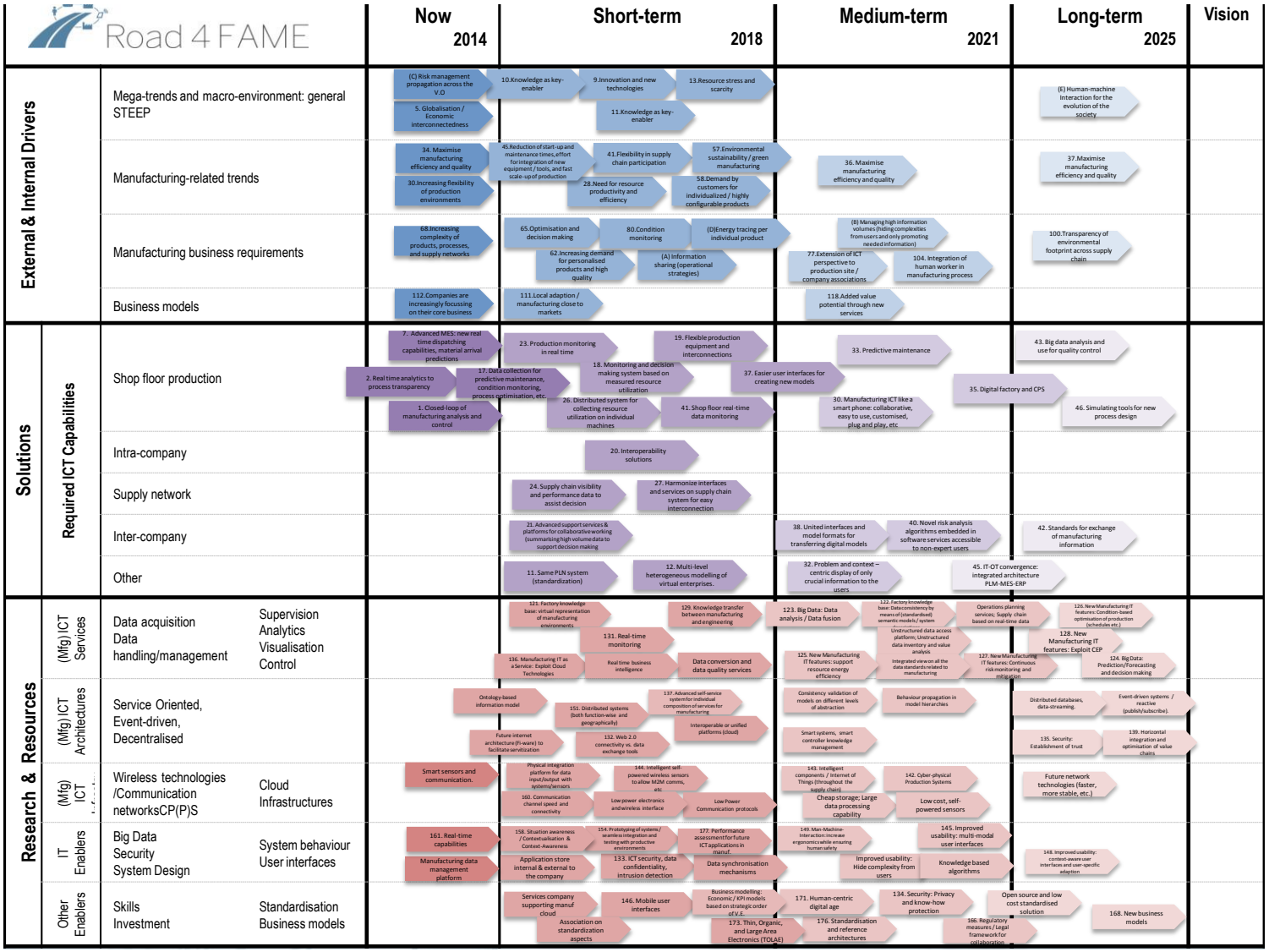


Figure 1: Initial roadmap derived for the Road4FAME project

2 Introduction

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 (information and communication technology) 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: Summary of roadmapping methodology for the Road4FAME project below[3].

This document describes the Initial Roadmap in 4 manufacturing settings, which draws upon the outputs from WP1 and WP2 and further validates them in the context of the draft roadmap architecture and the inputs of the experts present at this workshop on 23rd May 2014.

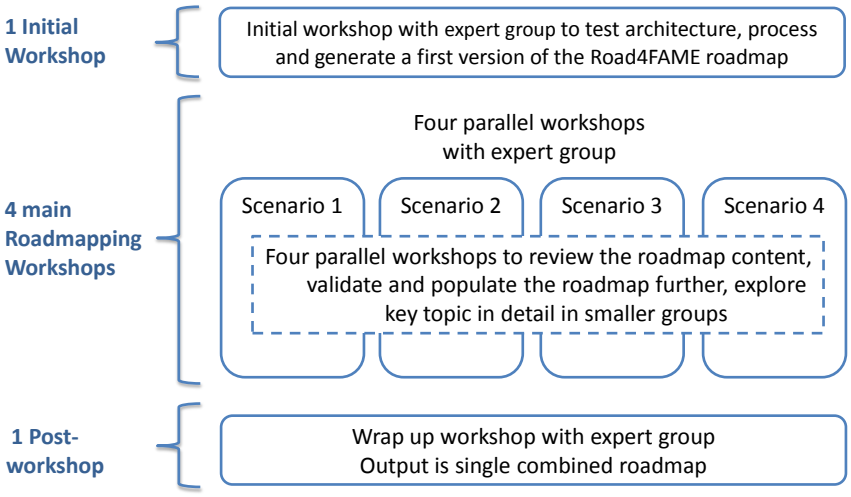


Figure 2: Summary of roadmapping methodology for the Road4FAME project

It is anticipated that Road4FAME project will incorporate six main roadmapping workshops overall, as shown in Figure 2, starting with this initial workshop (23rd May), involving members of the

[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.

Road4FAME Experts Group. Additionally, there was a pre-roadmapping workshop held in Brussels in March 2014.

Participants in this initial workshop (23rd May) were further populating a single landscape architecture, pre-populated with information from WP1 and WP2. The purpose of this initial workshop was to validate the intelligence gathered to date, verify whether or not the architecture requires further refinement, as well as gaining new insights into the Solutions necessary to meet manufacturing needs and join the current status and future vision. The initial workshop generated a first version of the Road4FAME roadmap and also incorporated the workshop originally planned in Task 2.3.

2.1 Roadmaps as a framework

As outlined more fully in Deliverable 3.1, roadmaps provide a structured visualization of particular strategic aspects. They are used to support strategic planning across a broad spectrum of applications. A common roadmap layout, or architecture, will contain two axes, as shown in Figure 3. There is a horizontal, time-based axis; often encompassing the past, short-, medium- and long-term, as well as the vision. The vertical axis usually pertains to perspectives, or dimensions, relevant to the focal point of the roadmap; often represented as horizontal layers, forming a matrix across the time dimension.

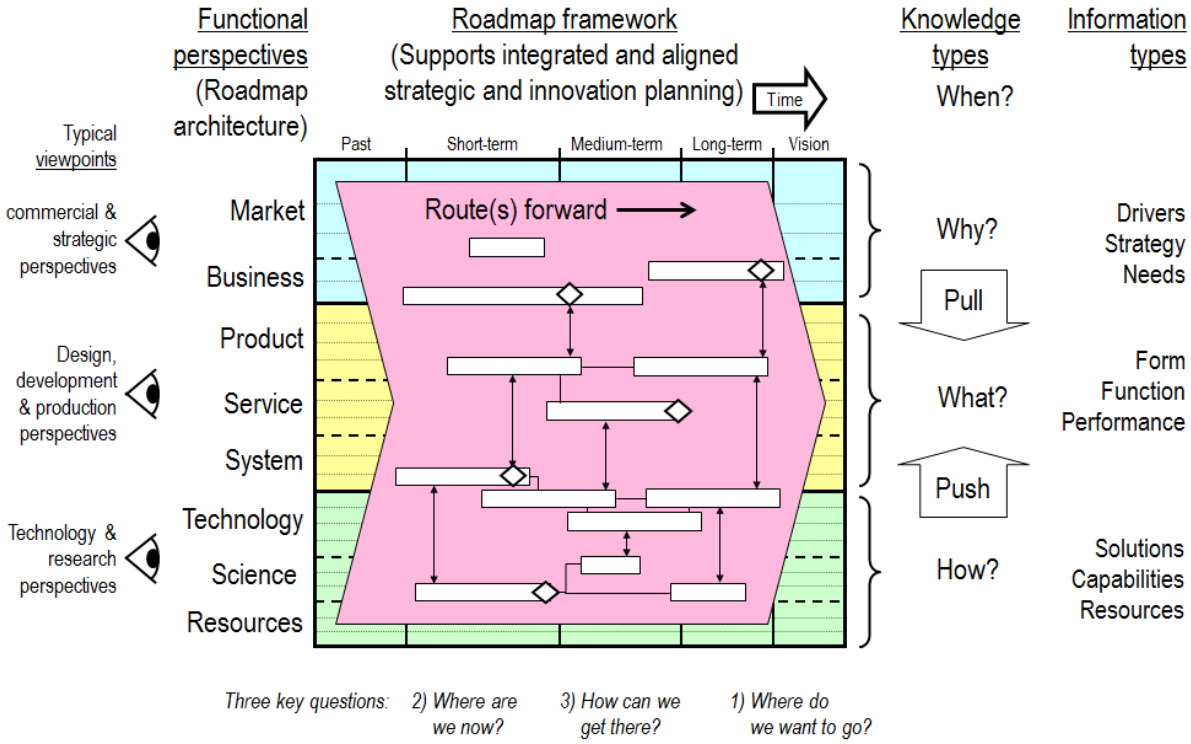


Figure 3: An architectural framework for roadmapping (Phaal et al., 2004a; Phaal and Muller 2009)

The roadmap allows the integration and alignment of a number of different perspectives across a broad time range. In this way, the development of currently developing, or short-term, underpinning science and technology to support long-term market trends and drivers can be explored. As a result of this flexibility, roadmaps can be applied at different levels – international, industry, company and

product-specific roadmaps have been produced (Phaal *et al.*, 2004b, Phaal & Muller 2009). They can also be applied in a hierarchy – with industry-level trends and drivers cascading down through organizational objectives into specific products and technology features and parameters (see ITRS Roadmap at www.itrs.net, for example).

2.2 Objectives of the Initial Roadmapping workshop on 23rd May 2014

The objectives of the initial roadmapping for 4 manufacturing settings were to:

- Review, expand and prioritise drivers and needs for ICT in Manufacturing;
- Discuss and refine different potential "end points" (Scenarios) in manufacturing;
- Identify most important ICT Solutions required in manufacturing overall and for each Scenario specifically;
- Review and prioritise the capabilities and underlying technologies that will be needed to deliver future ICT Solutions.

The workshop was designed to validate or explore further the 'why' (Drivers) layer of the roadmap; and explore the four Scenarios in more depth. It was also aimed at reviewing the pre-populated information from WP2 in terms of content, assumptions and timing, and checking if anything is missing.

Originally Deliverable 3.2 would have been a drawing together of the desk-based research of WP1 and WP2 into 4 Scenario maps, more populated in 'current position' and 'vision' rather than 'steps forward'. However the aim of this initial workshop was to provide an early holistic roadmap backed up by the underpinning background research undertaken.

The Scenarios are currently:

- **The Virtual Enterprise**: an association of manufacturing companies that cooperate to jointly identify and exploit new market opportunities, innovate products and to minimize costs.
- **The Green Enterprise**: a manufacturing company to which environmental awareness is an important part of the company image and objectives.
- **The Manufacturing as a Service Enterprise**: a manufacturing company which does not sell products, but offers manufacturing as a service.
- **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.

These reflect possible end points across two roughly independent (orthogonal) axis; 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).

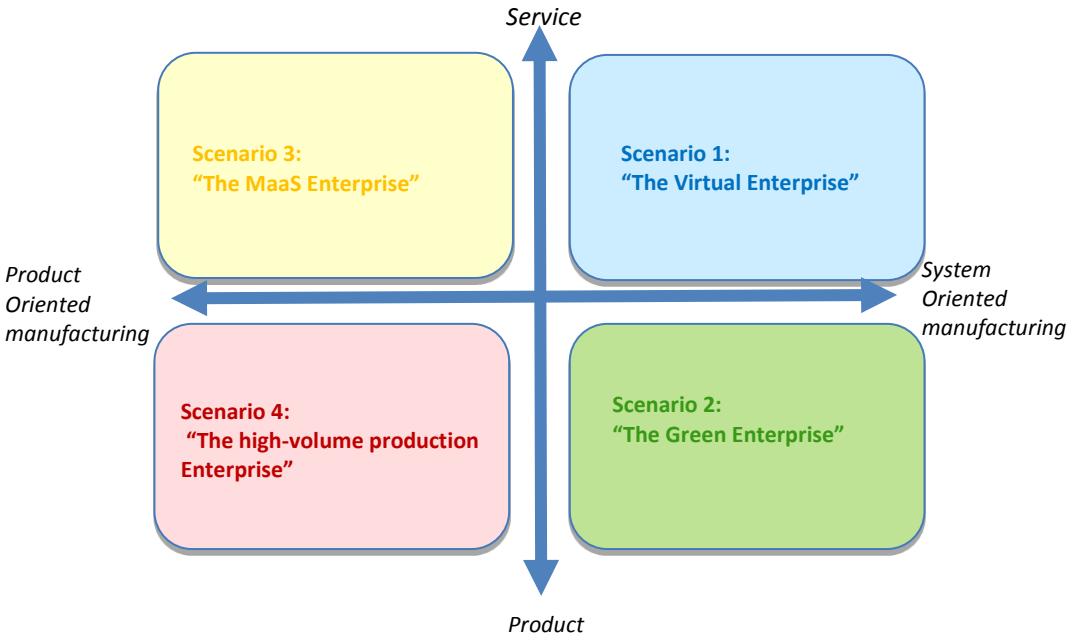


Figure 4: The four working Scenarios for the Road4FAME project

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

3 Initial Road4FAME Roadmap in 4 Manufacturing Settings Methodology

3.1 Road4FAME context

Road4FAME intends to generate a roadmap which can provide insight for research and innovation strategy relating to ICT architectures and services enabling manufacturing across Europe, as well as allowing businesses to identify new business models and opportunities relating to this field. Based on the roadmapping undertaken in Road4FAME, recommendations for future research and innovation strategies will be developed.

To develop a holistic roadmap, encompassing both the technology-push and the market-pull perspectives found in any domain, primary and secondary research has been undertaken to populate layers within the roadmap, as indicated in Figure 5: Road4FAME's roadmapping process.

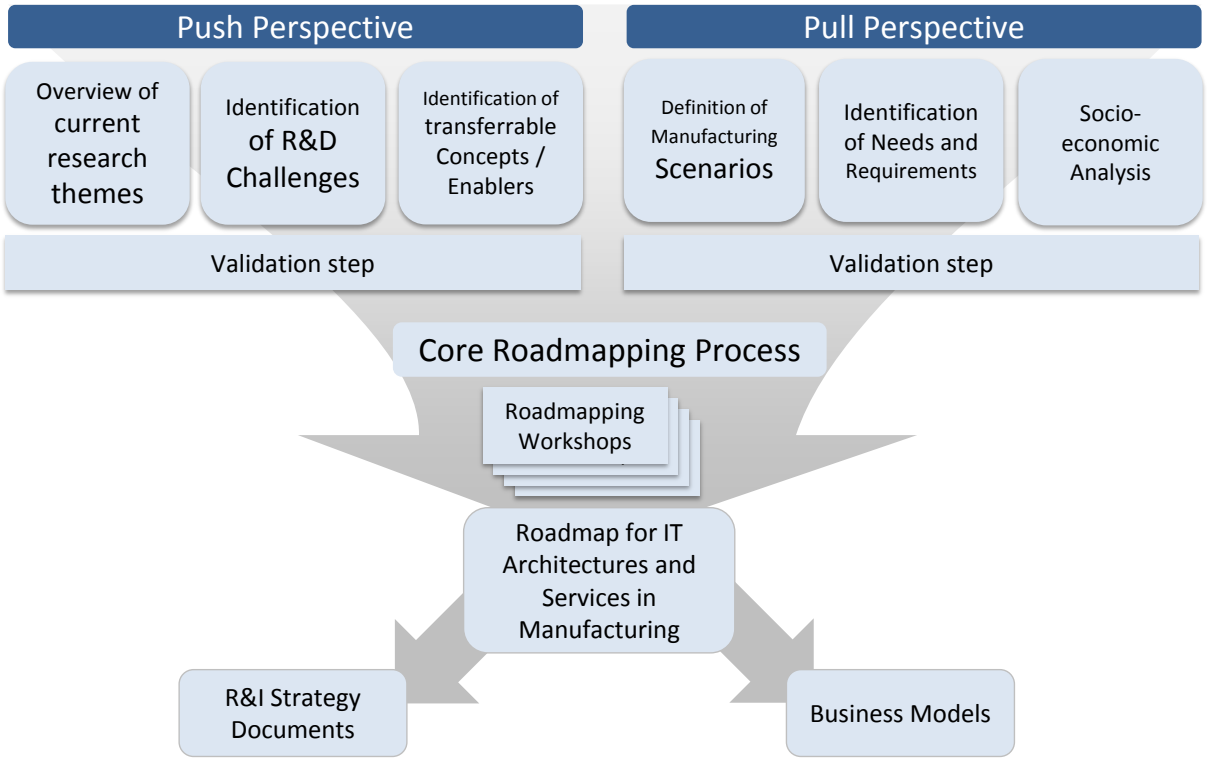


Figure 5: Road4FAME's roadmapping process

3.2 Architecture

The proposed roadmap architecture was initially sketched out at the project Kick-Off meeting in September 2013. This initial roadmap architecture built upon the work carried out in the ActionPlanT research programme to identify relevant time periods for the short-, medium-, long-term and vision sections.

The selection of the relevant layers to be included in a roadmap is a key part of any roadmapping process. Relevant horizontal dimensions were further considered and refined at the partner meeting held in November 2013, making use of content from the ActionPlanT research and other production-related roadmaps, to test both the architecture and a vision-led roadmapping process. This resulted in a first draft architecture.

However, through discussion with experts, review of other strategic documentation, production of Deliverables 1.1 and 1.2, and the first Expert Panel Workshop, held on 6 March 2014, the proposed architecture was further refined, and this second draft version is shown in Figure 6.

Road 4 FAME		Past	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: Strategic investment planning					
	Product development					
	Process planning & development					
	Factory planning					
	Production planning					
	Supply chain management					
	Purchasing					
	Order processing					
	Distribution / sales					
	Manufacturing					
	Stock / warehousing					
	Maintenance					
	Management / administration					
	Education / training					
Research & Resources	(Mfg) ICT Services: Data acquisition, Data handling/management, Supervision, Analytics, Visualisation, Control, Research Challenges					
	(Mfg) ICT Architectures: Service Oriented, Event-driven, Decentralised, Research Challenges					
	(Mfg) ICT Infrastructures: Cloud Infrastructures, Wireless technologies / Communication networks, CP(P)S, Research Challenges					
	IT Enablers: Big Data, Security, System Design, System behaviour, User interfaces					
	Other Enablers: Skills, Investment, Standardisation, Business models					

Figure 6: Revised proposed manufacturing ICT architectures and services roadmap architecture

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.

- 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 to manufacturing business.

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 detailed strategic, innovation and operational requirements.

This makes use of key themes around which the roadmap content is likely to be clustered, and should assist in the pre-population of existing data, as well as providing a 'prompt' or 'checklist' for expert participants during the workshops. By leaving some open layers within the architecture on wall charts, Road4FAME workshops encourages participants to add their own perspectives and thoughts, and not to be constrained by the pre-populated content.

- Required ICT capabilities - specifically considers the functionality required to support the stated manufacturing business requirements now and in the future.

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.

During the initial roadmapping workshop in Porto, it was evident that the Solutions Layer (middle layer) did not adequately represent the ICT Solutions put forward by the participants. Most Solutions span across the various sub-themes in this layer. The Solutions layer, was subsequently redesigned therefore to contain 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**

The new, proposed architecture is shown below:

Road 4 FAME				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 Architectures	Service Oriented, Event-driven, Decentralised						
	(Mfg) ICT Infrastruct	Wireless technologies /Communication networks CP(P)S	Cloud Infrastructures					
	IT Enabler	Big Data Security System Design	System behaviour User interfaces					
	Other Enabler	Skills Investment	Standardisation Business models					

Figure 7: Latest roadmap architecture for manufacturing ICT architectures and services

3.3 Initial Roadmapping Workshop Process

This section describes the practical activities and considerations during the initial roadmapping workshop held on 23rd May.

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.

To put it in context, the objectives of this workshop were:

- Review and prioritise the pre-populated post-it information in the External and Internal Drivers layer of the outline architecture for each Scenario (steps 1-3 in Figure 8 below). Total votes were counted also to highlight the drivers relevant to all Scenarios. (Note: the Resources & Research layer was reviewed and prioritised in a previous workshop in March 2014 so it not formally validated again at the Roadmapping Workshop. The content from the Resources & Research layer was used during group work to link each "landmark" selected to the required Resources & Research necessary for its implementation).
- Populate and prioritise the Solutions in the middle layer (steps 4-6 in Figure 8 below). Post-its were generated live during the workshop – no pre-work was requested.
- Split participants into groups picking up topic areas relevant to all Scenarios to explore in more detail (as shown in Figure 9 below). For each topic contributions from delegates participating in other groups was also collected during a 'carousel' session.

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.

A schematic of the workshop process is shown below:

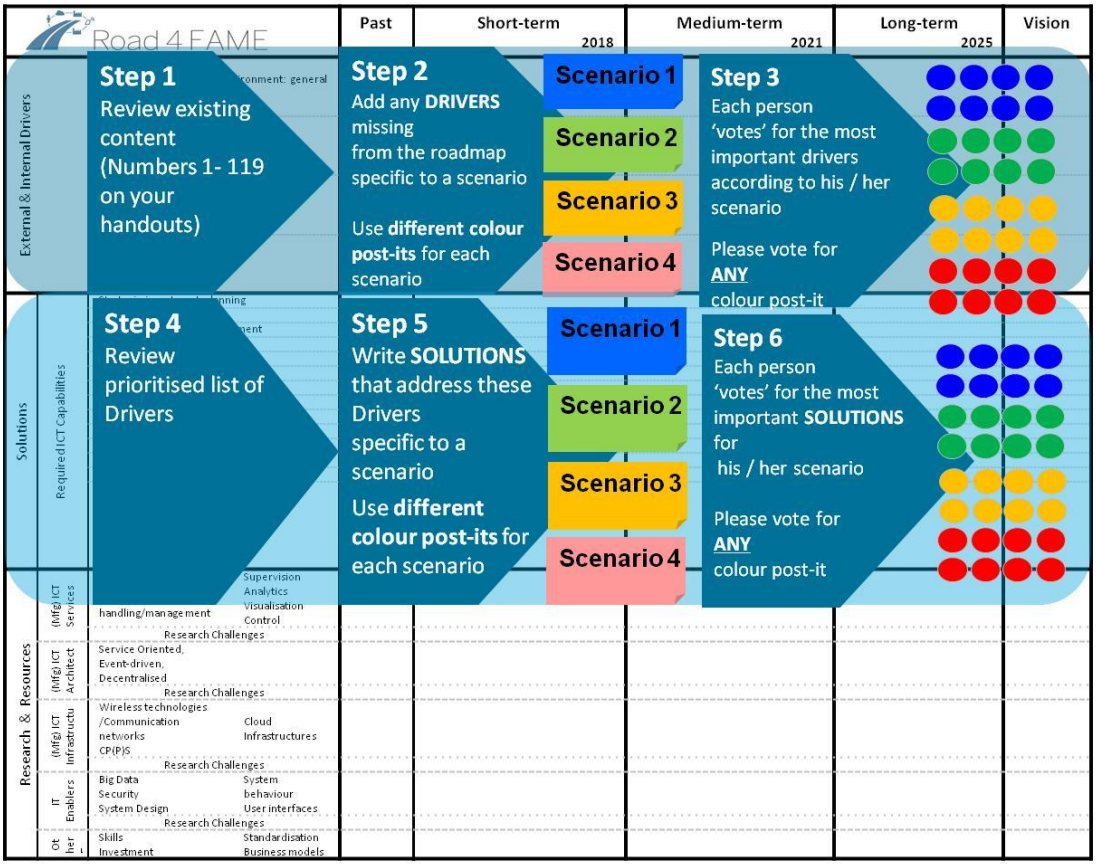


Figure 8: Workshop process for the plenary (morning) session

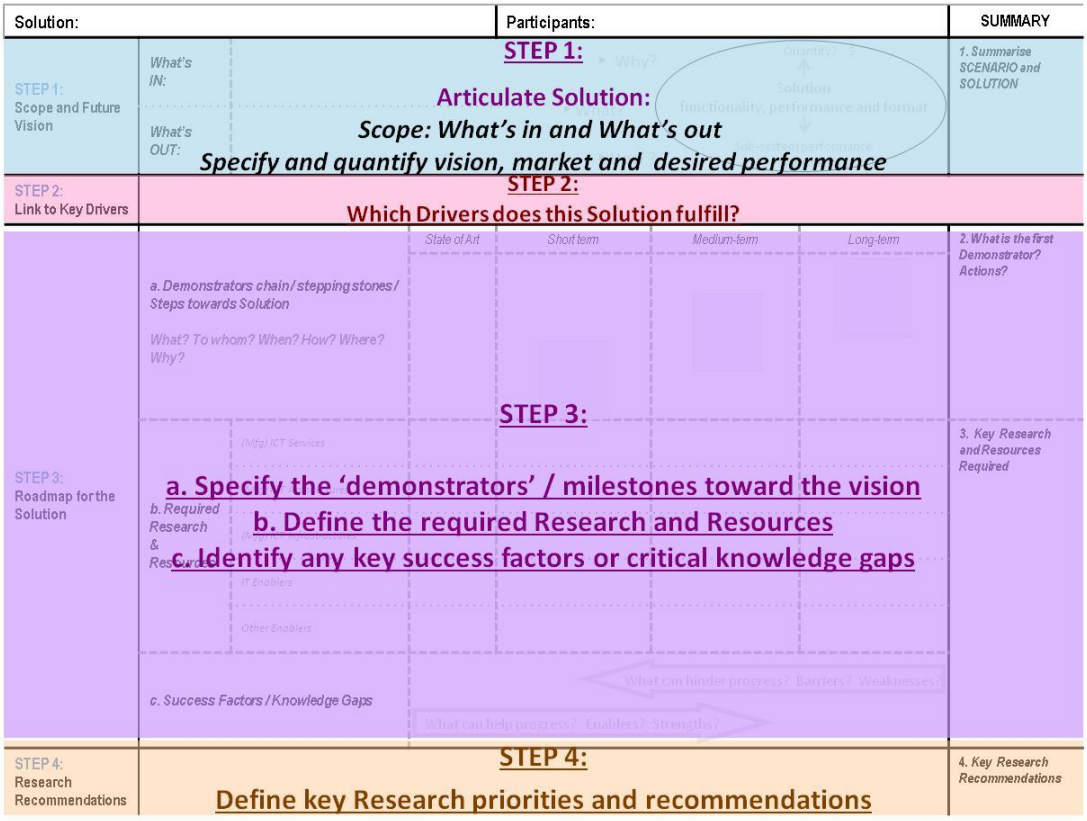


Figure 9: Workshop process for the group work (afternoon) session

3.3.1 Timing

The agenda for the initial workshop was as follows:

09.15	Arrival	
09.30	Welcome, Introductions and Overview	
09.45	Review of Drivers and Manufacturing business requirements	All
10.45	Prioritisation of Drivers and Manufacturing business requirements	All
11.15	Review of Solutions and ICT Capabilities	All
12.00	Prioritisation and Selection of Solutions based on different Scenarios	All
13.00	Lunch	
13.45	Break-out Group Work: Explore the selected Solutions	In Groups
15.30	Explore the Research and Resources required	In Groups
16.30	Feedback and Review	All
17.00	Close	

3.3.2 Follow up

In the immediate follow up of the workshop, the outputs on all the sticky notes were transcribed and captured electronically. The outputs of the initial workshop in terms of content and process will feed into a one-day event where four roadmaps – one in each of the manufacturing vision Scenarios - will be generated and explored simultaneously. This is consistent with the work planned in Task 3.3.

3.4 Input to the Development of Strategy Recommendations (WP5)

As already mentioned in previous sections, an output for all the roadmapping workshops, including this initial one, will be insights and expert opinions as to the recommendations and strategic actions required by the manufacturing ICT industry. These, together with outputs from WP 1 and WP 2 will serve as inputs to WP 5 - “Development of Strategy Recommendations” and are expected to be analyzed, and explored further during the specific tasks of this work package.

4 Roadmap – overall output from the workshop

The roadmap was generated iteratively and this initial roadmapping workshop aimed to refine the architecture through the creation of the four Scenario maps of the different manufacturing Scenarios, using outputs of WP1 and WP2, and content produced during this initial roadmapping workshop. The Scenario roadmaps as well as the overall initial Road4FAME roadmap can then be validated through consultation with the Road4FAME Expert Group and a refined process for the simultaneous workshops can be proposed.

For this initial holistic roadmap, a one-day workshop was planned, with a small number of participants from the Expert Group, who both validated information already gathered, and helped to refine the proposed architecture of the roadmap itself. This ensured when the main four Scenarios are explored simultaneously in roadmaps in the autumn of 2014, with a much larger group of participants, that the roadmap architecture and pre-populated information is robust, therefore maximizing the efficiency of the main roadmapping workshops, to elicit new information and insight from the participants.

In order to best ensure that time was used efficiently, it was decided to conduct this initial workshop using the perspective of all four Scenarios simultaneously. The Scenarios were clearly described and discussed prior to the start of the workshop, so that the participants would have a clear understanding of the standpoint and priorities on which they were to bring their expertise to bear.

Each Scenario was colour-coded and each participant was assigned to one of the four Scenarios. 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 participants were separated into four groups by Scenario, with those expressing a preference or interest in a specific Scenario being encouraged to join that group. The size of the groups was selected to be as even as possible (taken into account the travel arrangements and the early departure of few of the participants) and allowed for substantive group discussion as well as individual input. The following people participated in the each Scenario / group:

Blue Scenario: The Virtual Enterprise	**Green Scenario: The Green Enterprise**	**Yellow Scenario: The MaaS Enterprise**	**Red Scenario: The high-volume production Enterprise**
Jean-Bernard Hentz	Stefan Schleyer	Luis Carneiro	Javier Herrero
Haydn Thompson	Anibal Reñones	Raik Hartung	Vasco Figueiredo Teles
Christian Sonntag	Naoufel Cheikhrouhou	Silvia Catellvi	Giorgio Pasquettaz
Keith Popplewell	Pedro Gama		Andreas Nettsträter
Fernando Perales			Luis Costa

Table 1: List of Participants for each Scenario / group for the plenary discussion

4.1 Trends & Drivers

Exploration of the trends and drivers took place initially with group discussion. Each participant was given a hand-out listing the trends and drivers derived from deliverable 2.3, together with a brief description of each, and was encouraged to read these through. They were then asked to add any additional trends and drivers relevant to their Scenario by writing them on a colour-matched post-it note, speaking briefly about it to the other workshop participants and adding it to the landscape chart.

The groups added the following trends and drivers:

Group	Text
High Volume Production	Need for updating / integrating legacy systems
High Volume Production	Changes in economic purchasing power of customers and populations e.g. crises, rise of middle class
The Green Enterprise	Energy tracing for individual products
The Green Enterprise	Sustainability issues environmental societal economic
The Green Enterprise	Human machine interaction for the evolution of society / population
The Green Enterprise	Sharing of resources (energy and products) among different factories
The MaaS Enterprise	Increasing level of automation
The MaaS Enterprise	Mobilitiy of consumers
The MaaS Enterprise	Enterprise mobility
Virtual Enterprise	Information sharing; operational and strategic
Virtual Enterprise	Managing high information volumes / hiding complexity from users
Virtual Enterprise	Risk management and propagation across the virtual enterprise
Virtual Enterprise	IT service provision in the virtual enterprise
Virtual Enterprise	IP Management

Table 2: Additional trends and drivers

With these additional trends and drivers described to the workshop participants as a whole, each Scenario group was then asked to decide which trends and drivers were the most relevant to their Scenario, and to vote on them accordingly. Each group member was given eight colour-coded voting dots and asked to affix them to the most important trends and drivers on the landscape.

Where a trend or driver appeared in more than one timeframe, participants were asked to place their vote in the timeframe in which it became most relevant to their Scenario. Each participant was specifically asked not to vote more than once on the same post-it.

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

Swimlane 1	Text	Timeline	Votes
Manufacturing Business	Extension of ICT perspective to production site / company associations	M	5
Manufacturing Business	Optimisation and decision making	S	3
Manufacturing Business	Increasing complexity of products, processes, and supply networks	P	3
Megatrends	Knowledge as key-enabler	P	3
Manufacturing Business	Managing high information volumes / hiding complexity from users	M-L	3
Manufacturing Business	Increasing demand for personalised products and high quality	S	2
Manufacturing Business	Information sharing; operational and strategic	S-L	2
Manufacturing Business	Risk management and propagation across the virtual enterprise	P-L	2
Megatrends	Innovation and new technologies	S	1
Manufacturing-related	Maximise manufacturing efficiency and quality	P	1
Manufacturing-related	Flexibility in supply chain participation	S	1
Business Models	Companies are increasingly focussing on their core business	P	1
Megatrends	Globalisation / Economic interconnectedness	P	1
Manufacturing-related	Maximise manufacturing efficiency and quality	L	1
Manufacturing-related	Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production	P	1
Manufacturing Business	Condition monitoring	S	1
Manufacturing Business	Integration of human worker in manufacturing process	M	1
Manufacturing-related	Increasing flexibility of production environments	S	1
Manufacturing-related	Evolution and emergent behaviour of production networks	S	1
Manufacturing Business	Enhancement of products by embedded IT and integrated services	P	1
Manufacturing Business	Virtualisation and digitisation	M	1
Manufacturing Business	Integration of human worker in manufacturing process	L	1
Business Models	Emergence of smaller, more dynamic enterprises	P	1
Business Models	Emergence of smaller, more dynamic enterprises	S	1
Manufacturing Business	IT service provision in the virtual enterprise	M-L	1

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

Swimlane 1	Text	Timeline	Votes
Megatrends	Resource stress and scarcity	S	4
Manufacturing-related	Environmental sustainability / green manufacturing	S	2
Manufacturing Business	Transparency of environmental footprint across supply chain	L	2
	Energy tracing for individual products	S-L	2
Megatrends	Sustainability issues environmental societal economic	L	2
Manufacturing Business	Optimisation and decision making	S	1
Megatrends	Innovation and new technologies	S	1
Manufacturing-related	Maximise manufacturing efficiency and quality	P	1
Manufacturing Business	Increasing complexity of products, processes, and supply networks	P	1
Manufacturing-related	Need for resource productivity and efficiency	S	1
Manufacturing-related	Maximise manufacturing efficiency and quality	M	1
Manufacturing Business	Condition monitoring	S	1
Manufacturing Business	Integration of human worker in manufacturing process	M	1
Business Models	Added value potential through new services	M	1
Megatrends	Rise of environmental consciousness	M	1
Megatrends	Climate Change	P	1
Megatrends	Climate Change	L	1
Manufacturing-related	Volatility of raw material prices	S	1
Manufacturing-related	Environmental sustainability goals from regulatory side	S	1
Manufacturing Business	Predictive maintenance	S	1
Manufacturing Business	Product tracing	L	1
Manufacturing Business	Greater energy efficiency	S	1
Manufacturing Business	Greater energy efficiency	L	1
Megatrends	Human machine interaction for the evolution of society / population	L	1

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

Swimlane 1	Text	Timeline	Votes
Megatrends	Innovation and new technologies	S	3
Business Models	Companies are increasingly focussing on their core business	P	3
Business Models	Local adaption / manufacturing close to markets	S	3
Manufacturing-related	Maximise manufacturing efficiency and quality	P	2
Megatrends	Knowledge as key-enabler	S	2
Manufacturing Busines	Optimisation and decision making	S	1
Megatrends	Knowledge as key-enabler	P	1
Manufacturing Busines	Information sharing; operational and strategic	S-L	1
Manufacturing-related	Maximise manufacturing efficiency and quality	M	1
Manufacturing-related	Maximise manufacturing efficiency and quality	L	1
Business Models	Added value potential through new services	M	1
Megatrends	Knowledge as key-enabler	M	1
Manufacturing-related	Increasing flexibility of production environments	L	1
Manufacturing Busines	Additive manufacturing / 3D-printing	M	1
Manufacturing-related	Increasing level of automation	S-L	1

Table 5: Voting on trends and drivers by Scenario 3 (YELLOW)- The MaaS Enterprise

Swimlane 1	Text	Timeline	Votes
Manufacturing-related	Need for resource productivity and efficiency	S	4
Manufacturing-related	Flexibility in supply chain participation	S	4
Manufacturing-related	Increasing flexibility of production environments	P	4
Manufacturing Business	Optimisation and decision making	S	3
Manufacturing-related	Demand by customers for individualized / highly configurable products	S	3
Manufacturing-related	Maximise manufacturing efficiency and quality	P	2
Manufacturing Business	Increasing complexity of products, processes, and supply networks	P	2
Megatrends	Globalisation / Economic interconnectedness	P	2
Megatrends	Innovation and new technologies	S	1
Manufacturing-related	Environmental sustainability / green manufacturing	S	1
Manufacturing Business	Increasing demand for personalised products and high quality	S	1
Manufacturing-related	Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production	P	1
Manufacturing-related	Total product tracking	P	1
Manufacturing-related	Rising energy costs	S	1
Manufacturing Business	Increasing demand for personalised products and high quality	L	1
Manufacturing Business	Shortage of skilled staff	P	1
Manufacturing Business	Flexibility / high number of variants	S	1
Manufacturing Business	Identify/anticipate changes in demand	S	1
Manufacturing Business	Need for updating / integrating legacy systems	S-L	1

Table 6: Voting on trends and drivers by Scenario 4 (RED)- The high-volume production Enterprise

Swimlane 1	Text	Timeline					Total
Manufacturing Business	Optimisation and decision making	S	1	3	1	3	8
Megatrends	Innovation and new technologies	S	1	1	3	1	6
Manufacturing-related	Maximise manufacturing efficiency and quality	P	1	1	2	2	6
Manufacturing Business	Increasing complexity of products, processes, and supply networks	P	1	3		2	6
Manufacturing-related	Need for resource productivity and efficiency	S	1			4	5
Manufacturing-related	Flexibility in supply chain participation	S		1		4	5
Manufacturing Business	Extension of ICT perspective to production site / company associations	M		5			5
Megatrends	Knowledge as key-enabler	P		3	1		4
Megatrends	Resource stress and scarcity	S	4				4
Manufacturing-related	Increasing flexibility of production environments	P				4	4
Business Models	Companies are increasingly focussing on their core business	P		1	3		4
Megatrends	Globalisation / Economic interconnectedness	P		1		2	3
Manufacturing-related	Environmental sustainability / green manufacturing	S	2			1	3
Manufacturing-related	Demand by customers for individualized / highly configurable products	S				3	3
Manufacturing Business	Increasing demand for personalised products and high quality	S		2		1	3
Business Models	Local adaption / manufacturing close to markets	S			3		3
Manufacturing Business	Information sharing; operational and strategic	S-L		2	1		3
Manufacturing Business	Managing high information volumes / hiding complexity from users	M-L		3			3
Megatrends	Knowledge as key-enabler	S			2		2
Manufacturing-related	Maximise manufacturing efficiency and quality	M	1		1		2
Manufacturing-related	Maximise manufacturing efficiency and quality	L		1	1		2
Manufacturing-related	Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production	P		1		1	2
Manufacturing Business	Condition monitoring	S	1	1			2
Manufacturing Business	Transparency of environmental footprint across supply chain	L	2				2
Manufacturing Business	Integration of human worker in manufacturing process	M	1	1			2
Business Models	Added value potential through new services	M	1		1		2
Manufacturing Business	Risk management and propagation across the virtual enterprise	P-L		2			2
Manufacturing-related	Energy tracing for individual products	S-L	2				2
Megatrends	Sustainability issues environmental societal economic	L	2				2

Table 7: Voting on trends and drivers across all Scenarios

The ***four drivers*** important to three Scenarios or more were the following:

Optimisation and decision making
Real-time decisions for faster reaction to exceptions, higher planning reliability, optimised processes throughout production networks etc. to help increase competitiveness.

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.

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

Increasing complexity of products, processes, and supply networks
These changes require adequate action and infrastructures in order to maintain and optimise efficiency.

There were ***eight other important trends and drivers*** (selected by at least two Scenarios):

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.

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.

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.

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.

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.

Environmental sustainability / green manufacturing
In a certain markets, environmental sustainability is becoming a relevant parameter for the

company's competitiveness.

Increasing demand for personalised products and high quality
Purchasing decisions are being made based on brand perception of safety, quality and personalised/customisable products.

Information sharing; operational and strategic.
Sharing knowledge especially tacit within an organisation to enable better decision making and faster response to market pressures.

Finally the following ***five trends and drivers were important within a specific Scenario*** but not across the whole manufacturing domain:

BLUE Scenario: The Virtual Enterprise
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.

Managing high information volumes / hiding complexity from users

GREEN Scenario: The Green Enterprise
Resource stress and scarcity
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).

YELLOW Scenario: The MaaS Enterprise
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.

RED Scenario - The High-Volume production Enterprise:
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.

Demand by customers for individualized / highly configurable products
Customers increasingly demand highly customized products, ideally at no higher price than a comparable mass product.

Table 7 only shows those trends and drivers receiving two votes or more in total; beneath this, as shown in Table 8, are an additional 28 drivers which received only one vote each:

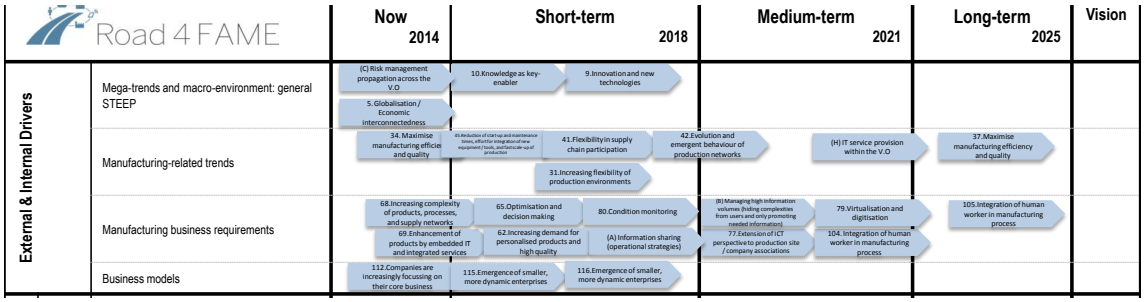
Swimlane 1	Text	Timel					Total
Megatrends	Knowledge as key-enabler	M			1		1
Megatrends	Rise of environmental consciousness	M	1				1
Megatrends	Climate Change	P	1				1
Megatrends	Climate Change	L	1				1
Manufacturing-related	Increasing flexibility of production environments	S		1			1
Manufacturing-related	Increasing flexibility of production environments	L			1		1
Manufacturing-related	Evolution and emergent behaviour of production networks	S		1			1
Manufacturing-related	Total product tracking	P				1	1
Manufacturing-related	Rising energy costs	S				1	1
Manufacturing-related	Volatility of raw material prices	S	1				1
Manufacturing-related	Environmental sustainability goals from regulatory side	S	1				1
Manufacturing Business	Increasing demand for personalised products and high quality	L				1	1
Manufacturing Business	Shortage of skilled staff	P				1	1
Manufacturing Business	Enhancement of products by embedded IT and integrated services	P		1			1
Manufacturing Business	Additive manufacturing / 3D-printing	M			1		1
Manufacturing Business	Virtualisation and digitisation	M		1			1
Manufacturing Business	Predictive maintenance	S	1				1
Manufacturing Business	Flexibility / high number of variants	S				1	1
Manufacturing Business	Product tracing	L	1				1
Manufacturing Business	Greater energy efficiency	S	1				1
Manufacturing Business	Greater energy efficiency	L	1				1
Manufacturing Business	Identify/anticipate changes in demand	S				1	1
Manufacturing Business	Integration of human worker in manufacturing process	L		1			1
Business Models	Emergence of smaller, more dynamic enterprises	P		1			1
Business Models	Emergence of smaller, more dynamic enterprises	S		1			1
Manufacturing Business	Need for updating / integrating legacy systems	S-L				1	1
Manufacturing-related	Increasing level of automation	S-L			1		1
Manufacturing Business	IT service provision in the virtual enterprise	M-L		1			1
Megatrends	Human machine interaction for the evolution of society / population	L	1				1

Table 8: Trends and drivers with a single vote

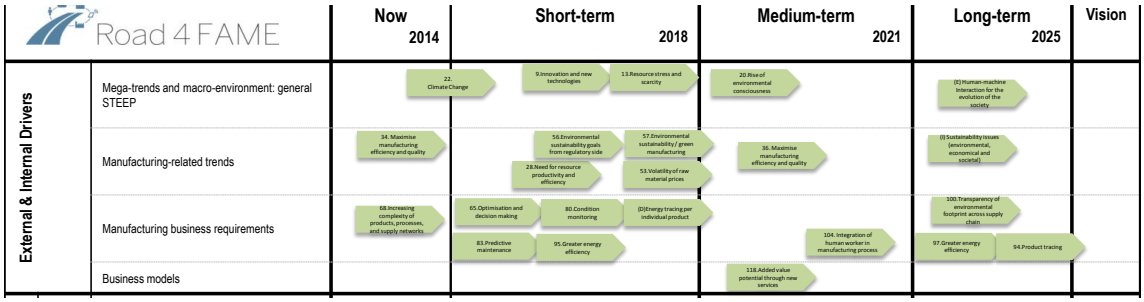
Interestingly, the split of the voting across the piece is sufficiently differentiated by Scenario – with the exception of a small handful of widely relevant trends and drivers – as to suggest that the Scenarios themselves really do represent largely discrete and demarcated manufacturing situations with different priorities. This is further evidence that the Scenarios are appropriately described. Since the relevance of trends and drivers varies across Scenarios, it is reasonable to expect that the needs for manufacturing ICT will vary accordingly. Thus, the examination of the several Scenarios seems justified.

A schematic of the most important trends and drivers per Scenario is shown in the figure below.

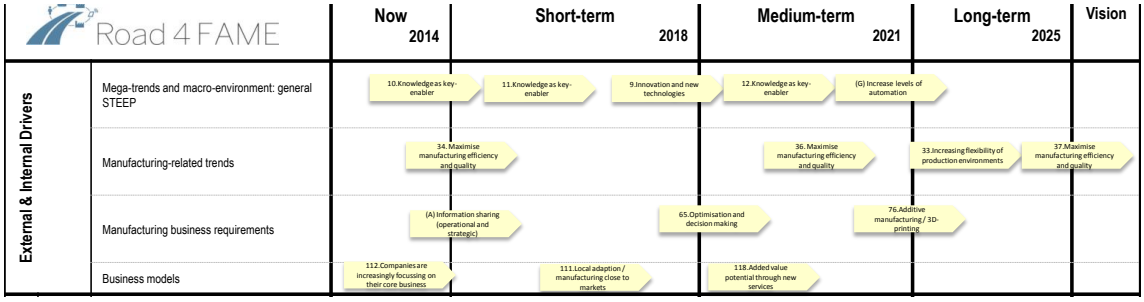
Blue Scenario



Green Scenario



Yellow Scenario



Red Scenario

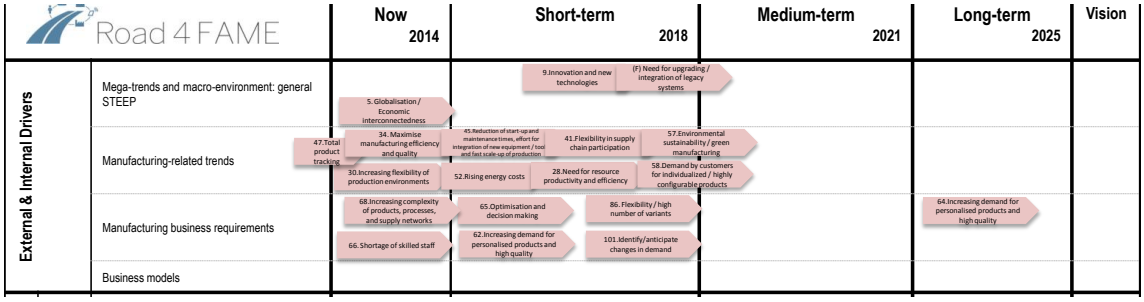


Figure 10: Most important trends and drivers per Scenario

4.2 Solutions – discussion of required ICT capabilities

With the trends and drivers prioritised, the list was displayed for the participants, who were then asked – still in their Scenario groups – to consider what Solutions (manufacturing ICT capabilities) would address them. They were asked to consider the trends and drivers pertinent to their Scenario, but also to consider those which were highly-ranked collectively but may originally have been considered less relevant for their Scenario.

As with the trends and drivers, each group was colour-coded to differentiate their output. When submitting their Solutions, they were also asked to note which trends and drivers were addressed in each case, in order to facilitate identification of linkages between them.

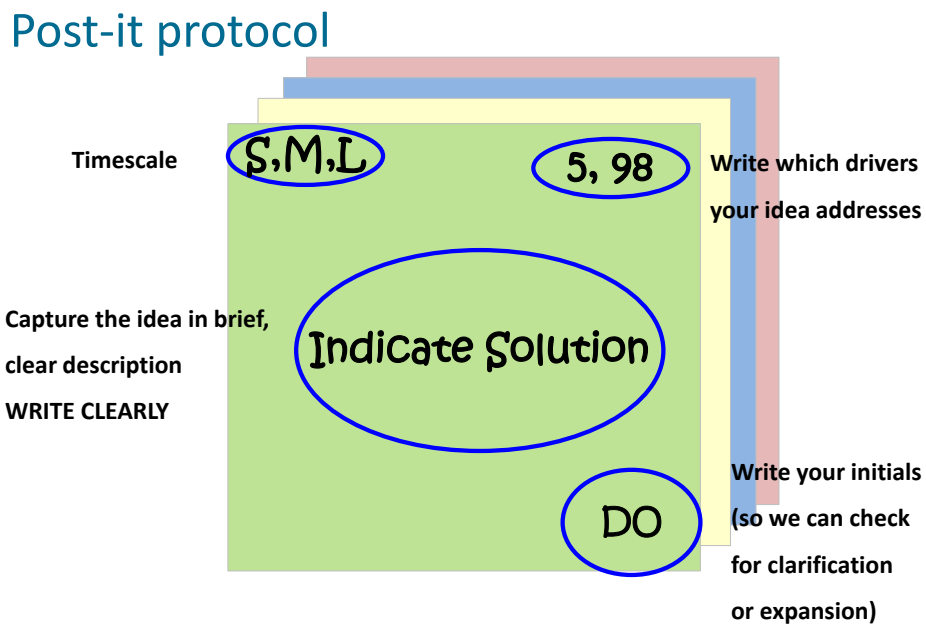


Figure 11: Post-it protocol for the Solutions layer

The post-its with Solutions, i.e. required ICT capabilities, were discussed in plenary and then placed onto the landscape. While some fitted neatly into a particular sub-layer of the Solutions layer (swimlanes) on the map, many were applicable to more than one. The reason for this seemed to be that the swimlanes were arranged into areas based on process and activity, whereas the Solutions – largely being technical or technological in nature – had applications which might span the entire value chain, or have far-reaching potential uses in a range of specific areas. There may be a case for further work to categorise the Solutions by technology in the landscape, but it is also important not to lose the identified applications in each case.

In total 47 Solutions were put forward as shown in the tables below. A full list is provided in Appendix 2. From these 13 were provided by the Blue team (the Virtual Enterprise), six by the Green team (the Green Enterprise), 23 were provided by the Yellow Scenario team (the MaaS Enterprise) and five by the Red team (the high-volume production Enterprise).

Number	Scenario	Roadmap sub-layer	Description	Timeline
11	Blue	Inter-company	Same PLM system (standardization)	S
12	Blue	Inter-company	Multi-level heterogeneous modelling of virtual enterprises	S
17	Blue	Shop floor production	Data collection for predictive maintenance, condition monitoring, process optimisation, etc.	S
21	Blue	Inter-company	Advanced support services & platforms for collaborative working (summarising high volume data to support decision making	S
22	Blue	Intra-company	Specialised companies for IT and method from- for and customization (e.g. SMEs) advanced system integration	S
23	Blue	Shop floor production	Production monitoring in real time	S
28	Blue	Intra-company	New virtual- enterprise- wide coordination methods for partly autonomous systems	M
29	Blue	Other	Open data and system integration platform for unstructured data environment.	M
30	Blue	Shop floor production	Manufacturing ICT like a smart phone: collaborative, easy to use, customised, plug and play, etc	S-M
31	Blue	Other	Information exchange tools (planning and schedule tracking). Data mining and filling for different goals. Data deluge!!	M
32	Blue	Other	Problem and context –centric display of only crucial information to the users	S-M
39	Blue	Supply network	Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain	M
40	Blue	Inter-company	Novel risk analysis algorithms embedded in software services accessible to non-expert users	M-L

Table 9: Manufacturing ICT Solutions identified by the Blue Scenario team: The Virtual Enterprise

Number	Scenario	Roadmap sub-layer	Description	Timeline
4	Green	Other	Multi-objective and multi-decision making with uncertainty in IT infrastructure	N
13	Green	Supply network	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S
15	Green	Inter-company	Compensation for contributors of information, platforms, tools etc	S
16	Green	Shop floor production	MES able to collect and process equipment energy consumption	S
34	Green	Inter-company	Sustainability tracing into products (energy, raw materials, social, recursive)	M
42	Green	Inter-company	Standards for exchange of manufacturing information	L

Table 10: Manufacturing ICT Solutions identified by the Green Scenario team: The Green Enterprise

Number	Scenario	Roadmap sub-layer	Description	Timeline
1	Yellow	Shop floor production	Closed-loop of manufacturing analysis and control	N
2	Yellow	Shop floor production	Real time analytics to process transparency	N
3	Yellow	Intra-company	Training, knowledge, collaboration tools	N
5	Yellow	Shop floor production	Quality measurement and management per process and equipment	N
6	Yellow	Shop floor production	Shortest routing, material grouping and reordering for shortest set up cycles	N
7	Yellow	Shop floor production	Advanced MES: new real time dispatching capabilities, material arrival predictions	N
8	Yellow	Supply network	Well defined KP1 to get insight	N
9	Yellow	Other	Training. E-learning	N
10	Yellow	Inter-company	Knowledge management tools	N
14	Yellow	Shop floor production	Separated production stations rather than fixed	S

			production lines; automated transportation systems serving the stations.	
20	Yellow	Intra-company	Interoperability Solutions	S
25	Yellow	Other	Performance Management	S
33	Yellow	Shop floor production	Predictive Maintenance	M
35	Yellow	Shop floor production	Digital Factory and CPS	M
36	Yellow	Inter-company	Co-design with customers (CAD)	M
37	Yellow	Shop floor production	Easier user interfaces for creating new models	M
38	Yellow	Inter-company	United interfaces and model formats for transferring digital models	M
41	Yellow	Shop floor production	Shop floor real-time data monitoring	L
43	Yellow	Shop floor production	Big data analysis and use for quality control	L
44	Yellow	Inter-company	Customer and demand data gathering and analysis	L
45	Yellow	Other	IT-OT convergence: integrated achitecture PLM-MES-ERP	L
46	Yellow	Shop floor production	Simulating tools for new process design	L
47	Yellow	Shop floor production	PLM Solutions for collaborative designs	L

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

Number	Scenario	Roadmap sub-layer	Description	Timeline
18	Red	Shop floor production	Monitoring and decision making system based on measured resource utilization	S
19	Red	Shop floor production	Flexible production equipment and interconnections	S
24	Red	Supply network	Supply chain visibility and performance data to assist decision	S
26	Red	Shop floor production	Distributed system for collecting resource utilization on individual machines	S
27	Red	Supply network	Harmonize interfaces and services on supply chain system for easy interconnection	S

Table 12: Manufacturing ICT Solutions identified by the Red Scenario team: The high-volume production Enterprise

The participants were asked to vote on the Solutions. They were asked to review ***all Solutions*** put forward and vote for the ones they considered most important for their own specific Scenario. They were also asked to not place any more than two votes to a single Solution. Each participant was again given eight colour-coded voting dots.

Between 13 and 20 Solutions were prioritized for each Scenario. The list of prioritized Solutions per Scenario is shown in the tables and figure below.

Number	Scenario	Roadmap sub-layer	Solution Description	Timeline	Votes
20	Yellow	Order Processing	Interoperability Solutions	S	4
23	Blue	Production Planning	Production monitoring in real time	S	3
32	Blue	Manufacturing	Problem and context –centric display of only crucial information to the users	S-M	3
43	Yellow	Process planning & Development	Big data analysis and use for quality control	L	3
12	Blue	Factory Planning	Multi-level heterogeneous modelling of virtual enterprises	S	2
21	Blue	Management/ administration	Advanced support services & platforms for collaborative working (summarising high volume data to support decision making	S	2
24	Red	Supply chain management	Supply chain visibility and performance data to assist decision	S	2
40	Blue	Supply chain management	Novel risk analysis algorithms embedded in software services accessible to non-expert users	M-L	2
42	Green	Manufacturing	Standards for exchange of manufacturing information	L	2
45	Yellow	Stock/warehousing	IT-OT convergence: integrated architecture PLM-MES-ERP	L	2
2	Yellow	Production Planning	Real time analytics to process transparency	P	1
3	Yellow	Production Planning	Training, knowledge, collaboration tools	P	1

11	Blue	Product Development	Same PLM system (standardization)	S	1
17	Blue	Maintenance	Data collection for predictive maintenance, condition monitoring, process optimisation, etc.	S	1
19	Red	Production Planning	Flexible production equipment and interconnections	S	1
26	Red	Process planning & Development	Distributed system for collecting resource utilization on individual machines	S	1
28	Blue	Product Development	New virtual- enterprise- wide coordination methods for partly autonomous systems	M	1
29	Blue	Factory Planning	Open data and system integration platform for unstructured data environment.	M	1
30	Blue	Supply chain management	Manufacturing ICT like a smart phone: collaborative, easy to use, customised, plug and play, etc	S-M	1
33	Yellow		Predictive Maintenance	M	1
35	Yellow	Factory Planning	Digital Factory and CPS	M	1
37	Yellow	Factory Planning	Easier user interfaces for creating new models	M	1
38	Yellow	Production Planning	United interfaces and model formats for transferring digital models	M	1
39	Blue	Purchasing	Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain	M	1
46	Yellow	Process planning & Development	Simulating tools for new process design	L	1

Table 13: Prioritised Manufacturing ICT Solutions for the Blue Scenario: The Virtual Enterprise

Number	Scenario	Roadmap sub-layer	Solution Description	Timeline	Votes
42	Green	Manufacturing	Standards for exchange of manufacturing information	L	3
46	Yellow	Process planning & Development	Simulating tools for new process design	L	3
7	Yellow	Distribution/sales	Advanced MES: new real time dispatching capabilities, material arrival predictions	P	2
15	Green	Order Processing	Compensation for contributors of information, platforms, tools etc	S	2
16	Green	Manufacturing	MES able to collect and process equipment energy consumption	S	2
24	Red	Supply chain management	Supply chain visibility and performance data to assist decision	S	2
26	Red	Process planning & Development	Distributed system for collecting resource utilization on individual machines	S	2
41	Yellow	Process planning & Development	Shop floor real-time data monitoring	L	2
43	Yellow	Process planning & Development	Big data analysis and use for quality control	L	2
45	Yellow	Stock/warehousing	IT-OT convergence: integrated architecture PLM-MES-ERP	L	2
11	Blue	Product Development	Same PLM system (standardization)	S	1
13	Green	Production Planning	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S	1
17	Blue	Maintenance	Data collection for predictive maintenance, condition monitoring, process optimisation, etc.	S	1
18	Red	Management/ administration	Monitoring and decision making system based on measured resource utilization	S	1
20	Yellow	Order Processing	Interoperability Solutions	S	1
21	Blue	Management/ administration	Advanced support services & platforms for collaborative working (summarising high volume data to support decision making	S	1
23	Blue	Production Planning	Production monitoring in real time	S	1
27	Red	Supply chain management	Harmonize interfaces and services on supply chain system for easy interconnection	S	1
34	Green	Production Planning	Sustainability tracing into products (energy, raw materials, social, recursive)	M	1
35	Yellow	Factory Planning	Digital Factory and CPS	M	1

Table 14: Prioritised Manufacturing ICT Solutions for the Green Scenario: The Green Enterprise

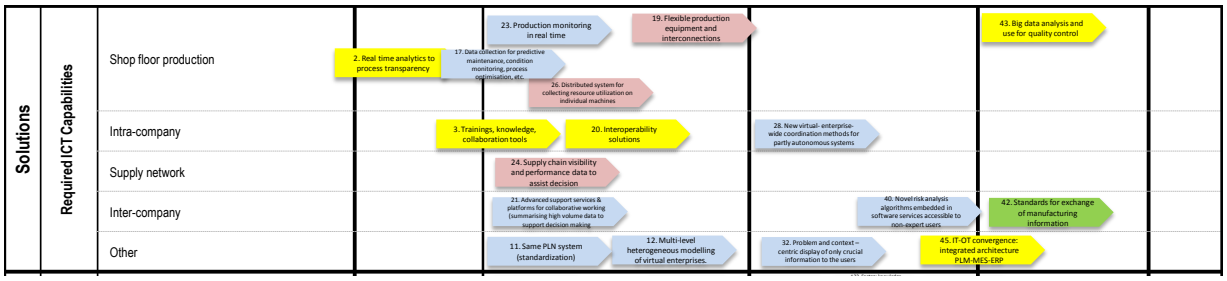
Number	Scenario	Roadmap sub-layer	Solution Description	Timeline	Votes
33	Yellow		Predictive Maintenance	M	3
10	Yellow	Education/training	Knowledge management tools	P	2
23	Blue	Production Planning	Production monitoring in real time	S	2
1	Yellow	Process planning & Development	Closed-loop of manufacturing analysis and control	P	1
2	Yellow	Production Planning	Real time analytics to process transparency	P	1
7	Yellow	Distribution/sales	Advanced MES: new real time dispatching capabilities, material arrival predictions	P	1
8	Yellow	Stock/warehousing	Well defined KP1 to get insight	P	1
18	Red	Management/ administration	Monitoring and decision making system based on measured resource utilization	S	1
24	Red	Supply chain management	Supply chain visibility and performance data to assist decision	S	1
27	Red	Supply chain management	Harmonize interfaces and services on supply chain system for easy interconnection	S	1
35	Yellow	Factory Planning	Digital Factory and CPS	M	1
45	Yellow	Stock/warehousing	IT-OT convergence: integrated architecture PLM-MES-ERP	L	1
46	Yellow	Process planning & Development	Simulating tools for new process design	L	1

Table 15: Prioritised Manufacturing ICT Solutions for the Yellow Scenario: The MaaS Enterprise

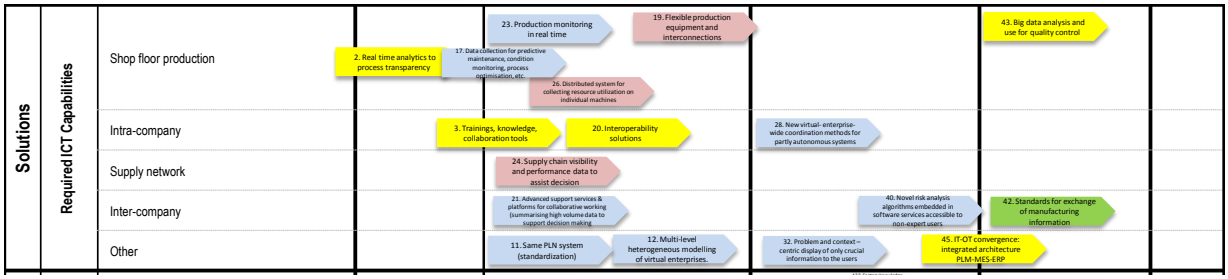
Number	Scenario	Roadmap sub-layer	Solution Description	Timeline	Votes
19	Red	Production Planning	Flexible production equipment and interconnections	S	3
23	Blue	Production Planning	Production monitoring in real time	S	3
24	Red	Supply chain management	Supply chain visibility and performance data to assist decision	S	3
30	Blue	Supply chain management	Manufacturing ICT like a smart phone: collaborative, easy to use, customised, plug and play, etc	S-M	3
18	Red	Management/ administration	Monitoring and decision making system based on measured resource utilization	S	2
37	Yellow	Factory Planning	Easier user interfaces for creating new models	M	2
42	Green	Manufacturing	Standards for exchange of manufacturing information	L	2
43	Yellow	Process planning & Development	Big data analysis and use for quality control	L	2
45	Yellow	Stock/warehousing	IT-OT convergence: integrated architecture PLM-MES-ERP	L	2
1	Yellow	Process planning & Development	Closed-loop of manufacturing analysis and control	P	1
20	Yellow	Order Processing	Interoperability Solutions	S	1
21	Blue	Management/ administration	Advanced support services & platforms for collaborative working (summarising high volume data to support decision making	S	1
26	Red	Process planning & Development	Distributed system for collecting resource utilization on individual machines	S	1
27	Red	Supply chain management	Harmonize interfaces and services on supply chain system for easy interconnection	S	1
32	Blue	Manufacturing	Problem and context –centric display of only crucial information to the users	S-M	1
38	Yellow	Production Planning	United interfaces and model formats for transferring digital models	M	1
40	Blue	Supply chain management	Novel risk analysis algorithms embedded in software services accessible to non-expert users	M-L	1
44	Yellow	Purchasing	Customer and demand data gathering and analysis	L	1
46	Yellow	Process planning & Development	Simulating tools for new process design	L	1

Table 16: Prioritised Manufacturing ICT Solutions for the Red Scenario: The high-volume production Enterprise

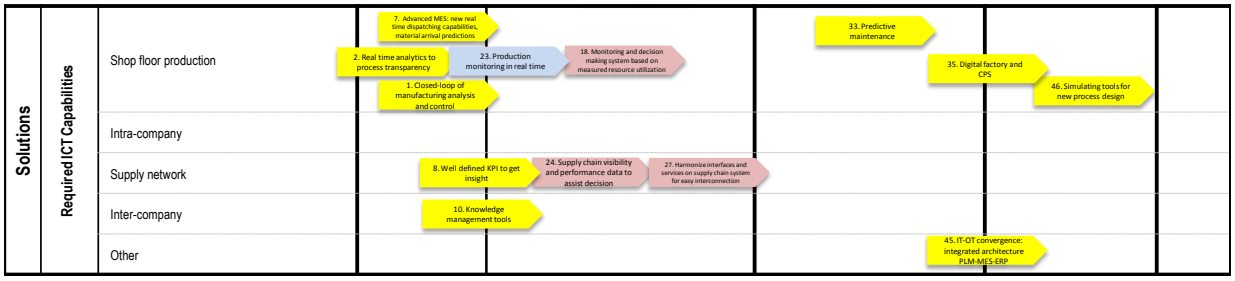
Blue Scenario



Green Scenario



Yellow Scenario



Red Scenario

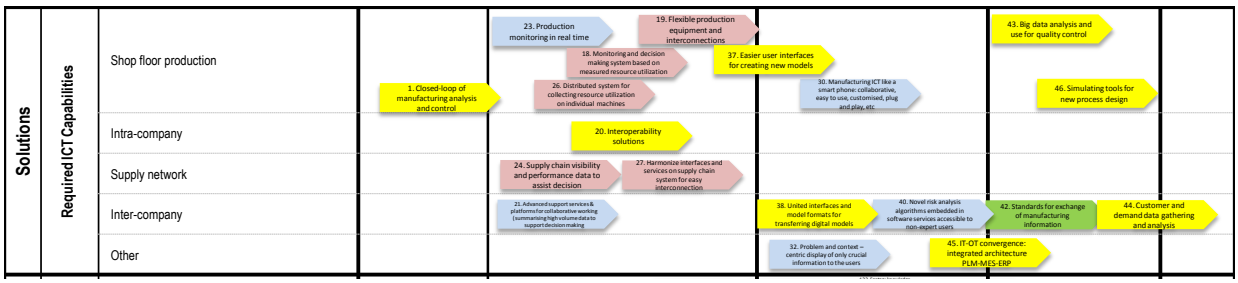


Figure 12: Prioritised ICT Manufacturing Solutions for the Blue, Green, Yellow and Red Scenarios

The summary roadmaps for each Scenario are laid out as shown in the figures below. The Technology layer is common for all four Scenarios. 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 Tables 13-16.

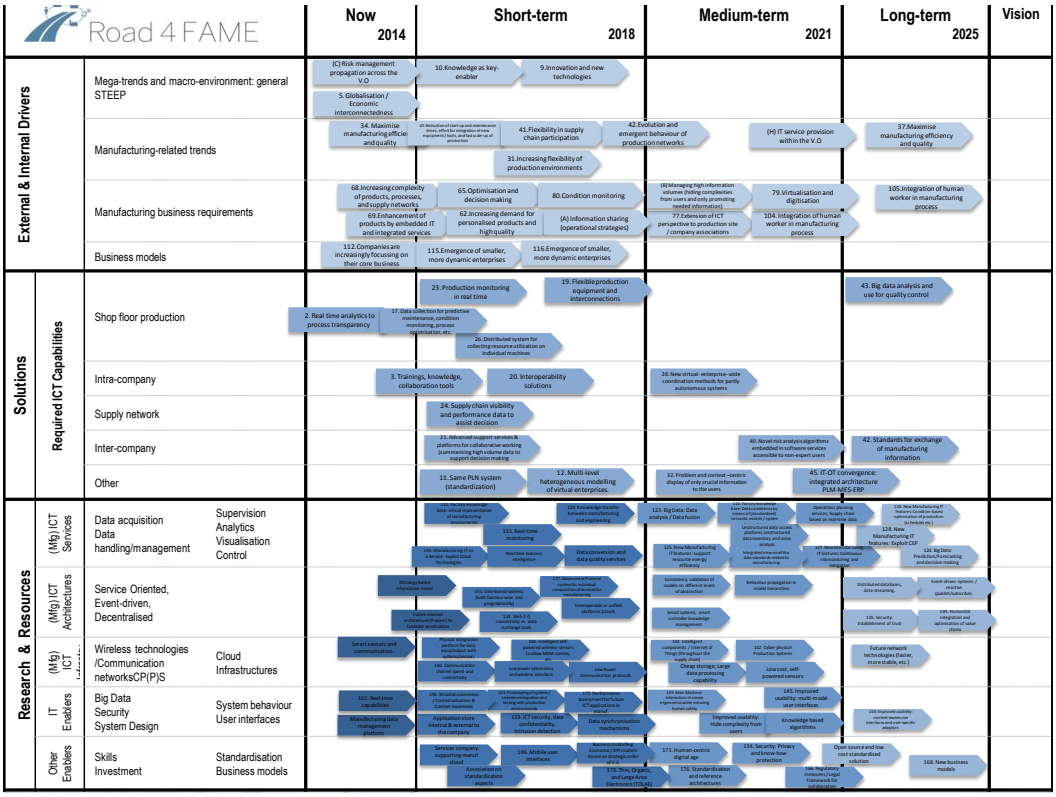


Figure 13: Summary roadmap for the Blue Scenario: The Virtual Enterprise

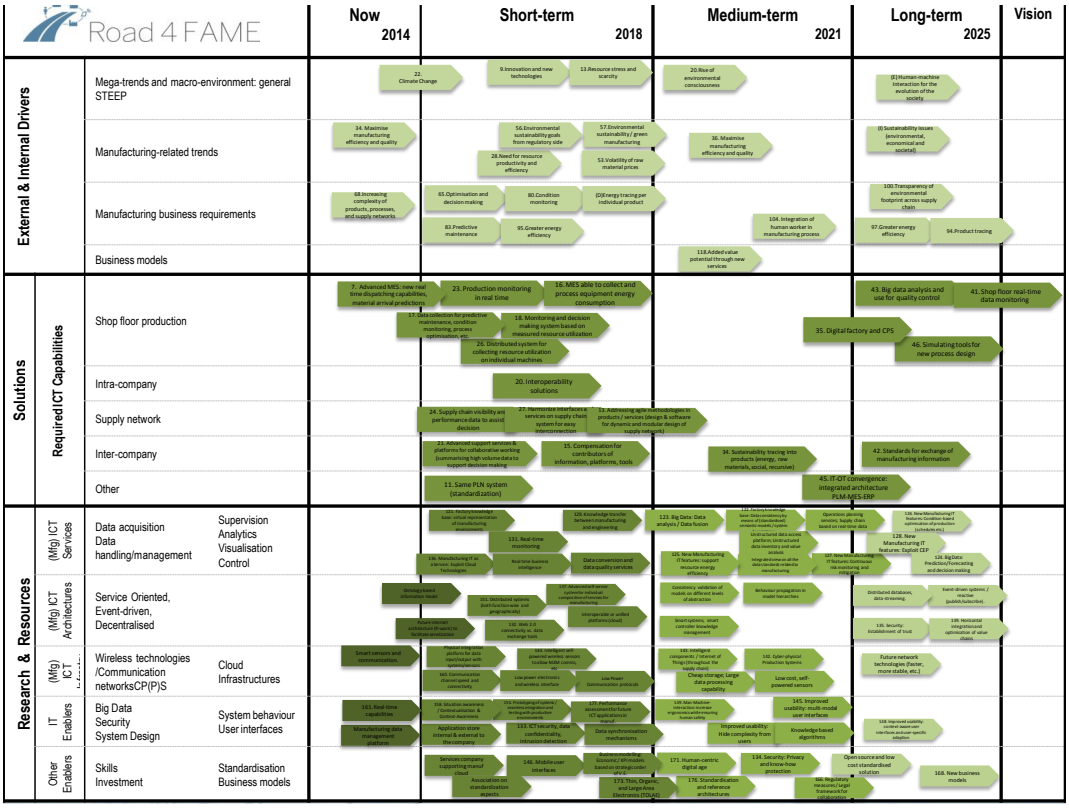


Figure 14: Summary roadmap for the Green Scenario: The Green Enterprise

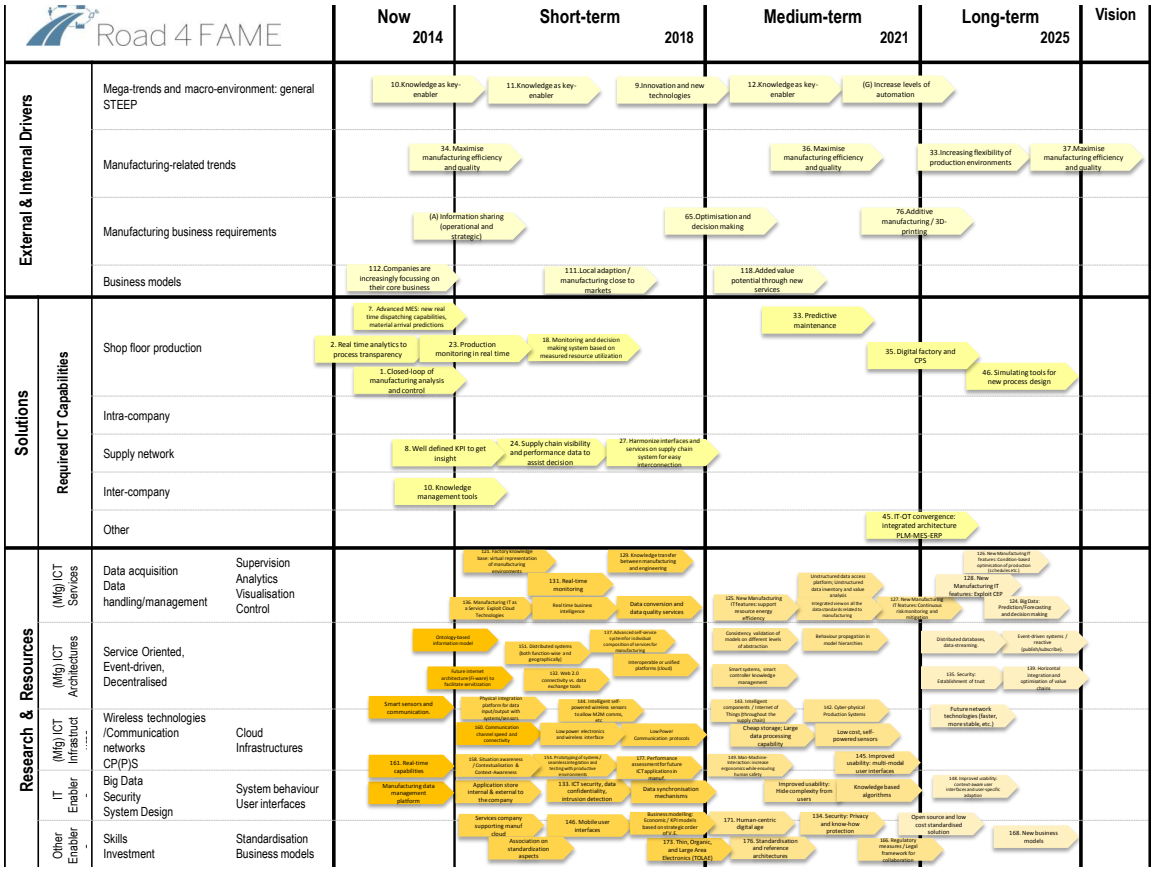


Figure 15: Summary roadmap for the Yellow Scenario: The MaaS Enterprise

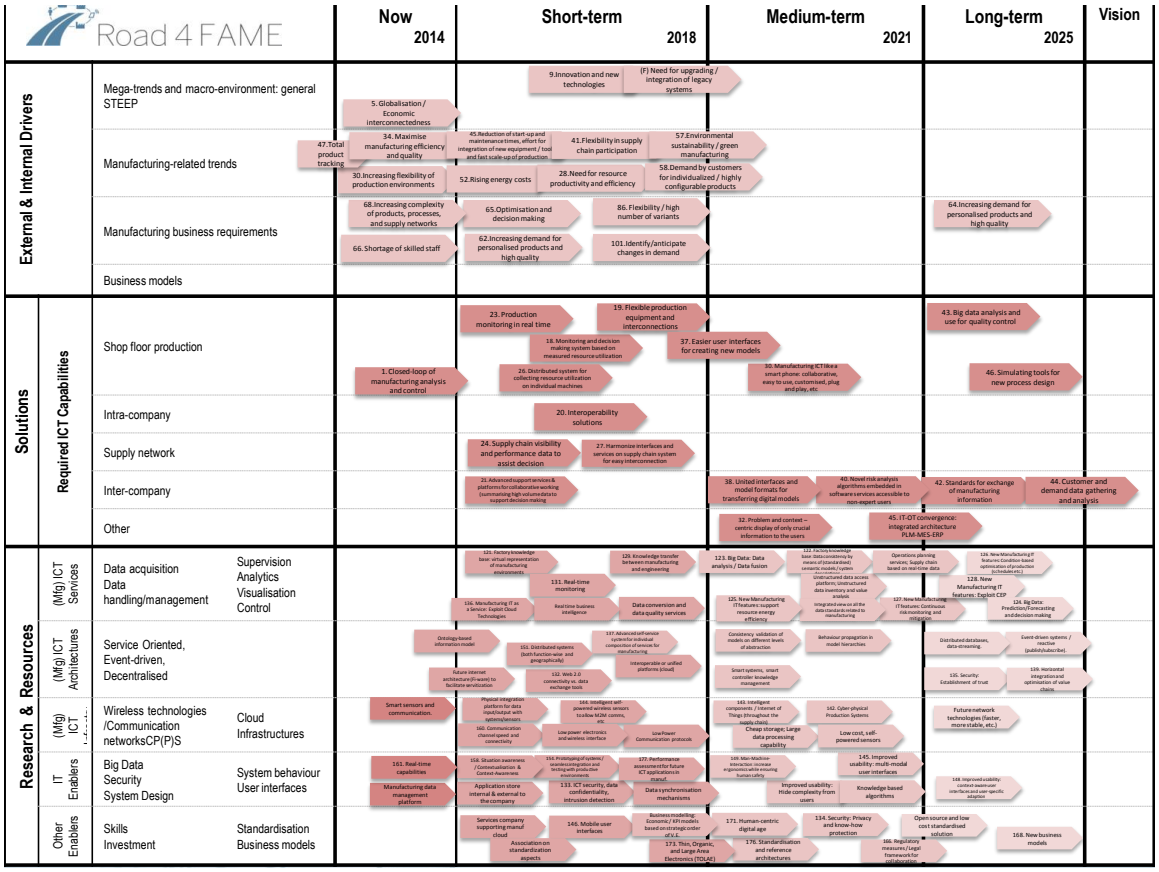


Figure 16: Summary roadmap for the Red Scenario: The High-Volume Production Enterprise

Subsequent analysis showed that the following ten ICT manufacturing Solutions are the most important ones and affect developments within most of the Scenarios:

Short Term:

1. Production monitoring in real time
   Improve the ability for real-time production monitoring and control to improve quality and reduce manufacturing costs.

2. Supply chain visibility and performance data to assist decision
   Optimise and improve the collection of performance data across an organisation's supply chain and facilitate data analysis to aid organisations make better decisions on their supply network performance and risks.

3. Interoperability Solutions
   Improve the interconnection of ICT systems within and between organizations to respond to the globalization of manufacturing.

4. Monitoring and decision making system based on measured resource utilization
   Develop ICT systems that are able to monitor the resource utilisation of an organisation (raw material, energy, water etc.) to reduce manufacturing costs

5. Advanced support services & platforms for collaborative working (summarising high volume data to support decision making)

6. Distributed system for collecting resource utilization on individual machines

Long-term

7. Standards for exchange of manufacturing information
   Standards are necessary to aid information exchange within and between organizations to facilitate knowledge sharing and manufacturing agility.

8. Big data analysis and use for quality control

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

10. Simulating tools for new process design

Once voting was complete, the Solutions that had been selected were recorded and added to a separate chart, as shown below:

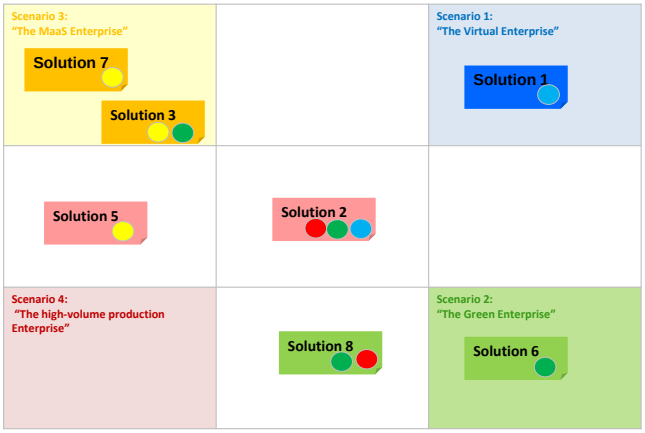


Figure 17: Solution/Scenario prioritisation chart

Because there was no pre-population of Solutions layer, each item was both new to the workshop and colour-coded by the Scenario group which submitted it. As the votes were also colour-coded by Scenario, this meant that both the absolute and relative importance of any Solution could quickly be seen.

Solutions would, by default, be placed in the same corner as the post-it colour representing the Scenario from which they originated. They would be moved depending on the number and colour of the votes they received; e.g. towards the red corner if they had red dots, the blue corner if they had blue dots etc. If they had dots of more than one colour, they would be placed towards the middle, indicating that the Solution was applicable to a range of Scenarios. In total, 37 Solutions received votes with 23 Solutions being important for more than two Scenarios. The populated Solution/Scenario prioritisation chart is shown below.

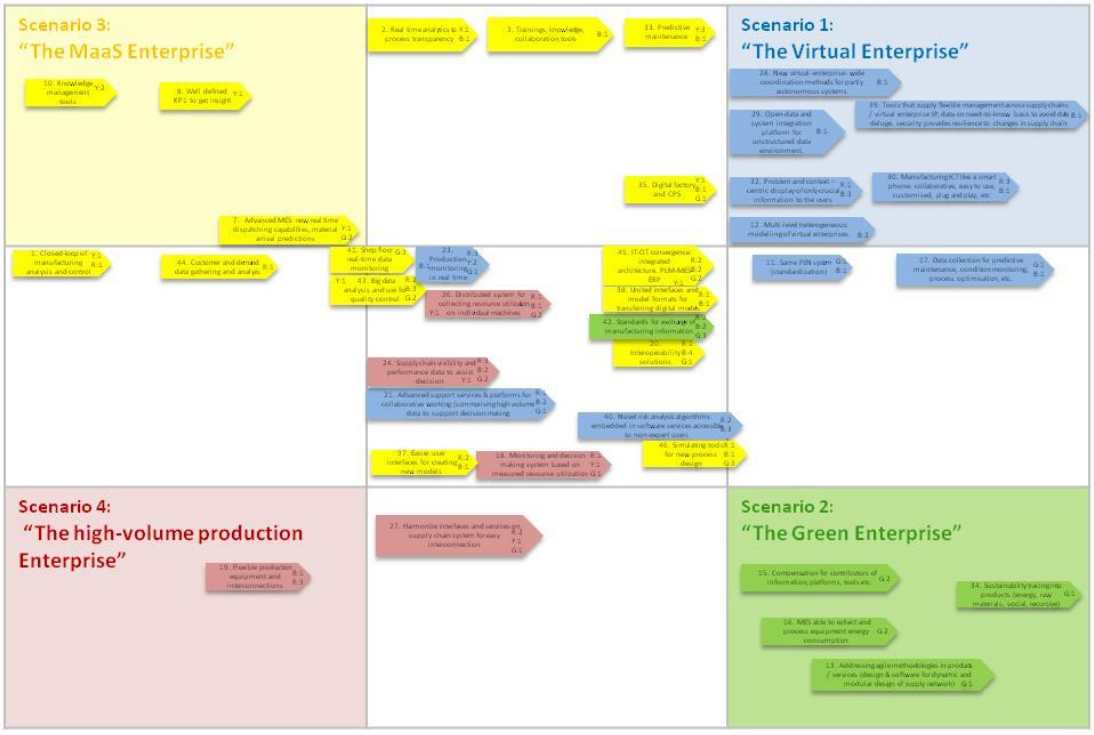


Figure 18: Populated Solution/Scenario prioritisation chart

Once the post-its were placed in this fashion, all the participants were asked to take part in a discussion to decide which Solutions would be explored further during the afternoon session. Emphasis was placed on Solutions in the centre of the chart as these were applicable to more than one Scenario. During the discussion, it became evident that some of the Solutions needed to be combined in order to allow greater coverage of the issues during the afternoon's group work. Four groups were created in this way as follows:

Group 1: Real time data acquisition and analysis

7. Advanced MES: new real time dispatching capabilities, material arrival predictions
23. Production monitoring in real time
26. Distributed system for collecting resource utilization on individual machines
29. Open data and system integration platform for unstructured data environment
41. Shop floor real-time data monitoring
43. Big data analysis and use for quality control

Group 2: ICT platform for advanced supply chain decision support

21. Advanced support services & platforms for collaborative working (summarising high volume data to support decision making
24. Supply chain visibility and performance data to assist decision

Group 3: Interoperability and standards

20. Interoperability Solutions
38. United interfaces and model formats for transferring digital models
42. Standards for exchange of manufacturing information
45. IT-OT convergence: integrated architecture. PLM-MES-ERP

Group 4: Modelling of virtual Enterprise

12. Multi-level heterogeneous modelling of virtual enterprises
40. Novel risk analysis algorithms embedded in software services accessible to non-expert users
46. Simulating tools for new process design

Nine of the ten priority ICT manufacturing Solutions mentioned in page 41 are included in the four groups above. The one not explicitly included "Monitoring and decision making system based on measured resource utilization" was considered to be covered better by similar Solutions within group 1.

From group 4, Simulation was specifically excluded from consideration as it was already the subject of other roadmapping programmes within the same EU Framework.

The results after the discussion are represented in Figure 19: Grouped Solutions in prioritisation chart, with similar or complementary Solutions grouped together.

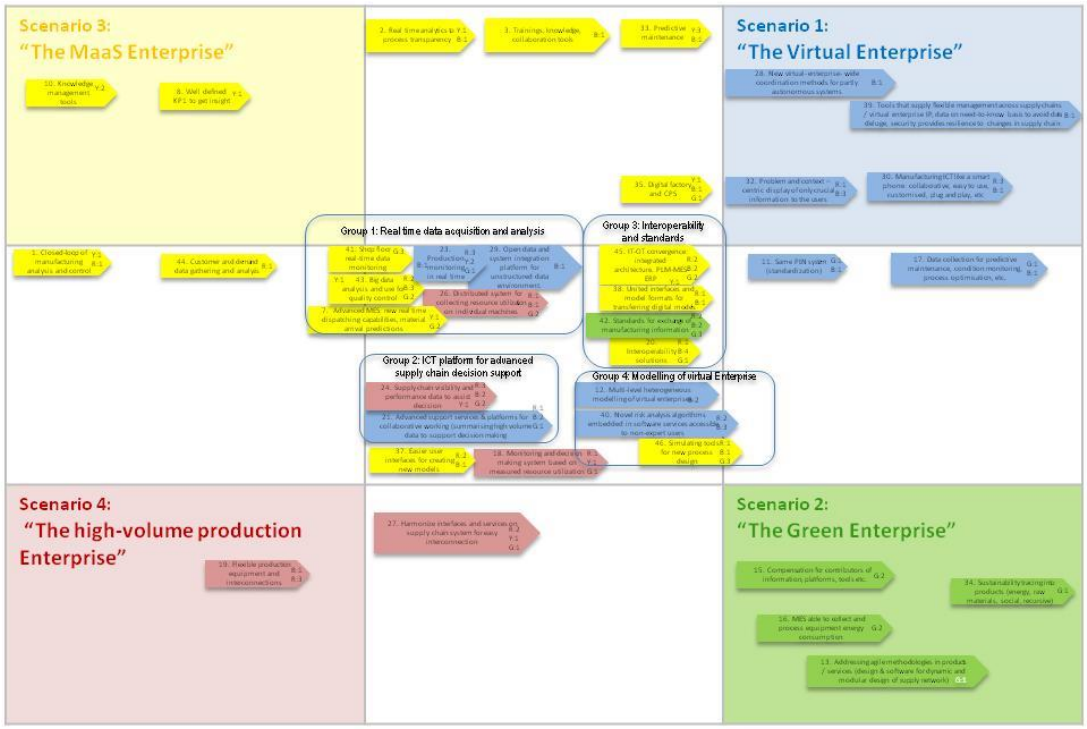


Figure 19: Grouped Solutions in prioritisation chart

Following this discussion, it was decided by the group that the four Solutions to be discussed during the afternoon session were:

- Real time data acquisition and analysis
- ICT platform for advanced supply chain decision support
- Interoperability and standards
- Modelling of the Virtual Enterprise

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. The table below shows the participants who contributed to each group.

Real time data acquisition and analysis	ICT platform for advanced supply chain decision support	Interoperability and standards	Modelling of virtual Enterprise
Haydn Thompson Fernando Perales Raik Hartung Silvia Catellvi Javier Herrero Giorgio Pasquettaz	Luis Carneiro Andreas Nettsträter Anibal Reñones Naoufel Cheikhrouhou Pedro Gama	Luis Costa Stefan Schleyer Jean-Bernard Hentz	Keith Popplewell Christian Sonntag Vasco Figueiredo Teles

Table 17: Participants per Solution group.

4.3 Exploration of Solutions

During the afternoon session, the participants rearranged themselves according to their interest in exploring the one of the four Solutions selected during the morning session. Within these new groups, they were given two roadmapping templates to provoke discussion and asked to complete them in preparation for presentation back to the workshop in plenary at the end of the day.

The first of these templates, seen in Figure 200 and explained in Figure 211, was designed in the same style as the landscape roadmap compiled during the morning session, with some additional questions to provoke discussion. The second template, as seen in Figure 22, was to be used as a textual summary of the ideas discussed in the first template, for ease of presentation back to the group.

The participants were also asked to take account of the pre-populated Research and Enablers elements on the landscape roadmap.

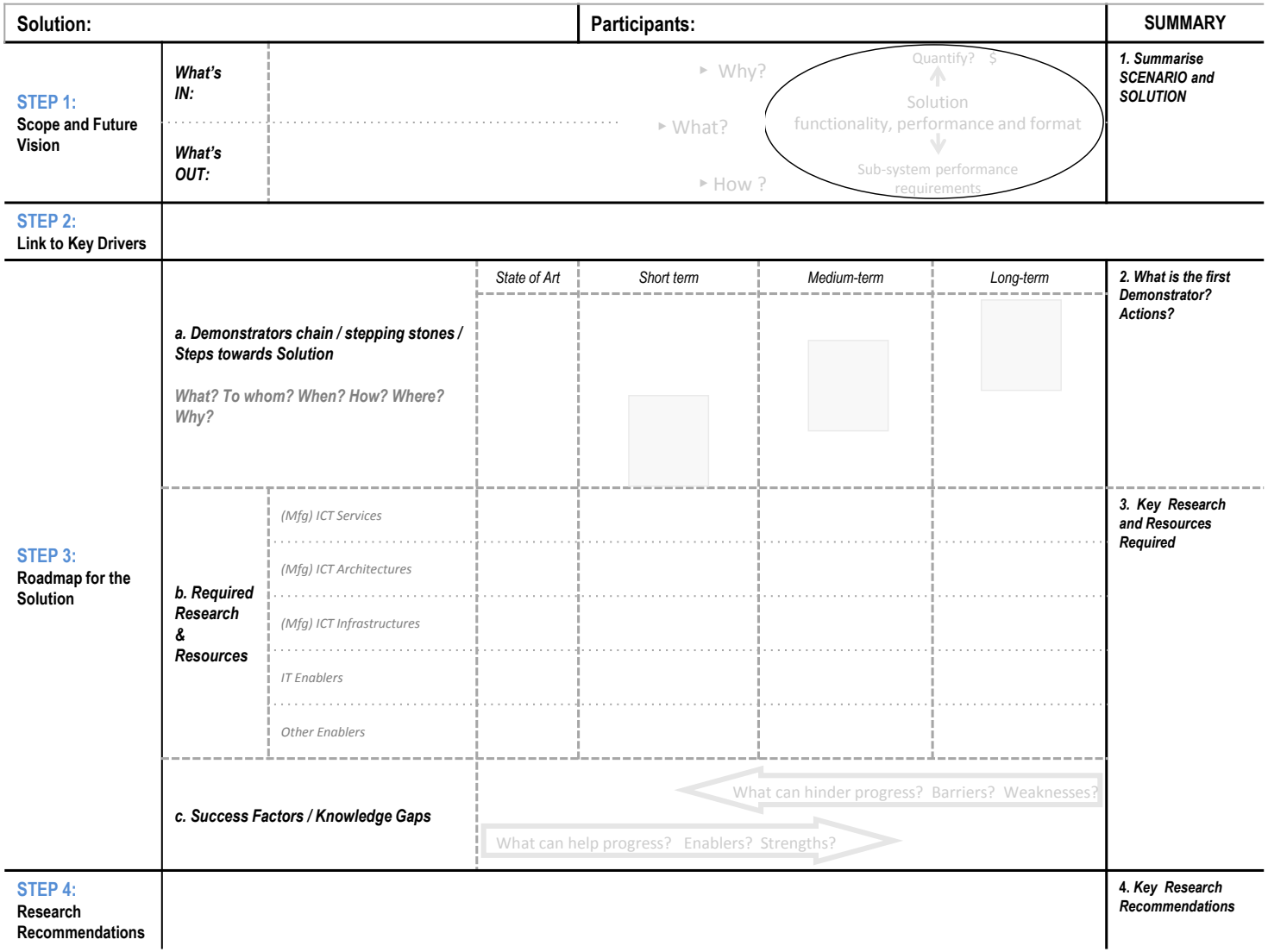


Figure 20: Exploration template 1

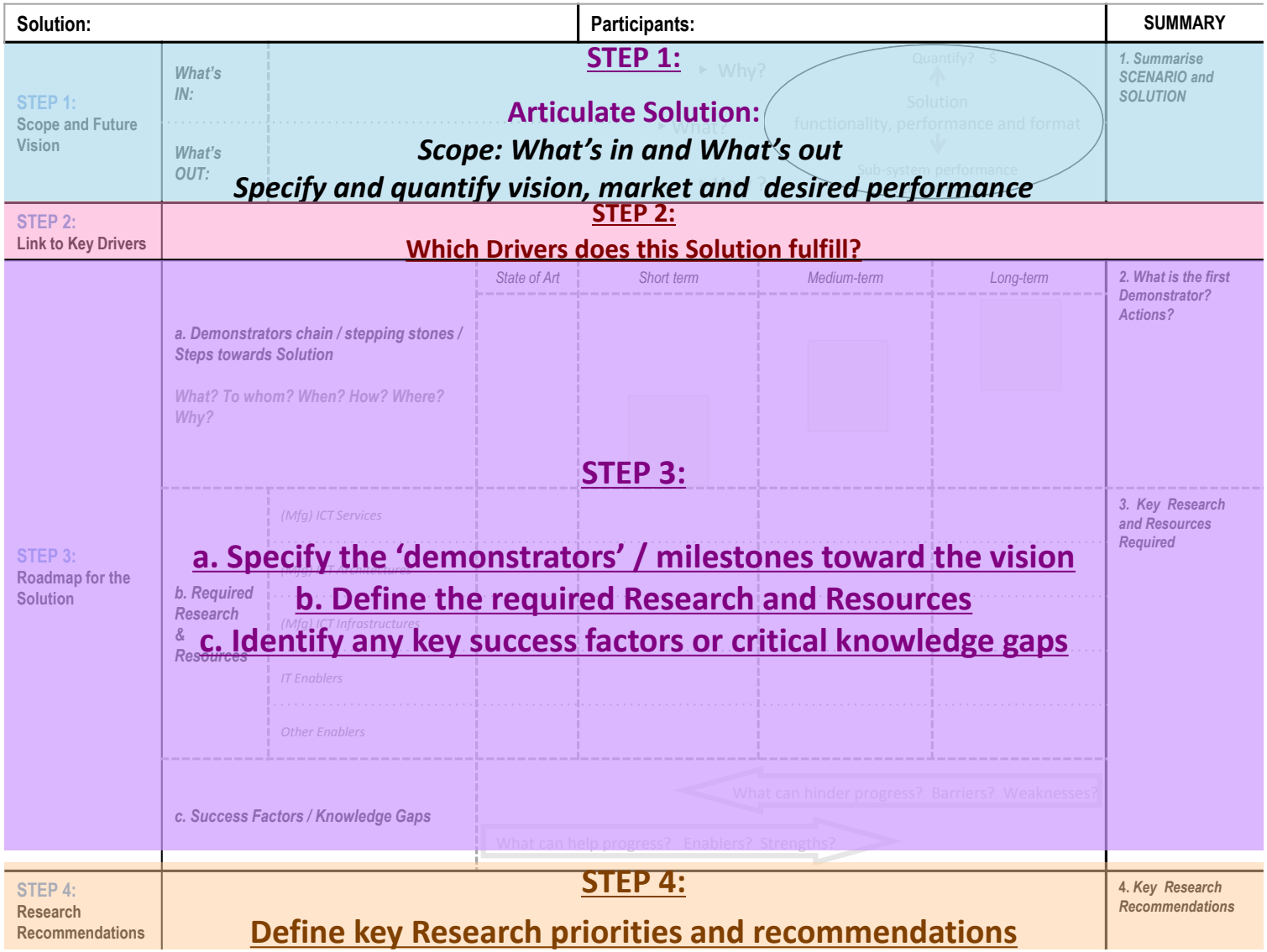


Figure 21: Exploration template 1 with process steps highlighted

Solution		Team members:	

Description of Solution	
Impact of Solution	
Links to Key Drivers	
Key skills, facilities and technology gaps	
What research would be needed?	
What needs to be done next?	

Figure 22: Exploration template 2

4.3.1 Solution Scope and Vision

Initially, each group was asked to define the Solution to be elaborated and to clarify the desired vision for this Solution (step 1). The specific boundaries for each Solution were described as follows:

- **Real time data acquisition and analysis**.
  This Solution includes Sensing and communication; Filtering, data fusion and mining; Visualization tools and user interfaces; Condition monitoring, performance optimization, quality control and predictive maintenance; Decision support sustainability. It excludes any model-generated data.

  The key value of this Solution is that it enables the ***Right data*** to reach the ***Right person*** at the ***Right time*** by being capable of acquiring and transmitting data in real time. It also facilitates optimization, availability and situational awareness within an organisation by monitoring throughput, sustainability, quality control and performance. It needs to incorporate additional technologies, e.g. smart sensors, communication, data processing and storage.

- **ICT platform for advanced supply chain decision support.**
  This Solution incorporates strategic, operational and tactical decision support throughout the supply network. It also includes information sharing design and redesign support for supply chains, operations planning and ability to react to unforeseen events within the chain. It excludes any product designs, internal operations or data collection Solutions.

  This is an ICT platform that increases the flexibility, speed and efficiency of an organisation's supply chain by providing the necessary information while maintaining the security, privacy, and real-time confidentiality of the supply network.

- **Interoperability and standards**
  This includes interoperability Solutions and standards for exchange of manufacturing information; Integrated architecture for PLM, MES, ERP information systems; Unified interface and model formats for transferring data; Open data and system integration platform for unstructured data environments. It excludes big data, CAD data exchange for engineering (design) and business models around exchange of data.

  This is an ICT Solution that aims to leverage the value of data, both structured and unstructured, across the whole manufacturing process as well as use data in a new and unforeseen context. It is also applicable and scalable to both big and small companies.

  This Solution will improve the manufacturing process efficiency and aid any monitoring prediction optimisation services. It needs to be able to integrate with new manufacturing systems.

- **Modelling of the Virtual Enterprise**

This includes a variety of modelling requirements and applications such as business modelling, simulation applications, discrete events, continuous, hybrid dynamics, stochastic and Bayesian modelling, multi-level modelling, human models, model management and multi-formalism heterogeneous modelling. It excludes simulation technology and any model-based software design.

This is an ICT service platform that delivers modelling services for both individuals and the organisation in a virtual enterprise. It is necessary to make a virtual enterprise more efficient as well as a safe basis for model-based design and validation. It should contain any arbitrary combination of mutually compatible services to support a user's decision making.

The market for this service platform is potentially huge and applicable to both large companies and SMEs, as long as the service model ensures it is affordable for the latter.

4.3.2 Links of Solutions to priority Trends and Drivers

During the second step of group work, each team was asked to assess which priority drivers and trends were met by each Solution. In addition, post-workshop the drivers put onto the individual post-its of the original ideas (before they were grouped into the four Solutions) were checked for completeness. The figure below shows the links (in grey) between the four Solutions and the twelve key drivers.

KEY DRIVERS AND TRENDS

Optimisation and decision making	Innovation and new technologies	Maximise manufacturing efficiency and quality	Increasing complexity of products, processes, and supply networks	Need for resource productivity and efficiency	Flexibility in supply chain participation	Knowledge as key-enabler	Companies are increasingly focusing on their core business	Globalisation / Economic interconnectedness	Environmental sustainability / green manufacturing	Increasing demand for personalised products and high quality	Information sharing; operational and strategic.	**SOLUTIONS**
65	9	34	68	28	41	10	112	5	57	62	A	
												Real time data acquisition and analysis
												ICT platform for advanced supply chain decision support
												Interoperability and standards
												Modelling of virtual Enterprise

Figure 23: Link between the four priority ICT Manufacturing Solutions and the twelve most important drivers and trends.

It is evident that although half of the Drivers and Trends are well linked, there are a few that are potentially weakly addressed or not met at all. These are:

- Innovation and new technologies
- Need for resource productivity and efficiency
- Flexibility in supply chain participation
- Globalisation / Economic interconnectedness
- Environmental sustainability / green manufacturing
- Information sharing; operational and strategic

However, it is true that just one link does not mean the Driver is 'weakly addressed'; it is possible that it is specifically linked to a single Solution which addresses it fully.

Additional Solutions may need to be considered to cover more fully these drivers. Some of the Solutions put forward but not fully addressed during the workshop were for example:

Driver	Solution that is addressing the Driver
Innovation and new technologies	Advanced support services and platforms for collaborative working (summarising high volume data to support decision making
	Problem and context –centric display of only crucial information to the users
Need for resource productivity and efficiency	Distributed system for collecting resource utilization on individual machines
Flexibility in supply chain participation	Monitoring and decision making system based on measured resource utilization
	Advanced support services and platforms for collaborative working (summarising high volume data to support decision making)
	Supply chain visibility and performance data to assist decision
	Harmonize interfaces and services on supply chain system for easy interconnection
	Information exchange tools (planning and schedule tracking). Data mining and filling for different goals. Data deluge!!
	Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain
Globalisation / Economic interconnectedness	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)
	Information exchange tools (planning and schedule tracking). Data mining and filling for different goals. Data deluge!!
	Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain
Environmental sustainability / green manufacturing	Data collection for predictive maintenance, condition monitoring, process optimisation, etc.
Information sharing; operational and strategic.	Advanced support services and platforms for collaborative working (summarising high volume data to support decision making)

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

Three of these Solutions in particular span across a few drivers and worth considering and exploring further in subsequent workshops. These were:

- Advanced support services & platforms for collaborative working (summarising high volume data to support decision making)
- Information exchange tools (planning and schedule tracking). Data mining and filling for different goals. Data deluge!!
- Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain

The Trend of 'Companies increasingly focusing on their core business' is not met at all, indicating that additional ICT manufacturing Solutions might be necessary to ensure that European manufacturing is able to expand beyond its core business and remains competitive in the long term.

4.3.3 Demonstrator chain/stepping stones toward Solutions

During the third step of group work, each team was asked to define the key demonstrators or milestones towards the vision, the required research and resources necessary to materialise the vision and any key success factors or critical knowledge gaps.

- **Real time data acquisition and analysis**.

The 'state of the art' was defined in terms of partial monitoring – condition monitoring – quality control (batch) and historical decision support. In the short term (5 years) development of full monitoring to provide data in real time was the key step. In the medium term (8-10 years) full situational awareness, data mining, analytics and visualisation tools were necessary steps. In the long term contact awareness, practical decision support, high availability by predictive maintenance and cloud look factor level control were highlighted requirements.

- **ICT platform for advanced supply chain decision support.**

The current state of the art was defined as heterogeneous data, inconsistent information data, and predominantly local optimisation e.g. at factory level. In the short term the first stepping stones to the vision were seen to be collaboration models including protocols and regulations and platform architecture deployment. The medium term milestones were integration of companies and information, and precision making in small clusters. In the longer term, real-time decision support system at global level was identified as a key step.

- **Interoperability and standards**

The current state of the art was defined in terms of physical integration platform, data input and output and process programming. In the short term the milestone was for a current PLM/MES/ERP (3 main software) system. In the medium term a key milestone was demonstration

of critical systems (NC machining) of 100/factory max. In the long term the milestone was IOT implementation in thousands of manufacturing systems.

- **Modelling of the Virtual Enterprise**

The state of the art was defined in terms of the established methods that need servitisation (e.g. business modelling, distributed simulation), basic research required (e.g. multi-scale modelling) and early research into theory methodology. The short term, medium and long term timescales were defined as 2018, 2021 and 2025 respectively. Key milestones / actions in progressing from the current state of the art to fully servitised levels were spread over this time scale, prioritising the business modelling, co-simulation and distributed simulation in the short term.

4.3.4 Links of Solutions to key Technologies

Different research priorities and technologies were deemed necessary by the delegates to enable the realization of the short-listed Solutions.

- **Real time data acquisition and analysis**.

The key short, medium and long term technology requirements were defined over a range of ICT services, architectures and infrastructures. Specifically, technologies around distributed data collection, cloud data mining and analytics, distributed databases and data-streaming were important as well as event-driven or reactive systems able to publish/subscribe.

Low cost and power consumption sensors, power electronics, communication protocols and wireless technologies were important for facilitating the implementation of the technologies as well as faster, more stable network technologies.

- **ICT platform for advanced supply chain decision support.**

The short term requirements covered all five sub-layers of the roadmap in this section. (Mfg) ICT Services (Apps) highlighted data conversion and data quality services, while (Mfg) ICT Architectures listed data synchronisation mechanisms, interoperable or unified cloud platforms. (Mfg) ICT Infrastructures raised a key requirement for security, establishment of trust. In the Enablers sub-layers, distributed systems both function-wise and geographically were important, as well as governance and collaboration models.

In the medium term (Mfg) ICT Services (Apps) highlighted the need for both operation planning services and supply chain based on real-time data to support the key milestone. The enablers were knowledge based algorithms and decision making under uncertainty.

In the longer term, there was a need for new manufacturing IT features such as continuous risk monitoring and mitigation, and support and resource energy efficiency. In the (Mfg) ICT Infrastructure layer large data process capability and Real time information availability were raised.

- **Interoperability and standards**

The key short, medium and long term requirements spanned Mfg ICT Services, Architectures and Infrastructures. For services important developments included SOA data access on PLM/ MES / ERP search engines, development of an unstructured data access platform and ability for implementing and accessing MES systems across different companies. New or updated architectures need to enable real time business intelligence and incorporate unstructured data inventory and value analysis, and provide an integrated view on all the data standards related to manufacturing. For infrastructures it is important to have an open source, low cost standardised manufacturing data management platform that offers physical integration for data input/output with a range of systems and sensors.

Important enablers included security, knowledge management and standardisation issues.

- **Modelling of the Virtual Enterprise**

The key short term requirements were in four main areas. The first (Mfg) ICT services (Apps) was to improve the factory knowledge base via virtual representation of the manufacturing environment and improve usability. In (Mfg) ICT Architectures, semantic model integration, ontology based information models and future internet architecture (Fi-ware) were required to facilitate servitisation were highlighted. No hardware requirements were noted, but IT and Other Enablers showed the need for ICT security and business modelling of virtual enterprises as important in the short term. In the medium term consistency validation of models on different levels of abstraction and behaviour propagation in model hierarchies were listed under (Mfg) ICT Architectures.

The table below shows the technologies and enablers that were identified as important for each of the Solutions. Numbered technologies were previously identified by the consortium and validated as important by the delegates during the workshop. Un-numbered technologies were indicated by the workshop participants.

The most important **(Mfg) ICT Services (Apps)** identified (applicable to more than one Solutions) were:

- 125. New Manufacturing IT features: support resource energy efficiency
- 127. New Manufacturing IT features: Continuous risk monitoring and mitigation, support resource energy efficiency
- 131. Storage: Real-time monitoring. Providing ad-hoc information (KPIs etc.)

		Real time data acquisition and analysis	ICT platform for advanced supply chain decision support	Interoperability and standards	Modelling of virtual Enterprise
(Mfg) ICT Services (Apps)					
	Virtual representation				
	Improved usability: Hide complexity from users				
	Application store internal & external to the company				
	Unstructured data access platform; Unstructured data inventory and value analysis				
	Data conversion and data quality services				
	Operations planning services; Supply chain based on real-time data				
121	Factory Knowledge-base: Virtual representation of manufacturing environments				
122	Storage: Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions.				
123	Big Data: Data analysis / Data fusion.				
124	Big Data: Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global.				
125	New Manufacturing IT features: support resource energy efficiency				
126	New Manufacturing IT features: Condition-based optimisation of production (schedules etc.)				
127	New Manufacturing IT features: Continuous risk monitoring and mitigation, support resource energy efficiency				
128	New Manufacturing IT features: Exploit CEP (Complex Event Processing) Technologies				
129	Knowledge transfer between Engineering, Manufacturing & other decision makers				
131	Storage: Real-time monitoring.				
(Mfg) ICT Architectures					
	Distributed data collection and data centre				
	Cloud data mining and analytics				
	Distributed databases, data-streaming.				
	Event-driven systems / reactive (publish/subscribe).				
	Data synchronisation mechanisms				
	Interoperable or unified platforms (cloud)				
	Real time business intelligence				
	Integrated view on all the data standards related to manufacturing				
	Smart systems, smart controller knowledge management				
	Ontology-based information model				
	Future internet architecture (Fi-ware) to facilitate servitization				
	Consistency validation of models on different levels of abstraction				
	Behaviour propagation in model hierarchies				
132	Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently)				

133	ICT security, data confidentiality, intrusion detection (Operational safety and reliability; Establishment of trust)				
134	Security: Privacy and know-how protection				
135	Security: Establishment of trust				
136	Manufacturing IT as a Service: Exploit Cloud Technologies; Service-oriented architecture				
137	Advanced self-service system for individual composition of services for manufacturing				
139	Horizontal integration and optimisation of value chains; SOA data access on PLM/ MES / ERP search engine				
	(Mfg) ICT Infrastructures (Hardware)				
	Smart sensors and communication.				
	Manufacturing data management platform				
	Physical integration platform for data input/output with systems/sensors				
	Open source and low cost standardised Solution				
142	Cyber-physical Production Systems				
143	Intelligent components / Internet of Things (throughout the supply chain)				
144	Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.				
145	Improved usability: multi-modal user interfaces				
146	Mobile user interfaces				
148	Improved usability: context-aware user interfaces and user-specific adaption				
149	Man-Machine-Interaction: increase ergonomics while ensuring human safety				
	IT Enablers				
	Cheap storage; Large data processing capability				
	Low cost, self-powered sensors				
	Low Power Communication protocols				
	Future network technologies (faster, more stable, etc.)				
	Security & IP protection for cloud distributed systems (134, 135)				
	Knowledge based algorithms				
151	Distributed systems (both function-wise and geographically)				
154	Prototyping of systems / seamless integration and testing with productive environments				
158	Situation awareness / Contextualisaton & Context-Awareness				
160	Communication channel speed and connectivity				
161	Real-time capabilities				
	Other Enablers				
	Low power electronics and wireless interface				
	Services company supporting manufacturing cloud & industry 4.0 implementation – process & methods & tools				
	Association on standardization aspects				
	Business modelling: Economic / KPI models based on strategic order of Virtual Enterprise				
166	Regulatory measures / Legal framework for collaboration in federated manufacturing environments				
168	New business models				
171	Human-centric digital age - Knowledge about human behaviour using digital media				
176	Standardisation and reference architectures (Semantic model integration)				
173	Thin, Organic, and Large Area Electronics (TOLAE)				
177	Performance assessment for future ICT applications in manufacturing				

Table 18: List of priority technologies and enablers identified for ICT Manufacturing Solutions.

The most important **(Mfg) ICT Services (Apps)** identified (applicable to more than one Solutions) were:

- 132. Web 2.0 connectivity vs. data exchange tools (to allow collaborative virtual enterprises to work together efficiently). Information integration rather than system integration.
- 133. ICT security, data confidentiality, intrusion detection (Operational safety and reliability; Establishment of trust)
- 135. Security: Establishment of trust
- 136. Manufacturing IT as a Service: Exploit Cloud Technologies; Service-oriented architecture. Cost models, security, privacy, trust etc. are important topics.

The most important **(Mfg) ICT Infrastructures (Hardware)** identified (applicable to more than one Solutions) were:

- 143. 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.
- 144. Intelligent self-powered wireless sensors to allow M2M communications, gather process data, KPIs etc.
- 146. Mobile user interfaces e.g. for instant KPIs on the shop floor.
- 148. 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.

The most important **(IT Enablers**) identified (applicable to more than one Solutions) were:

- Cheap storage; Large data processing capability
- Low cost, self-powered sensors
- 151. Distributed systems (both function-wise and geographically)
- 161. Real-time capabilities. Information available and processed "meeting the deadline".

Finally, a key **Other Enabler** was:

- 176. Standardisation and reference architectures (Semantic model integration) to enable interoperability among systems (syntax & semantics for interface definitions), functional descriptions and basic system architectures.

4.3.5 Success Factors and Knowledge gaps

Key success factors or critical knowledge gaps identified during the exploration of the four Solutions were as follows:

- **Real time data acquisition and analysis**.
  The key enabler was wireless sensors and a key hindrance was seen to be lack of security.
- **ICT platform for advanced supply chain decision support.**
  Enablers were Big Players and Demonstrators.
  Barriers were Competition culture and Lack of culture of sharing of information.

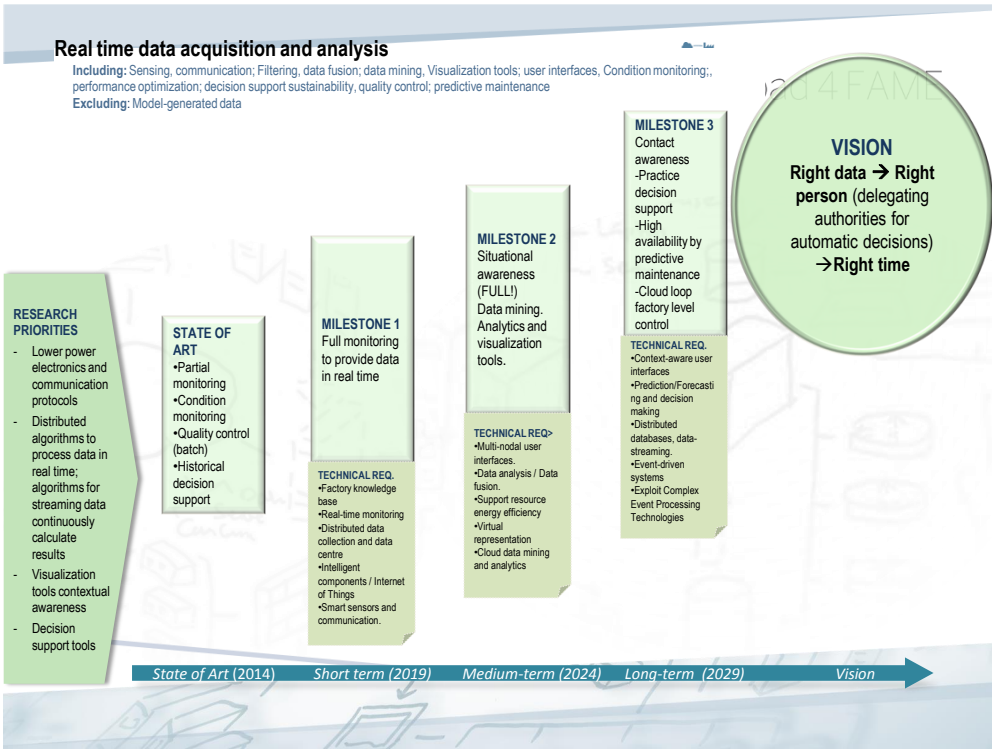
- **Interoperability and standards**

Key enablers were seen the existence of small and innovative IT companies, living labs and relationships with SMEs though regional initiatives, and H2020 projects.
The key hindrance was seen to be lack of interest in the subject from big companies, difficulty with engaging with SMEs and need for short term benefits supporting a long term vision.

- **Modelling of the Virtual Enterprise**
  The key enabler was seen to be European research and innovation which is strong in the relevant areas, while a key hindrance was the lack of dedicated funding and unstable lifespans for project funding opportunities.

4.3.6 Solution roadmaps

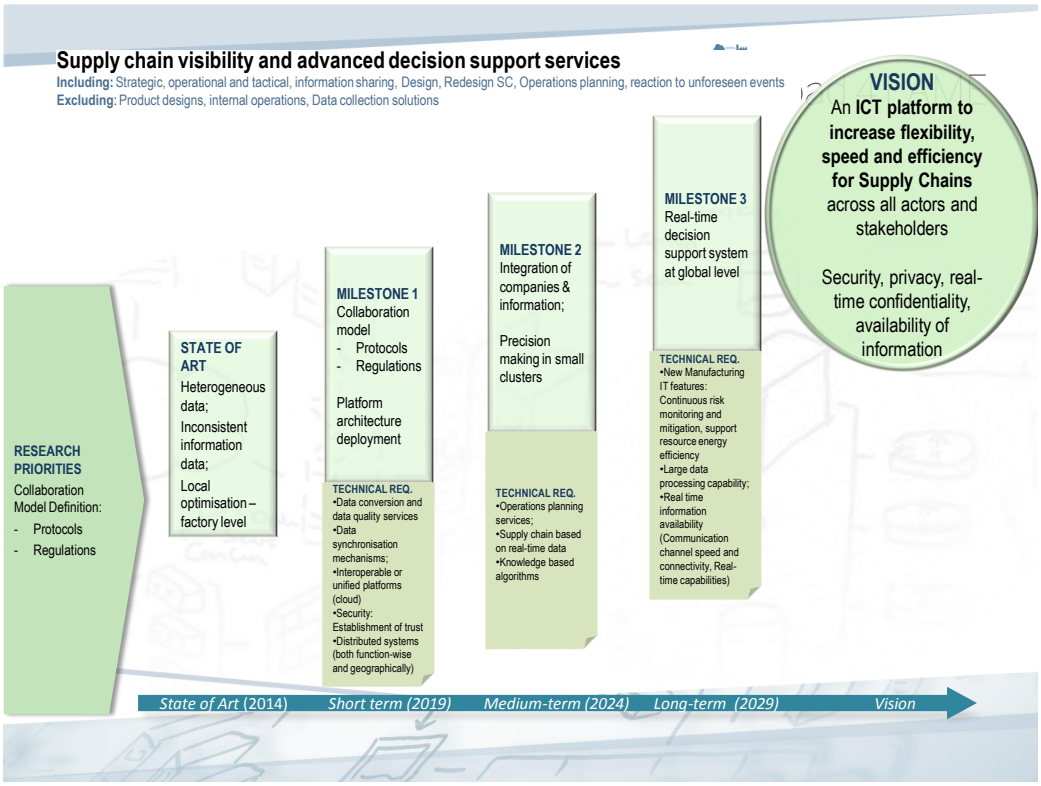
The four summary roadmaps derived for the ICT manufacturing Solutions explored during the initial roadmapping workshop are shown below.



Solution	Real time data acquisition and analysis	Team members:	Haydn Thompson, Fernando Perales, Raik Hartung, Silvia Catellvi, Javier Herrero, Giorgio Pasquettaz

Description of Solution	Right data to right person at the right time
Impact of Solution	Situation awareness Availability Quality and performance Sustainability
Links to Key Drivers	Innovation and new technologies; Need for resource productivity and efficiency; Maximise manufacturing efficiency and quality; Reduction of lead times to produce and deliver a product; Rising energy costs; Optimisation and decision making; Increasing complexity of products, processes, and supply networks and Extension of ICT perspective to production site / company associations
Key skills, facilities and technology gaps	Sensors network; data centre; data fusion; algorithms; visualization tools; decision support tools; automated decision making
What research would be needed?	- Lower power electronics and communication protocols - Distributed algorithms to process data in real time; algorithms for streaming data continuously calculate results - Visualization tools contexctual awareness - Decision support tools
What needs to be done next?	

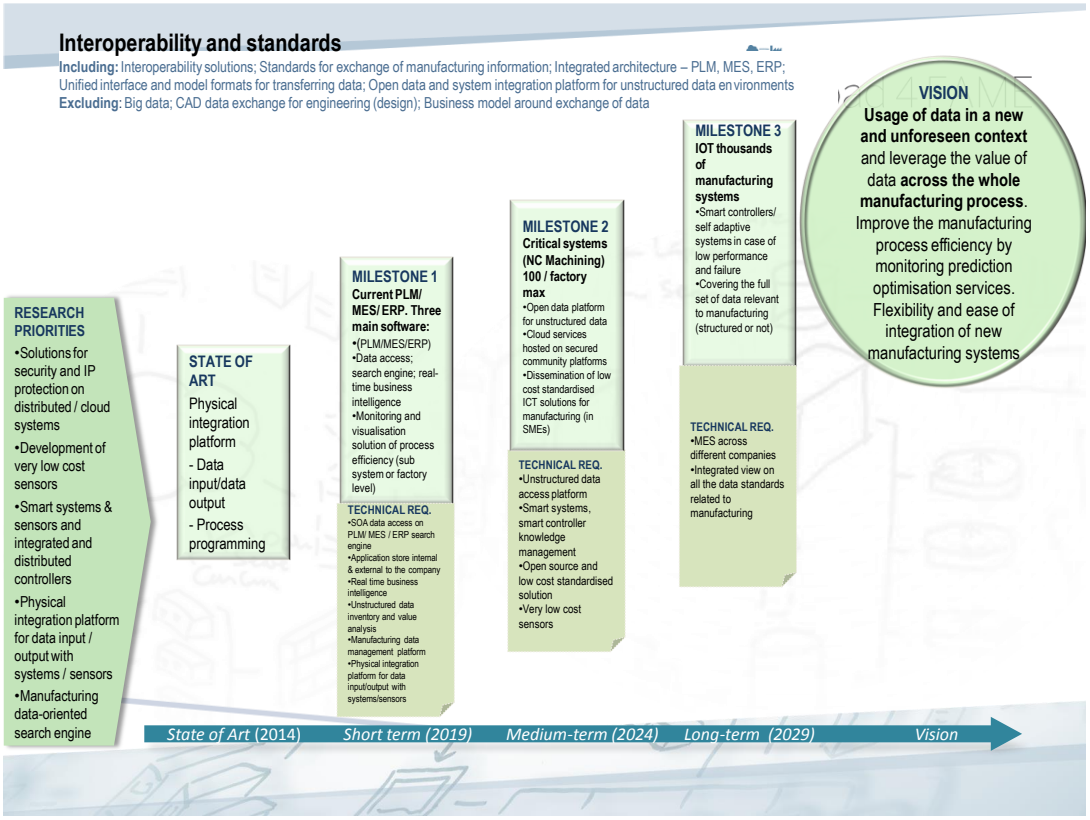
Figure 24: Roadmap and Summary for the Real Time Acquisition and analysis Solution



Solution	ICT platform for advanced supply chain decision support	Team members:	Luis Carneiro, Andreas Nettsträter, Anibal Reñones, Naoufel Cheikhrouhou, Pedro Gama

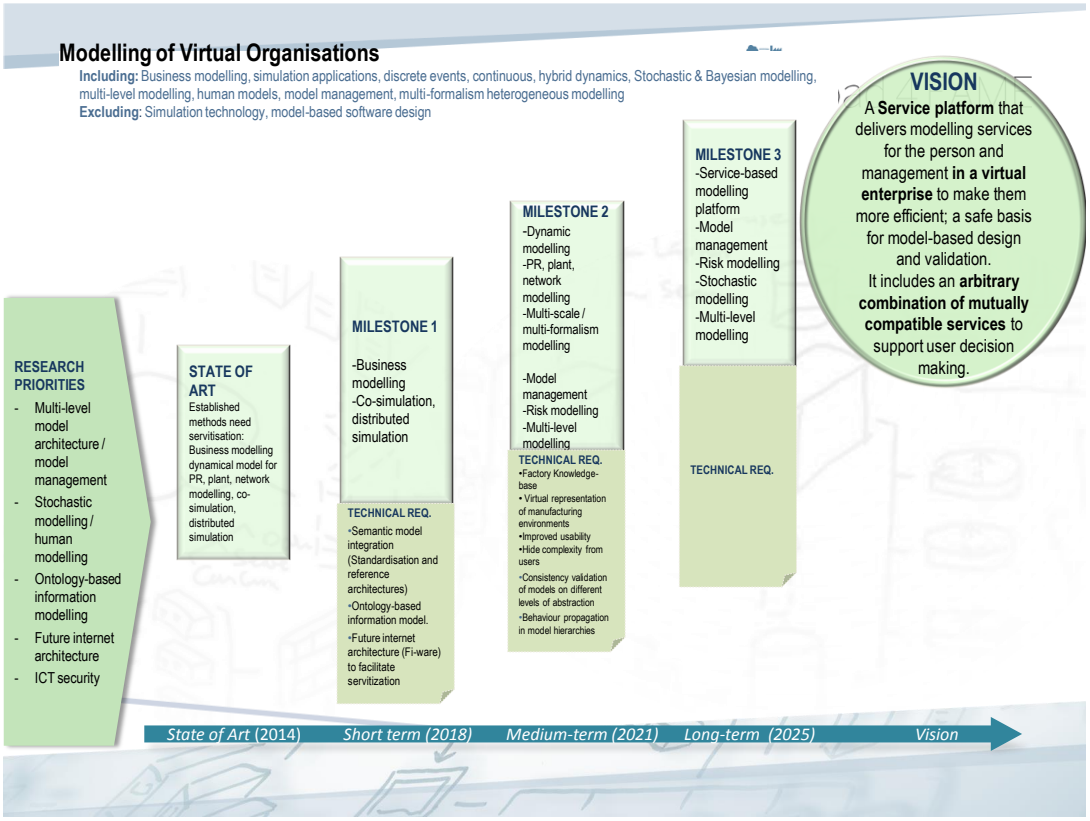
Description of Solution	Supply Chain: Strategic, operational and tactical Supply Chain management Visibility
Impact of Solution	Increase Supply Chain flexibility, speed and efficiency Reaction to unforeseen events Quicker partner selection
Links to Key Drivers	Large data processing capabilities Interoperability, standards and architectures Supply Chain management expertise Data conversion and date synchronization mechanisms
Key skills, facilities and technology gaps	Knowledge-based algorithms Decision support under uncertainty Collaboration models → S.C. Dynamic Supply Chain design
What research would be needed?	Collaboration Model Definition: - Protocols - Regulations
What needs to be done next?	

Figure 25: Roadmap and Summary for the ICT Platform for advanced supply chain decision support Solution



Solution	Interoperability and standards	Team members:	Luis Costa Stefan Schleyer JB Hentz
Description of Solution	Define standards, services, unified interface, models and platforms for easier: - Data exchange - System integration and communication Also define an integrated architecture. All in the name of manufacturing systems (scalable from big to small companies)		
Impact of Solution	Foundation for industry 4.0 and internet of things Leverage the value of data (structured or not) Allow usage of data in future new and unforeseen context Enable and support improvements in manufacturing process efficiency+ monitoring, prediction and optimising services Flexibility and integration of new / different manufacturing systems		
Links to Key Drivers	Rise of environmental consciousness; Need for resource productivity and efficiency; Maximise manufacturing efficiency and quality; Increasing hybrid cross-over solutions / use of ICT technologies; Evolution and emergent behaviour of production networks; Reduction of lead times to produce and deliver a product		
Key skills, facilities and technology gaps	Proper framework / infrastructure to handle data capture from thousands of sensors and devices Lack of proper architecture / system to protect IP on distributed systems; Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production; Optimisation and decision making; Additive manufacturing / 3D-printing and Extension of ICT perspective to production site / company associations.		
What research would be needed?	Solutions for security and IP protection on distributed / cloud systems Development of very low cost sensors Smart systems & sensors and integrated and distributed controllers Physical integration platform for data input / output with systems / sensors Manufacturing data-oriented search engine		
What needs to be done next?	Champion the creation of an association on standardization aspects with ICT and manufacturing companies on board (both Big and SMEs)		

Figure 26: Roadmap and Summary for the Interoperability and standards Solution



Solution	Modelling of virtual Enterprise	Team members:	K. Popplewell, C. Sontag, V. Teles

Description of Solution	Service platform, delivering virtually compatible modelling services for the design and management of virtual enterprises
Impact of Solution	Required to make virtual enterprises more efficient, competitive, innovative and safe by providing a basis for model-based design and validation. Market potential is huge and service model ensures that it is accessible and affordable by Large and SMEs
Links to Key Drivers	Increasing flexibility of production environments; Maximise manufacturing efficiency and quality; Optimisation and decision making; Increasing complexity of products, processes, and supply networks; Integration of human worker in manufacturing process; Integration of human worker in manufacturing process; Virtualisation and digitisation; Knowledge as key-enabler
Key skills, facilities and technology gaps	EU research and innovation is strong in all relevant areas Lack of dedicated funding and unsuitable time spans for project funding opportunities
What research would be needed?	- Multi-level model architecture / model management - Stochastic modelling / human modelling - Ontology-based information modelling - Future internet architecture - ICT security
What needs to be done next?	Servitisation of technologies already sufficiently nature Commission basic research on topics in early concept stage

Figure 27: Roadmap and Summary for Modelling of Virtual Enterprise Solution

5 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:

- **Real time data acquisition and analysis**.
  - Lower power electronics and communication protocols
  - Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results
  - Visualisation tools contextual awareness
  - Decision support tools

- **ICT platform for advanced supply chain decision support**
  - Collaboration model definition: protocols and regulations

- **Interoperability and standards**
  - Solutions for security & IP protection on distributed/cloud systems
  - Development of very low cost sensors
  - Smart systems & sensors and integrated and distributed controllers
  - Physical integration platform for data inputs/output with systems/sensors
  - Manufacturing data-orientated search engine

- **Modelling of the Virtual Enterprise**
  - Future internet architectures
  - ICT security
  - Multilevel architecture models and model management
  - Stochastic/human modelling
  - Model integration – ontology-based information modelling

A summary of the key milestones, success factors, knowledge gaps and research recommendations are shown in the table below.

Solution	Key milestones	Success factors/ knowledge gaps	Research Recommendations
Real time data acquisition	Implement full monitoring to provide data in real time	Wireless Sensors Lack of security	• Lower power electronics and communication protocols • Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results • Visualisation tools contextual awareness • Decision support tools

Supply chain visibility and advanced decision support services	See Research recommendation	Big players and demonstrators Competition Culture, lack of culture of sharing information	Collaboration model definition: • protocols • regulations
Interoperability and standards	• Champion the creation of an association on standardization aspects with ICT and manufacturing companies on board (both big and SMEs)	Small and innovative IT cos, living labs and relationships with SMEs though regional initiatives, and H2020 projects. Lack of interest from big cos, difficult with engaging with SMES and need for short term benefits supporting a long term vision	• Solutions for security & IP protection on distributed/cloud systems • Development of very low cost sensors • Smart systems & sensors and integrated and distributed controllers • Physical integration platform for data inputs/output with systems/sensors • Manufacturing data-orientated search engine
Modelling of Virtual Organisations	• Servitisation of technologies already sufficiently mature • Commission basic research on topics in early concept stage	European research and innovation which is strong in the relevant areas Lack of dedicated funding and unstable lifespans for project funding opportunities.	• Future internet architectures • ICT security • Multilevel architecture models and model management • Stochastic/human modelling • Model integration – ontology-based information modelling

Table 19: Summary of the key milestones, success factors, knowledge gaps and research recommendations for the four ICT manufacturing Solutions explored during the initial roadmapping workshop

6 Conclusions

An initial holistic roadmap for the ICT in Manufacturing was produced through literature research, expert panel meetings, interviews and a one-day workshop involving 17 participants from the Core Group and Expert Groups. The participants validated the information already gathered, added additional content to the roadmap, prioritized all content and helped refine the architecture of the roadmap itself.

The four manufacturing Scenarios put forward by the consortium to explore and stretch the roadmap content were proven sufficiently diverse and robust to elicit new information and insight from the participants, therefore maximizing the efficiency of the workshop.

Four priority ICT manufacturing Solutions were explored in detail during the workshop:

- Real time data acquisition and analysis
- ICT platform for advanced supply chain decision support
- Interoperability and standards
- Modelling of virtual Enterprise

Additional ICT manufacturing Solutions will be necessary to address the key market drivers and needs and fully and ensure that European manufacturing remains competitive in the long term.

The main research recommendations put forward by the delegates, necessary for realising the four ICT manufacturing Solutions were:

- Distributed algorithms to process data in real time; algorithms for streaming data continuously to calculate results; manufacturing data-orientated search engine
- Visualisation tools contextual awareness
- Decision support tools
- Collaboration model definition: protocols and regulations
- Future internet architectures
- ICT security and Solutions for security & IP protection on distributed/cloud systems
- Multilevel architecture models and model management including stochastic/human modelling and model integration i.e. ontology-based information modelling
- Development of lower power electronics and communication protocols
- Development of very low cost sensors and their physical integration into smart systems and distributed controllers

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Appendix 1: List of Trends and Drivers

Megatrends

1-5. 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: **P-L**

5-7. 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: **P-L**

8. 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**

9. 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**

10-12. 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: **P-L**

13-15. Resource stress and scarcity

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**

16. 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: **P-L**

17. 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: **P-L**

18-20. Rise of environmental consciousness

Environmental consciousness throughout society, and herewith also the production domain, will lead to lower energy consumption and less waste.

Timeline: **P-L**

21. 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 health-care advances.
Timeline: **M-L**

22-25. 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: **P-L**

26-27. 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**

Manufacturing-related Trends

28-29. 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**

30-33. 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: **P-L**

34-37. 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: **P-L**

38-40. Increasing hybrid cross-over Solutions / use of ICT technologies
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: **P-L**

41. 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**

42. 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**

43-44. 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: **P-L**

45. Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production

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

Timeline: **P-L**

46. Reduction of inventories

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

Timeline: **P-L**

47-49. 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: **P-L**

50. Increasing rate of technological change

Timeline: **S-L**

51. Half-life of knowledge decreases

In certain fields, the rate of human knowledge acquisition will soon be exceeded by the rate at which such knowledge becomes irrelevant.

Timeline: **M-L**

52. Rising energy costs

Timeline: **S-L**

53. Volatility of raw material prices

Although the cost of raw materials used in manufacturing has eased somewhat since hitting a historic, mid-recession peak in 2008, the raw materials market remains volatile. Manufacturers continue to be concerned about coping with pricing fluctuations, and many companies are seeking new ways to mitigate risks associated with raw materials instability.

Timeline: **S-L**

54. Stricter/more requirements imposed by large buyers

Timeline: **M-L**

55. 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**

56. Environmental sustainability goals from regulatory side

Timeline: **S-L**

57. Environmental sustainability / green manufacturing

In a certain markets, environmental sustainability is becoming a relevant parameter for the company's competitiveness.

Timeline: **S-L**

58. 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**

59. Increasing education required for workers

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

and skills.
Timeline: **M-L**

60. 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**
61. 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**

Manufacturing Business Needs

62-64. Increasing demand for personalised products and high quality
Purchasing decisions are being made based on brand perception of safety, quality and personalised/customisable products.
Timeline: **S-L**

65. Optimisation and decision making
Real-time decisions for faster reaction to exceptions, higher planning reliability, optimised processes throughout production networks etc. help to increase competitiveness.
Timeline: **S-L**

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

67. Increasing demand for products and services
With population projected to grow 20% over the next 20 years, to over 8 billion people by 2030, demand will be generated by over a billion additional, increasingly wealthy customers.
Timeline: **P-L**

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

69-71. Enhancement of products by embedded IT and integrated services
The rising 'digital economy' and its impact on 'traditional' products, processes and services as well as creation of 'new' demands by embedding ICT to products.
Timeline: **P-L**

73-74. Urban production
The trend to re-locate manufacturing facilities to cities in order to shorten commuting times, etc.
Timeline: **S-L**

75. 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: **P-L**

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

77. 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**

79. 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**

80-82. 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**

83-85. 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**

86-88. 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**

89-91. Product tracking

Product tracking is the capability to follow the path of a specified unit of a product through the supply chain as it moves between organisations. Products are routinely tracked for obsolescence, inventory management and logistical purposes.
Timeline: **S-L**

92-94. Product tracing

Product tracing is the capability to identify the origin of a particular unit and/or batch of product located within the supply chain by reference to records held upstream in the supply chain. Products are traced for purposes such as product recall and inventory management.
Timeline: **S-L**

95-97. Greater energy efficiency

Timeline: **S-L**

98-100. Transparency of environmental footprint across supply chain

To realize green manufacturing; for environemental sustainability to became an available optimization parameter.
Timeline: **S-L**

101-103. Identify/anticipate changes in demand

Timeline: **S-L**

104-105. 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**

Business Models

106. 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: **P-L**

107-110. 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: **P-L**

111. 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**

112. 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: **P-L**

113-114. 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**

115-117. 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: **P-L**

118-119. Added value potential through new services
Provision of new (B2B or B2C) services and business models enabled by intelligent products.
Timeline: **M-L**

Appendix 2: List of Solutions

Number	Scenario	Roadmap sub-layer	Description	Timeline
1	Yellow	Process planning & Development	Closed-loop of manufacturing analysis and control	P
2	Yellow	Production Planning	Real time analytics to process transparency	P
3	Yellow	Production Planning	Training, knowledge, collaboration tools	P
4	Green	Process planning & Development	Multi-objective and multi-decision making with uncertainty in IT infrastructure	P
5	Yellow	Supply chain management	Quality measurement and management per process and equipment	P
6	Yellow	Purchasing	Shortest routing, material grouping and reodering for shortest set up cycles	P
7	Yellow	Distribution/sales	Advanced MES: new real time dispatching capabilities, material arrival predictions	P
8	Yellow	Stock/warehousing	Well defined KP1 to get insight	P
9	Yellow	Education/training	Training. E-learning	P
10	Yellow	Education/training	Knowledge management tools	P
11	Blue	Product Development	Same PLM system (standardization)	S
12	Blue	Factory Planning	Multi-level heterogeneous modelling of virtual enterprises	S
13	Green	Production Planning	Addressing agile methodologies in products / services (design & software for dynamic and modular design of supply network)	S
14	Yellow	Purchasing	Separated production stations rather than fixed production lines; automated transportation systems serving the stations.	S
15	Green	Order Processing	Compensation for contributors of information, platforms, tools etc	S
16	Green	Manufacturing	MES able to collect and process equipment energy consumption	S
17	Blue	Maintenance	Data collection for predictive maintenance, condition monitoring, process optimisation, etc.	S
18	Pink	Management/administration	Monitoring and decision making system based on measured resource utilization	S
19	Pink	Production Planning	Flexible production equipment and interconnections	S
20	Yellow	Order Processing	Interoperability Solutions	S
21	Blue	Management/administration	Advanced support services & platforms for collaborative working (summarising high volume data to support decision making	S
22	Blue	Process planning & Development	Specialised companies for IT and method from- for and customization (e.g. SMEs) advanced system integration	S
23	Blue	Production Planning	Production monitoring in real time	S
24	Pink	Supply chain management	Supply chain visibility and performance data to assist decision	S
25	Yellow	Maintenance	Performance Management	S
26	Pink	Process planning & Development	Distributed system for collecting resource utilization on individual machines	S
27	Pink	Supply chain management	Harmonize interfaces and services on supply chain system for easy interconnection	S
28	Blue	Product Development	New virtual- enterprise- wide coordination methods for partly autonomous systems	M
29	Blue	Factory Planning	Open data and system integration platform for unstructured data environment.	M
30	Blue	Supply chain management	Manufacturing ICT like a smart phone: collaborative, easy to use, customised, plug and play, etc	S-M

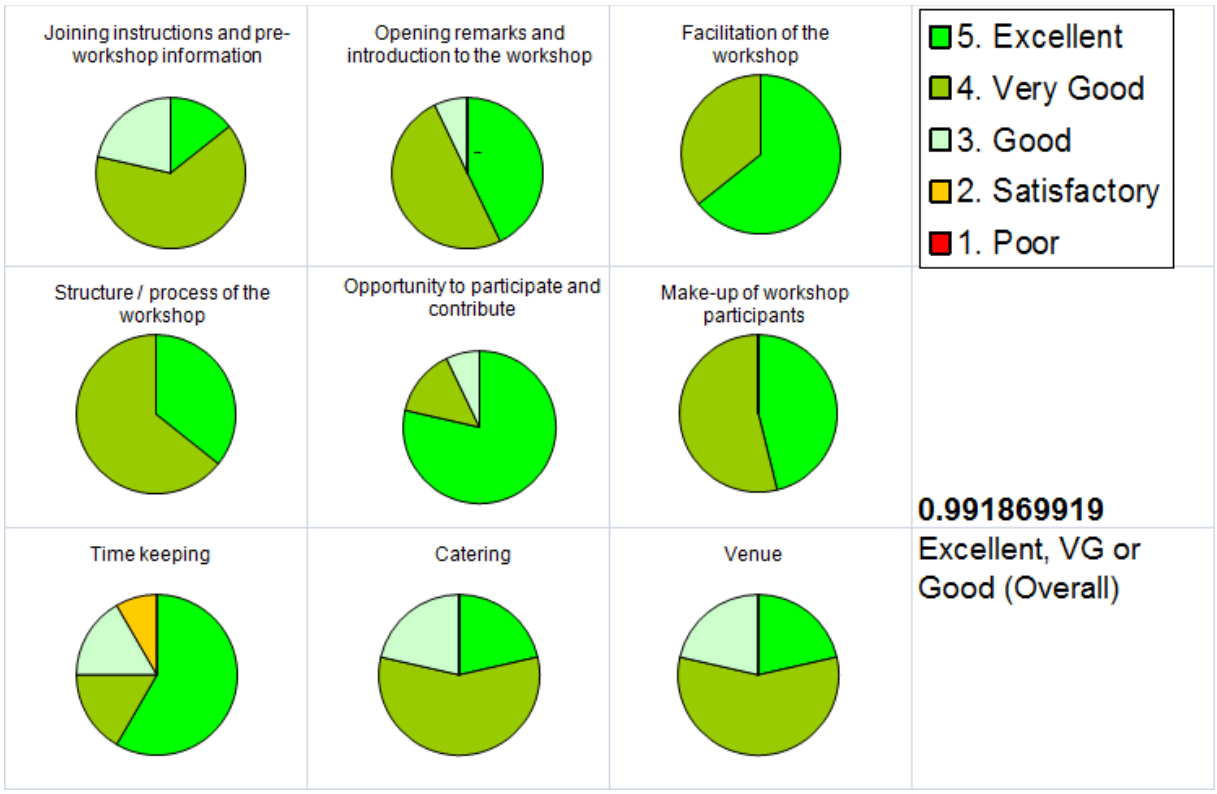
31	Blue	Order Processing	Information exchange tools (planning and schedule tracking). Data mining and filling for different goals. Data deluge!!	M
32	Blue	Manufacturing	Problem and context –centric display of only crucial information to the users	S-M
33	Yellow		Predictive Maintenance	M
34	Green	Production Planning	Sustainability tracing into products (energy, raw materials, social, recursive)	M
35	Yellow	Factory Planning	Digital Factory and CPS	M
36				
37	Yellow	Factory Planning	Easier user interfaces for creating new models	M
38	Yellow	Production Planning	United interfaces and model formats for transferring digital models	M
39	Blue	Purchasing	Tools that supply flexible management across supply chains / virtual enterprise IP, data on need-to-know basis to avoid data deluge, security provides resilience to changes in supply chain	M
40	Blue	Supply chain management	Novel risk analysis algorithms embedded in software services accessible to non-expert users	M-L
41	Yellow	Process planning & Development	Shop floor real-time data monitoring	L
42	Green	Manufacturing	Standards for exchange of manufacturing information	L
43	Yellow	Process planning & Development	Big data analysis and use for quality control	L
44	Yellow	Purchasing	Customer and demand data gathering and analysis	L
45	Yellow	Stock/warehousing	IT-OT convergence: integrated achitecture PLM-MES-ERP	L
46	Yellow	Process planning & Development	Simulating tools for new process design	L
47	Yellow	Production Planning	PLM Solutions for collaborative designs	L

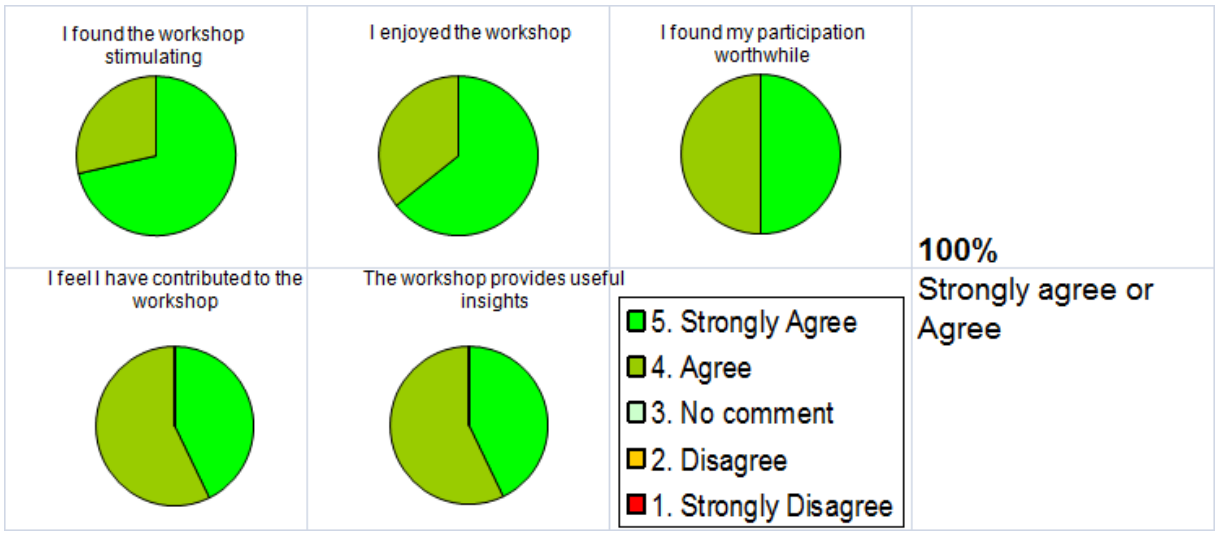
Appendix 3: List of Participants

Name	Organisation
Andreas Nettsträter	Fraunhofer Institute for Material Flow and Logistics
Anibal Reñones	CARTIF
Christian Sonntag	euTeXoo GmbH / TU Dortmud
Fernando Perales	Innovalia Association
Giorgio Pasquettaz	Centro Ricerche FIAT
Haydn Thompson	THHINK Wireless Technologies Ltd.
Jean-Bernard Hentz	Airbus SAS
Keith Popplewell	Coventry University
Luis Carneiro	INESC Porto
Javier Herrero	Aeronova
Naoufel Cheikhrouhou	Ecole Polytechnique Fédérale de Lausane
Raik Hartung	SAP AG
Silvia Castellvi	Atos Spain
Stefan Schleyer	SKF GmbH
Vasco Figueiredo Teles	INESC Porto
Pedro Gama	Critical Manufcaturing
Luis Costa	Critical Manufcaturing

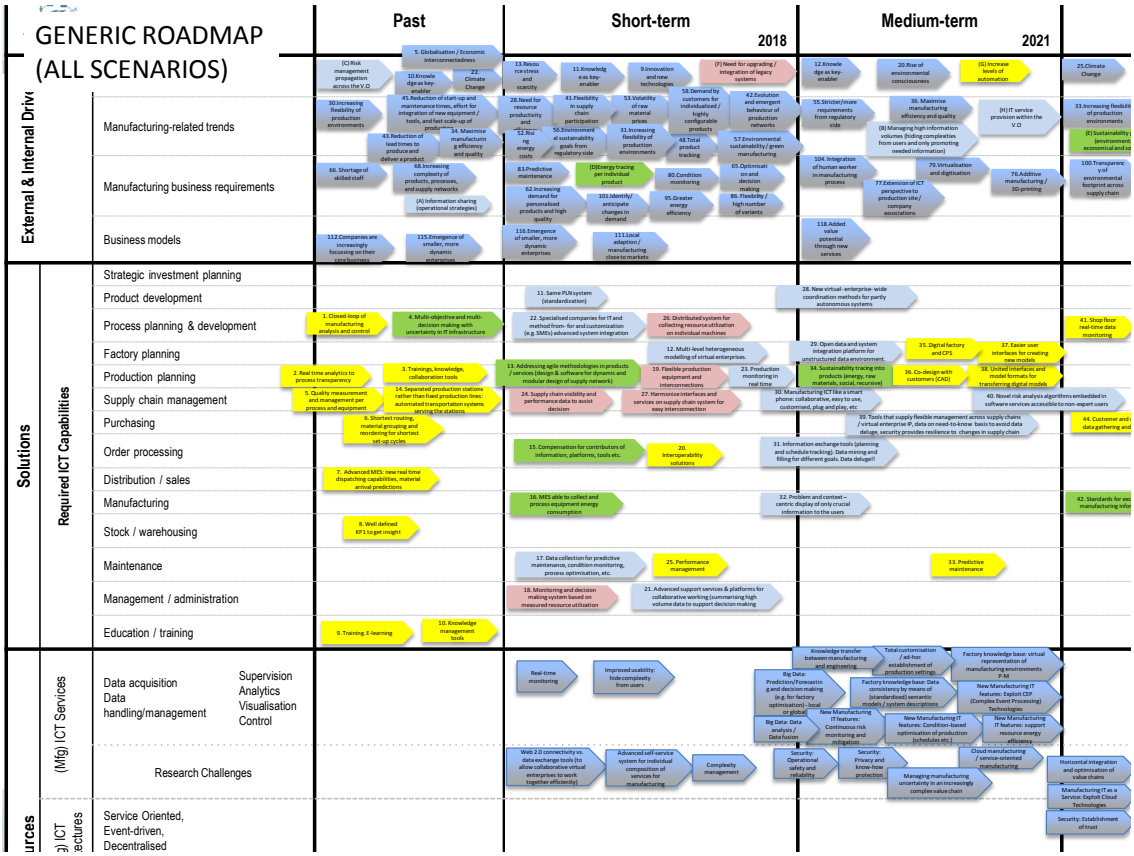
Appendix 4: Participants Feedback

Feedback was received from 14 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.

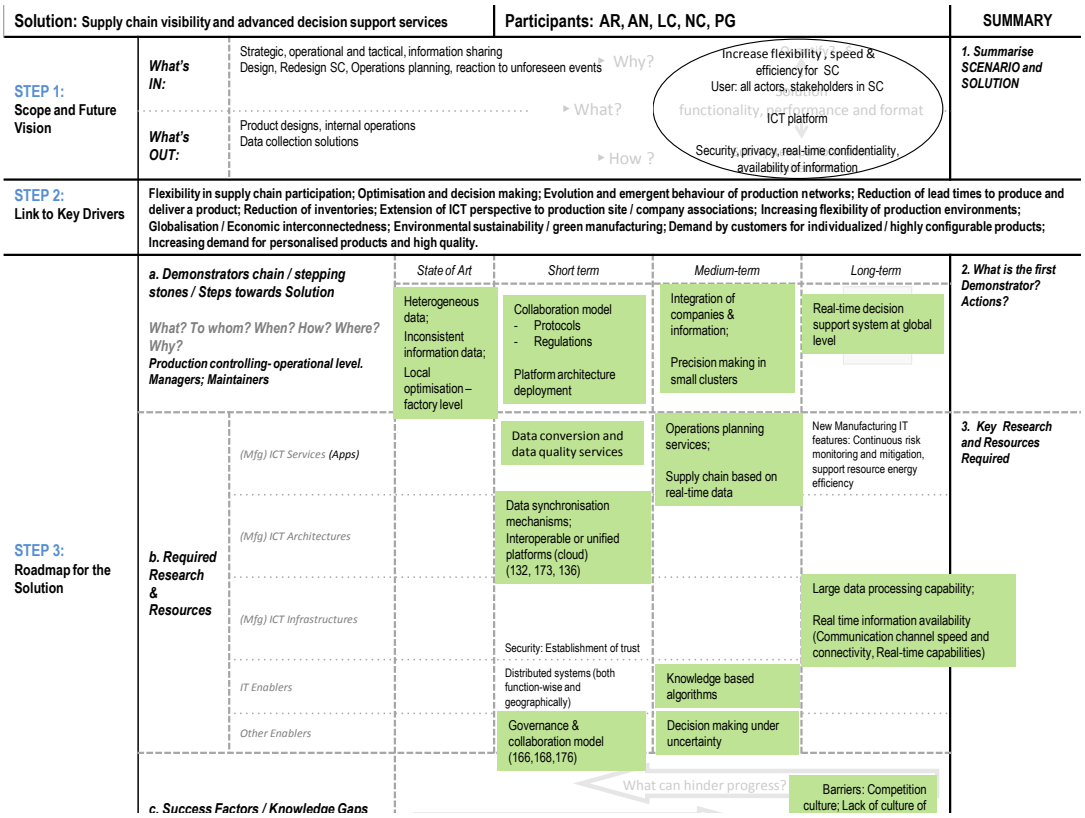


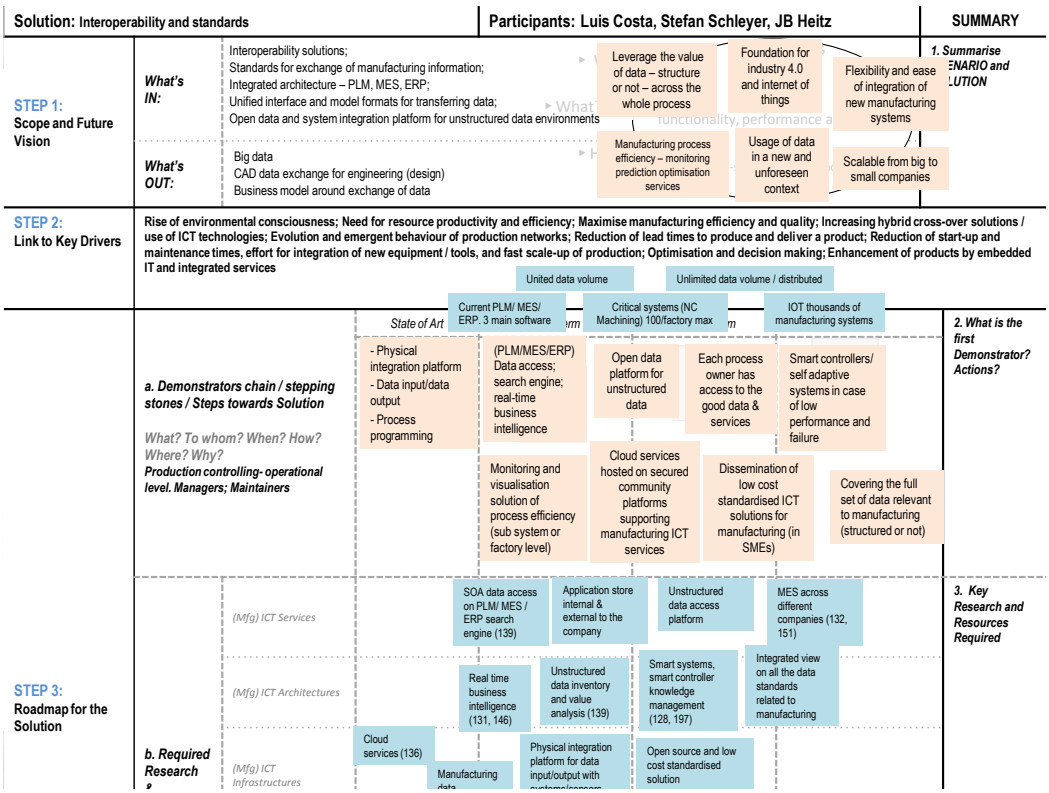


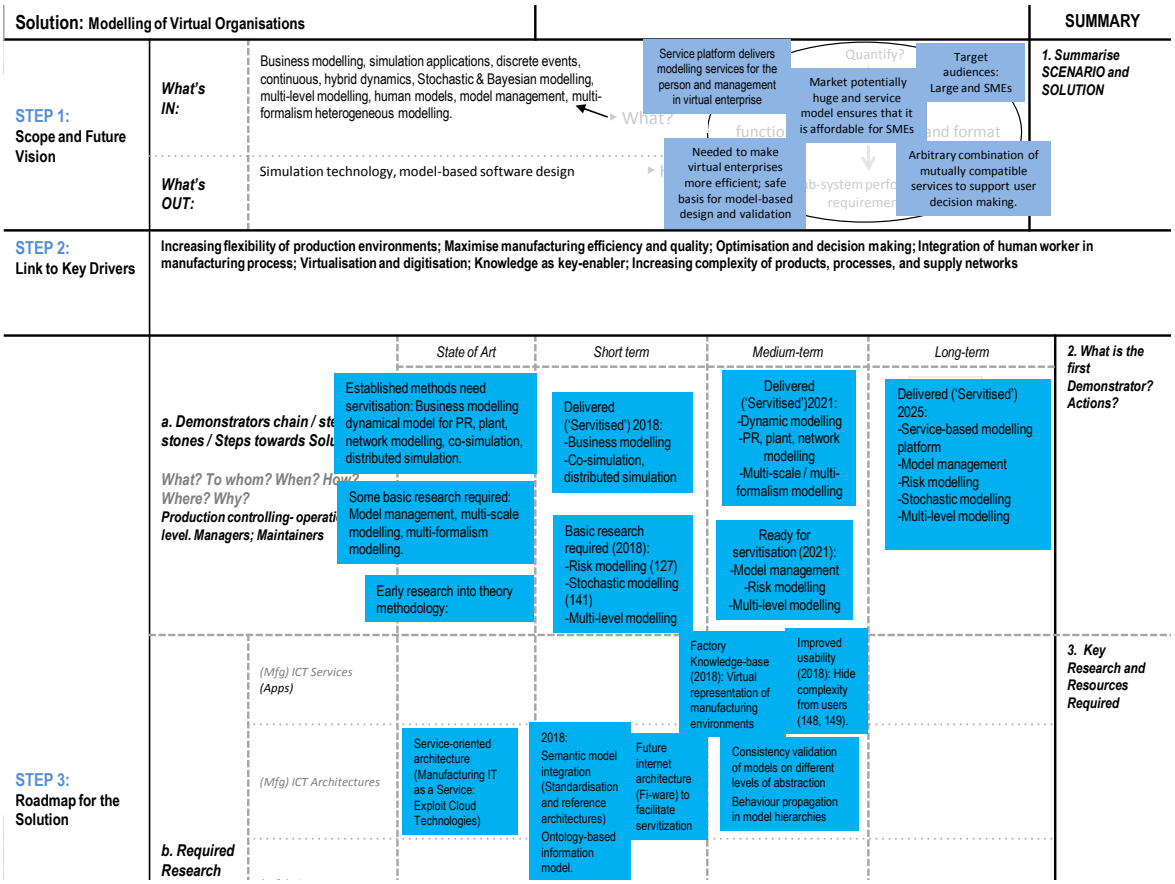
Appendix 5: Electronic Transcription of Workshop Outputs



Solution: Real time data acquisition and analysis			**Participants:**			**SUMMARY**
STEP 1: Scope and Future Vision	***What's IN:***	- Sensing, communication; - Filtering, data fusion; data mining - Visualization tools; user interfaces - Condition monitoring; performance optimization; decision support sustainability, quality control; predictive maintenance	▸ Why?	Quantify? $ Optimization, availability, situational awareness (throughput, sustainability, quality control, performance) Right data → Right person (delegating authorities for automatic decisions) → Right time		***1. Summarise SCENARIO and SOLUTION***
	What's OUT:	Model-generated data	▸ What?			
			▸ How ?	Acquire and transmit data in real time. smart sensors, communication, processing, storage		
STEP 2: Link to Key Drivers	**Maximise manufacturing efficiency and quality; Increasing complexity of products, processes, and supply networks; Need for resource productivity and efficiency Increasing demand for personalised products and high quality; Optimisation and decision making; Rising energy costs Innovation and new technologies; Extension of ICT perspective to production site / company associations**					
STEP 3: Roadmap for the Solution			*State of Art*	*Short term (5yrs)*	*Medium-term (8-10yrs)*	*Long-term (15-20yrs)*	***2. What is the first Demonstrator? Actions?***
	a. Demonstrators chain / stepping stones / Steps towards Solution *What? To whom? When? How? Where? Why?* ***Production controlling- operational level. Managers; Maintainers***		Partial monitoring - condition monitoring -quality control (batch). Historical decision support	Full monitoring to provide data in real time	Situational awareness (FULL!) Data mining. Analytics and visualization tools.	-Contact awareness -Practice decision support -High availability by predictive maintenance -Cloud loop factory level control	
		(Mfg) ICT Services ***(Apps)***		Storage: -Factory knowledge base: Data consistency by means of (standardised) semantic models / system descriptions. -Real-time monitoring. -(136, 137, 146)	-Multi-nodal user interfaces. -Big Data: Data analysis / - Data fusion. -New Manufacturing IT features: support resource energy efficiency. -(126, 127, 128, 145,158) -Virtual representation	-Improved usability: context-aware user interfaces and user-specific adaption -Big Data: - Prediction/Forecasting and decision making (e.g. for factory optimisation) - local or global.	***3. Key Research and Resources Required***
		(Mfg) ICT Architectures		Distributed data collection and data centre	Cloud data mining and analytics	-Distributed databases, data-streaming. -Event-driven systems / reactive (publish/subscribe). -New Manufacturing IT features: Exploit CEP (Complex Event Processing) Technologies	
	b. Required			Intelligent components /			


Solution: Supply chain visibility and advanced decision support services
Participants: AR, AN, LC, NC, PG
SUMMARY
STEP 1: Scope and Future Vision
What's IN:
Strategic, operational and tactical, information sharing
Design, Redesign SC, Operations planning, reaction to unforeseen events
What's OUT:
Product designs, internal operations
Data collection solutions
Why?
What?
How ?
Increase flexibility , speed & efficiency for SC
User: all actors, stakeholders in SC
functionality, performance and format
ICT platform
Security, privacy, real-time confidentiality, availability of information
1. Summarise SCENARIO and SOLUTION
STEP 2: Link to Key Drivers
Flexibility in supply chain participation; Optimisation and decision making; Evolution and emergent behaviour of production networks; Reduction of lead times to produce and deliver a product; Reduction of inventories; Extension of ICT perspective to production site / company associations; Increasing flexibility of production environments; Globalisation / Economic interconnectedness; Environmental sustainability / green manufacturing; Demand by customers for individualized / highly configurable products; Increasing demand for personalised products and high quality.
STEP 3: Roadmap for the Solution
a. Demonstrators chain / stepping stones / Steps towards Solution
What? To whom? When? How? Where? Why?
Production controlling- operational level. Managers; Maintainers
State of Art
Short term
Medium-term
Long-term
Heterogeneous data;
Inconsistent information data;
Local optimisation – factory level
Collaboration model
- Protocols
- Regulations
Platform architecture deployment
Integration of companies & information;
Precision making in small clusters
Real-time decision support system at global level
2. What is the first Demonstrator? Actions?
b. Required Research & Resources
(Mfg) ICT Services (Apps)
(Mfg) ICT Architectures
(Mfg) ICT Infrastructures
IT Enablers
Other Enablers
Data conversion and data quality services
Data synchronisation mechanisms; Interoperable or unified platforms (cloud) (132, 173, 136)
Security: Establishment of trust
Distributed systems (both function-wise and geographically)
Governance & collaboration model (166,168,176)
Operations planning services;
Supply chain based on real-time data
Knowledge based algorithms
Decision making under uncertainty
New Manufacturing IT features: Continuous risk monitoring and mitigation, support resource energy efficiency
Large data processing capability;
Real time information availability (Communication channel speed and connectivity, Real-time capabilities)
3. Key Research and Resources Required
What can hinder progress?
c. Success Factors / Knowledge Gaps
Barriers: Competition culture; Lack of culture of


Solution: Interoperability and standards
Participants: Luis Costa, Stefan Schleyer, JB Heitz
SUMMARY
STEP 1: Scope and Future Vision
What's IN:
Interoperability solutions;
Standards for exchange of manufacturing information;
Integrated architecture – PLM, MES, ERP;
Unified interface and model formats for transferring data;
Open data and system integration platform for unstructured data environments
What's OUT:
Big data
CAD data exchange for engineering (design)
Business model around exchange of data
Leverage the value of data – structure or not – across the whole process
Foundation for industry 4.0 and internet of things
Flexibility and ease of integration of new manufacturing systems
Manufacturing process efficiency – monitoring prediction optimisation services
Usage of data in a new and unforeseen context
Scalable from big to small companies
1. Summarise SCENARIO and SOLUTION
STEP 2: Link to Key Drivers
Rise of environmental consciousness; Need for resource productivity and efficiency; Maximise manufacturing efficiency and quality; Increasing hybrid cross-over solutions / use of ICT technologies; Evolution and emergent behaviour of production networks; Reduction of lead times to produce and deliver a product; Reduction of start-up and maintenance times, effort for integration of new equipment / tools, and fast scale-up of production; Optimisation and decision making; Enhancement of products by embedded IT and integrated services
United data volume
Unlimited data volume / distributed
STEP 3: Roadmap for the Solution
a. Demonstrators chain / stepping stones / Steps towards Solution
What? To whom? When? How? Where? Why?
Production controlling- operational level. Managers; Maintainers
State of Art
Current PLM/ MES/ ERP. 3 main software
Critical systems (NC Machining) 100/factory max
IOT thousands of manufacturing systems
- Physical integration platform
- Data input/data output
- Process programming
(PLM/MES/ERP) Data access; search engine; real-time business intelligence
Open data platform for unstructured data
Each process owner has access to the good data & services
Smart controllers/ self adaptive systems in case of low performance and failure
Monitoring and visualisation solution of process efficiency (sub system or factory level)
Cloud services hosted on secured community platforms supporting manufacturing ICT services
Dissemination of low cost standardised ICT solutions for manufacturing (in SMEs)
Covering the full set of data relevant to manufacturing (structured or not)
2. What is the first Demonstrator? Actions?
b. Required Research
(Mfg) ICT Services
(Mfg) ICT Architectures
(Mfg) ICT Infrastructures
SOA data access on PLM/ MES / ERP search engine (139)
Application store internal & external to the company
Unstructured data access platform
MES across different companies (132, 151)
Real time business intelligence (131, 146)
Unstructured data inventory and value analysis (139)
Smart systems, smart controller knowledge management (128, 197)
Integrated view on all the data standards related to manufacturing
Cloud services (136)
Manufacturing data
Physical integration platform for data input/output with
Open source and low cost standardised solution
3. Key Research and Resources Required


Solution: Modelling of Virtual Organisations
SUMMARY
STEP 1: Scope and Future Vision
What's IN:
Business modelling, simulation applications, discrete events, continuous, hybrid dynamics, Stochastic & Bayesian modelling, multi-level modelling, human models, model management, multi-formalism heterogeneous modelling.
What's OUT:
Simulation technology, model-based software design
Service platform delivers modelling services for the person and management in virtual enterprise
Market potentially huge and service model ensures that it is affordable for SMEs
Target audiences: Large and SMEs
Needed to make virtual enterprises more efficient; safe basis for model-based design and validation
Arbitrary combination of mutually compatible services to support user decision making.
1. Summarise SCENARIO and SOLUTION
STEP 2: Link to Key Drivers
Increasing flexibility of production environments; Maximise manufacturing efficiency and quality; Optimisation and decision making; Integration of human worker in manufacturing process; Virtualisation and digitisation; Knowledge as key-enabler; Increasing complexity of products, processes, and supply networks
State of Art
Short term
Medium-term
Long-term
2. What is the first Demonstrator? Actions?
a. Demonstrators chain / stones / Steps towards Solu
What? To whom? When? How? Where? Why?
Production controlling- operati level. Managers; Maintainers
Established methods need servitisation: Business modelling dynamical model for PR, plant, network modelling, co-simulation, distributed simulation.
Some basic research required: Model management, multi-scale modelling, multi-formalism modelling.
Early research into theory methodology:
Delivered ('Servitised') 2018: -Business modelling -Co-simulation, distributed simulation
Basic research required (2018): -Risk modelling (127) -Stochastic modelling (141) -Multi-level modelling
Delivered ('Servitised')2021: -Dynamic modelling -PR, plant, network modelling -Multi-scale / multi-formalism modelling
Ready for servitisation (2021): -Model management -Risk modelling -Multi-level modelling
Delivered ('Servitised') 2025: -Service-based modelling platform -Model management -Risk modelling -Stochastic modelling -Multi-level modelling
STEP 3: Roadmap for the Solution
(Mfg) ICT Services (Apps)
(Mfg) ICT Architectures
b. Required Research
Factory Knowledge-base (2018): Virtual representation of manufacturing environments
Improved usability (2018): Hide complexity from users (148, 149).
Service-oriented architecture (Manufacturing IT as a Service: Exploit Cloud Technologies)
2018: Semantic model integration (Standardisation and reference architectures) Ontology-based information model.
Future internet architecture (Fi-ware) to facilitate servitization
Consistency validation of models on different levels of abstraction
Behaviour propagation in model hierarchies
3. Key Research and Resources Required