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Strategic Research and Engineering Roadmap

in the domain of Integrated Multi-site Manufacturing

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

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EXECUTIVE SUMMARY

Multi-site manufacturing system of systems (SoS) are complex systems of geographically dispersed manufacturing organisations that self-organise in response to customers' needs, dissolving once these needs have been satisfied. This report describes the process through which a roadmap of multi-site manufacturing SoS has been developed through a combination of two surveys and a roadmapping workshop with academic and industry experts. The roadmap that is the product of this process (Figure 1 below) depicts the five most significant technological advances that have been identified as necessary for the realisation of the future manufacturing vision, along with detailing the current needs, the industry drivers and enablers that will support the development of these technologies. The report concludes by providing a number of policy recommendations, spanning both the technological and socio-economic.

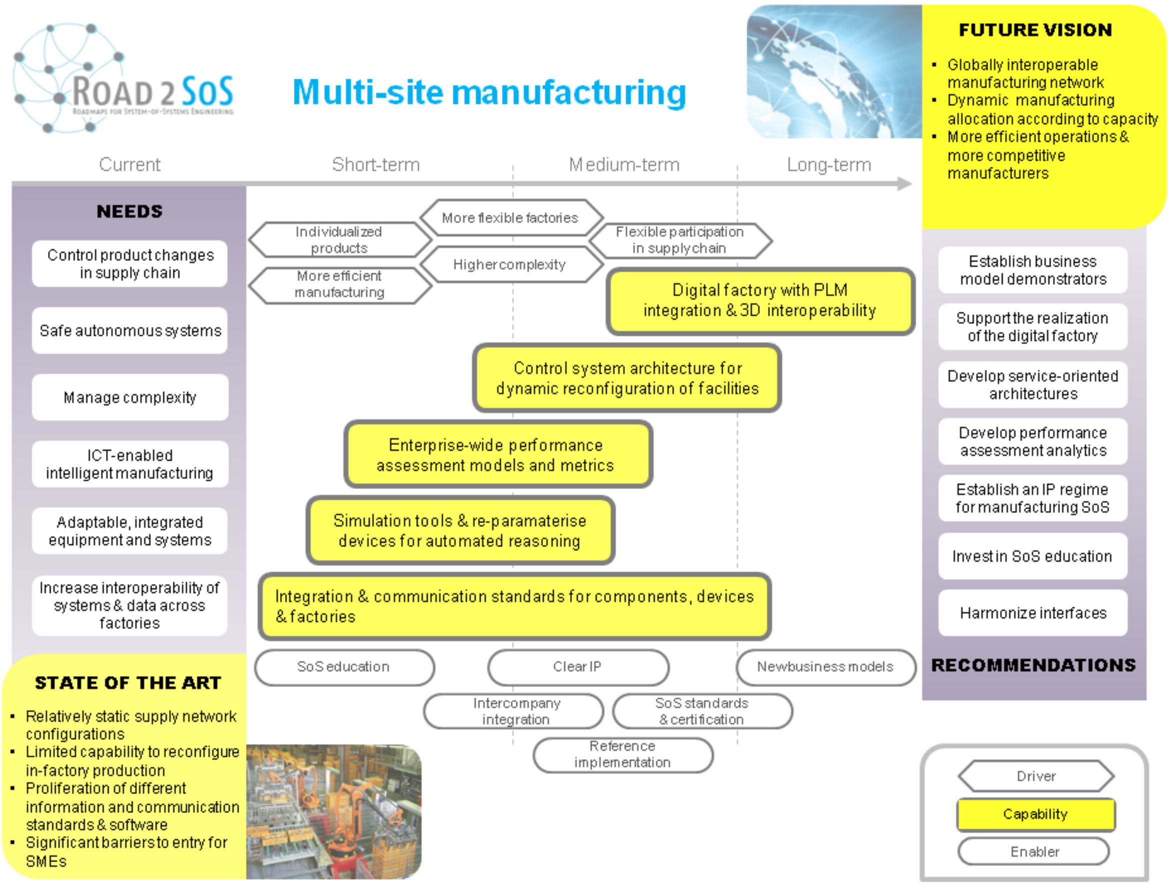


Figure 1 - Simplified SoS roadmap for the domain of Multi-site manufacturing

1. INTRODUCTION

The trend of an increasing interconnection of formerly self-contained systems into Systems of Systems (SoS) is expected to yield – by synergy and emergence – unprecedented capabilities in many domains. SoS approaches can be expected to improve the competitive position of companies, especially SMEs, and help tackle a range of societal challenges.

To effectively design, develop, run, and maintain SoS, a range of technologies and capabilities are necessary. To provide a clear view of the required technologies/capabilities but also barriers and enabler relevant with regards to SoS, the Road2SoS project develops research and engineering roadmaps in four selected application domains: (1) integrated multi-site manufacturing, (2) multimodal traffic control, (3) smart grid and distributed energy generation, and (4) emergency and crisis management. The identification of common strands arising independently in several application domains leads to recommendations for research priorities and shall inform future SoS-related R&D in Europe.

This report provides an overview of the roadmap developed in the domain of integrated multi-site manufacturing. Following a description of the roadmapping methodology, the roadmap's main aspects will be presented, covering the range of socio-economic trends, drivers and needs, along with the technological challenges and the enablers that are facilitating SoS-approaches modes.

2. METHODOLOGY

There are two contrasting approaches to creating roadmaps. The first approach, a technology-push prospective roadmap, starts with existing research projects and fills in the remainder of the roadmap to identify the diversity of capabilities to which this research could lead. In contrast, the second approach, a requirements-pull prospective roadmap, begins by envisioning the desired technology, system or other end products, before working backwards to identify the critical research and development required to fill in the remainder of the roadmap to arrive at these products.

In the Road2SoS project, roadmaps have been created by combining the technology-push and requirements-pull perspectives. Starting with existing science and technology development programs which are more technology- or requirements-driven, research gaps were identified that obstruct forward progress and the diversity of end products to which successful development could lead (Figure 2).

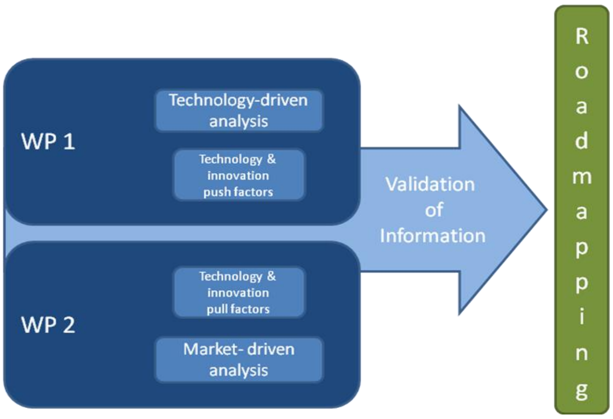


Figure 2 - Representation of the integration of the results coming from the technology-driven/push and the market-driven/pull analyses

Prospective analyses cover time frames from the present to typically a decade or more into the future. A time frame of 15 years into the future was selected due to the EC's planning horizons and objectives and the need to include SME participation. The roadmaps developed present information at a medium aggregation level.

2.1 Common roadmap architecture and workshop process

A common roadmap architecture and workshop process was developed and adopted in order to facilitate the collection and analysis of similar data across the four domains examined in Road2SoS, enabling the identification of key drivers, technologies and enablers that are relevant to make SoS approaches work in the selected application domains.

This common roadmap architecture (Figure 3) considers three time periods on its horizontal axis: the short-term (+5 years), the medium-term (+10 years), and the long-term (+15 years). On the vertical axis, four layers, each comprising a number of sub-layers, are included.

2.2 Phases of development

The roadmaps were developed through the following three phases.

Phase 1: Data collection and analysis
During this phase, the collection and analysis of RTD and innovation results (push perspective), domain needs and relevant trends/drivers (pull perspective) took place. This was conducted through literature review, interviews and surveys with stakeholders from research institutions, companies and governmental organisations.

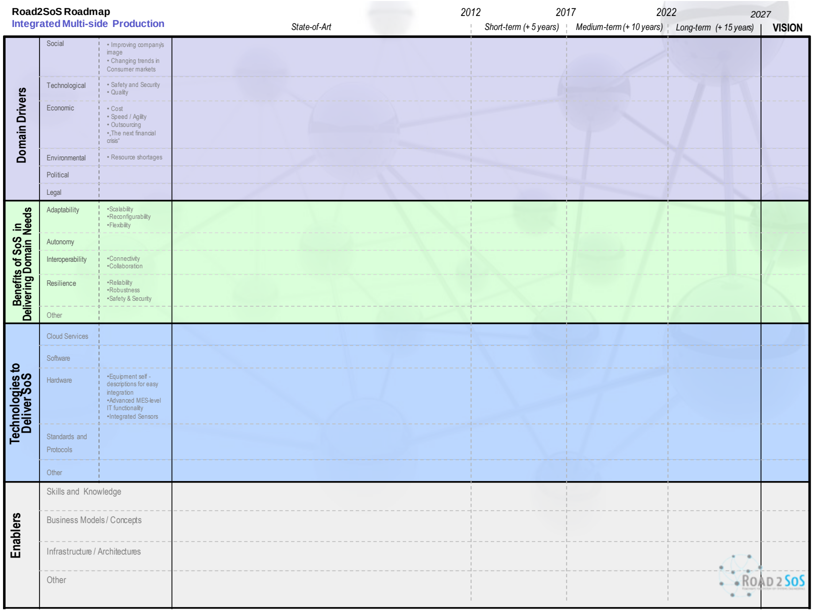


Figure 3 - Common roadmap architecture

Phase 2: Development of technology roadmaps

In this phase, a roadmapping workshop was used to validate the Phase 1 findings, complement them, and analyze them for mutual implications of push and pull perspective. Aspects captured in the roadmap furthermore underwent prioritization and in-depth discussions were devoted to top-priority aspects.

The full-day roadmapping workshop, 13th September 2012 in Brussels, involved a group of 14 selected experts from industry, academia and governmental organisations across Europe.

Phase 3: Cross-sectoral approach

In this final phase of development of the roadmaps, cross-domain analysis for common drivers, technologies and enablers arising independently in two or more application domains was conducted. The results were validated by means of several case studies in each of the four domains.

3. ROADMAP

The result of the roadmapping process is shown in Figure 4. Each item is colour-coded to show its relative priority against other items within its layer. In the following sections, the highest priority items are explained in turn, beginning with the domain vision that was presented to participants at the roadmapping workshops. A glossary of the terms contained within the roadmap is included in Appendix A.

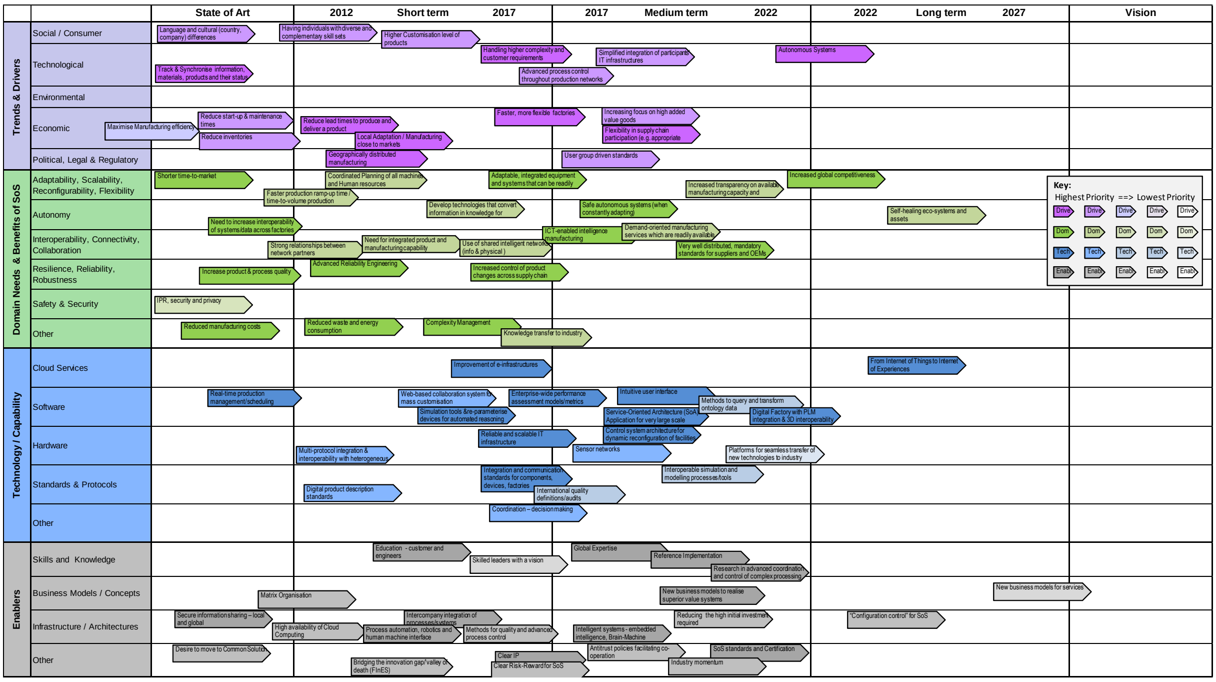


Figure 4 - Roadmap Landscape

3.1 *Possible future vision for the domain*[3]

The vision for multi-site manufacturing is for a global network of interoperable factories, allowing the dynamic allocation of manufacturing. In such a scenario, manufacturing enterprises will be able to assign production to available capability and capacity, wherever it may be.

Investing in production capabilities can also be very costly and in some sectors the ability to outsource production to the manufacturing SoS may reduce the barriers to market entry. The ability

[3] This vision of multi-site manufacturing was developed through consultation with participants at the Expert Panel meeting in Karlsruhe on 22nd May 2012, and was used to guide participants at subsequent roadmapping workshops.

to 'switch-on' production at such factories can enable companies to respond more rapidly to changes in customer demand as they do not have the sunk costs associated with capital equipment. Economies of scale will not be as significant as they are today; instead the ability to individualize products according to customer demands will be more important.

In order to be able to individualize products, such factories will need to be both reconfigurable and adaptable, with communication interfaces to the outside world that are globally accepted. The dynamic allocation of capacity also holds potential for the more dynamic formation of SoS. While the majority of multi-site manufacturing SoS take the form of supply chains and supply networks, the flexibility that will exist within and across these factories of the future will enable supply and distribution systems to be created more rapidly, and without companies using computer-based auctions to contract for work.

In summary, in this vision, the global manufacturing network will bring about increased transparency on available manufacturing capacity and capability, allowing greater participation from SMEs, and fostering a more efficient manufacturing system in which competition drives down costs.

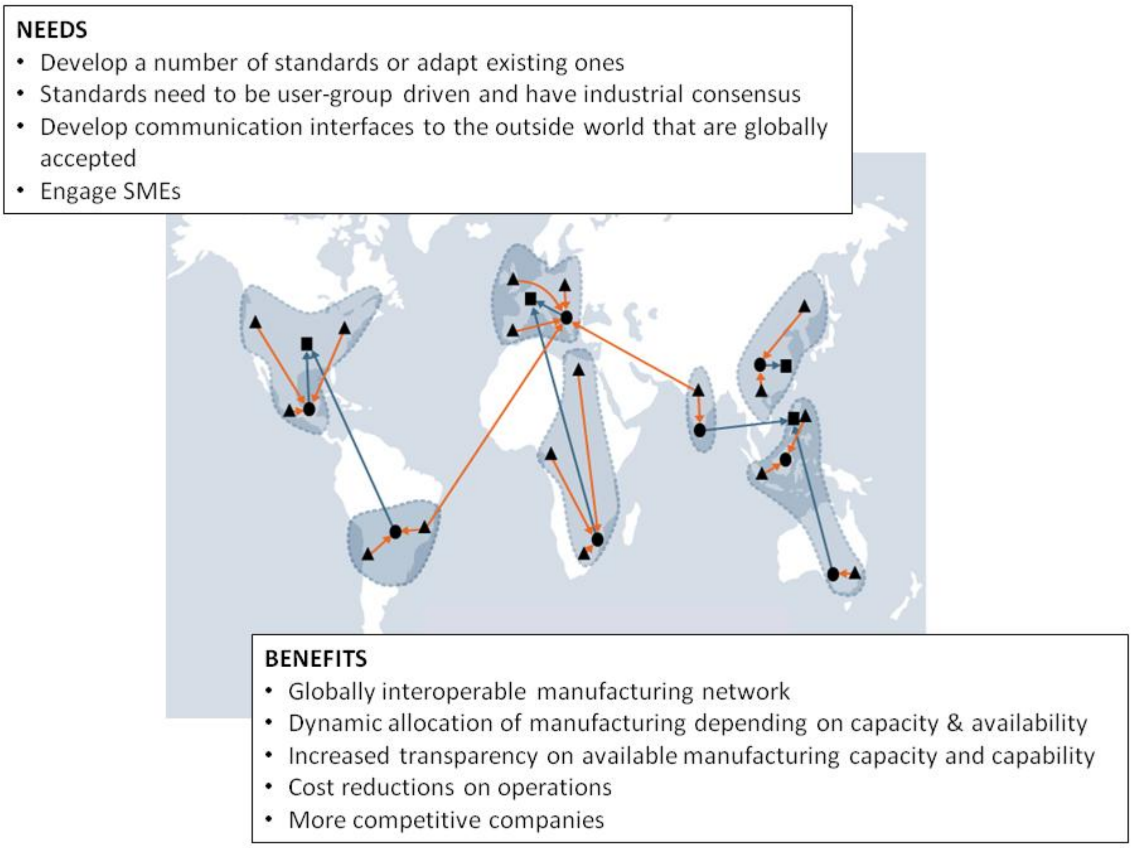


Figure 5 - Future vision of multi-site manufacturing SoS

3.2 Trends and drivers

The top layer of the roadmap pertains to the wider social, technological, environmental, economic and political trends (STEEP) changes that are envisioned that will affect the multi-site manufacturing domain. A detailed view of this layer is depicted in

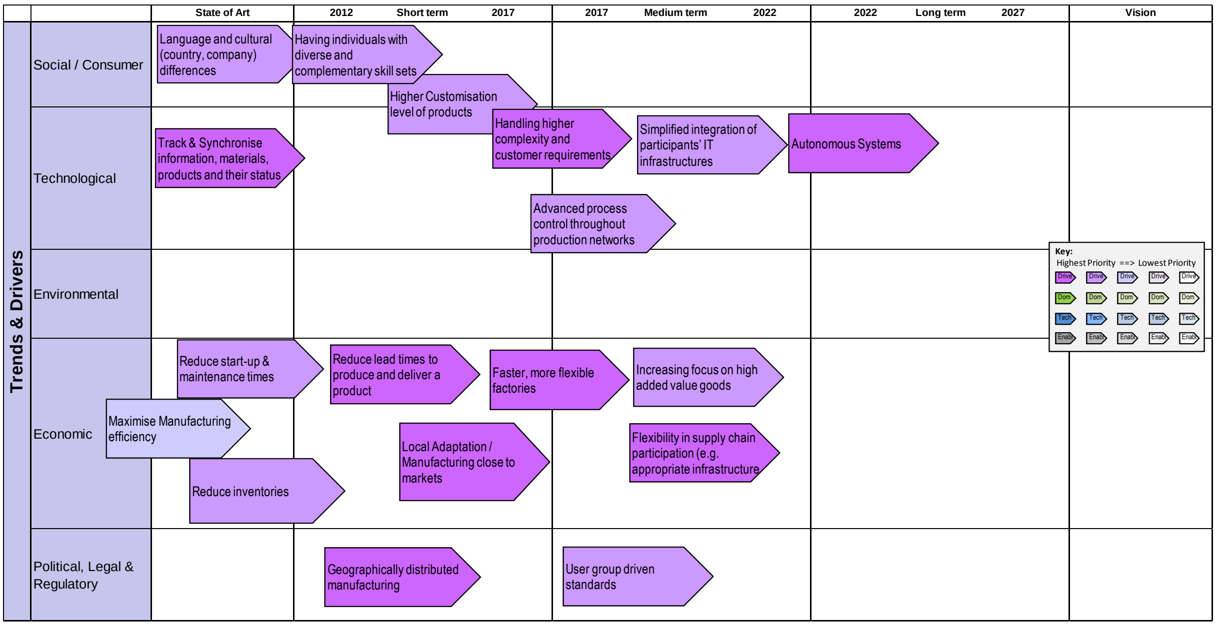
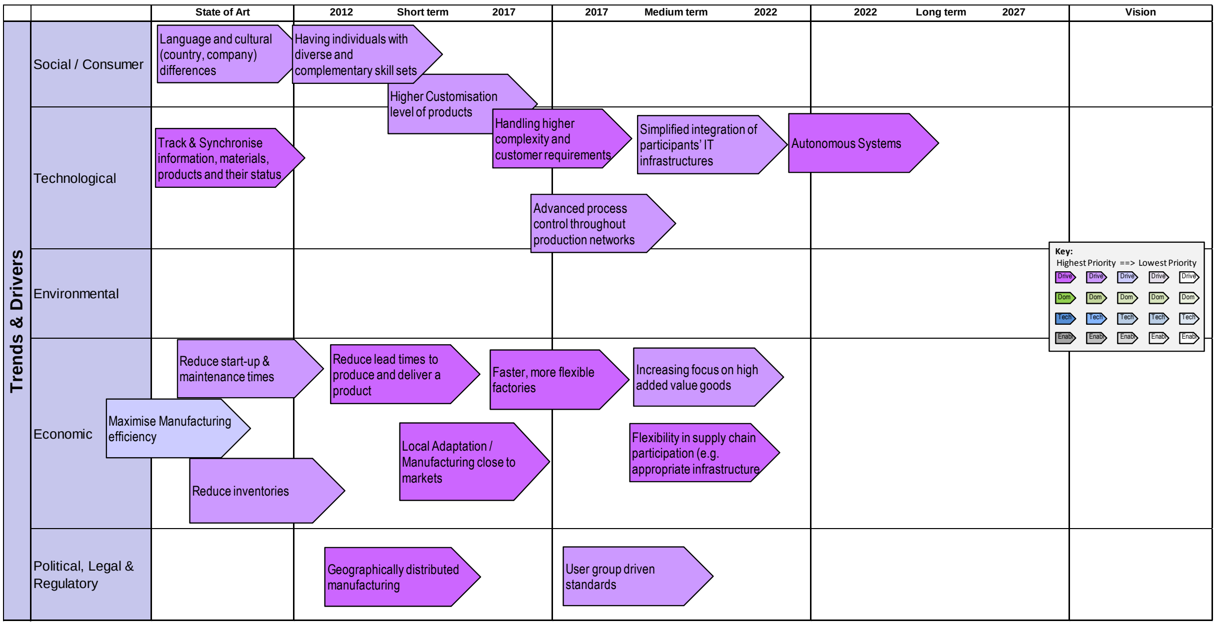


Figure 6.



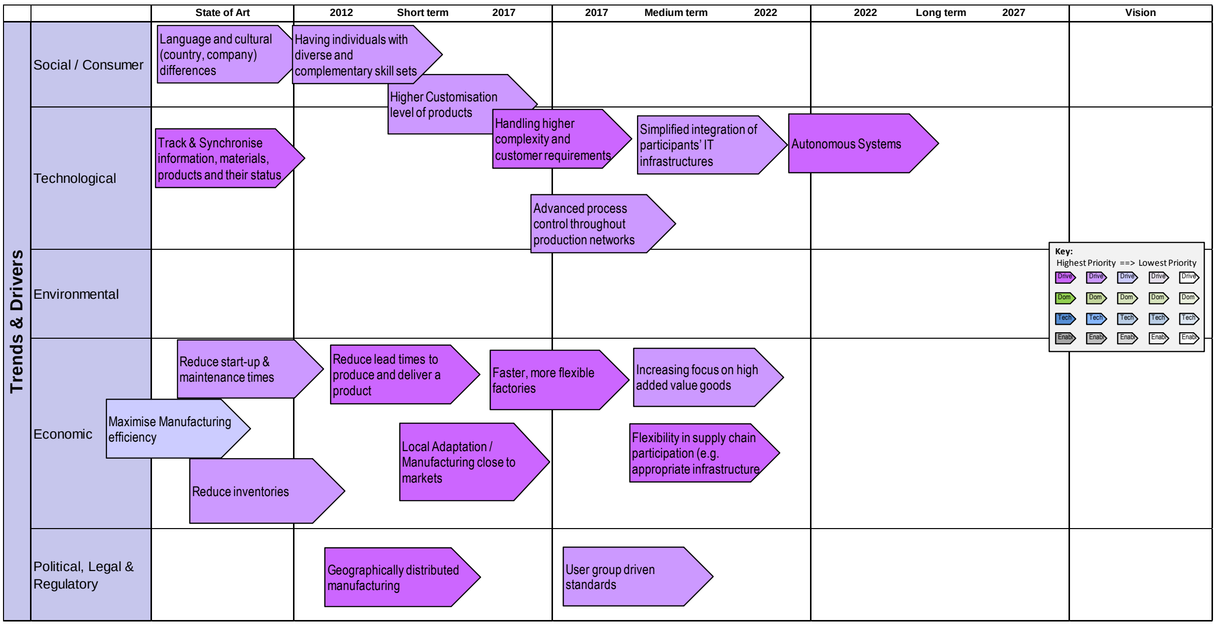


Figure 6 - Trends and drivers

As in Figure 4, the darker shades indicate those items that were identified by roadmapping workshop participants as being of higher significance. The most significant trends and drivers are described in the following sections.

3.2.1 Reduction of costs and lead times / More efficient manufacturing

The need to improve the economics of production, reducing costs and lead times, was identified as the most important trend that is driving change in multi-site manufacturing. These are ever-present drivers, which in recent years have been emphasised through the implementation of lean manufacturing principles and just-in-time production.

3.2.2 Handling higher complexity and customer requirements

Manufacturing has become more complex, in terms of the organization of the supply network, the degree of product customization and satisfying customer requirements. The increasingly complexity of the supply network means that a company must improve its partner management, while the global nature of manufacturing networks means that it has a wider range of potential partners.
Greater attentiveness to customer requirements means the customization and personalization of the product, so increasing the product complexity, and also affecting the supply network configuration as a greater number of manufacturers are involved in the delivery of such products. In combination, these factors require improved transparency of the overall production systems and its related interdependencies.

3.2.3 Faster, more flexible factories and supply chain participation

With the need to deliver customized and personalized products, factories are becoming more flexible in order to rapidly adapt to changing market demands. This not only means that respective interfaces and knowledge about the facilities' capabilities has to be available on-demand, but also that common master data (e.g. to enable the control of product changes across manufacturing environments) has to be synchronized throughout the production network.

3.2.4 Local adaptation/manufacturing close to markets

A further trend which has been identified is the local adaption of production, i.e. manufacturing close to customer markets. This, together with the reduction of waste and resource/energy consumption, contributes to the improved environmental sustainability of production systems. Of course, SoS are not the only way to address these trends, drivers, and needs in manufacturing. However, they can help to overcome the related challenging by providing appropriate architectures and services.

3.3 Domain needs

The second layer of the roadmap pertains to the domain needs and benefits of a multi-site manufacturing SoS. The sub-layers describe key SoS characteristics, including adaptability, autonomy, interoperability, resilience and security. A detailed view of this layer is depicted in Figure 7.

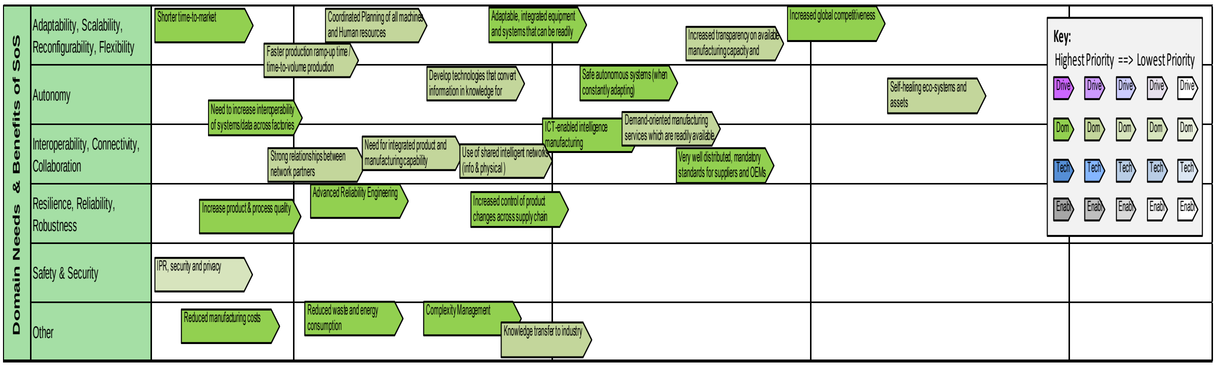


Figure 7 - Domain needs

As in Section 3.2, the highest items are now described in more detail.

3.3.1 Increase interoperability of systems and data across factories

Multi-site manufacturing requires the interconnection of systems across these multiple sites. As manufacturing has become more interconnected and global, this need for interoperability has become of increased significance. The interoperability of systems and data across production networks has to be ensured throughout various layers of the related IT systems. This starts with the vision of adaptable, integrated equipment and systems which enable the implementation of “plug and produce” and involves standardized interfaces for supply chain integration on business, manufacturing process and engineering levels. These have to address not only message-level communication, but also data-level alignment, e.g. by means of semantics.

3.3.2 Adaptable, integrated equipment and systems that can be readily configured

If a dynamically reconfigurable manufacturing SoS is become a reality then the network must be capable of reconfiguration, as must the manufacturing sites within the network. It is this latter need that has been highlighted, with adaptable, integrated equipment and systems necessary that can be rapidly reconfigured in order to respond to the changing requirements of the network and end customers. Current adaptive manufacturing includes single step, flexible reconfiguration and process technology that can adapt to feedstock of different types and compositions and mass customisation techniques.

3.3.3 Complexity management

There is complexity throughout the manufacturing SoS, from the technical complexity of managing a manufacturing system across multiple sites, to managing the relationships with other manufacturers within the system, and sharing the information across all of these sites. Managing this complexity is a key need as manufacturing systems transition from being a complex system to an SoS, and if the dynamic reconfiguration of the manufacturing SoS is to be realised.

3.3.4 Increased control of product changes across supply chain

Changes in another part of the supply chain affect have consequences for the activities of a manufacturer. Organisations need to manage complex value delivery across the supply chain in multiple locations and exploit ‘economies of small scale’ to develop and produce close to the customer, whoever that might be. Techniques for anticipating changes include real-time market analysis and response and systems to reduce development time. Combining marketing, design, manufacturing, standards, regulations and procurement and early user engagement.

3.4 Key innovation opportunities identified in the domain

In order to address the trends, drivers, and needs explained in Sections 3.2 and 3.3, technologies, capabilities and enablers where identified and assigned. In the following subsections, it is explained why and how those technologies, capabilities, and enablers help to support the trends, drivers, and needs by means of the four priority innovation opportunities identified in the workshop.

	Technologies, Capabilities, Enablers									
Trends, Drivers, Needs	Integration and Communication Standards	Enterprise-wide performance assessment analytics and models	Control system architecture to enable dynamic reconfiguration of assembly, production and transportation	Reliable and scalable IT infrastructure	Digital Factory with PLM integration & 3D interoperability between design and manufacturing 3DMBE	Education - customer and engineers	Global Expertise	Intercompany integration of processes/systems	Clear IP	Research in advanced coordination and control of complex processing systems and fragmented modelling and integration technologies
Reduction of costs and lead times	*	X	X	*		*		*	*	
Handling complexity	X	X	X	X	X	*		X	*	X
Increased flexibility	X		X	X	X	*		X	*	X
Increased interoperability	X	X	X	X	X	*	X	X	*	X
Local adaptation						*			*	
Increased control of product changes across supply chain	X		X	X	X	*		X	*	X

Table 1 - Key innovation opportunities (X = contributes directly, * = contributes indirectly)

SEVENTH FRAMEWORK PROGRAMME

Priority Technologies			Total
A	Integration & Communications standards (Linking People <=> Process <=> Devices)	12	19
B	Enterprise-wide performance assessment analytics & models	9	10
C	Service-Oriented Control system architecture for dynamic reconfiguration	11	13
D	Digital Factory & 3D interoperability between design and manufacturing (3DMBE)	8	15

Trends & Drivers	Reduce lead times to produce and deliver a product	Faster, more flexible factories	Increase interoperability of systems/data across factories	Flexibility in supply chain participation (e.g. appropriate infrastructure and m	Reduce start-up & maintenance times	Local Adaptation / Manufacturing close to markets	Track & Synchronise information, materials, products and their status	Maximise Manufacturing efficiency	Costs / finance structure / accounting models	Increase product & process quality	Geographically distributed manufacturing	Simplified integration of participants' IT infrastructures
	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1	1	1	1	1	1		1	1	1	1
B	1	1	1		1		1	1	1			
C	1	1	1	1		1					1	
D	1	1	1	1	1	1		1		1		
	4	4	4	3	3	3	2	2	2	2	2	1

Domain Needs	Shorter time-to-market	Increased control of product changes across supply chain	Reduced manufacturing costs	Increased global competitiveness	Complexity Management	Very well distributed, mandatory standards for suppliers and OEMs	Adaptable, integrated equipment and systems that can be readily configure	Faster production ramp-up time	Demand-oriented manufacturing services which are readily available, safe,	Common design knowledge	Coordinated Planning of all machines and Human resources	Increased transparency on available manufacturing capacity and capability
	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1	1	1	1	1	1	1	1	1	1	1
B	1	1	1	1	1		1			1	1	1
C	1	1	1	1	1	1	1	1	1		1	1
D	1	1	1	1		1		1	1	1		
	4	4	4	4	3	3	3	3	3	3	3	3

Related Technologies	Simulation tools &re-parameterise devices for automated reasoning	Enterprise-wide performance assessment models/metrics	Control system architecture to enable dynamic reconfiguration of assembly,	Real-time production management/scheduling	Integration Standards for components, devices and factories	Service-Oriented Architecture (SoA). Application for very large scale distribu	Digital product description standards	Coordination – decision making	Process automation, robotics and human machine interface	Communication Standards	Improvement of e-infrastructures	Web-based collaboration system for mass customisation
	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1	1		1	1	1	1	1	1	1	1
B	1	1		1	1			1				
C	1		1	1	1	1	1	1				1
D	1	1	1	1		1	1		1	1	1	
	4	3	3	3	3	3	3	3	2	2	2	2

Enablers	Education - customer and engineers	Global Expertise	New business models to realise superior value systems	Secure information sharing – local and global	SoS standards and Certification	Intercompany integration of processes/systems	Intelligent systems - embedded intelligence, Brain-Machine interaction	Enterprise-wide performance assessment models/metrics	Research in advanced coordination and control of complex processing syst	Reference Implementation	Matrix Organisation	Clear IP
	1	2	3	4	5	6	7	8	9	10	11	12
A	1	1		1	1	1	1	1		1		
B		1	1			1		1	1			
C	1		1	1	1		1					
D	1	1	1	1	1						1	
	3	3	3	3	3	2	2	2	1	1	1	0

Figure 8 - Linkages between the four main technological opportunities and the trends and drivers, domain needs, related technologies, and enablers

3.4.1 Integration and communication standards

Standards need to be developed to provide integration across multiple manufacturing sites so that diversity can be included and heterogeneity mitigated, so that knowledge can be shared more easily, and so that manufacturers can become more agile to changing customer requirements. Standards supporting these features would contribute to more effective set-up and management of multi-site manufacturing SoS by means of simplifying communication among people, processes, devices, etc. with regard to syntax and semantics. The latter are required within the manufacturing SoS, along with a constraintless factory demonstrator to show how the communication standards can be applied in operation. As integration and communication standards help to make information exchange more effective and easy, they also contribute to the handling of complexity, increase flexibility and interoperability and help to deal with product changes across the supply chain.

Large enterprises with de facto standards are significant barriers to the creation of such standards as they protect their existing products, including lobbying activities to influence the development of standards and regulations. Public-private partnerships and joint ventures within the industry may enable these barriers to be overcome.

3.4.2 Enterprise-wide performance assessment analytics & models

Improved analytics and models offer the potential for better collaboration between different SoS, the ability to reconfigure the manufacturing system based on real-time data, and higher end-to-end reliability. A skills deficit is a barrier here, with systems engineers requiring multi-disciplinary design skills. Furthermore, the availability of necessary information has to be overcome in order to enable those enterprise-wide features, as well as the integration of related systems.

Besides this development of these analytics and models is limited by the short term views of management, with organizational buy-in essential if support for the cost of development is to be found. The formation of pre-competitive consortia using public funding may be one way of ensuring their development.

3.4.3 Service-Oriented Control System architecture for Dynamic reconfiguration

The creation of service-oriented control system architectures for dynamic reconfiguration will allow more open engineering and manufacturing, with engineer-to-order reducing time to market and improved control of product changes. Achieving this is difficult because there is a lack of intelligence in the system, in terms of both people and processes. Knowledge transfer is also a barrier but better infrastructure could allow it to become an enabler in the future.

The intention of such an infrastructure is to enable dynamic reconfiguration of assembly, production, and transportation, and herewith to react faster to changing market demands. However, also the IT systems behind should be reconfigurable in order to put together functionalities as needed, to scale up or down functionality and performance, and to ensure reliability. Those technologies and capabilities are known in principle from IT concepts. However, they are often not implemented in manufacturing environments as they would have to be integrated with existing systems.

3.4.4 Digital Factory & 3D interoperability between design and manufacturing (3DMBE)

A completely integrated digital factory environment for the whole multi-site manufacturing SoS would enable and accelerate the joint planning of new products, optimization of production, and herewith to increase competitiveness of the SoS, also be reducing costs or development effort.

However, at present no integrated set of tools and processes exists for the simulation of manufacturing operations. The availability of consistent data will allow integration and reconfiguration, and the added benefits of greater reliability and security. The absence of SoS thinking in this area is leading to local optimization, with seed funding thought necessary to define the interfaces and standards.

In order to overcome these issues, it is necessary to develop appropriate tools / technologies on the one hand, but also to clarify open issues with regard to IP or acceptance of SoS in multi-site manufacturing. Especially the latter is a single-point-of-failure for SoS in manufacturing as stakeholders have to know about SoS concepts and advantages which results in a need for respective education.

Figure 9 shows the technologies and capabilities layer of the roadmap, including sub-layers for hardware, software, standards and protocols, cloud services and other technologies. During the roadmapping process, the following topics have been identified to be relevant technologies or capabilities. They are necessary to be developed or applied in order to implement SoS for multi-site industrial production.

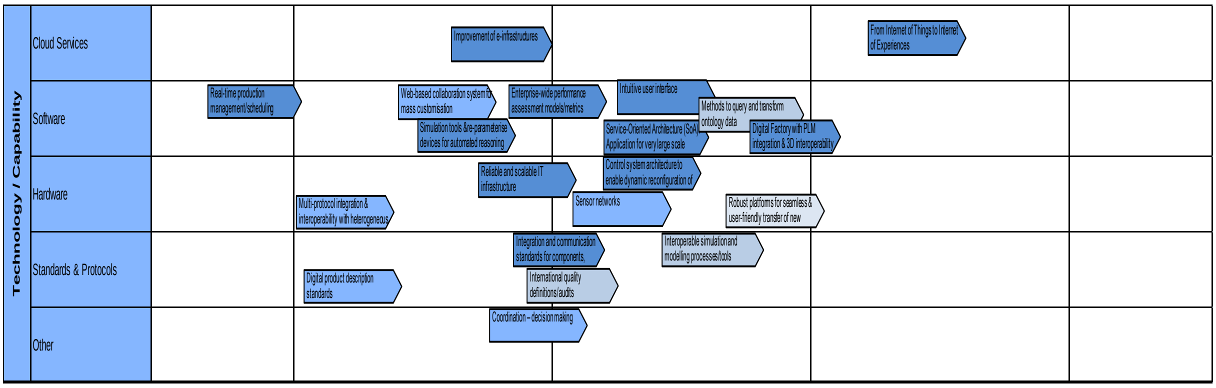


Figure 9 - Technologies and capabilities

3.4.5 Integration and communication standards

Integration and communication standards are one of the most important technologies which are needed in order to apply sound multi-site industrial production. Those standards have to be set up among various actors and components of a production network such as people, processes, devices, technologies, etc. They have to specify syntax and semantics for a certain domain or even globally in order to enable simplified information exchange and communication among systems without any additional effort or misunderstandings.

Nowadays, there exist integration and communication standards. However, they are restricted to certain industries or application cases and – even more important – there is not one standard for each case but various ones (e.g. company-specific quasi-standards). In order to enable SoS in manufacturing, those standards have to be harmonized or transferred into a standard which is universally applicable by organizations that intend to participate in multi-site manufacturing SoS.
Further support for the establishment of appropriate standards would be a certification of these standards or organizations which apply them.

3.4.6 Enterprise-wide performance assessment analytics and models

There are some research approaches which aim e.g. at integrated APC (Advanced Process Control) across the production network. Besides this, there exist models for the optimization of value creation in supply chains. However, comprehensive enterprise-wide performance and assessment analytics with regard to technical and economic issues do almost not exist at all in practice. This means that those analytics and models have to be developed. Therefore, it is necessary to consider appropriate algorithms and tools, integration standards, IP protection, etc.

In a second step, the application of those technologies enable to improve the exploitation of planning tools, e.g. for scheduling, order dispatching, or production process updates throughout the production network. For that, decision making techniques play an important role. However, it has to be ensured that all participants of the manufacturing SoS are treated fair. Negative side-effects in case every sub-system optimizes for its own purpose have to be avoided.

3.4.7 Control system architecture to enable dynamic reconfiguration of assembly, production and transportation

As faster changes of market demands cause the demand for flexibility with regard to products and their production, the manufacturing environment as a whole is required to become more flexible. In order to achieve this, reconfigurable concepts for products, production, and supply chains / transportations are needed. These concepts also have to consider “plug and produce” aspects, flexibility and scalability with regard to the type of products produced (e.g. integration of additional processes, the amount of products produced (e.g. increasing throughput) and the markets addressed (e.g. roll-out of products to / manufacturing in additional regional markets). This requires to integrate self-organising or self-adapting aspects to the architectures.

The occurrence of emerging behavior (positive and negative) also plays an important role when designing reconfigurable SoS with regard to factory, automation, and IT infrastructures since unexpected demands or exceptions may require the integration of additional components, or to remove or exchange certain components.

Furthermore, it has to be taken into account that usually new systems are not established independently, but evolve from existing ones. Therefore, appropriate migration strategies have to be covered by respective architecture concepts. Partially, those concepts are already considered in research projects. However, comprehensive approaches that involve not only products or hardware-setup of manufacturing or software systems or supply chain setup are rare.

In order to realize them, control system architectures are needed which enable dynamic reconfiguration of assembly, production, and transportation. Those architectures can e.g. be service-oriented and involve applications for very large scale distributed systems in process control.

Governance structures for centralized (e.g. for one large OEM integrating its suppliers) or decentralized (e.g. for SME associations) systems should be considered, too during drafting appropriate architectures.

3.4.8 Digital Factory with PLM integration & 3D interoperability between design and manufacturing (3DMBE)

For the realization of integrated digital factory with PLM integration and 3D interoperability between design and manufacturing (3DMBE), several supporting technologies and capabilities have to be developed. Those range from design and manufacturing interoperability standards to software systems that are able of recognizing e.g. product changes made somewhere else and to adapt to these changes automatically, e.g. by updating respective equipment parameters. Those software systems have not only to integrate design and manufacturing features, but also other life cycle phases of products but also production environment.

3.4.9 Other

Further Technologies and capabilities that would drive forward the application of SoS in the manufacturing domain are:

- Process automation, robotics and human machine interface: This means that the optimization of these technologies and capabilities supports the application of SoS in manufacturing in general
- (Physical) situation recognition and sensor / actuator integration to sub-components of the overall production environment. This would enable to better keep track of the overall production processes and progress in order to allow better performance assessment and planning features.
- Real-time customer-oriented production management/scheduling, i.e. the ad-hoc processing of orders on an IT level throughout the whole production network would increase the responsiveness of multi-site manufacturing SoS considerably. Therefore, appropriate communication technologies, access right definitions, and global optimization models are needed.

3.5 Enablers

The enablers for SoS in multi-site industrial manufacturing which have been identified during the roadmapping process are mainly of non-technical nature. These are depicted in Figure 10, and include sub-layers on skills and knowledge, business models and concepts, infrastructures and architectures, and other enablers outside of those categories. Such enablers are essential for the establishment of SoS in production as they are a pre-condition for their acceptance in many cases.

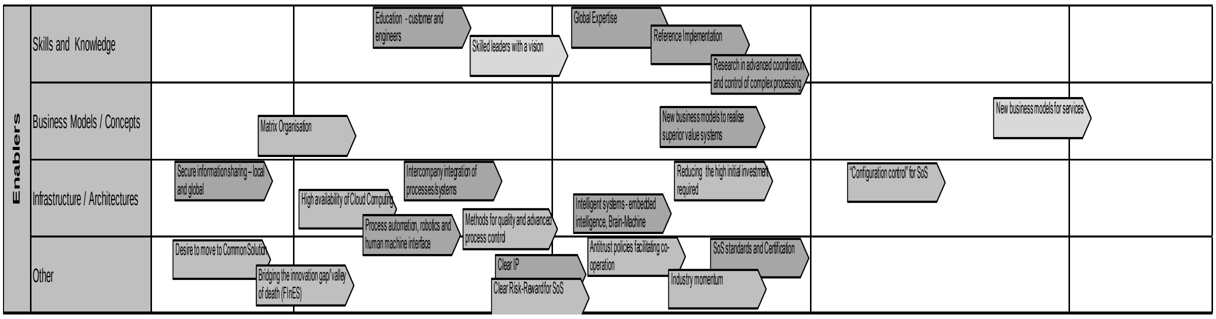


Figure 10 – Enablers

3.5.1 Education – customer and engineers

Education of SoS applicants and users is a high-priority enabler for SoS in production as it is the pre-condition for understanding and acceptance of SoS. Especially in the manufacturing domain, a conservative mind-set is present which tells stakeholders to never change a running system and to be very sensitive with regard to IP and security issues. This can only be overcome by education which tells stakeholders about the advantages of SoS applications and how issues they regard as critical are resolved there.

3.5.2 Global Expertise

In order to apply SoS in global production networks, expertise is needed with regard to the roll-out and operation of multi-site manufacturing SoS on a global level. This is based on knowledge about global supply chains in general, but has also to include knowledge about SoS-specific technologies and capabilities. The global aspect is important for this point as manufacturing SoS are setup globally and there exist differences among regions with regard to level of automation, application of IT systems and their acceptance, education of stakeholders, etc.

3.5.3 Intercompany integration of processes/systems

Multi-site manufacturing SoS do not only require technical integration of production sites / systems but also integration of the related business and production processes in order to achieve an comprehensive and efficient manufacturing execution throughout the whole network. This means that all organizations related to the network should be connected to it and implement compatible business processes, complementary manufacturing processes, and interoperable IT systems.

3.5.4 Clear IP

As in multi-site manufacturing SoS organizations are sharing knowledge about manufacturing processes, product design, cost models, etc., it is essential to define clear frameworks for handling

this intellectual properties. So it has to be specified, to which level of detail information are provided, who will get access to it and who not, what parties that get access are allowed to do with this information and which penalties are applied in case of violating those agreements. These aspects have to be considered also during technical implementations of manufacturing SoS in order to ensure privacy of participants and know-how protection.
But also other legal issues like the responsibilities for warranties, maintenance etc. towards the customer have to be agreed in multi-site manufacturing SoS.

3.5.5 Other

Further important enablers for SoS in multi-site industrial production which have been identified are:

- Research in advanced coordination and control of complex processing systems and fragmented modeling and integration technologies as there exists a lack of appropriate algorithms, models, integration standards, etc. that are adapted to each other.
- Reference implementations that demonstrate SoS in manufacturing, their advantages, principles, concepts, etc. to potentially interested parties.
- New business models to realize superior value systems. Those business models should give guidance on how to operate SoS in production and therefore provide comprehensive information e.g. about technical concepts, standards, legal issues, education, etc. for a set of application cases like mass production vs. individual products, large global companies vs. virtual organizations set up by SMEs, etc.

4. RECOMMENDATIONS

This section provides our recommendations for the multi-site industrial production domain arising from the barriers and opportunities identified during the SoS roadmapping process. It is divided into two sections: (1) technological and (2) socio-economic recommendations.

4.1 Technological Recommendations

4.1.1 Interface harmonization

Standards need to be developed to provide integration across multiple manufacturing sites so that diversity can be included and heterogeneity mitigated, so that knowledge can be shared more easily, and so that manufacturers can become more agile to changing customer requirements. There is currently a proliferation of existing information and communications standards, e.g. EDI (Electronic Data Interchange) based, which have been developed for specific industry branches or applications, but which now need to be able to communicate and share information within SoS, i.e. across industry branches or certain application areas or OEM supply chains. Furthermore, those standards currently mainly consider business related aspects such as purchasing processes but do not include information exchange at the manufacturing level, e.g. for product or process data, test results, etc. While the creation of new standards would be one possible path for the industry, previous attempts at achieving consolidated industry standards have simply caused greater diversity at the expense of efficiency. It is therefore necessary for attempts to be made towards that harmonization of these existing standards rather than the creation of new standards.

The harmonization process also needs to recognize that large enterprises with de facto standards may represent significant barriers to the creation of such standards. These enterprises may seek to protect their existing market share by lobbying and trying to influence the shape of standards development. Accordingly, public-private partners and joint ventures within the industry should be created to enable these barriers to be overcome.

In addition to this, it may be useful to not only develop harmonized interfaces but also IT methodologies and tools which enable the automatic translation of information and messages exchanged between the different (standard) interfaces used with regard to protocols, syntax (data structure) and semantics (logic contents).

4.1.2 Support the development of performance assessment analytics and models

Improved analytics and models offer the potential for better collaboration between different SoS, the ability to reconfigure the manufacturing system based on real-time data, and higher end-to-end reliability. For the performance of manufacturing SoS to be improved, analytics must first be developed to identify where local optimisation needs to be overcome and for global satisficing to be realized.

The creation of such analytics and models is both time consuming and expensive. Due to the low maturity of SoS, it is difficult for single organizations to be able to make a business case for developing these analytics and models. Instead, pre-competitive consortia using public funding should be created to ensure that analytics and models are development. Such consortia will reduce a single organization’s exposure to risk and facilitate the pooling of capabilities from multiple organizations. Furthermore, those consortia will enable the collection of all necessary data (globally / across the whole production network) in order to exploit the analytics and optimisation potential which derives from the knowledge which can be created from the data.

4.1.3 Support the development of service-oriented control system architectures (SoA)

Service-oriented control system architectures (SoA) refer to a specific form of reliable and scalable IT infrastructure. They can enable the flexible integration of functional components (IT services) such as process control, in order to adapt the overal SoS system to the needs of the specific production network. The creation of SoA for dynamic reconfiguration will allow more open engineering and manufacturing, with engineer-to-order improving response times to changing market demands, reducing time-to-market, and improving control of product changes.

Therefore, it is necessary to equip the components and sub-systems of SoS with appropriate interfaces, describe them in repositories, and flexibly compose them to higher-level functionalities, e.g. up to the overall control and optimization of the SoS.

At present, the principles of these technologies and capabilities are known but their full implementation in manufacturing environments, involving the integration with existing manufacturing systems, has rarely been realized. Funding for the development of SoA demonstrators should be provided, with such funding initially supporting demonstration at technology readiness levels (TRLs) 4-6, with industry-matched funding to support demonstration at TRLs 7-9.

4.1.4 Support the realization of the digital factory

A completely integrated digital factory environment for the whole multi-site manufacturing SoS could enable and accelerate the joint planning of new products and their manufacturing, improve global production efficiency, so leading to the increased competitiveness of the SoS, while also reducing the development costs and time. The following three integration aspects have to be considered therefore:

- Integration of product design throughout the network;
- Integration and alignment of product design and production (production planning);
- Integration of production planning throughout the network.

The challenge is that communication protocols differ considerably due to the many proprietary solutions that have previously been implemented. Accordingly, the integration of manufacturing systems has to be enabled for multiple protocols (i.e. flexible adapted to the specific needs). Even if there are standards like STEP (Standard Protocol for the Exchange of Product model data), at present there is no integrated set of tools and processes for the simulation of manufacturing operations and steps which is required for such an integrated set to be realized.

Furthermore, the absence of SoS thinking in this area is leading towards local optimization at the expense of global optimization or even satisficing. Seed funding is therefore necessary so that the interfaces and standards can be defined to overcome local optimization.

4.2 Socio-economic recommendations

4.2.1 Establish business model demonstrators

There are two kinds of business models which may support the establishment of SoS. One of them is the realisation of superior values, e.g. by means of providing additional information about products to customers, while the other is the provision of additional services, e.g. the hosting of platforms, provision of additional IT services for tracking, process control, etc. via such a platform.

Along with the creation of SoS demonstrators for SoA, SoS demonstrators are necessary to show what the real financial and operational benefits of multi-site manufacturing SoS can be and to improve practitioner (decision makers and potential users) acceptance of SoS. Such business model demonstrators should be established for technology readiness levels 7-9 and beyond.

4.2.2 Invest in SoS education

The concept of SoS is foreign to most practitioners. Within manufacturing, some SoS governance modes can be identified in the form of supply chains and networks, distributed and dispersed manufacturing, and virtual enterprises. However, the adoption of collaborative forms of SoS (e.g. virtual enterprise) is low relative to the directed SoS of supply chains and networks.

As the technical feasibility of creating more dynamic SoS entities becomes realized, the challenge shifts towards reducing resistance to change and educating stakeholders as to the benefits of SoS. This will require the identification of successful SoSs and SoS demonstrators in operation and the communication of these successes. Case studies are one technique that can be used as a promotional device in business-oriented publications and should be developed and published in appropriate print and electronic media. Furthermore, the main doubts about SoS, e.g. regarding security and IP aspects, have to be overcome by communicating the underlying concepts. This will make sure that stakeholders have understanding of the systems and remove unnecessary doubts.

In addition to educating stakeholders, specific groups need their SoS education to be further advanced in order to develop higher level skills. Training programmes need to be initiated to improve the ability of individuals to operate complex IT systems and to be able to understand the operation of other IT systems across the entire SoS.

4.2.3 Establish an IP regime for multi-site manufacturing SoS

Sharing knowledge about manufacturing processes, product design, cost models, and orders is an essential function of multi-site manufacturing SoS. In order to further reduce concerns and resistance to the adoption of the SoS concept, it is necessary to define clear frameworks for handling this intellectual property.

Such frameworks should specify what levels of detail should be provided, who will have access to what information, what parties are allowed to do with the information they have access to, and what penalties will be applicable when these agreements are violated.

Each of these issues is already addressed within intellectual property law but should be translated and consolidated into forms accessible to those implementing SoS. The creation of guidelines for the SoS IP framework, along with standardised contract templates, will support such individuals and organizations, particularly those in resource-constrained SMEs.
Such guidelines could even be complemented by a validation / verification / certification of potential participants in order to make sure that only compliant organisations will join multi-site manufacturing SoS.

4.3 Summary of recommendations

1. **Interface harmonization**
   i. Due to the proliferation of existing standards, the emphasis should be on the harmonization of these existing information and communication standards rather than the creation of new standards.
   ii. The harmonization process should be achieved through a public-private process or a joint venture to overcome industry self-interest.

2. **Support the development of performance assessment analytics and models**
   i. Fund pre-competitive consortia to ensure that performance analytics and models are developed for multi-site manufacturing SoS.

3. **Support the development of service-oriented control system architectures (SoA)**
   i. Provide funding for SoA demonstrator projects at technology readiness levels 4-6.
   ii. Fund SoA demonstrator projects at TRLs 7-9 through industry-matched funding.

4. **Support the realization of the digital factory**
   i. Fund the development of an integrated set of tools and processes for the simulation of manufacturing operations.
   ii. Provide seed funding to define interfaces and standards in order to overcome local optimization.

5. **Establish business model demonstrators**
   i. Create business model demonstrators for technology readiness levels 7-9 and beyond.

6. **Invest in SoS education**
   i. Communicate the benefits of SoS to stakeholders through case studies.
   ii. Initiate training programmes to improve SoS skills.

7. **Establish an IP regime for manufacturing SoS**
   i. Provide guidelines for the SoS IP framework.
   ii. Create and make available standardized contract templates.

5. Appendix A: Glossary of Terms

Trends and drivers

Term	Explanation
Language and cultural (country, company) differences	Cultural differences result in communication issues and - due to that - may decrease efficiency. This should be overcome by SoS
Having individuals with diverse and complementary skills	Staff in companies has various knowledge and experience backgrounds. This can be an advantage with regard to the multidisciplinar challenges brought by SoS, but also be a challenge with regard to different levels of knowledge etc. which have to be bridged during cooperation.
Higher customisation level of procucts	Products are demanded by customers with an increasing level of individualisation options. As an extreme, this could end up in self-engineering-to-order solutions for consumer goods.
Handling higher complexity and customer requirements	Product individualisation, outsourcing, increasing product complexity, growing IT-systems, etc. result in an overall increasing complexity of production systems which has to be managed.
Advanced process control throughout production networks	Due to companies which focus on their core business, more and more processes are outsourced. However, those processes and their results also influence the quality of the end products. This is why process control should be extended to the whole production network.
Simplified integration of participant's IT infrastructures	In order to enable close cooperation of production network participants (e.g. in terms of process control, product tracking, order forecasting, …), the integration of their IT systems is necessary. Nowadays, this is possible but often causes huge integration implementation efforts which should be reduced.
Autonomous systems	Autonomous systems are able to act without control by master systems. For production systems that would mean that they make decisions on their own, e.g. to schedule production tasks, optimise process parameters, accept orders, etc.
Maximise manufacturing efficiency	This is the main economic driver in the production domain from which all others can be derived. The overall objective is to save costs or to increase competitiveness which both can be achieved by this.
Reduce start-up and maintenance times	Those times are waste with regard to economics as production is not really running then. For this reason, the intention is to reduce this times to a minimum and to schedule the related activities to time slots where they cause as less delays in production as possible.
Reduce inventories	Inventories means to store values (i.e. money). For this reason, the concept of lean manufacturing suggests to reduce inventories in order

	to release the money for other purposes. However, this cannot be done without limitations. It has to be ensured, that the production flow is not jeopardised.
Reduce lead times to produce and deliver a product	In order to reduce inventories and to increase customer satisfaction, lead times (time from receiving an order till delivery) should be reduced
Local Adaptation / Manufacturing close to markets	This trend has several reasons: The regulatory or customs duty restrictions of some countries, but also the reduction of lead times. They should be overcome by manufacturing or at least final assembly close to the customer market.
Geographically distributed manufacturing	Besides the strategical manufacturing close to markets, also other reasons like outsourcing to low-wages countries, keeping high-value added processes or core know-how in the headquarters, etc. cause complex and global production networks which have to be managed efficiently.
Faster, more flexible factories	Factories should become faster and more flexible (with regard to production times, products to be manufactured, etc.) in order to faster react on changing market demands (increase competitiveness).
Increasing focus on high added value goods	Many European Companies are increasingly focusing on high added value goods or processes since other manufacturing tasks can easily be outsourced to low-wages countries. However, customers expect highter quality for this products, etc. This has to be considered within the manufacturing environments.
Flexibility in supply chain participation	Factories (especially SMEs) should easily be able to join production networks in order to be able to quickly react on market demand changes, to extend the market opportunities, etc. However, nowadays this is often very restricted since business process and IT interface integration causes huge efforts.
User group driven standards	Standards for the integration of production networks should be defined by real users in order to ensure that they really address the needs of the user groups.

Table 2 - Terms relating to trends and drivers

Term	Explanation
Shorter time-to-market	The need for a shorter time-to-market results from faster changing market demands and addresses the time from new product ideas till the product can really be sold.
Faster production ramp-up time / tome-to-volume production	This need addresses the driver "maximise manufacturing effectiveness". The goal is to have a running production system as fast as possible.
Coordinated planning of all machines and human resources	In order to manage complex manufacturing SoS, it is necessary to plan the activities executed in a production network.
Adaptable, integrated equipment and systems that can be readily configured	Fast-changing markets require fast-changing factories, i.e. manufacturing equipment which can easily be adapted to e.g. updated product designs.
Increased transparency on available manufacturing capacity and capability, bringing about competition & cost reductions	In manufacturing systems, information is often available but not accessible. By overcoming this issue, it will be possible to do further optimisations on production planning and execution.
Increased global competitiveness	Companies will increasingly not only have to be competitive on a local, but also on a global level.
Develop technologies that convert information in knowledge for effective decision making	In manufacturing systems, information is often available but not accessible. Additionally, the potential of information which is accessible is often not exploitated completely. So e.g. information from product tracing cannot only be used for quality control towards customers, but also for the creation of forecasts, etc.
Safe autonomous systems (when constantly adapting)	Increasing complexity of manufacturing systems results in the need for systems which don't need to be managed by humans but which react reliable.
Self-healing eco-systems and assets	As manufacturing systems evolve over the time and exceptions are expected to occur, it is necessary to implement systems with an emergent behaviour.
Need to increase interoperability of systems / data across factories	Close cooperation in, advanced process control etc. throughout production networks require considerable information exchange among factories. For this reason, systems have to be integrated with each other, with platforms, etc.
Strong relationships between network partners	Cooperation in production networks, especially when much information is exchanged, autonomous systems influence each other, etc., strong relationshops between partners are required, which e.g. are the basis for the trust among them.

Need for integrated product and manufacturing capability management	In order to be able to manage flexible production which should response automatically to product needs, it is necessary to integrate the management of equipment capabilities and the related product features.
Use of shared intelligent networks (IT & physical)	In order to support seamless integration of manufacturing systems, shared intelligent networks have to be used.
ICT-enabled intelligent manufacturing	The overall potential of multi-site manufacturing SoS can only be exploited by introducing intelligence into manufacturing systems by means of appropriate IT systems.
Demand-oriented manufacturing services which are readily available	An option to setup or reconfigure production networks within a short time is to implement service-orientation in manufacturing. This means that factories provide manufacturing services, i.e. capabilities and capacities (semi-) automated to the network or its management infrastructure.
Very well distributed, mandatory standards for suppliers and OEMs	Nowadays, integration standards for supply chains exist on business level (e.g. EDI-based standards). However, each industry branch defined its own standard, on production level often only proprietary solutions exist.
Increase product & process quality	In order to increase (global) competitiveness, not only costs can be reduced, also product and process quality can be increased. However, this requires often high-sophisticated control methods.
Advanced reliability engineering	This is the need to setup production systems which are more reliable than the state-of-the-art. It is closely related to increasing process quality, but also to the reduction e.g. of maintenance or unscheduled downtimes.
Increased control of product changes across supply chain	Since products are rarely manufactured within one factory, it is necessary to exchange (sub-)product specifications throughout the production network. And since product updates are occurring more frequently, it is necessary to manage the efficient exchange of the related changes.
IPR, security and privacy	Companies will not participate in multi-site production SoS as long as they have doubts about the protection of their IPR, security, and privacy.
Reduced manufacturing costs	Refer to drivers (maximise manufacturing efficiency)
Reduced waste and energy comsumption	Since sustainability is an emerging topic and partially used by companies for marketing / esteblishment of USP / increasing competitiveness, several options can be taken into account how to achieve this. The implementation of SoS is one option, e.g. in order to optimise transport, schedule production with regard to consumables used, etc.
Complexity management	Refer to drivers (Handling higher complexity and customer

	requirements)
Knowledge transfer to industry	Knowledge about SoS concepts, architectures, methods, etc. has to be transferred to stakeholders in industry in order to ensure that they can be accepted and applied in practice.

Table 3 - Terms relating to needs and benefits

Term	**Explanation**
Improvement of e-infrastructures	The improvement of e-infrastructures in general contributes to the simplified participation in manufacturing SoS since software systems nowadays often are hosted on-site and require lots of maintenance. By e.g. improving those infrastructures or providing them remotely, the treshold for IT applications in manufacturing is lowered.
From Internet of Things to Internet of Experiences	Internet of Things (i.e. intelligent products, equipment, etc.) is a first step towards SoS in production. However, when thinking further, intelligence should not stop at this level but also be integrated to manufacturing services, capabilities, etc. which would result in not only providing e.g. sensor data for a certain product, but in providing knowledge / experience which was gathered by interlinking lots of those information.
Real-time production management / scheduling	Since market demands change faster and faster, products are increasingly customised, and lead times should be reduced, production management has to become faster in order to react as fast as possible, i.e. in real time, on emerging orders etc.
Simulation tools & re-parameterise devices for automated reasoning	Tools which, by means of simulation, recognise reasons, e.g. for process quality deviations or too high lead times, automatically and autonomously re-parameterise the concerned equipment.
Web-based collaboration system for mass customisation	Web based collaboration systems in many cases simplify the exchange of information which is especially necessary, e.g. to communicate individualisation options for certain orders throughout the supply chain.
Enterprise-wide performance assessment models / metrics	Optimisation of manufacturing environments first requires information about where is potential for optimisatons. For this reason, it is necessary to monitor the overall production network / SoS and to assess its performance.
Service-oriented architecture (SoA) application for very large scale distributed systems in Process Control applications	Refer to technologies (reliable and scalable IT infrastructure). In addition, SoA enable the flexible integration of functional components such as for process control, in order to adapt the overal SoS system to the needs of the specific production network.
Intuitive user interface	For acceptance of IT-tools in manufacturing environements / by

	workers, it is important to enable intuitive usage of the systems. As an optimum, the complexity of the systems behind is not visible to the user.
Methods to query and transform ontology data	Data structures differ from company to company. However, the information have to be mapped to each other within manufacturing SoS. This can be done by intelligent mechanisms which e.g. use ontologies to represent the knowledge about this mapping.
Ditigal Factory with PLM integration & 3D interoperability between design and manufacturing	Beyond STEP for certain industries, the transfer of product specifications from design to manufacturing, but also the feedback about manufacturability from production to design is lacking. Tools which overcome this gap would be appreciated.
Multi-protocol integration & interoperabilty with heterogeneous devices	Especially for non-standard equipment, communication protocols differ considerably since there are mainly proprietary solutions implemented. Due to this reason, the integration of manufacturing systems has to be enabled for multiple protocols (i.e. flexible adapted to the specific needs).
Reliable and scalable IT infrastructure	Refer to technologies (improvement of e-infrastructures). In addition, the infrastructures have to ensure reliability and availability of the overall system, and to enable scale-up or scale-down of systems, e.g. with regard to the amounts of data handled, number of companies involved, etc.
Control system architecture to enable dynamic reconfiguration of assembly, production and transportation	Refer to needs (adaptable, integrated equipment and systems that can be readily configured)
Sensor networks	Sensor networks - within equipments, production lines, factories, etc. - enable to access additional information which can be used to mange the SoS, e.g. by tracking products, receiving measurment results, etc.
Robust platforms for seamess & user-friendly transfer of new technologies to industry	The introduction of new IT-technologies, methods, tools, algorithms, etc. to the manufacturing environments often takes long time. Platforms which provide easy access to those new developments could help to overcome this, and herewith to faster establish SoS in manufacturing.
Digital product description standards	In order to easily transfer knowledge about product specifications throughout the supply chain, existing standards may have to be extended in order to cover or integrate various manufacturing options / production technologies.
International definitions / audits	In order to ensure communication quality in manufacturing SoS,
Integration and communication standards	Existing standards (e.g. EDI-based) have to be harmonised since they are established mainly for certain industry branches, etc. Besides this,

for components, devices, factories	they have to be extended from business to manufacturing level for the exchange of additional information, e.g. in order to enable inter-factory process control.
Interoperable simulation and modelling processes / tools	In order to ensure that simulation, modelling of manufacturing enviroments, etc. really can complement each other throughout the production network, it is necessary that the related processes and tools are interoperable with each other, e.g. by providing / applying defined interfaces.
Coordination - Decision making	Refer to needs (safe autonomous systems). One major feature of those autonomous systems is to make decisions without manual interactions. Therefore, sound methods have to be implemented which ensure that the decisions made are as good as possible. This is a challenging task which has to be executed by appropriate IT mechanisms.

Table 4 - Terms relating to technological capabilities and opportunities

Term	**Explanation**
Education (customers and engineers)	In order to overcome doubts about SoS in manufacturing, it is essential to educate the stakeholders, i.e. to explain why doubts are not necessary.
Skilled leaders with a vision	Staff which thinks beyond well-known procedures and systems is essential for companies in order to increase competitiveness by introducing new IT-functionalities etc. to their manufacturing environment.
Global expertise	Expertise about SoS applications in manufacturing has to be gathered and shared in order to extend the related production networks and herewith the exploitation of market opportunities for the companies.
Reference implementation	When introducing new concepts, tools, etc. to manufacturing companies, one of the first questions asked is mostly "where can I see a prototype / demonstration of this system?" or similar questions. For this reason, it is necessary to implement reference implementations which also can help to explain the SoS concepts in general (support education).
Research in advanced coordination and control of complex processing systems and fragmented modelling and integration technologies	For some aspects of coordination and control of complex manufacturing systems, i.e. SoS, existing algorithms should be optimized or new ones developed. This also applies for fragemented modeling, e.g. of simulation models throughout different production sites, and integration technologies. Research is needed here in order to develop new methodologies and tools which enable efficient exploitation of SoS potentials.
Matrix Organisation	Nowadays, manufacturing companies are mainly organised hierarchically. However, structuring the organisations also horizontally,

	i.e. exchanging ideas e.g. with other production lines, even if they belong to other business units, could increase the level of education and support the identification of new optimisation potentials. For SoS, this applies especially due to the fact that IT infrastructures may be integrated there also not only hierarchical, but also horizontal.
New business models to realise superior value systems	There are two kinds of business models which may support the establishment of SoS. One of them is the realisation of superior values, e.g. by means of providing additional information about products to customers, etc.
New business models for services	There are two kinds of business models which may support the establishment of SoS. One of them is the provision of additional services, e.g. the hosting of platforms, provision of additional IT services for tracking, process control, etc. via such a platform, etc.
Secure information sharing - local and global	In order to achieve acceptance for SoS in manufacturing, it is essential to have and communicate security and privacy mechanisms which enable secure information sharing, e.g. via collaboration platforms.
Process automation, robotics and human machine interface	This is a basic enabler for manufacturing SoS since without automated systems, the management of SoS with all the information required causes too much effort to be efficient for a company.
High availability of cloud computing	Refer to technologies (improvement of e-infrastructures)
Intercompany integration of processes / systems	Refer to needs (need to increase interoperability of systems / data across factories)
Methods for quality and advanced process control	Refer to drivers (advanced process control throughout production networks)
Intelligent systems - embedded intelligence, Brain-Machine interaction	In order to exploit the full potential of all the information available in production networks, intelligent systems have to be integrated there which autonomously analyse and suggest optimisations in the overall manufacturing environment.
Reducing the initial investment required	Currently, the investment (development work, IT-tools, e-Infrastructures) which are necessary to establish manufacturing SoS are quite high. In order to spread SoS throughout industry, this should be reduced.
"Configuration control" for SoS	In order to ensure that SoS can be easily established, managed, etc., those activities should be enabled by means of configuration mechanisms instead of implementing customisations (for certain companies) with high effort.
Desire to move to common solution	Nowadays, many factory-internal IT systems are homemade by the respective companies. This often causes maintenance and interoperability issues. Companies have to be ready to leave those solutions behind in order to really participate in high-sophisticated SoS systems.

Bridging the innovation gap / valley of death (FInES)	Methods, etc. which help to support the transfer of SoS research results to commercial solutions.
Clear IP	IP has to be clarified, e.g. by means of general terms and conditions for a certain multi-site production SoS, by contract templates, etc. in order to address the doubts which many manufacturing companies have.
Clear Risk-Reward for SoS	The risks in the SoS, e.g. when product failures occure, have to be clearly defined and distributed amon the partners.
Antitrust policies facilitating cooperation	Since SoS are focussing on collaboration and cooperation of manufacturing companies, policies should be established which support this.
Industry momentum	For a wide-ranged establishment of SoS in the manufacturing domain, some kind of industry trend has to emerge. The German Industry 4.0 initiative which is very popular and well-known in the mean time could be an example therefore.
SoS standards and certification	In order to establish manufacturing SoS, the related standards have to be defined. But to make participation even more secure and efficient, certification of companies which fulfil those standards would be useful.

Table 5 - Terms relating to enablers

6. REFERENCES

This deliverable is based on inputs from Road2SoS deliverables D1.1 (Report on data collection and analysis of relevant European and international RTD projects/ initiatives), D1.2 (Interviews summary report), D2.2 (Market survey summary report) and D2.3 (Socio-economic summary report), which built the basis for the "pre-populated" roadmap (see 2.2 Phase 1: Data collection and analysis). References can be found in the respective deliverables.

To build the roadmaps, various Road2SoS workshops have been held, namely the "Road2SoS Expert Panel" May 22nd 2012 in Karlsruhe, "Road2SoS-Roadmapping Workshops" September 2012 – October 2012 in Paris, Brussels, Madrid. More information on these workshops can be found in the deliverables D1.3 (Expert Panel meeting minutes) and D3.2 (Minutes of the Roadmapping Workshops).

To mature and validate the roadmaps, 12 "case studies in industry" and 8 "dissemination workshops" have been conducted. Detailed information can be found in the deliverables D4.1 (Case Studies) and D6.2 (Dissemination Workshops Report).