

D3.1

MaaS Roadmap and Pathways towards 2040

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1 Executive Summary

This report presents the strategic roadmap developed by the MASTT2040 project to support the evolution of Manufacturing-as-a-Service (MaaS) in Europe by 2040. The roadmap outlines how MaaS can drive the transformation of the European manufacturing industry in support of the EU's Twin Transition, addressing urgent needs for enhanced resilience, circularity, and human-centricity in industry.

The roadmap was developed using a participatory foresight approach. It was implemented by way of a series of roadmapping workshops involving a broad range of stakeholders, built on previous outcomes of the MASTT2040 project, and integrated input from MaaS-related EU-funded projects. A backcasting approach was applied to translate a shared vision of MaaS in 2040 into concrete pathways for action across three time horizons: short-term (2025–2030), medium-term (2030–2035), long-term (2035–2040). The process yielded a structured set of actions and recommendations taking into account key enabling conditions such as technologies, skills, and standardisation needs.

The 2040 vision expects MaaS to be the trustworthy, fully digital, and decentralised industrial backbone of European industry, enabling on-demand, high-quality, and adaptive production. Manufacturing ecosystems are driven by real-time data, resilient networks, and circular value chains, while human workers take on empowered, creative roles supported by intelligent systems. The three aspects central to the vision and roadmap, i.e. resilience, circularity, and human-centricity, are detailed by way of priority issues and based on these, recommendations for industry, policymakers, and ecosystem actors. The roadmap specifically features considerations on standardisation, regulation, and legislation, which will be further developed in the upcoming MASTT2040 Industry Strategy & Action Plan.

To depict concrete pathways for how European industry can successfully exploit MaaS approaches in the future, five use cases are outlined to guide the implementation of MaaS in the coming years. These show how MaaS models can reshape European industry through new forms of production, collaboration, and value creation. In addition, a set of capability development pathways outlines how key technological and organisational features must evolve step by step to enable the realisation of the 2040 vision.

To conclude, the vision, roadmap, use cases and capability pathways developed by the MASTT2040 project provide a strategic foundation to support European industry, policy, and innovation actors in realising a future-proof, competitive, and sustainable MaaS ecosystem by 2040.

2 Introduction: Manufacturing as a Service and the MASTT2040 project

2.1 The MASTT2040 project and the deliverable at hand

This report presents the roadmapping activities undertaken and the final roadmap elaborated to outline pathways towards the future of Manufacturing-as-a-Service (MaaS) by 2040. It also includes possible future use cases of MaaS that can support the realisation of this roadmap. The work has been performed as part of the EC co-funded MASTT2040 (Manufacturing as a Service for the EU's Twin Transition until 2040) strategic foresight project. The aim of MASTT2040 is to build an understanding of the industry changes, opportunities and disruptions emerging both inside and outside of the "Manufacturing as a Service" (MaaS) domain to guide decision making, strategies and actions for the EU manufacturing sector in the context of the Twin Transition up to 2040. Notably, MaaS promises a unique value proposition compared to the existing traditional centralised manufacturing approaches by offering increased flexibility and resilience, and scale-up driven by rapid advances in connectivity, digitalisation, access to vast amounts of data and the exploitation of AI.

Overall, the MASTT2040 project analyses key aspects of MaaS in 4 phases as shown in Figure 2 with the following objectives:

- **Scan & Scope:** Phase 1 analyses the "Manufacturing as a Service" approaches, business models and best practices, and their current contribution to advance circularity, decarbonisation, and sustainability of industrial production.
- **Envisioning the Future:** Based on foreseeable developments and trends, phase 2 develops four scenarios for Europe until 2040 including the potential advantages and disadvantages, with respect to distributed Manufacturing as a Service vs. centralized manufacturing.
- **Strategic Roadmap:** Phase 3 elaborates a strategic MaaS roadmap and action plan addressing the short-term (5 years), medium-term (10 years) and long-term (15 years) timescales to identify desired developments in order to anticipate these changes and advance digitalization, circularity, sustainability, resilience and human-centricity of industrial production towards the 2040 vision.
- **Recommendations:** Phase 4 develops recommendations to enable Europe to target strategic MaaS investments and identify the needs for industrial data standardisation to promote uptake of MaaS.

Using strategic foresight methods in an inclusive and participatory manner will enable building a shared understanding of which changes, opportunities or disruptions are present and emerging both inside and outside of the "Manufacturing as a Service" (MaaS) domain to guide decision making, strategies and actions for the EU manufacturing sector in the context of the twin transition up to 2040. This project actively engages various target groups, stakeholders and experts in the project activities (research, workshops, webinars, events, evaluations), widely disseminates the project results and transfers information and technologies with/between Horizon Europe (HE) projects and relevant initiatives. This includes all relevant stakeholders from industry, projects and networks such as EFFRA, the Manufacturing Data Spaces and the network of European Digital Innovation Hubs (EDIHs).

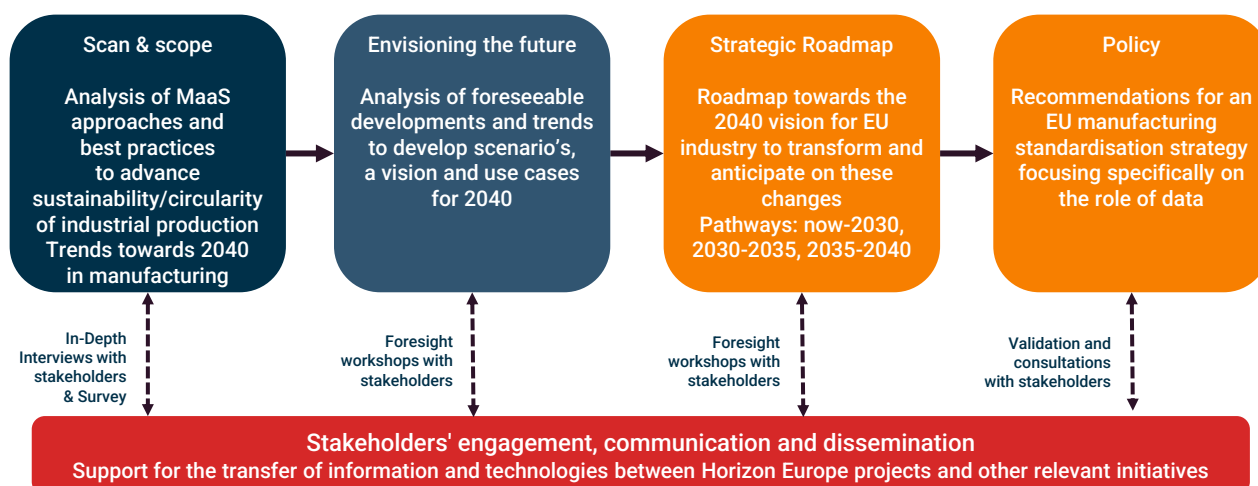


Figure 1: Overview of MASTT2040 Phases

The document at hand outlines the roadmap elaborated in early 2025 and is based on the activities undertaken during the previous phases and builds upon their results, among others the trends identification, scenario development and use case elaboration. It depicts in much detail the roadmapping approach and its implementation by way of several participatory exercises.

2.2 MaaS vs other manufacturing approaches

As digitization, connectivity and Industry 4.0 enable many functional areas of manufacturing to be delivered as services, MaaS offers a paradigm shift in modern manufacturing. Different definitions for MaaS can be found in the literature. Following is the definition of MaaS provided by the European Commission, which was the starting point for the MASTT2040 project.

Manufacturing as a Service
 is a distributed system of production in which resources (including data and software) are offered as services, allowing manufacturers to access distributed providers to implement their manufacturing processes.

Apart from the key aspects mentioned in the definition above, other common characteristics observed for all MaaS approaches are:

- Easy to use, instant cloud services with short lead-times,
- Digitized and highly automated processes which can be hyper-scaled in a cost-effective way while retaining the ability for micro-caring on the specific needs of a customer,
- The integration of in-depth manufacturing knowledge in the digitized services limiting the need for highly skilled workers.
- The cloud services highly rely on real-time data exchange and learning algorithms to improve over time.
- Their development requires new skills in manufacturing, to combine software development, data analytics and Artificial Intelligence with manufacturing expertise.

Subcontracting, on demand manufacturing and services have existed in the industrial manufacturing sector for a very long time. The Figure 3 below graphically shows where MaaS is located compared to Contract Manufacturing and Centralized Manufacturing.

- Centralized Manufacturing is a manufacturing approach where all manufacturing activities are concentrated in a single location or a few strategically chosen locations.
- Contract Manufacturing is the outsourcing of the production process, which makes that MaaS is a specific form of Contract Manufacturing. At the same time not all Contract Manufacturing is MaaS, as most types of manufacturing do not comply with the definition of MaaS being digitalized, automated and decentralized with different possible suppliers. MaaS facilitates manufacturing activities to be spread across multiple suppliers and locations.
- Centralized Manufacturing can be used in combination with Contract Manufacturing (incl. MaaS) for the manufacturing of parts/components in a supply chain, but it stops being centralised if most of the manufacturing process is being outsourced to third parties.

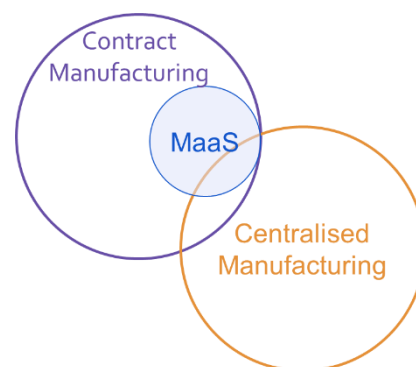


Figure 2: Overview of the position of MaaS within the main existing Manufacturing approaches

2.3 The structure of this document

The document at hand presents the MASTT2040 roadmap and the process which was developed and implemented to arrive at the final roadmap.

- This first introductory chapter informs on the MASTT2040 project and gives a definition of MaaS vs traditional manufacturing approaches.
- The following chapter 3 describes the approach that was designed for the roadmapping activities and describes its implementation.
- Chapter 4 shows the MASTT2040 vision that was drafted and validated during the roadmapping process.
- The roadmap as a result of the participatory process undertaken in this workpackage is depicted in Chapter 5. It includes the priority actions and recommendations that were developed by the stakeholders during the second participatory workshop.
- Chapter 6 outlines the aspects of standardisation, regulation and legislation that were addressed during the roadmapping work and that will be taken up in the Industry Strategy & Action Plan as well as in the follow-on activities on standardisation in project phase 4.
- In Chapter 7, based on the use cases developed during earlier WPs and on the roadmapping work, five future use cases are sketched that concretise how the findings from the roadmapping process might be implemented in industry in the future, leading to more flexible, competitive, sustainable, resilient and circular products, processes and services.
- Finally, we wrap up the findings of this document in Chapter 8 and give an outlook on how the findings will be used in the next phase of the project.

3 The MASTT2040 Roadmapping approach & implementation

3.1 Objectives of project phase 3

The MASTT2040 activities implemented in phase 3 of the project are a continuation of the previous project activities and aim to achieve the following:

- Develop a roadmap with three time frames (2030-2035-2040) showing desirable and impactful pathways for the development of future MaaS supporting the realization of the key EC goals for the benefit of European industry as a whole.
- Involve all key stakeholders in envisioning the future development of MaaS.
- Outline future MaaS use cases that depict concrete applications of MaaS in future manufacturing industry and considering enhanced sustainability, circularity and resilience.
- Draft an industry strategy including pathways for the highest impact exploitation of MaaS within Europe and priority actions in the short, medium and long term.

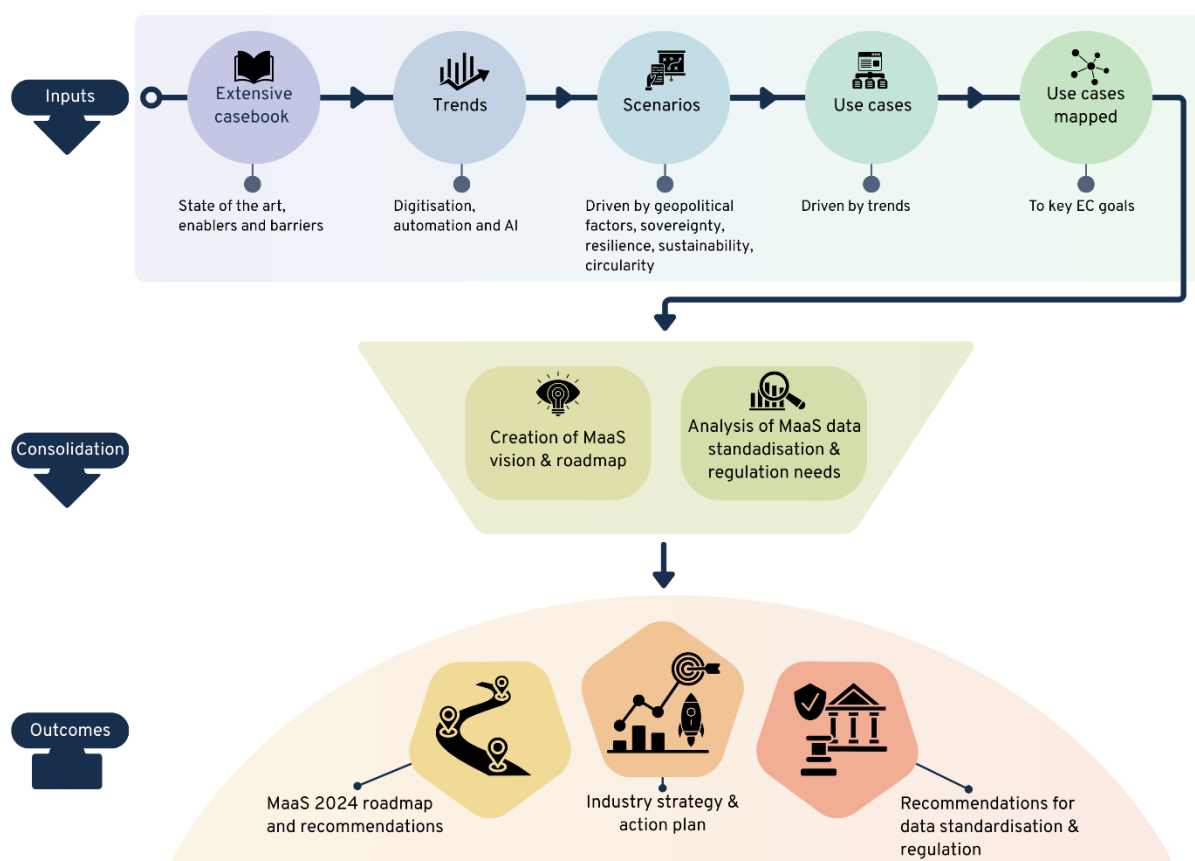


Figure 3: Inputs to and outputs from MASTT2040 roadmapping process

One main outcome of the phase 3 activities realising these objectives is a roadmap identifying priority areas, actions and recommendations that need addressing in order to achieve the outlined vision and identified pathways for MaaS with the highest potential impact towards the key EC goals of sustainability & circularity, resilience and human-centric, digitised industry.

How the pathways outlined in the MASTT2040 roadmap can be realized is 1) sketched in the case studies that depict concretely how future use cases of sustainable, circular and resilient MaaS might look like, and 2) detailed in the Industry Strategy and Action Plan that – supported by stakeholders – defines and concretises the actions and recommendations that need to be undertaken to realise the pathways and efficiently exploit the opportunities which arise with increasing the application of MaaS in European industry in the coming years.

3.2 The Roadmapping approach and implementation in a nutshell

The roadmapping work addresses **why** we need to act (visions, trends, driver), **what** needs to be done (enablers, barriers, gaps), **how** this will be achieved (prioritization and recommendations) and the timescales of **when** specific actions are required.

The roadmapping work built on the preparatory work done by the consortium and based on the outcomes of the scenario work implemented in project phase 2. The most impactful aspects identified thereof as well as overarching trends and technologies built the basis of both the MASTT2040 vision and the roadmapping work.

For the roadmapping, we use a backcasting approach. Backcasting means that we started the activity from a vision of MaaS that is made up of the high-impact MaaS aspects of the scenarios that were developed in project phase 2 regarding circularity, sustainability, resilience and human-centric approaches. During the first roadmapping workshop, this vision was further detailed by the participants to enable the vision to give a very comprehensive picture of how circular, sustainable, resilient and human-centric MaaS could look like in 2040 and which impact MaaS can have on circularity, sustainability, resilience and human factors of EU industry and society at large in 2040.

Looking back from this future 2040 vision until today, the roadmap of how MaaS can evolve between now and 2040 is elaborated. To do this, the participants of two participatory workshops identified along a number of categories and in three time frames (2025 – 2030, 2030 - 2035, 2035 – 2040) the issues (including challenges and barriers) that need to be addressed to realise this vision by 2040. How the approach was implemented is depicted in Figure 4 and outlined in more detail below. Related EU-funded projects also tackling MaaS or aspects thereof (e.g. circular assembly lines, human-centric robotics) were identified in the beginning of the MASTT2040 project and invited to get involved in all project phases. A list of relevant projects is given in Annex 1. A number of project representatives even participated in the roadmapping activities to share the views and (preliminary) outcomes of the projects.

The roadmapping exercise was kicked-off in January 2025 during a project-internal workshop. The project partners identified the high-impact MaaS aspects from the scenarios elaborated in phase 2 and applied them to draft a preliminary MASTT2040 vision and to pre-populate the roadmapping template to be used during the participatory workshops to come. This way, the workshop participants were



Figure 4: First roadmapping workshop

able to use this as a basis and employ the draft vision and roadmap to easily validate, add and combine issues during the first external workshop to come.

The first external roadmapping workshop took place on 26th February 2025 in Brussels. After a comprehensive introduction into the MASTT2040 project and the relevance of MaaS for industry and policy, the first interactive session was kicked off. The participants were split into four groups and



Figure 5: Roadmap development during first workshop

discussed, adapted and validated the draft MaaS vision. In the second part, participants were again split into groups to identify aspects that are relevant to achieve the MaaS vision by discussing, aligning and complementing the roadmapping template with input along the nine roadmapping categories used. Each group was guided by a facilitator from the project consortium. The three groups focused specifically on the key EC goals the MASTT2040 project is tackling, namely sustainability & circularity,

resilient value chains, and human-centric and automated manufacturing.

Between the first and the second roadmapping workshop, the consortium members discussed the workshop results and thoroughly followed-up the workshop activities. This resulted in an adapted, final version of the MASTT2040 vision outlined in the next chapter and a combined roadmap where the three individual workshop templates were merged into one overall MASTT2040 roadmap that included those issues that were rated as being of high impact by the participants of the first workshop. When combining the high-impact issues into one roadmap, for each key aspect of sustainability & circularity, resilient value chains, and human-centric and automated manufacturing four clusters of issues emerged which reflect the most relevant aspects that will form the pathways towards the 2040 vision

The second roadmapping workshop took place online on 28th April 2025. It started in the first part with reflecting on the results of the first workshop, and presented the MASTT2040 vision and the merged roadmap which have been finalized since then. Having done that, the participants elaborated in three break-out groups, facilitated by consortium partners, actions that should be implemented to realise the high-impact issues identified during the first roadmapping workshop. After a short report-back for all participants, the second interactive session was kicked-off. In the same break-out groups as previously, the participants elaborated

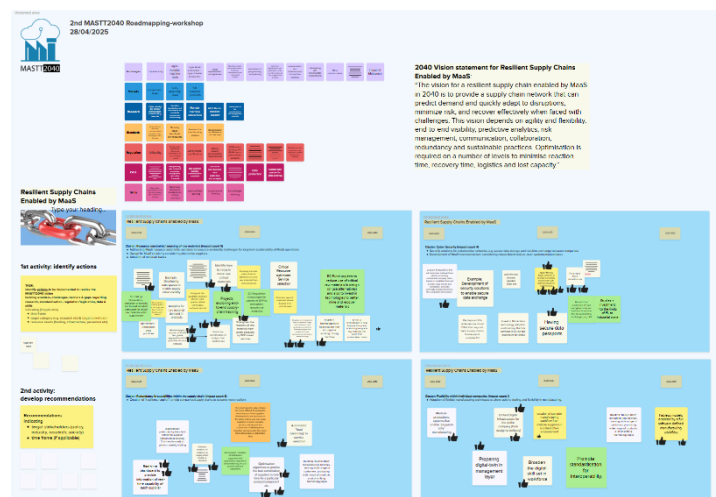


Figure 6: Virtual Whiteboard used during second workshop

recommendations towards stakeholders on what should be done to realise the actions identified during the first session.

This workshop resulted in a comprehensive outline of both future actions and stakeholder recommendations for each key aspect of sustainability & circularity, resilient value chains, and human-centric and automated manufacturing.

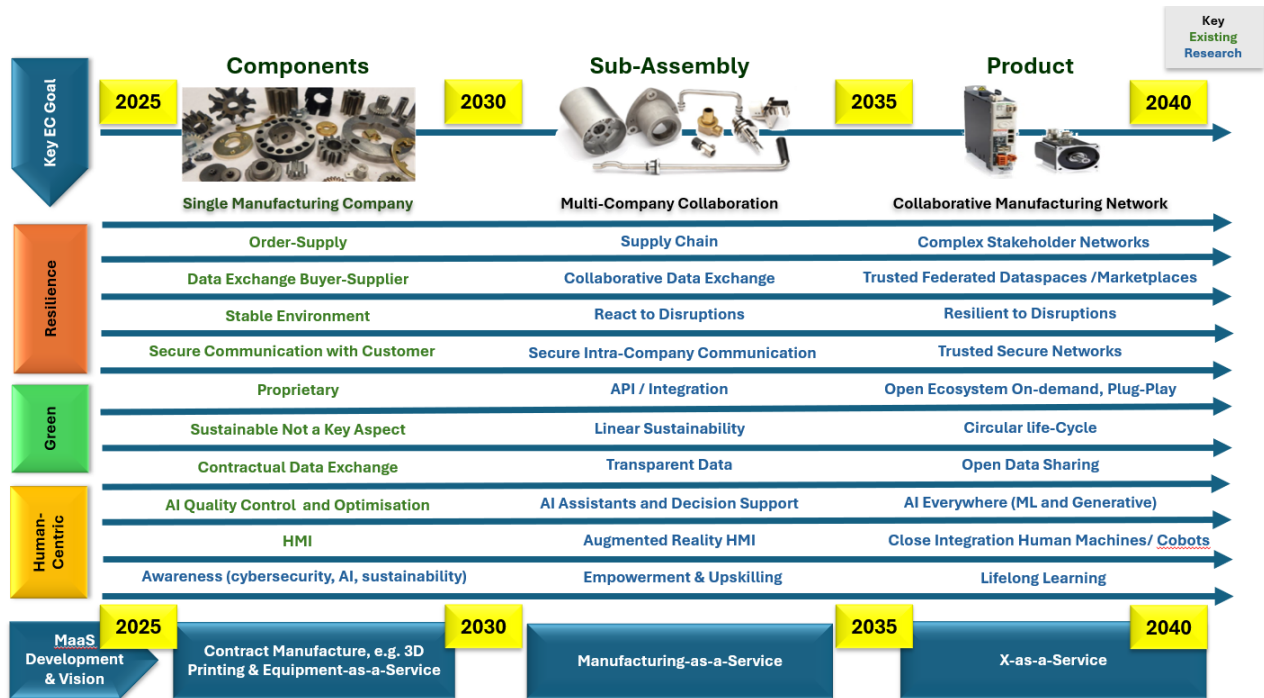


Figure 7: The MASTT2040 roadmap

From the results of both roadmapping workshops, a visual representation of the MASTT2040 roadmap was created and is given above. It includes the overall future MaaS development towards the 2040 vision, the three key aspects addressing the key EC goals and related short-, mid- and long-term requirements of MaaS. Concretely, today MaaS is mainly applied for manufacturing of components by single or very few connected manufacturing companies. In the coming five to ten years, we expect that there will be a considerable increase in collaboration and data sharing between companies driving MaaS towards manufacturing of sub-assemblies and even complete products by 2040. As is depicted below, considerable advancements in manufacturing technologies, processes and culture will need to take place to realise this vision, bringing Europe closer to the twin transition goals by enhanced resilience, sustainability and circularity as well as human centricity.

Based on this MASTT2040 roadmap, Chapter 6 outlines how MaaS use cases could look like that depict concrete and tangible pathways to be used by companies, industry associations and policy to develop own strategies to valorise the concept of MaaS for their own or their member's operations or for European industry as a whole.

4 The MASTT2040 Vision

The MASTT2040 vision was discussed and validated by the participants of the first roadmapping workshop. The validated MASTT2040 vision, including the three aspects of Resilient Supply Chains enabled MaaS, Circular and Sustainable MaaS, and Human-Centric and Flexible Automated Production System MaaS is given below.

4.1 The Manufacturing-as-a-Service Enterprise

2040 Vision statement of the overall MaaS model

“The 2040 vision of Manufacturing as a Service (MaaS) value network is to provide on-demand, flexible production of high quality parts within precise cost and timescales to customers via a flexible, efficient, and accessible manufacturing ecosystem that exploits digital technologies at all levels, real-time data, and decentralized production capabilities. A future MaaS in 2040 could provide a fully digitalized and highly autonomous ecosystem where artificial intelligence and machine learning algorithms will control the pre-production, production and post-production processes as well as predict market needs, optimize raw material procurement, and automatically adjust production schedules, driving cost reductions, accelerating innovation cycles, and making manufacturing more agile and customer-centric. MaaS can



Figure 8: Validation of Vision during first workshop

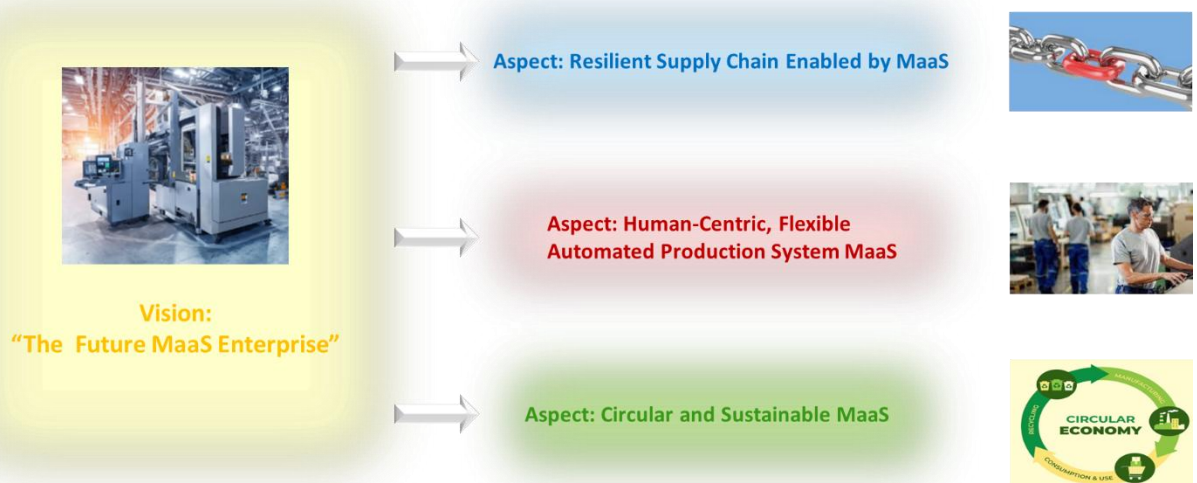


Figure 9: MASTT2040 vision and key aspects

provide greater resilience to geopolitical instability affecting interrelationships and access to raw materials through flexibility in manufacturing networks and adoption of sustainable and circular supply chains. MaaS can also benefit from collective learning and knowledge sharing within ecosystems as well as creation of interdependencies. The adoption of MaaS also changes the role of humans within the production process with implications for skills development and breadth of skills required.”

Characteristics of MaaS in 2040

The MaaS enterprise offers an on-demand ecosystem of manufacturing micro-services enabling flexible, on-demand production of custom parts and components with short lead time. The manufactured goods can be complex and fully customized. A key characteristic is that the MaaS enterprise can face short-notice requests for both low volume and high volume orders. This requires the enterprise to have extreme flexibility and a high degree of automation to quickly reconfigure and scale up its office processes and production system depending upon requirements and to quickly configure for bespoke product production. This requires a high degree of digitization and interoperable platforms to allow the rapid sharing of information with customers, the ability to integrate with other suppliers if required, and to be able to rapidly enter into business agreements to fulfil new orders appropriately. Data sharing at all levels is thus core leading to concepts of collaborative productivity and sustainability. Core company values are to provide a 'what you see is what you get' (WYSWYG) capability with fast turnaround and with competitive pricing.

Other Services That May Be Offered

The range of services offered may go beyond the pure manufacturing process, extending across the value chain, for example providing product design services, with opportunities for after sales support and product maintenance if the company has appropriate capabilities. Other service opportunities are also present such as data as a service, manufacturing operations as a service and logistics as a service. Another form of service provision is in the provision of equipment as a service to manufacturers from machine builders. This is so that manufacturers do not incur the high capital costs of purchasing equipment but rather pay for equipment on a usage basis moving this financial risk to the equipment manufacturers. In practice this service approach is challenging as finance companies are unwilling to lend money to support this as companies face the risk of underutilization of machinery.

Dependencies

A MaaS ecosystem is strongly dependent on an efficient mechanism for providing its services such as open source systems and an efficient interface with customers to provide fast quotations based upon integration with design and manufacturing software (computer-aided design (CAD)/computer-aided manufacturing (CAM)) that the company and its clients use. Interoperability is a key factor as to maximize the client base it is necessary to support a myriad of different software packages that clients use. Fundamental to a service company's strategic plan is to be able to anticipate changes in demand from customers and to constantly innovate with respect to manufacturing technologies to improve efficiency and services provided to meet ad hoc orders. Companies may also exploit data mining from a variety of data sources, including social networks, to predict market trends in order to provide on-demand services.

Core Requirements

Digitization is core to the success of broad-based application of MaaS by 2040 in order to cover the complete design and manufacture life cycle exploiting highly digitized and automated office processes and tools for design, costing, engineering, prototyping, production, qualification and logistics. This requires all partners in the MaaS ecosystem to have a certain level of digital maturity to engage and an appropriate management mindset. Key to success is a high level of plant automation, and the customization of production requires short reconfiguration and tool change cycles, as well as short ramp-up and scale-up cycles. Such cycles need to include tests/experimental production, fast re-programming of machines and frequent updates of information to the workers. Providing inline and automated quality control to obtain appropriate certifications and qualifications is also a core requirement requiring installation of sensor systems to record production parameters of interest which can also be used to improve the production process, products and services. To support mass customization the MaaS supply network needs to provide a mix of long-term and ad-hoc co-operation relying on extensive digitalization and exploitation of technologies like AI for optimization and orchestration in product development, production planning and engineering, production execution and manufacturing. A key challenge is to provide a competitive price based dynamic pricing while meeting the required degree of customization and product quality in a short development cycle. Strategic use of regulation can be used to support strategic autonomy with respect to critical raw materials and circular economy approaches.

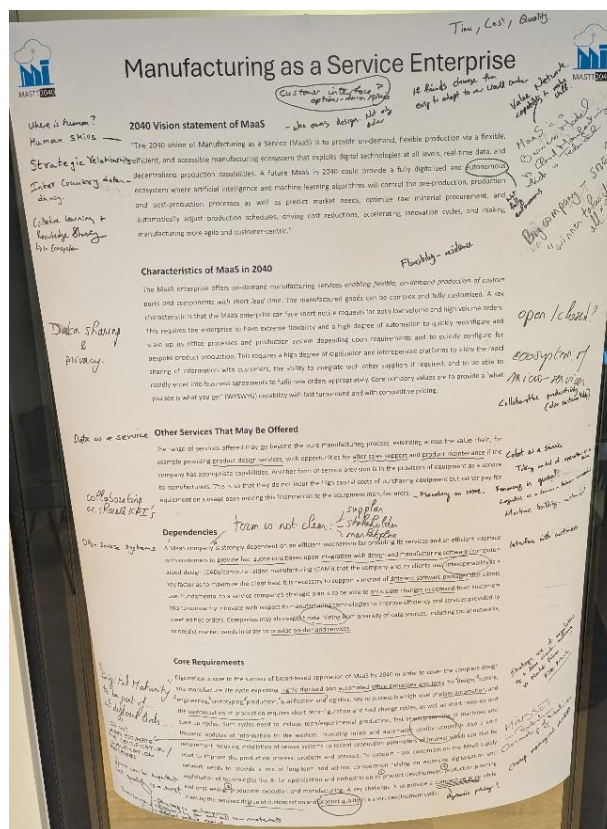


Figure 10: Adapted MaaS vision

4.2 Aspect 1: Resilient Supply Chain Enabled by MaaS

2040 Vision statement for Resilient Supply Chains Enabled by MaaS

“The vision for a resilient supply chain enabled by MaaS in 2040 is to provide a supply chain network that can predict demand and quickly adapt to disruptions, minimize risk, and recover effectively when faced with challenges. This vision depends on agility and flexibility, end-to-end visibility, predictive analytics, risk management, communication, collaboration, redundancy and sustainable practices. Optimisation is required on a number of levels to minimise reaction time, recovery time, logistics and lost capacity.”

Characteristics

Resilience in the supply chain is vital and an association of companies can act as a production and/or innovation network to form a resilient MaaS enterprise. The supply chain for the MaaS may be totally based in Europe or it may cross world-wide borders. Companies flexibly co-operate as and when required, reacting to market opportunities and volatilities, developing new or improved products as well as adopting circular approaches to manufacturing. Companies can also share inventory data and trade new materials or components between businesses. To be efficient the resilient supply chain must minimize the costs and risks involved in targeting new markets with new products. The supply chain must also have sufficient redundancy in capabilities such that different partners can interchange seamlessly within the chain. Beyond pure manufacturing the supply chain may also perform research together in order to improve products and processes.

Key Driver - Flexibility at level of supply chain and its participating companies

Companies must ensure flexibility within their complex supply chain and have the ability to quickly re-configure their production lines utilizing agile modular machine tools and robots to meet changing consumer requirements and be able to integrate new partners when needed. This drives requirements for flexibility at company level and flexibility in the supply chain with the goal of collaborative productivity. The resilient supply chain enterprise may be established ad hoc to meet a short-term need and dissolved after the desired outputs have been achieved or it may be based on a long standing commercial relationship. The companies involved must join forces effectively in order to form what is in essence one business out of several separate ones in a distributed manufacturing network. This will require transparent sharing of information requiring standardisation, rules for sharing IP and other confidential information as well as a means of measuring resilience within the supply chain. As multiple partners may well have overlapping capabilities, it is important that companies are able to bid internally for selection. This automatically introduces a self-healing capability into the supply chain.

Commercial Advantages

A resilient supply chain made up of SMEs, for instance, may enable them to complement each other's strengths to produce products or be able to rival the capacities of large enterprises to bid for orders. This may also link with providing dynamic labour support between companies to meet demand and provide specific skills. When both large and small companies are combined, large companies can bring in their manufacturing capacity, while the small companies can provide flexibility and power to innovate proving modular manufacturing capacity. An example of this is through the provision of local additive manufacturing capabilities. A resilient supply chain enterprise enables a much broader product and service portfolio than any individual company could provide by working alone.

Core Requirements

Key to success is the exploitation of digitization for communication and sharing of information to allow efficient networking, collaboration and integration. This requires a high degree of data collection and knowledge management covering the entire production cycle from design to sales and after sales service supply. Key to this is providing full virtualization of resources through an interoperable platform that connects and synchronizes critical business processes along the value chain aligning priorities, managing resource demand and supply, and exchanging critical product and production data information in order to enable fast ad-hoc decision making. This will require trustworthy data spaces that collect and exchange standardized information as well as support for contracts that allow networks to be built quickly and flexibly. This can build upon ideas already being used in existing value chain activities such as in aerospace. This heavy reliance on gathering and processing critical data, which may include commercial information, makes cyber resilience in the manufacturing network a core requirement. Means of measuring resilience also need to be introduced for key sectors of importance to Europe. This will require rules and legislation to support partnerships and equal rights to remove the barriers of sharing sensitive product data at regional, national, European and levels for different sectors.

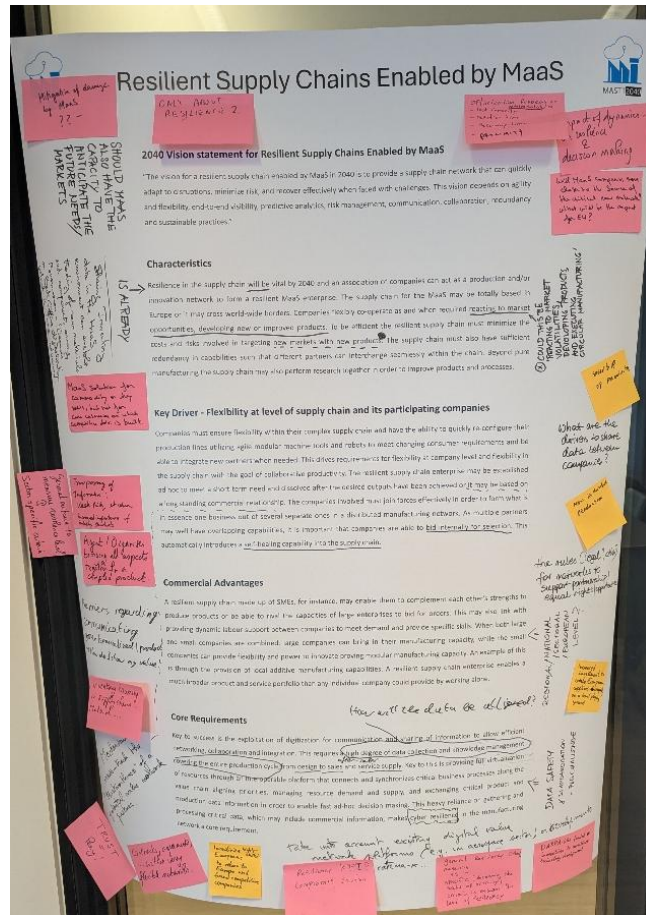


Figure 11: Adapted resilient MaaS vision

4.3 Aspect 2: Circular and Sustainable MaaS

2040 Vision statement for Circular and Sustainable MaaS

“The 2040 vision for circular and sustainable MaaS focuses on creating a network of MaaS ecosystems where products, materials, and resources are continuously reused, repurposed, or recycled, with minimal waste and environmental impact. The vision closes the loop on the production process and ensures that every product and material within the MaaS ecosystem is continuously cycled back into the system, reducing the need for new resources such as critical materials, minimizing environmental impact, and creating a sustainable, regenerative economy. Within this more local reuse of materials will allow a reduction in emissions from transportation and logistics activities. This will be achieved by comprehensive exploitation of interoperability, data usage and transfer to support all aspects of the R-cycle.”

Characteristics

In a circular and sustainable enterprise by 2040 environmental awareness is an essential part of corporate identity. The company's goal is to go beyond mere 'green washing' of its image and products to the introduction of environmental sustainability as a key parameter in all steps of the product life cycle, including sourcing of raw materials providing resilience to external geopolitical factors, reducing usage of materials, energy and waste in production and recycling products via a circular economy. Many companies are now concentrating on minimizing resource consumption and energy efficiency is a critical performance indicator. In particular, adapting energy demand and supply could result in major economies. Already regulation is in place for Corporate Sustainability reporting and many companies have installed renewable energy sources and reduced energy and materials consumption, however, with the aid of new regulation to drive circular approaches the future circular and sustainable enterprise vision is for a step change in sustainable approaches through the adoption of R-cycles requiring much greater networking withing the supply chain.

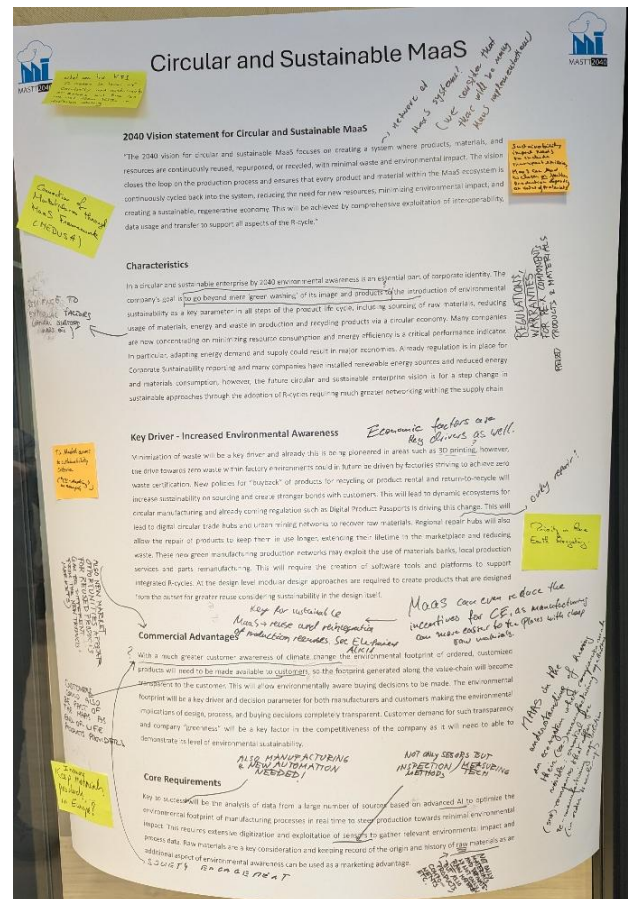


Figure 12: Adapted circular MaaS vision

Key Driver - Increased Environmental Awareness

Reducing cost is a key driver in the minimization of raw materials usage, energy, water and production of waste. Already new approaches are being pioneered in areas such as 3D printing, however, the drive towards zero waste within factory environments could in future be driven by factories striving to achieve zero waste certification. New policies for "buyback" of products for recycling or product rental and return-to-recycle will increase sustainability on sourcing and create stronger bonds with customers. This will lead to dynamic ecosystems for circular manufacturing and already coming regulation such as Digital Product Passports is driving this change. This will lead to digital circular trade hubs and urban mining networks to recover raw materials with priority being given to rare earth materials. Regional repair hubs will also allow the repair of products to keep them in use longer, extending their lifetime in the marketplace and reducing waste. These new green manufacturing production networks may exploit the use of materials banks, local production services and parts remanufacturing. This will require the creation of software tools and platforms to support integrated R-cycles. At the design level modular design approaches are required to create products that are designed from the outset for greater reuse considering sustainability in the design itself and this may be supported by European CE marking of green products.

Commercial Advantages

With a much greater customer awareness of climate change the environmental footprint of ordered, customized products will need to be made available to customers, so the footprint generated along the value-chain will become transparent to the customer who may well become part of the MaaS ecosystem providing products back to be recycled. This will allow environmentally aware buying decisions to be made. The environmental footprint will be a key driver and decision parameter for both manufacturers and customers making the environmental implications of design, process, and buying decisions completely transparent. Customer demand for such transparency and company “greenness” will be a key factor in the competitiveness of the company as it will need to be able to demonstrate its level of environmental sustainability.

Core Requirements

Key to success will be new manufacturing approaches, automation and the analysis of data from a large number of sources based on advanced AI to optimize the environmental footprint of manufacturing processes in real time to steer production towards minimal environmental impact. This requires extensive digitization and exploitation of sensors, inspection and measuring technologies to gather relevant environmental impact and process data. Keeping record of the origin and history of products, components and raw materials as an additional aspect of environmental awareness can be used as a marketing advantage and to ensure that critical materials are kept in Europe. This requires a fundamental shift in societal engagement in a circular economy.

4.4 Aspect 3: Human-Centric, Flexible Automated Production System MaaS

2040 Vision statement for Human-Centric, flexible automated production system MaaS

“The 2040 vision for human-centric flexible automated production system MaaS focuses on creating an environment that prioritizes the well-being, skills, and meaningful experiences of the workers directly involved in the production process as well as end consumers. In the vision technological innovation is reinforced by worker empowerment and safety, creativity, upskilling, inclusion, job creation and seamless integration of people with manufacturing systems to promote both well-being and increased efficiency.”

Characteristics

Within a human-centric and automated MaaS enterprise in 2040, there is an extremely high integration between workers and automated/supported office processes and production systems with the aim of producing products with increasingly shorter product life cycles and in a more relaxed work environment. This drives the need for seamless integration between the manufacturing systems and workers placing emphasis on human centric approaches. This starts with consumer directed approaches to manufacturing to provide increasing degrees of customization in order to remain competitive and extensive co-operation between humans, machines and data to manage the production of the final products. This will change the role of humans creating a new type of highly adaptive knowledge worker integrated with a human friendly production environment reducing stress and automating many repetitive jobs like quotation, ordering, planning, programming and logistics.

The adaptiveness of workers will be prized as much as experience and workers will have more freedom to move between MaaS entities.

Key Driver - Seamless Human Integration

The factory will be highly digitized gathering data at a much higher granularity level and exploiting optimization of processes via data aggregation and through the use of greater automation. The exploitation of data analytics for trend monitoring, fault identification and predictive modelling will provide smart and automated ways to support production personnel in decision-making and may also improve safety. Organisational structures may need to change to reflect new worker responsibilities. Workers will also work alongside cobots allowing much greater efficiency through collaboration with machines. A key challenge is that workers will swiftly need to acquire new knowledge and the rate of human knowledge acquisition becomes a limiting factor for companies attempting to keep pace with technological progress. Approaches will be required to effectively preserve knowledge and share it between workers. Humans need to be embedded in the digital factory, provided constantly with context-relevant information from knowledge-based decision support systems or self-learning systems based on AI and Machine Learning. There is also an opportunity for companies to provide these features as services to support the production system.

Commercial Advantages

Close integration of the human within the factory allows for more efficient operation, increased productivity and better worker welfare. The need for highly skilled workers within MaaS leads to more rewarding jobs and a more motivated workforce. The operation of workers alongside cobots allows for much greater efficiency in production allowing the integration of human decision making and adaptability into the manufacturing process. This will also open up labor market opportunities for workers with physical and neuro disabilities. It is likely that workers will also have more responsibility and handle more sensitive data leading to a more empowered workforce. The democratization of manufacturing will also open up opportunities for new start-ups to develop products leading to more entrepreneurship.

Core Requirements

A human centric approach is needed and the workers themselves need to be suitably skilled and frequently re-trained not only in the latest production approaches but also in sustainability and circularity. Here there are opportunities for the AI-augmented workforce and the exploitation of smart augmented reality tools placing a greater emphasis on Industry 5.0, human factors and cobots. These will need to be seamlessly linked with manufacturing execution systems (MES) and enterprise ICT systems to create a de-centralised, flexible automation architecture. A key need is context-awareness of production facilities to allow better decision making based on data gathered from sensors and monitoring systems. This allows real-time adaptation of production to meet product specifications and customer demands as well as to quickly react and schedule order execution. Creativity will be valued more at work than craftsmanship and workers will need to be flexible to change. Changes in education will be required to support this with the introduction of MaaS models in business schools.

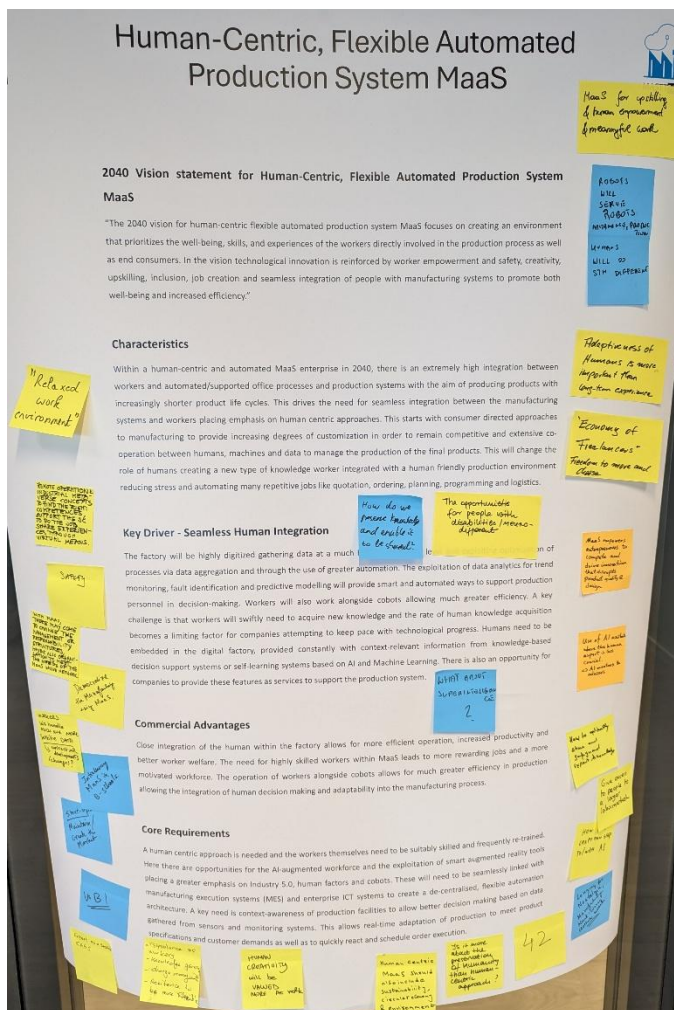


Figure 13: Adapted human-centric MaaS vision

5 The MASTT2040 Roadmap

5.1 Key outcomes from the roadmapping work

The exercise to update the MaaS vision undertaken in the first roadmapping workshop enabled participants to immerse themselves into the topic of MaaS and was a perfect introduction to the roadmapping exercise that was conducted next. An overview of the different steps of the roadmapping exercise can be found in Figure 16 below. As outlined above, the roadmapping tackled the three key aspects of Resilient Supply Chains enabled MaaS; Circular and Sustainable MaaS; and Human-Centric and Flexible Automated Production System MaaS which reflect the key EC goals to be addressed. The categories used to identify the roadmapping issues were the following (see template in Figure 15):

- Overarching trends
- Possible future MaaS applications
- Digital technologies: Digitalisation, Robotics & automation, AI, Systems integration, others
- Circularity, decarbonization & sustainability
- Resilience, supply chains & strategic autonomy
- Human centred industry/human factors
- Markets (most relevant for/impacted by MaaS)
- Research needs (public & private)
- Enablers & barriers & strategic gaps: Standards, Regulation & legislation, Data, skills

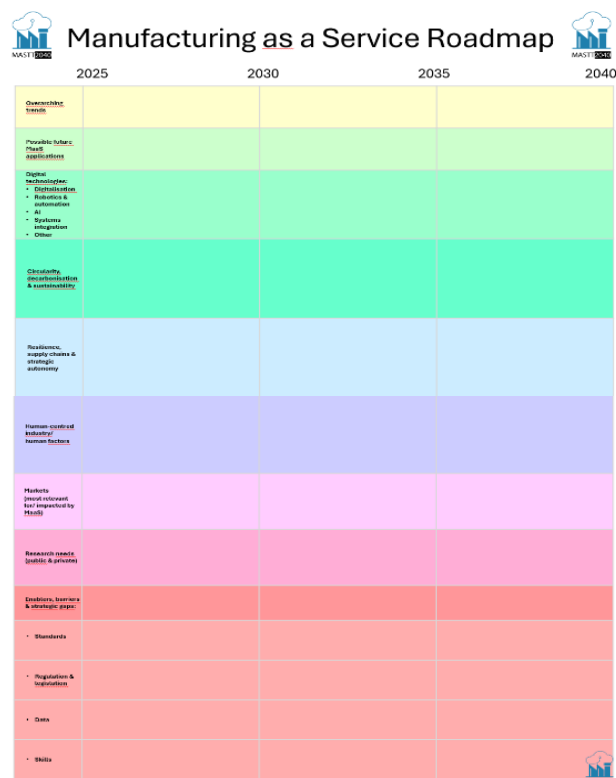


Figure 14: The MASTT2040 roadmapping template



Figure 15: Roadmapping implementation overview

In the following sections, special focus is given to the three key aspects discussed in MASTT2040, namely Resilient Supply Chains enabled MaaS; Circular and Sustainable MaaS; and Human-Centric and Flexible Automated Production System MaaS. The other categories discussed during the roadmapping workshops, e.g. future trends & technologies, research needs, standardisation & regulation, are tackled in more detail in the follow-on document, the MASTT2040 Industry Action Plan, that is available from the MASTT2040 website.

The roadmapping exercise was led by the guiding question: Which issues will be important/need to be realised in the respective timeframe to enable EU industry to incorporate/ develop towards a "green/resilient/human-centred" MaaS enterprises by 2040? Participants were made aware that these also can/should include issues in other categories, e.g. in another key aspect or any other on the template (trends, technology, regulatory etc.).

Following this roadmapping session, the participants were asked to rank those aspects that were analysed during the discussions as to the impact they would exert on future MaaS implementation and success. To this end, 10 stickers were given to each person, two sticker were allowed to be cumulated. Then participants were asked to put the sticker on those issues that in their view reflected the most important aspects that were put forward during the discussions.



Figure 16: MASTT2040 Roadmap merged & clustered

5.1.1 Clustering of priority areas

After the workshop, the three roadmaps elaborated by the participants were joined into one overall MaaS roadmap by taking from each individual roadmap the issues that were regarded as being of high impact by the participants during the voting exercise and those that were added by participants (to make sure that these were not lost). These issues were combined, redundancies removed and then clustered into a small number of relevant clusters that were easier to handle in the follow-on activities and process (see picture in Figure 17: MASTT2040 Roadmap merged & clustered).

The resulting clusters of issues expected to exert the highest impact on future MaaS development, applications and business models are given below. They include the titles, the number of votes each cluster was assigned by the participants as well as the issues that were clustered under each headline.

Resilient supply chains enabled by MaaS

Cluster 1: Resource constraints/ sourcing of raw materials (impact count 9)

- Addressing MaaS resource constraints: solutions to resource availability challenges for long-term sustainability of MaaS operations
- Design for MaaS circularity considering alternative suppliers
- Adoption of materials banks

Cluster 2: Cyber Security (impact count 4)

- Security solutions for collaborative networks, e.g. secure data storage and real-time exchange between companies
- Development of MaaS trust mechanism: considering closed (black box) vs. open systems/marketplaces

Cluster 3: Redundancy in capabilities within the supply chain (impact count 3)

- Creation of “resilience copilot” to help companies/supply chains to become more resilient

Cluster 4: Flexibility within individual companies (impact count 1)

- Adoption of flexible manufacturing techniques to allow rapid re-tooling and flexibility in manufacturing.

Circular & Sustainable MaaS

Cluster 1: Enabling sustainable manufacturing & circularity in all steps of the product life cycle (impact count 27)

- Making environmental sustainability a key parameter in all steps of the product life cycle
- Promoting modular design to encourage/allow reuse at higher levels
- Mainstream adoption of recycling hubs and recycling companies
- Introduction of digital circular trade hubs and urban mining networks
- Establishment/expansion of circular hubs for repurposing products
- Introduction of materials banks
- Adoption of local renewable energy generation for more sustainable manufacturing.
- Development of complete R-cycles

Cluster 2: Increasing environmental consciousness in the economy & society (impact count 11)

- EU Sustainable MaaS leadership: prioritising resource efficiency and circularity through design and remanufacturing excellence, fostering the twin transition
- Making environmental awareness an essential part of corporate identity
- Raising environmental awareness within society

Cluster 3: Transparency (impact count 8)

- Fostering trust and transparency through initiatives such as DPPs for MaaS services
- Creating a transparent Co2 footprint along the value chain
- Making environmental implications of design, process and buying decisions transparent
- Providing supply chain visibility and decision assistance to synchronise, coordinate and communicate within the supply chain via a flexible, bi-directional information exchange system

Cluster 4: Digital Product Passports (DPP) (impact count 7)

- Digital Product Passports for MaaS services to engender transparency and trust
- Widescale application of Digital Product Passports guiding the development of the circular economy & sustainability
- Gathering of real data (not standardized data) to generate DPP

Human-centric, flexible automated production system MaaS

Cluster 1: Future skills-embracing mindset (impact count 9)

- Changing attitudes such as resistance to change and to learning of new required skills
- Changing worker mindset to engender creativity, innovativeness, and more open-mindedness
- Enabling workers to more easily shift skill sets and adopt a dynamic set of skills, through teaching on the job, interactive learning via VR, or via AI advisors
- Encouraging employee co-ownership so they feel in charge of transformation via learning projects and lighthouses
- Develop new ways of knowledge sharing, while keeping key commercial knowledge in the company

Cluster 2: Social and human acceptance/trust (impact count 5)

- What information does the worker need to know to feel empowered?
- Provision of fair working conditions
- Assessment of the MaaS impact on the labour market within the EU
- Impact on knowledge related jobs from AI automation
- Approaches to enhance worker flexibility
- Approaches to enhance worker wellbeing & inclusion

Cluster 3: Accessible HMI technologies (impact count 5)

- How to effectively present crucial problem and context-centric information to users to avoid information overload
- Development of human-centric adaptive interfaces to enhance usability, e.g. tailored to supervisors, operators, product managers, etc., for problem solving
- Gathering knowledge about human behaviour and interaction with machines/interfaces/solutions
- Development of Augmented Reality systems to provide real-time process data to human workers
- Development of Multicriteria Decision Support Systems exploiting AI that combine machine data and human expertise

Cluster 4: Empowering entrepreneurs, workers and citizens (impact count 6)

- Developing cocreation approaches between customers and employees to create new products and services
- Developing new mechanisms to bring forward ideas into practice (fables production, turning ideas into a product/business)
- Enabling new companies to provide their own services into the MaaS network
- Provide approaches to democratize and spread earnings between MaaS stakeholders
- disclosing data about suppliers on a platform will enhance trusted relationships and enable choices based on sustainability, resilience and human-aspects considerations: local versus global choices & avoiding choosing the cheapest

5.2 Suggested actions and recommendations for reinforced MaaS impact by 2040

The above clusters built the basis for the next step of the roadmapping work. The second workshop was implemented online and facilitated by consortium partners working on a virtual whiteboard in three break-out groups. During this exercise, concrete actions and recommendations per cluster were developed and ranked. These in turn build the basis for the MASTT2040 Industry Action plan which outlines issues that should be addressed in the coming years to reinforce MaaS impact for European industry.

Below, the identified actions and related time frames as well as stakeholder recommendations for the four clusters per MASTT2040 key aspect are given. Where available, related use cases from the MASTT2040 case book¹ are given to depict good practices and challenges related to each cluster.

5.2.1 Resilient supply chains enabled by MaaS

5.2.1.1 Cluster 1: Resource constraints/ sourcing of critical raw materials

2025-2030

In the short term it will be important to concentrate on monitoring critical raw materials via material tagging (e.g. passports) to enable fast global aggregation of low quantities of critical materials. This needs to be combined with predictive tools to identify supply chain bottlenecks. This will need to be supported with dataspace to enable supply chain visibility, scheduling and AI tools and creation of use cases to demonstrate how pain points can be addressed. It is noted that the Chips Act has already implemented an observatory and there are lessons to be learnt from the aerospace industry.

2030-2035

In the medium term it is important to concentrate on actions that identify technologies to strengthen the recovery of raw materials (supported by Digital Product Passports). Europe should develop circular value chains especially for materials where there are critical European needs.

2035-2040

In the long term the key actions are to develop technologies that reduce critical raw materials usage (or allow use of alternatives) while providing the same performance in products and to improve technologies to better mine raw materials with less wastage and to enable the better extraction and enhancement of lower grade raw materials.

¹ [D1.1 Casebook- Current state of MaaS approaches and best practices to advance the CE - Mastt2040](#)

Recommendations

The recommendation in the short term would be for the EC to set up an observatory, with prediction tools to flag potential scarcities in critical materials backed by an industrial dataspace covering critical raw materials within the supply chain. In the medium term, Europe should introduce regulation encouraging the uptake of Digital Product Passports to strengthen recovery of critical raw materials and at the same time fund projects exploring end-to-end supply chain tracking. In the long term, the EC should fund projects that demonstrate how critical raw materials can be reduced or replaced by alternatives in products and to fund technologies to enable better mining or recover materials.

5.2.1.2 Cluster 2: Cybersecurity

2025-2030

In the short term it will be important to concentrate on development of AI algorithms that will allow materials flows to be monitored without providing access to confidential company data. This will require exchange of sensitive financial and investor data, trends and similarities, etc. and it is important to try and minimise the data that is exchanged. This will be enabled by security solutions to enable secure data exchange, technologies such as blockchain and potentially via the development of an EU-wide secure cloud.

2030-2035

In the medium term it is important to concentrate on actions that minimise the attack surface such as moving target defence to avoid data being intercepted and secure federated data infrastructures to support federated AI algorithms. Secure data passports that contain the minimum data necessary also need to be explored.

2035-2040

Cybersecurity is a continuum as new threats appear all the time, thus there will be a need to continually monitor and counter new threats which will require investment.

Recommendations

The recommendation in the short term would be for the EC to explore the feasibility of an EU wide secure cloud solution and to fund activities that support the uptake of security solutions in SMEs such as blockchain. In the medium term, Europe should continue to fund research on cybersecurity to protect data. However, in addition there is a need for projects to be funded that identify how the amount of confidential data that needs to be transferred can be minimised. It was noted that smaller scale projects on federated architectures and learning have been funded by the EC, however, it is necessary to fund larger industrial scale projects to demonstrate their worth to industry.

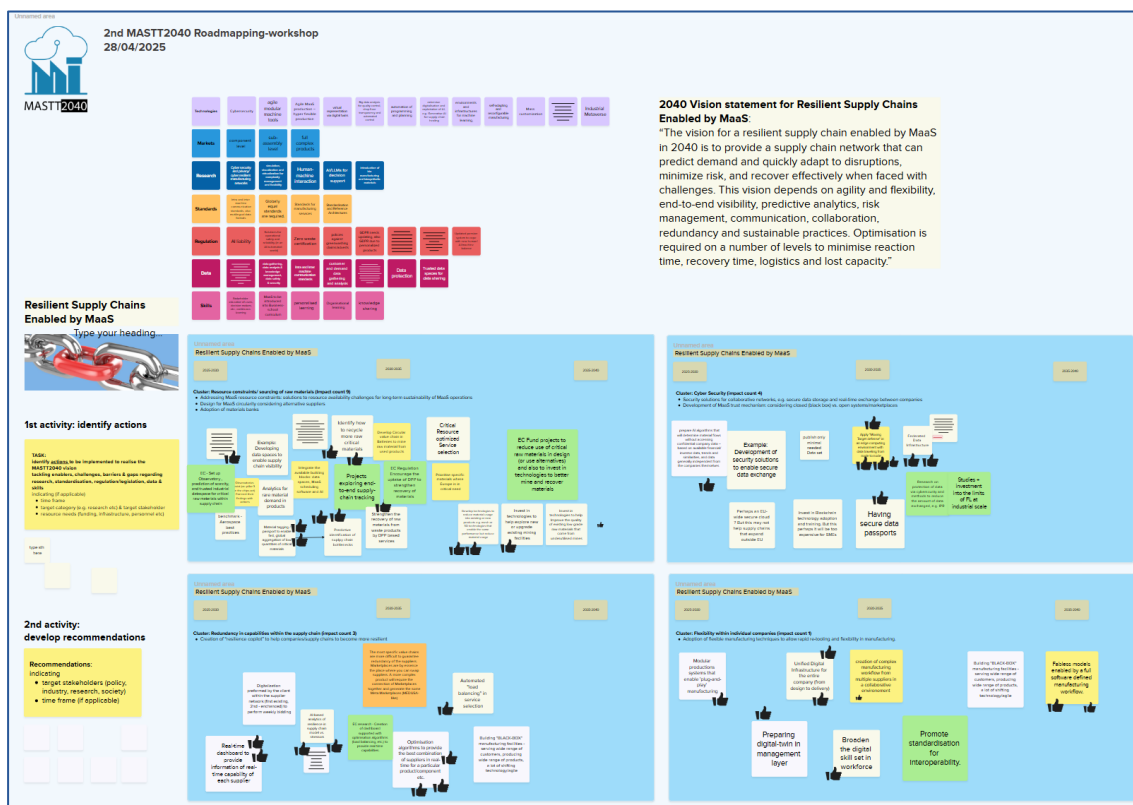


Figure 17: Resilient supply chains virtual whiteboard

5.2.1.3 Cluster 3: Redundancy in capabilities within the supply chain

2025-2030

In the short term it will be important to concentrate on development of a real-time dashboard to provide information on the real-time capabilities of each supplier in the supply chain. This needs to be coupled with digital twins of the supply chain to simulate recovery strategies and the impact of disruptions. At a base level there is a need for support for companies in the supplier network to digitise so that they can exchange data and bid for work. Additionally, AI-based tools need to be developed that can identify weaknesses and stressors in the supply chain to ensure resilience. It was noted that a marketplace approach to MaaS naturally allows suppliers to be swapped within the supply chain and as products get more complex there will be a need to connect multiple marketplaces together.

2030-2035

In the medium term it is important to concentrate on actions that address optimisation tools that allow the best combination of suppliers in real time for specific product/component production. This needs to be supported with automatic load balancing in service selection.

This would be an enhancement of the tools produced in the recommended actions for 2025-2030 timeframe but with deployment/uptake in real cases.

2035-2040

The expectation for the long term is that manufacturing services will become a “black box” that can provide services and products for a wide range of customers with great flexibility and agility.

Recommendations

The recommendation in the short term would be for the EC to fund projects that create a dashboard supported by optimisation algorithms (load balancing, etc.) to provide real-time optimisation of supply chains for resilience.

5.2.1.4 Cluster 4: Flexibility within Individual Companies

2025-2030

In the short term it will be important to concentrate on development of modular production systems that enable “plug-and-play” manufacturing. This will require a unified digital infrastructure going from design to delivery and the use of a digital twin management layer.

2030-2035

In the medium term it is important to concentrate on the creation of a collaborative environment for manufacturing allowing multiple suppliers to come together. This will need support to educate and upskill the workforce with a broader set of digital skills.

2035-2040

The expectation for the longer term is that manufacturing services will become a “black box” that can provide services and products for a wide range of customers with great flexibility and agility. It is envisaged that this could lead to “fabless models” of manufacturing like those seen in the semiconductor industry.

Recommendations

The recommendation in the short term would be to encourage appropriate standardisation for interoperability to allow exchange of information at machine level. The main recommendation in the medium term would be to encourage appropriate standardisation to allow exchange of information between companies to allow collaboration. At the same time actions for upskilling workers will be required.

5.2.2 Circular and sustainable MaaS

5.2.2.1 Cluster 1: Enabling sustainable manufacturing & circularity in all steps of the product life cycle

2025-2030

In the short term it will be important to demonstrate how MaaS can support more complex stakeholder relationships. It is also important to create use cases and publish results from these to share knowledge and provide inspiration to other companies. To support SMEs, in particular, there is a need for easy-to-use bottom-up solutions which should be provided by start-ups and scale-ups to

avoid vendor lock-in to big players. The aim would be to provide open tools that can be easily integrated which focus on sustainability with features such as trade-off analysis between sustainability and cost. These tools should also have APIs (via a standardised data interface) that link to materials banks. Supporting uptake of circular and sustainable practices there is a need for stakeholder education especially for decision makers and management. There is also a need for continuous learning. Incentives, such as tax breaks, are required to stimulate companies to research into and adopt resource efficient manufacturing processes.

2030-2035

In the medium term it is important to concentrate on the establishment of regional digital circular trade hubs. R&D also needs to be performed into creating circular materials that can be reused. Underpinning this there is a need to develop standards for interoperability within MaaS ecosystems.

2035-2040

In the longer term the expectation is that knowledge driven AI will be used to support SMEs in adopting circular practices.

Recommendations

The recommendation in the short term would be for the EC to fund pilot projects to develop tools that promote sustainability and circular practices and to back this up by developing eco design standards. At a national level tax breaks should be provided to incentivise companies to adopt circular and sustainable manufacturing processes. The recommendation in the medium term is to provide regional support for industrial stakeholders to demonstrate the benefits of circular approaches, e.g. via creation of digital circular trade hubs, which can then be scaled towards the wider community.

5.2.2.2 Cluster 2: Increasing environmental consciousness in the economy & society

2025-2030

In the short term it is important to develop comparison tools to support decision making that can analyse alternative sustainable/circular solutions. This will require analysis tools that calculate the real sustainability impact of different actions. These tools can then be used to organise manufacturing systems to be more sustainable. It is also important to encourage companies to make sustainability and circularity part of their strategy so that it is standard in development processes. This is linked with making sustainability and circularity part of corporate identity.

2030-2035

In the medium term it is important to concentrate on actions that promote sustainable implementation of manufacturing supply chains. This can be through introduction of Digital Product Passports and by establishing clear guidelines for circular manufacturing processes in MaaS business models. For this to be successful there is a need to provide access to remanufacturing data and to share best practices for remanufacturing so that trusted providers can be developed that can serve several companies.

2035-2040

In the longer term the key actions would be to provide tools that automate sustainability reporting and to also provide tools that help companies partially automate process adjustment to continuously optimise sustainability.

Recommendations

The recommendation in the short term would be for the EC to fund decision making tools for companies to optimise their processes. Initiatives are also required to raise awareness and encourage the uptake of sustainable and circular practices. The recommendation in the medium term would be for the EC to concentrate on rolling out Digital Product Passports and investigate the development of European standards, eco labels and certification. At a regulatory level mandatory ESG (environmental, social and governance) reporting standards are needed. There is also a need for environmental impact training and this could be supported by the EC creating a European platform for exchange of best practices in sustainable production and consumption, underpinned by national and regional initiatives.

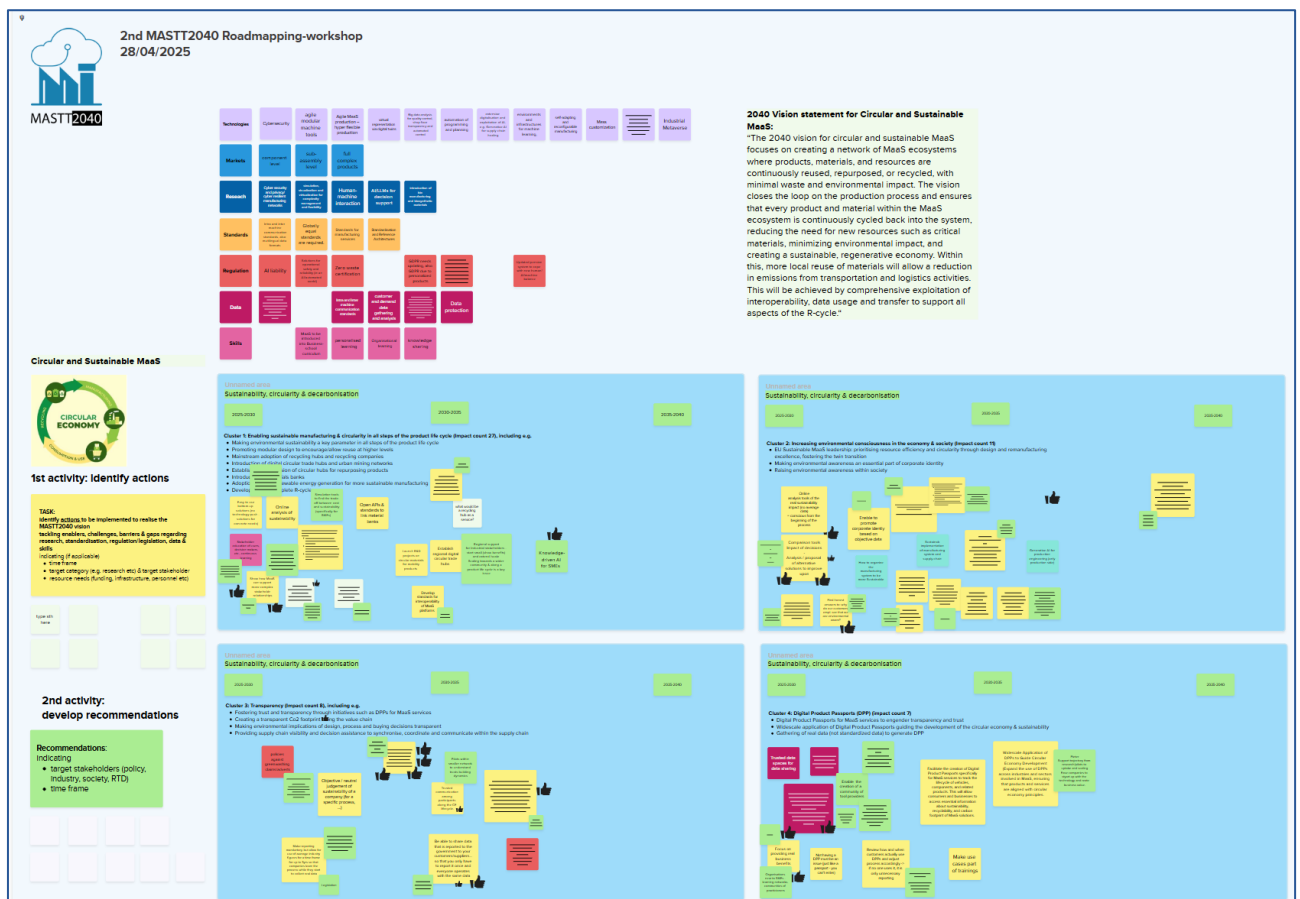


Figure 18: Circular and Sustainable MaaS Virtual Whiteboard

5.2.2.3 Cluster 3: Transparency

2025-2030

In the short term there is a need to put in place a methodology that allows a neutral approach to judgement of sustainability for a company or process. This is to combat companies greenwashing. The implementation of this would require a common and easy to use reporting system. Reporting should be made mandatory, but companies should be allowed to use average figures for a period of 3 years to allow them to collect real data.

2030-2035

In the medium term actions should concentrate on industry assessments and legislation in order to provide guidelines and standards for reporting data for product groups (this should firstly be a limited set of products which is then expanded over time). For reporting it is important to put in place a mechanism that allows trusted communication among participants within the circular economy. The key aim will be to report and share CO2 footprint data transparently in a trusted way with government, customers and suppliers via a single portal so that it is only done once. This lifecycle information will enable consumers and businesses to make informed sustainability decisions.

Recommendations

The recommendation in the short term would be for the EC to introduce regulation to make reporting of a key subset of sustainability data mandatory with a phased 3-year introduction. The recommendation in the medium to long term is for the EC to implement mandatory CO2 footprint reporting at every stage of the product and service for key products. Supporting the introduction of this, the EC should fund pilots in smaller networks to better understand and demonstrate trust dynamics for exchange of data. Certification should also be explored for MaaS value chains considering emissions, social, and economic factors. There is also a need for certification to prevent unsafe products being

5.2.2.4 Cluster 4: Digital Product Passports (DPP)

2025-2030

It will be important in the short term to concentrate on supporting SMEs, providers and customers in data gathering, data analysis and knowledge management for Digital Product Passports (DPPs). An enabler for this is the creation of a trusted data space for data sharing utilising open data formats that ensures data safety and security. It is also important to gather lessons learnt from early adopters which in turn will enable creation of a community of tool providers. CO2 and sustainability data should be directly incorporated into the DPP for transparency. The data format should be reviewed by industry associations and standardised. The data stored should also be reviewed to see how customers use the DPP to adjust processes. The aim is to identify real business benefits of using DPPs for SMEs, learning networks, and practitioners. The ultimate goal is to make “not having a DPP” an issue for a company.

2030-2035

In the medium term it is important to concentrate on development of Digital Product Passports for MaaS to track vehicles, components and other products. This will allow consumers and businesses to access essential information about sustainability, recyclability, and CO2 footprint of MaaS solutions.

2035-2040

In the longer term the aim will be to encourage the wider scale adoption of DPPs to guide circular economy development in other sectors where MaaS is deployed.

Recommendations

The recommendation in the short term would be for the EC to concentrate of funding projects that demonstrate data gathering and trusted data exchange (e.g. trusted data spaces) of Digital Product Passport data. This needs to be backed by industry driven standardisation initiatives. The EC projects should also clearly demonstrate the business benefits of DPPs which should be widely publicised to stakeholders. The recommendation in the medium term is for the EU to introduce regulation encouraging the uptake of Digital Product Passports to strengthen circular approaches and at the same time fund projects that create use cases for training. The recommendation in the long term would be for the EC to fund projects in key sectors and demonstrate how the approaches can be adopted to make it easier for SMEs to embrace DPPs and circular practices.

5.2.3 Human-centric, flexible automated production system MaaS

In all clusters of human-centric MaaS, both actions and recommendations were mainly addressed to the first timeframe until 2030 as it was perceived that there are very many urgent and pressing issues that need to be tackled immediately.

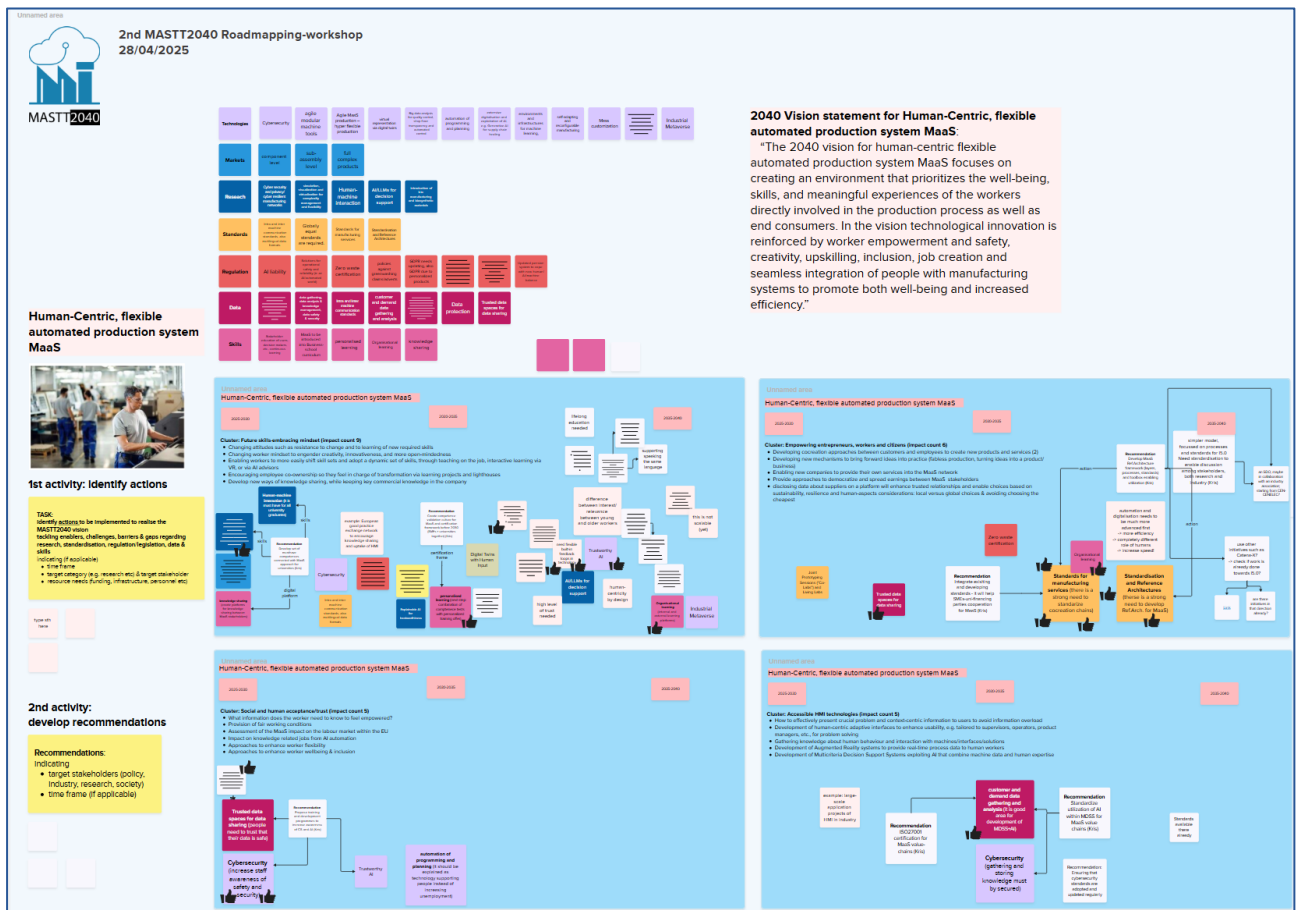


Figure 19: Human-centric MaaS virtual whiteboard

5.2.3.1 Cluster 1, Future skills-embracing mindset

2025–2030

In the short term it is important to concentrate on human-machine interaction, simulation, and visualisation to address complexity management and provide greater flexibility. Skills in these areas will be essential for all university graduates. There is also a need to develop digital knowledge-sharing platforms to allow MaaS stakeholders to share experience. At a technical level, there is a need to standardise components to create MaaS value chains, standardise interaction and inner machine communication standards, and support multilingual interfaces. For trusted communications, cybersecurity will be essential.

2030–2035

In the medium term, personalised learning is required, supported by competence tests. AI will be a key enabler for workers' expertise, while there will be a need for trustworthy, explainable AI governed by regulation for the use of AI on the shop floor. This may also require changes to occupational health and safety rules and actions to enforce work security. The interaction between digital twins in smart manufacturing communities of practice.

2035–2040

In the long term, there is a need to ensure a high level of trust for AI and machine learning tools used in decision support processes. A fundamental need is to avoid "tech overload" during this period, when digital twins will be extensively used in conjunction with operator feedback. Workers should be empowered to give feedback on the technology via user-friendly interfaces, bringing about human centricity that helps them feel more comfortable as they work with digital tools. It is important not to capitulate on this knowledge-sharing aspect or lose valuable knowledge gained by workers. There will still be a requirement for workers' expertise at an excellent level of understanding. MaaS stakeholders in research and development innovation have indicated that it is important we continue this, supported by international academic partnerships. In the long term, this will lead to increased productivity.

Recommendations

The main recommendation in the short term would be to develop a "must-have" set of competences for MaaS approaches within academia and industry, which can be shared via networks such as the European good practice newsletter. The recommendation in the medium term is for SMCs to understand the creation of new learning materials. This should be backed by both top-down and bottom-up approaches, recognised Europe-wide, and built on good practice via success stories from SMCs. Sharing insights at the local level should encourage exchange between Digital Innovation Hubs. Learning platforms should be funded to allow knowledge sharing between older and younger workers.

5.2.3.2 Cluster 2, Empowering entrepreneurs, workers and citizens

2025–2030

In the short term there is a critical need for trusted data spaces to allow data sharing. To encourage the uptake of MaaS there is also a need to support joint prototyping sessions in collaborative labs and living labs.

2030–2035

In the medium term there is a need for standardisation for manufacturing services with a strong need to standardise cocreation chains.

2035–2040

In the long term automation and digitalisation will lead to completely different role for humans. There is a need to create a reference architecture for MaaS covering layers, processes, standards and toolboxes. A simpler model is required that focusses on processes and standards for Industry 5.0. Creation of such a model would stimulate discussion among stakeholders from research and industry bringing together activities such as Catena-X and Industry 5.0.

Recommendations

The recommendation in the short term is to fund projects to create trusted data spaces for MaaS and activities that will promote the uptake of MaaS such as collaborative labs and living labs. The recommendation in the medium term is to look at existing and developing standards and see how they can be integrated to help SMEs create services and cocreation chains. The EC should encourage industry along with standards body such as CEN-CENELEC to develop a reference architecture for MaaS.

5.2.3.3 Cluster 3, Social and human acceptance & trust

2025–2030

To encourage social acceptance in the short term, work should concentrate on the creation of trusted dataspace for data sharing and actions to enable trust in the output from AI models. There is also a need to increase awareness of cybersecurity to demonstrate to people that their data is safe.

2030–2035

In the medium to long term, there will be increased automation including automation of machine programming and production planning. A key need will be education of workers to explain how the technology supports them in their jobs rather than leading to unemployment.

Recommendations

In the short term, the key recommendation is to support training and development programmes to raise awareness of cybersecurity and AI as well as to support the creation of trusted dataspace for MaaS. The recommendation in the medium to long term is to promote the benefits of increasing automation of processes and how it enhances existing jobs needs to workers.

5.2.3.4 Cluster 4, Accessible HMI technologies

2025-2030

In the short term, there is a need to implement large-scale HMI projects in industry to demonstrate their benefits and to encourage uptake

2030-2035

In the medium to long term, in order to support increasing optimisation of processes via tools such as AI, there will be a need to gather more customers and demand data this will need to be maintained and shared via cybersecure data spaces.

Recommendations

In the short term, the EC should fund deployments of HMIs in industry leading to the deployment at a larger scale. In the medium to long term, certification for MaaS value chains should be developed along with standardisation for AI. To secure data cybersecurity standards should be adopted and updated regularly to meet new threats.

5.3 Synthesis of MASTT2040 Roadmap

The two roadmapping workshops highlighted a number of expected impacts from the increasing digitalisation of industry which will allow much greater flexibility in manufacturing and collaboration within supply chains. Notably, experts identified that this will lead to much greater capabilities allowing SMEs to work together to produce components, subassemblies and full products using MaaS in the future. This led to the visual representation of the MASTT2040 roadmap given below which shows the evolution of MaaS from its current status in 2025 identifying functionalities which already exist to the visions presented for 2040 and the key research and technology areas that need to be addressed in order to achieve them. The roadmap specifically shows the overall future MaaS development towards the 2040 vision, driven by the three key aspects addressing the key EC goals and related short-, mid- and long-term functionality requirements of MaaS. Concretely, today MaaS is mainly applied for manufacturing of components by single or very few interacting manufacturing companies. In the coming five to ten years, the expectation is that there will be a considerable increase in collaboration and data sharing between companies driving MaaS towards manufacturing of sub-assemblies. In the longer term these MaaS manufacturers will evolve to be capable of producing complete products by 2040. As is highlighted in the roadmap below, considerable advancements in manufacturing technologies, processes and culture will be needed to realise this vision, bringing Europe closer to the twin transition goals by enhanced resilience, sustainability and circularity as well as human-centric automation.

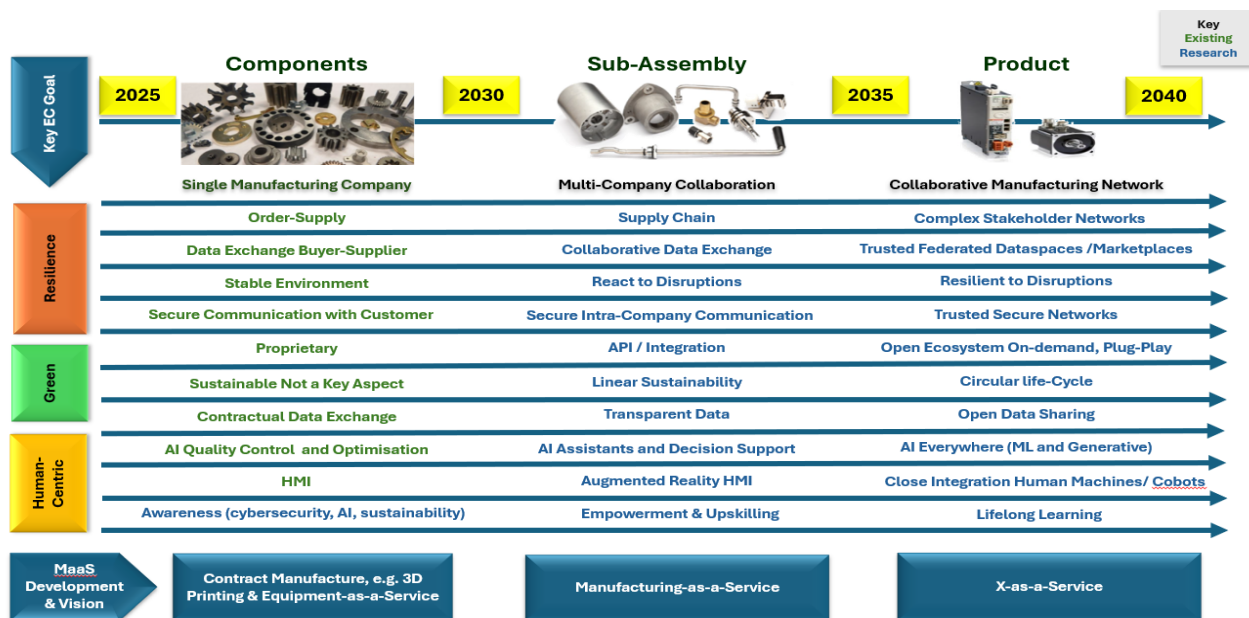


Figure 20: MASTT2040 Roadmap

By 2040 the expectation is that MaaS will mature into a trusted, resilient, and adaptive industrial backbone, enabling on-demand, high-quality, and precisely timed production making it accessible to all players from SMEs to global integrators. Flexible, efficient, and open fully digital autonomous

manufacturing networks governed by federated models will provide robustness to disruption. AI and machine learning will be exploited from design to post-production, forecasting demand, orchestrating supply, optimising resource use and adapting to change in real time. Trust, traceability and control will be essential through exploitation of sovereign industrial data spaces, decentralised governance models and access rights controlled via permissions and roles. Actors will need to retain full control over their IP, data and services encouraging innovation. Orchestration engines will be required to match demand and supply across domains, enabling agile assembly of supply chains from distributed resources.

A key enabler will be standardisation so that machines, processes or capabilities are easily discoverable, semantically described and dynamically composable. Sustainability and resilience can be built into MaaS platforms considering energy, resources and raw materials usage to optimise for low-carbon manufacturing, avoid use of critical raw materials and encourage circular approaches. All of the above will lead to change redefining what it means to work in manufacturing. Roles, skills and careers will shift as humans take on orchestration, supervision and innovation tasks supported by intelligent, secure HMIs and Augmented Reality systems designed to empower human workers. Human insight will remain essential in hybrid decision systems to combine human context with machine intelligence to enhance creativity, situational judgement and oversight.

To further concretise the research and technology areas depicted in the roadmap, Chapter 6 below drafts concrete industry pathways to realise future MaaS organisations, products and services.

6 Pathways to MaaS impact: the MASTT2040 Future Use Cases

The MASTT2040 roadmap shows how MaaS could develop by 2040. It is important, however, to also depict industry use cases of how such advancements can be exploited. In this section concrete and tangible pathways are presented that can be used by companies, industry associations and policy advisers to develop strategies to take forward and valorise the concept of MaaS at regional, national and European level.

6.1 MASTT2040 Future Use Cases

The MASTT2040 Casebook² outlines in great detail the current status of MaaS practices in Europe. During project phase 2, 20 forward-looking use cases for 2040³ were elaborated that built on the casebook, the trends analysis and the scenario work. These use cases were mapped to the main future MaaS development aspects (resilience, sustainability and circularity, human centric aspects) and used as input to the roadmapping process. There, they were discussed by the participants and incorporated into the roadmap development. A key driver of MaaS is the shift towards a more decentralised manufacturing approach in the coming years. This is expected to be the main influencing factor for evolving future MaaS use cases. Factors reinforcing this development were discussed in great detail during the roadmapping process, i.e. the need for increased resilience (including cybersecurity) and the need for increased sustainability, the two triggered by the need to source raw materials from

² [D1.1 Casebook- Current state of MaaS approaches and best practices to advance the CE - Mastt2040](#)

³ [MASTT2040 D2.1 Future of MaaS in Europe - the 2040 vision, trends, scenarios and use cases - Mastt2040](#)

secondary sources; requests from standardisation & legislation to support B2B & B2C customers, and the need for human-centricity as manufacturing rapidly changes resulting in more targeted education and training needs in the future.

Today's MaaS platforms are still overwhelmingly oriented toward virgin material flows and new part production. Solutions like materials banks, circular substitution libraries, or dynamic sourcing based on geopolitical factors are absent from real-world MaaS implementations. While Resourcly is cited as an early example of shared inventory in the MASTT2040 Casebook, it's still rare. From the MASTT2040 casebook, it becomes apparent that most current MaaS platforms operate on proprietary architectures with centralized control (e.g. Xometry, Protolabs), not federated or zero-trust data governance models. Catena-X is mentioned as a rare case promoting federated secure exchange, but it is still an emerging model, not mainstream. Real-time digital capability mapping and stress-testing for redundancy are not yet embedded in MaaS platforms. Platforms enable scaling and access to distributed capacity, but do not support resilience diagnostics or substitution simulation. Overall, some flexibility exists via modular, automated production (e.g. 247TailorSteel, RobCo), but true composability (e.g. Lego-like reconfiguration) or Equipment-as-a-Service (EaaS) is only emerging and not common outside of pilot projects.

Most MaaS platforms focus on new part manufacturing and are “only weakly driven by green goals”. Services supporting remanufacturing, repair, reuse orchestration, or micro-repair hubs are virtually absent. The Casebook flags this as a significant missed opportunity. Environmental impact or eco-design support tools are not systematically integrated. Customer interfaces focus on cost, speed, and manufacturability, not on lifecycle emissions, eco-scores, or sustainability dashboards. Although a few companies like Circularise offer DPPs, CO₂ transparency, real-time emissions tracking or decision support for sustainable routing are largely conceptual. The Casebook calls DPPs a potential game changer but notes that standardisation and application remain immature. DPPs are in prototype stage in separate platforms not yet linked to MaaS, and very few are in active industrial use in some industrial sectors. Circularise is one of the rare examples. According to the Casebook, initiatives are underway, but fragmentation and lack of convergence limit industrial impact today.

Current MaaS platforms prioritise automation over human involvement with emphasis on “cost-effective hyperscaling with limited need for human resources”. While P2P platforms lower access barriers for SMEs, the ecosystem is still hierarchical, with large providers offering pre-defined services. There is no support for user-driven service creation, cocreation or micro-enterprise onboarding tools. Missing from current practice are 1. Self-onboarding APIs for micro-providers, 2. Fair value-sharing mechanisms, 3. Citizen involvement in product-service lifecycles, 4. Tailored, cognitive-load-aware HMI for different roles, 5. Multimodal AR/VR for process feedback, and 6. Decision interfaces combining sensor data + worker expertise. Platforms integrate automated quoting, planning and order processing, but often with minimal human-machine collaboration. There is no mentioning of context-aware or emotion-aware AR interfaces, or adaptive decision-support interfaces tailored to operators.

Based on the above aspects taken from the MASTT2040 Casebook and the ones identified during the roadmapping process, five key future use cases have been identified and discussed with more than 20 participants during the third MASTT2040 webinar on July 8th 2025. Each of these five use cases is

graphically displayed in the MASTT2040 roadmapping approach in Figure 22 and explored in further detail in the following sections:

- Use case 1: Local manufacturing networks for components and sub-assemblies
- Use case 2: Resilient supply chains through MaaS-based disruption prediction and autonomous adaptation
- Use case 3: A Dynamic MaaS Ecosystem for Circular Manufacturing
- Use case 4: EaaS: Equipment as a Service – smart, flexible, usage-based equipment access
- Use case 5: XaaS: Everything as a Service for a human-centric end-to-end manufacturing

Each use case is accompanied by a visual overview of its key capability feature developments along the roadmap timeline. Red arrows indicate the main future capabilities that require progress beyond today’s state of practice to achieve the 2040 vision. While AI is expected to play a major enabling role across all use cases, it is not shown as a distinct capability within the figures.

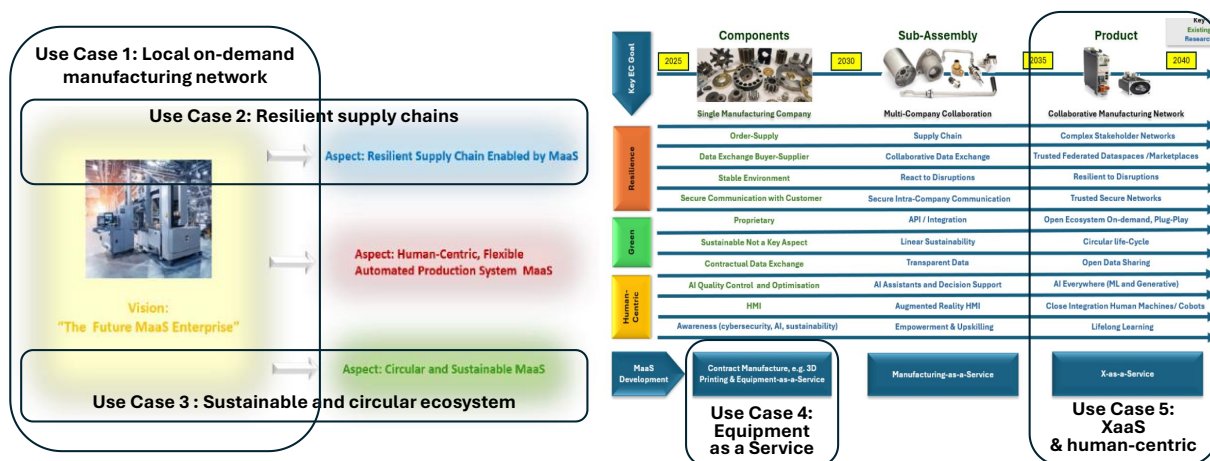


Figure 21: Identification of use cases in MASTT2040

6.1.1 Use case 1: Local manufacturing networks for components and sub-assemblies

By 2040, Europe envisions a resilient, distributed manufacturing ecosystem anchored in local networks. This transformation leverages a federated Manufacturing-as-a-Service platform that connects regional suppliers through open standards, ensuring interoperability and avoiding vendor lock-in. Such a system enhances supply chain transparency, security, and sustainability, fostering a robust local collaborative production landscape for components and sub-assemblies.

Open platforms integrate advanced technologies like AI, blockchain, and Digital Product Passports to facilitate real-time collaboration, lifecycle tracking, and environmental impact assessments. This digital backbone supports SMEs in accessing specialised marketplaces, enabling them to offer and procure services efficiently, thereby promoting local manufacturing and reducing dependency on external

suppliers. Through this approach, Europe can bolster its manufacturing autonomy, ensuring that components are produced locally, sustainably, and efficiently.

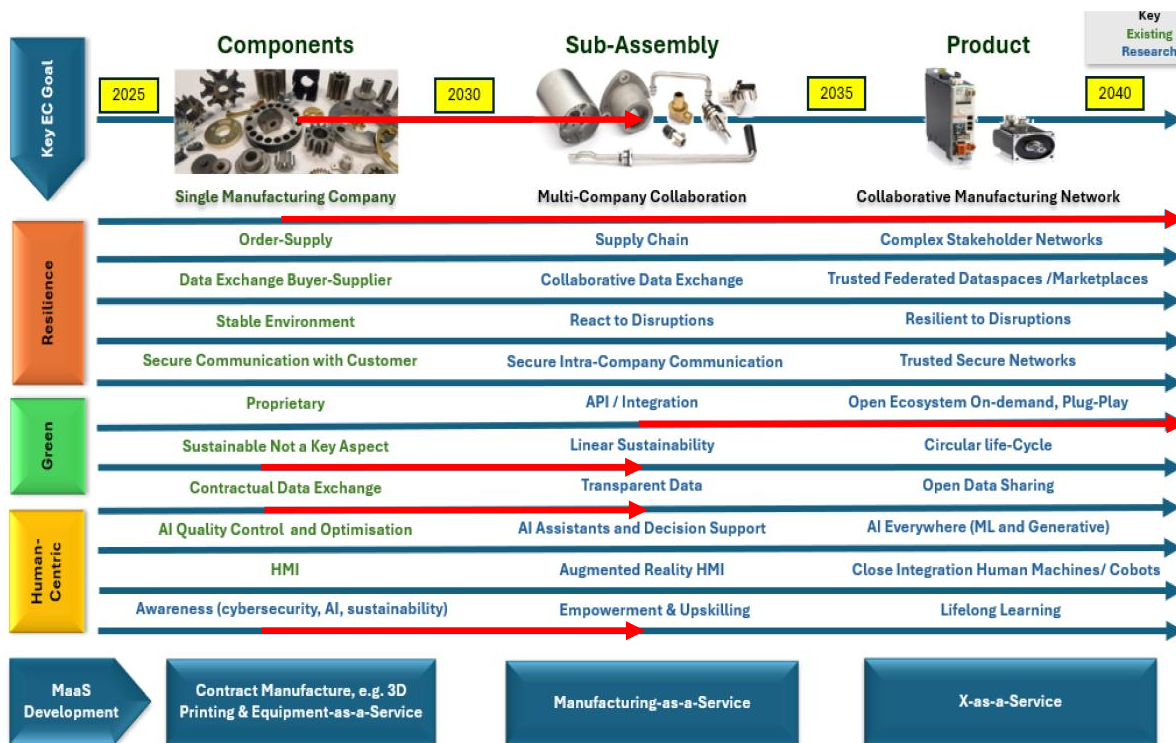


Figure 22: Use case 1: Local manufacturing networks for components and sub-assemblies

MaaS services that can be offered in this use case:

- **Matchmaking and vetting services:** Open platforms offer AI-driven matchmaking services that connect buyers with local and European suppliers based on quality, capacity, and sustainability metrics. Matchmaking is not limited to one supplier, suppliers can collaborate to fulfill manufacturing orders for complex components or sub-assemblies. New suppliers, especially SMEs, can easily join the ecosystem and present their capabilities. A vetting process evaluates supplier reliability and ensures high-quality production standards.
- **AI-powered marketplaces:** Dynamic marketplaces match production demands with available capacities, facilitating peer-to-peer communication for seamless collaboration. Integrated microservices provide real-time analytics, matchmaking, and workflow automation, enhancing efficiency and responsiveness in the manufacturing process.
- **Ecosystem for B2B microservices:** Open APIs foster a developer-friendly environment where innovators can deploy a variety of microservices integrating in-depth manufacturing knowledge i.e. for quotation, process optimization, planning or quality control. This ecosystem ensures constant technological evolution, providing suppliers with affordable, easy-to-implement tools that are configurable and adaptable to their production environments, thereby supporting competitiveness and reducing lead times.
- **Sustainable-aware manufacturing:** Services enable the sharing of production capacity, optimising supply chains by shortening them and reducing environmental impact. Digital Product Passports

support transparent production processes, providing real-time data on sustainability metrics like carbon footprints and material origins. Environmental impact analysis tools assess energy consumption, material waste, and emissions, offering recommendations for improvement and highlighting inefficiencies in production lines.

- **Sourcing of raw materials:** marketplaces offer material sourcing insights, evaluating the need for raw materials, proposing sustainable alternatives, and facilitating access to necessary resources for production. On top, marketplaces allow manufacturers to share the availability of critical raw materials, ensuring transparency and trust through secure peer-to-peer exchanges.
- **Human-centric interfaces & skills support:** Adaptive, intuitive interfaces guide the human in real time, with built-in AI that offers seamless skills support and personalised training exactly when it's needed.

6.1.2 Use case 2: Resilient supply chains through MaaS-based disruption prediction and autonomous adaptation

By 2040, European manufacturers will rely on a decentralised network of MaaS-enabled nodes to ensure resilient, self-healing supply chains. AI-driven platforms detect and respond to disruptions by rerouting logistics, reallocating manufacturing capacity, and adjusting production schedules. These systems integrate real-time data from sensors, digital twins, and external sources (e.g. geopolitical risk, weather, logistics data) to trigger autonomous adaptation across the supply network.

A key enabler is the integration of dynamic supplier substitution through interoperable digital twins and semantic capability maps. In the event of a disruption, be it a material shortage, logistics blockage, or machine failure, MaaS platforms automatically identify and activate capable alternatives. Platforms orchestrate local, on-demand manufacturing responses using modular production capacity within federated networks. This reduces dependence on global supply chains while increasing Europe's strategic autonomy.

Responsiveness is secured by digital inventories providing access to nearby available components or digital twins and material passports enabling on-demand manufacturing. These systems, embedded in trusted data spaces, ensure traceability, versioning, and IP compliance anywhere in the network when critical components need to be produced locally and quickly.

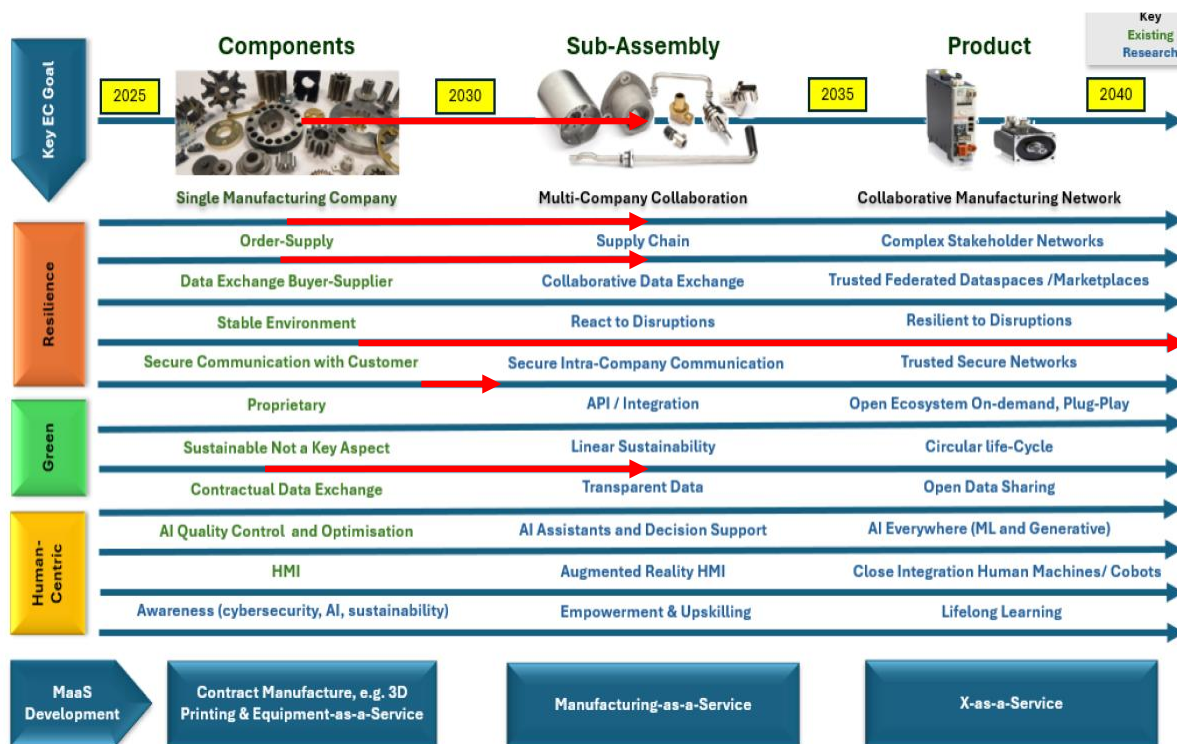


Figure 23: Use case 2: Resilient supply chains through MaaS-based disruption prediction and autonomous adaptation.

MaaS services that can be offered in this use case:

- **Predictive stress testing:** Simulation environments allow companies to stress-test their supply chain using digital twins, helping them plan fallback scenarios and strengthen network robustness before disruptions occur.
- **Disruption detection & adaptive rerouting:** AI monitors real-time data and digital twins to detect disruptions early, simulate impacts, and automatically reroute logistics or activate backup suppliers ensuring uninterrupted production flow.
- **Local on-demand manufacturing:** When disruptions strike, MaaS platforms shift production to nearby partners using modular, on-demand manufacturing nodes reducing delays, emissions, and dependency on distant supply chains.
- **Digital inventories:** Secure digital inventories provide encrypted access to product manufacturing data, enabling fallback manufacturers to produce parts while respecting IP, quality, and compliance standards.
- **Dynamic material sourcing:** AI-driven tools suggest alternative materials and suppliers based on availability and environmental data, while material banks and design libraries support fast, resilient adaptation.

6.1.3 Use case 3: A Dynamic MaaS Ecosystem for Circular Manufacturing

By 2040, European manufacturing will be supported by dynamic, circular ecosystems that are digital, decentralized, low-carbon, and resource-resilient. MaaS platforms will orchestrate sustainability across the entire product lifecycle from design and production to R-cycles (repair, remanufacturing, reuse) and recycling. AI-driven decision engines continuously optimise production choices based on CO₂ footprint, energy availability, material circularity, and customer demand. This enables real-time routing of manufacturing jobs to low-emission periods or locations, smart load-balancing across the network, and avoidance of overproduction through just-in-time customisation. Sustainability will not be a layer added after design, but embedded into orchestration rules, procurement decisions, and platform identity.

At the product level, modular design and design for disassembly will be the norm, with every product linked to a Digital Product Passport that captures emissions, repairability, material content, and usage history. Green metrics and DPPs, fully integrated into MaaS platforms, will enable lifecycle carbon monitoring and provide transparent environmental impact data to end-users and buyers. Federated data spaces allow OEMs, SMEs, and recyclers to share sensitive data securely and collaborate on circular value retention without losing control of IP or commercial risk.

Manufacturing operations will embed reverse logistics and R-cycle services as standard, orchestrating in real time a network of regional hubs for repair, reuse, and remanufacturing. Material banks support component recovery. Product-as-a-Service models shift the focus from ownership to usage, effectively closing the loop and delaying end-of-life. The ecosystem will support training programmes, micro-credentials, and SME toolkits to equip workers and companies with the skills and capabilities to participate in circular production all the way from remanufacturing protocols to compliance-by-design.

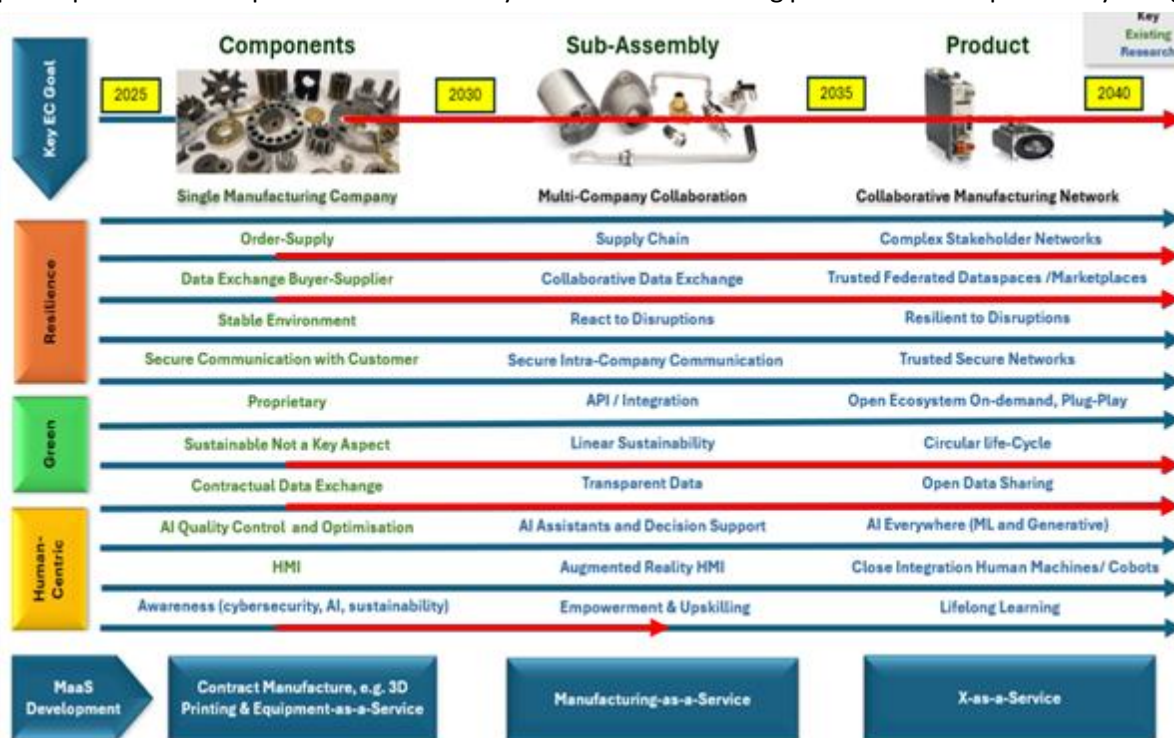


Figure 24: Use case 3: A Dynamic MaaS Ecosystem for Circular Manufacturing.

MaaS services that can be offered in this use case:

- **Digital Product Passports Integration:** DPPs will be essential for tracking product information throughout the lifecycle, including CO₂ emissions, repairability, material content, and usage history. They will enable predictive disassembly, lifecycle carbon monitoring, and transparent environmental impact information for stakeholders.
- **Reverse Logistics and Remanufacturing Services:** MaaS platforms will integrate reverse logistics and remanufacturing services, facilitating the return of products for reuse, remanufacturing, or recycling. This integration enhances value recovery and supports the circular economy by ensuring efficient management of end-of-life products.
- **R-cycle orchestration:** MaaS manages real-time routing of end-of-use products and components to regional repair, reuse, or remanufacturing hubs. AI matches each item with its most sustainable next use, whether reconditioning, part harvesting, or recycling, optimising logistics and circular value retention across the network.
- **Urban mining & material banks:** MaaS platforms link to distributed stocks of reclaimed materials and reusable components via urban mining networks and material banks. AI evaluates CO₂ savings and traceability through DPPs, enabling circular sourcing decisions.
- **Circularity-by-design skills & training service:** Built-in training and support systems offer SMEs toolkits, and AI-assisted guidance for their transition to circular design, remanufacturing, and regulatory compliance.
- **Carbon-Aware Production Scheduling:** MaaS platforms will incorporate carbon-aware scheduling, shifting or optimizing workloads based on the carbon intensity of electricity at a given time or location. This practice aims to run manufacturing processes when and where energy is cleanest, typically when more renewable energy is on the grid.
- **Federated Data Spaces for Secure Collaboration** Federated data spaces will enable secure and sovereign data sharing among manufacturers, suppliers, R-service providers and recyclers. These spaces support the exchange of sensitive information, fostering collaboration without compromising intellectual property or commercial interests.

6.1.4 Use case 4: Equipment as a Service: smart, flexible, usage-based equipment access

By 2040, manufacturers across Europe can access production equipment, robots, and entire modular lines as-a-Service through trusted, interoperable platforms. These platforms decouple asset ownership from usage and offer advanced digital services that extend far beyond traditional equipment rental. Machines are remotely monitored, configured, and upgraded by the OEM or service integrator. This allows manufacturers to pay only for use and performance outcomes while the provider retains ownership and lifecycle responsibility.

Equipment as a Service (EaaS) models rely on open, cloud-based platforms that integrate advanced predictive maintenance, automated service updates, real-time usage metering, and remote diagnostics. Equipment is no longer purchased. EaaS business models convert CapEx (*Capital Expenditures*, one-time investments in long-term assets) to OpEx (*Operating Expenditures*, recurring

costs to keep things running) based on success-based KPIs. Manufacturers, particularly SMEs, benefit from lower entry barriers, flexible scalability, and risk reduction. OEMs and service providers are incentivised to ensure high uptime, energy efficiency, and process optimisation across diverse production contexts.

The industrial landscape is reshaped: asset-sharing networks offer modular, interoperable production capacity, enabling ad-hoc alliances and shared investments. EaaS drives circularity through refurbishment, reuse, and lifetime tracking, and promotes a human-centric shift where workers collaborate with smart equipment, aided by remote support, AR interfaces, and digital twins. This outcome-oriented model aligns well with Europe’s strategic goals of digital sovereignty, productivity growth, and the green transition.

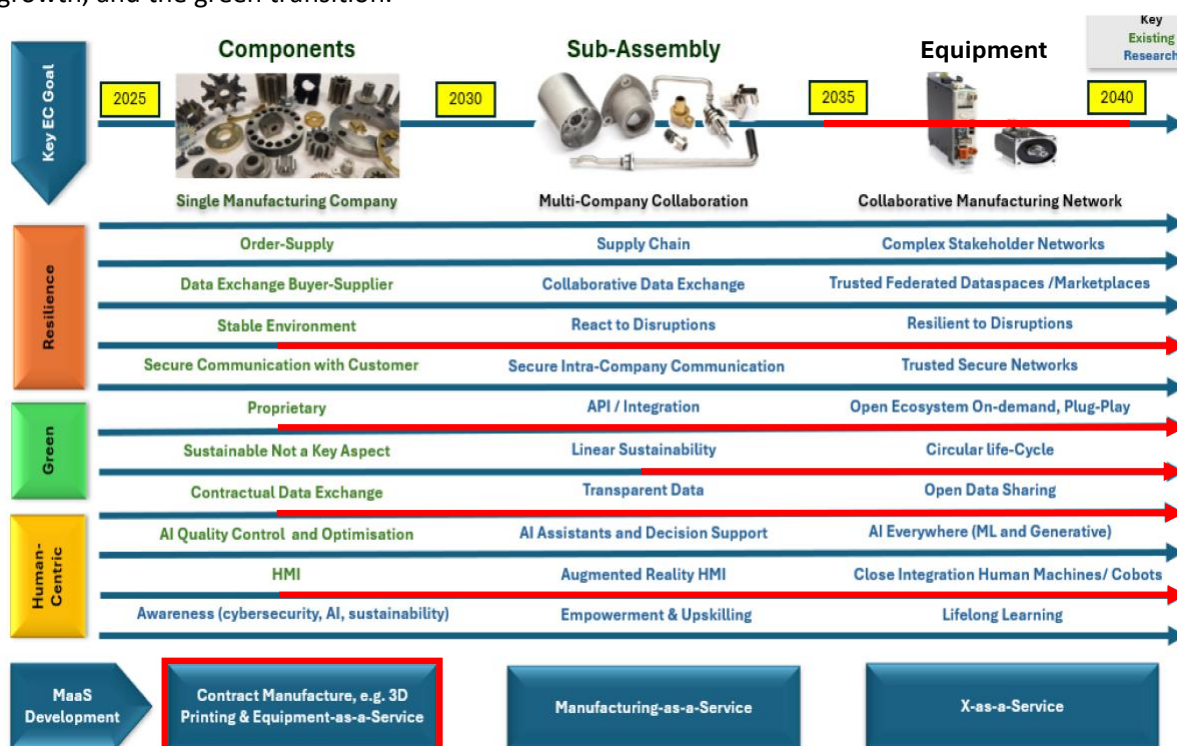


Figure 25: Use case 4: Equipment as a Service: smart, flexible, usage-based equipment access.

MaaS services that can be offered in this use case:

- **Equipment as a Service (EaaS) subscription models:** Customers access production assets based on “use” or “outcome,” enabled by smart metering and contract automation. The provider assumes both investment and operational risk. Service contracts define expectations around availability, quality, energy consumption, and throughput — creating incentives for continuous improvement. Algorithms monitor real usage and recommend model upgrades or reconfigurations. Equipment data feeds into digital twins and audit trails, strengthening trust among stakeholders.
- **Remote monitoring and performance optimisation:** Integrated equipment platforms provide real-time monitoring and AI-supported diagnostics. OEMs can intervene proactively, offer performance upgrades, and adapt configurations remotely. Machine learning tools identify patterns of underperformance or misuse, triggering suggestions or automatic adaptations. AR support interfaces guide local operators.

- **Equipment sharing:** SMEs and large OEMs alike can share idle equipment within their region or domain. Platforms enable temporary reservations, trusted logistics, usage verification, and secure access to machine configurations. Equipment passports and encrypted access ensure traceability and IP control.
- **Open equipment service platforms:** Future EaaS platforms will be open, modular, and vendor-neutral. Third-party software providers can offer services such as advanced analytics, planning support, or compliance certification directly on the equipment interface. Plug-and-play apps support predictive maintenance, tool recognition, or energy optimisation. This reduces vendor lock-in and supports competitive ecosystems.
- **Lifecycle services and circular tracking:** Lifecycle services are embedded from the start: refurbishment, reuse, and end-of-life services are included in the offering. Usage and health data feed circular KPIs, enabling better recovery or secondary use. Equipment providers are responsible for end-of-life strategies, spare parts logistics, and environmental performance.

6.1.5 Use case 5: XaaS Everything as a Service for a human-centric end-to-end manufacturing

By 2040, manufacturing has shifted from selling equipment or products to delivering modular, lifecycle-based outcomes: Everything as a Service. Manufacturers, OEMs, and service providers collaborate and interact through federated platforms where equipment, design expertise, and knowledge are all available as services. These platforms enable constant adaptation across the full product lifecycle, from concept and production to maintenance, reuse, and redesign, shifting value creation from isolated transactions to long-term service relationships.

Dynamic labour support systems enable seamless human-platform and production system collaboration. They allocate tasks between skilled workers, remote experts, and autonomous platforms and systems based on real-time production data, task complexity, and availability. MaaS platforms connect manufacturers to both skilled labour and robotic systems on demand scaling operations up or down, flexing around disruptions, and optimising cost-efficiency without compromising quality or adaptability.

Human workers are central as they supervise AI, configure services, intervene where needed, and contribute knowledge modules. Platforms host “knowledge-as-a-service”, microservice offerings and learning modules that learn and grow with each use. Everything as a Service (XaaS) platforms enhance workforce autonomy and learning, reduce routine work, and open new roles thus turning human intelligence into a core service component.

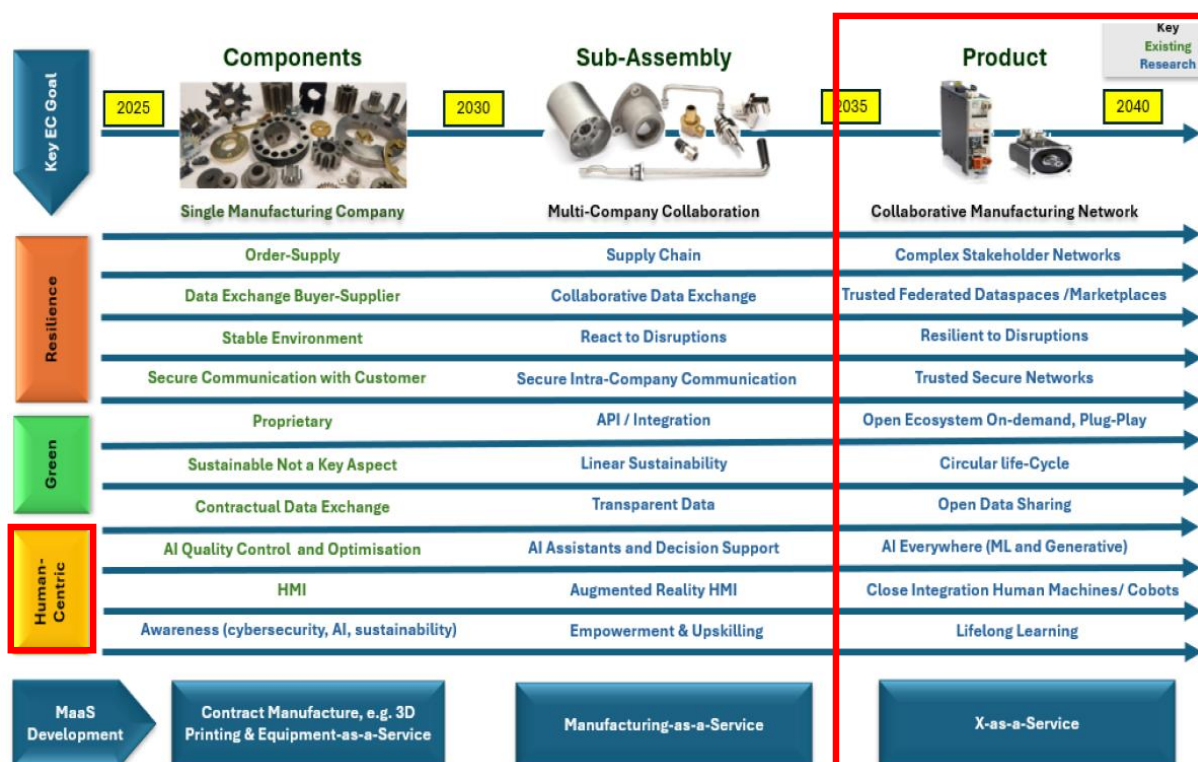


Figure 26: Use case 5: Everything as a Service for a human-centric end-to-end manufacturing. The red boxes indicate that all capability feature developments contribute to XaaS that integrates the four previous use-cases with a human-centric focus.

MaaS services that can be offered in this use case:

- **Product-Lifecycle-as-a-Service:** Manufacturers offer full lifecycle coverage as a service: design, production, use, monitoring, maintenance, upgrade, reuse. Digital twins and version-controlled designs allow adaptation over time. Physical products are no longer sold once, but constantly evolved. Lifecycle data feeds back into design and production creating circularity by default.
- **Co-design & co-customisation platforms:** Customers actively co-create the products or systems they need. Online configurators and collaborative design tools, backed by AI, let clients tweak product specs and performance goals. Designers and engineers can provide support remotely. This shortens lead times, raises satisfaction, and increases sustainability through better fit-for-use.
- **Dynamic labour & automation orchestration:** platforms dynamically allocate tasks between human operators, remote experts, and autonomous machines based on current needs adjusting workforce size and composition in real time.
- **Knowledge-as-a-Service:** Experts, developers, or OEMs offer microservices built on know-how. These can be reused, certified, and integrated into production systems by others. It turns expertise into plug-and-play service assets and lets small players scale what they're good at.
- **Usage- and performance-based contracts:** Instead of selling machines or systems, providers get paid per outcome: uptime, quality, energy saved, units produced. All parties share operational risk and align incentives. Advanced monitoring tools ensure transparent performance tracking. This shifts business models from transaction to partnership.

- **Human-centric orchestration and supervision:** Workers take on higher-value roles as orchestrators, coaches, and supervisors of digital services. They configure workflows, validate AI decisions, and ensure ethical, safe operation. These services make manufacturing more adaptable and human-aware, in addition to value-added automated.

6.2 MASTT2040 Pathways: Capability feature development towards 2040

Above, we have outlined five potential future use cases of MaaS in industry by 2040. Underpinning these use cases, the table below lists concrete development pathways of how the capabilities outlined in the MASTT2040 roadmap should evolve between now and 2040 to enable the realisation of the MASTT2040 vision.

Capability feature	State of Practice	Expected by 2030	Expected by 2035	Vision for 2040
Progressive On-Demand Production	On-demand production limited to individual components; mostly isolated service delivery.	Sub-assembly on-demand production emerges in specialised domains with integration via MaaS platforms.	Product-level on-demand production becomes feasible for configurable goods, enabled by modular architectures and digital twins.	Full product-level on-demand production integrated with MaaS platforms; seamless configuration and distributed execution across the network.
Distributed Collaborative Manufacturing	Production concentrated within a single company or tightly controlled OEM supply chains.	Multi-actor collaboration through contractual agreements or time-limited alliances on selected projects.	Distributed co-manufacturing becomes possible; platforms coordinate resource, quality, and process standards between autonomous players.	Collaborative manufacturing networks flexibly coordinate product realization; shared resources, real-time integration, and co-owned processes.
From Supply Chain to Networked Orchestration	Rigid, bilateral relationships dominate. Platforms offer limited transparency or intelligence in partner	Early-stage digital supply networks emerge, enabling limited visibility and traceability across tiers. Matchmaking	Trusted orchestration platforms coordinate multiple suppliers per order. Semantic capability mapping and rule-based AI support	AI-driven orchestration dynamically reconfigures partners and services across federated networks, enabling

	matchmaking. No flexibility to reconfigure.	begins to use static capability data.	allow adaptive responses to disruption.	responsive, resilient, and scalable collaboration.
Resilience Maturity	Stable production environments with limited flexibility and reactive measures to disturbances.	Real-time monitoring and initial predictive alerting via digital twins and data platforms.	Systems anticipate disruptions and automatically adjust operations at the node level.	Resilient networks adapt supply, production, and delivery in real time through predictive simulations and dynamic reconfiguration..
Trusted and Secure Communication Networks	Customer interaction and internal coordination often rely on unsecured channels; fragmented cyber measures.	End-to-end encryption for customer and intra-company data; secure digital identities in place.	Expansion to multi-party trusted networks; secure MaaS-based federated ID systems for partner authentication.	Fully trusted and secure data exchange across dynamic, distributed manufacturing networks — with role-based access, traceability, and governance built-in.
Open Plug-and-Play Ecosystems	Dominance of proprietary systems with limited interoperability; integration efforts are costly and vendor-specific.	Adoption of common APIs and integration standards accelerates; modular integration in pilot ecosystems.	Vendor-neutral plug-and-play capability emerges; marketplaces support discoverability and low-effort onboarding.	Fully open, interoperable ecosystems where assets, services, and software modules can be composed and reconfigured on demand without vendor lock-in.
Sustainability and Lifecycle Circularity.	Sustainability seen as compliance or branding. No traceability in on-demand MaaS. DPP pilots isolated from MaaS.	Broader adoption of sustainable practices in MaaS. Emerging links between MaaS and DPP. Basic digital inventories and	Circularity embedded in service models (remanufacturing, reuse). Secure, encrypted traceability across lifecycle. DPPs	Circular-by-default design and production. Fully traceable lifecycle data enabling automated decisions, shared KPIs, and trusted

		traceability start to support circularity.	integrated in federated MaaS platforms.	IP-respecting DPPs across distributed networks.
Transparent and Open Data Sharing	Data exchange between customer and single supplier. No transparency in how data are shared by platform outside the organisation.	Transparent data access expands via secured platforms; contractual templates define rights and obligations.	Usage-controlled open data sharing emerges between trusted partners; semantic data models support shared insights.	Context-aware, governed data sharing with usage control and audit trails enables secure, real-time collaboration across ecosystems.
Pervasive usage of AI in MaaS	AI used in isolated optimisation tools; limited integration in decision-making or core workflows.	AI assistants emerge to support planning, quality, and maintenance; trust-building around explainability gains traction.	AI embedded in end-to-end service orchestration, decision support, and predictive systems across workflows.	AI is embedded everywhere, continuously learning to support human decisions, automation, and adaptive platform services.
Open federated platforms & interoperability	Mostly siloed OEM/vendor-specific platforms. Limited interoperability.	Platforms adopt open APIs. Early federated models. Basic data sharing.	Widespread federated platform use. Advanced interoperability standards.	Seamless data sharing across vendors via trusted, open platforms.
Human-centric collaboration & task allocation	Workers not well integrated with AI systems. Few task allocation tools.	Operators guided by cobots/AR. Adaptive task dashboards.	Real-time human-AI task coordination. Dynamic staffing platforms.	Human-machine teaming via intelligent task allocation. Worker autonomy.
Context-Aware Human-Machine Interfaces (HMI)	Standard HMI provide static information to trained users; limited adaptability to user profiles or context.	AR-supported and context-driven HMI emerge in maintenance, training, and configuration tasks.	HMIs adapt to roles and cognitive load; AI customises support based on sensor data and real-time user feedback.	Intelligent, augmented HMIs deliver context-sensitive guidance tailored to user needs, supporting safety, quality, and productivity in dynamic environments.
Knowledge reuse &	Knowledge is siloed, with limited	Microservices modularising	Open developer ecosystems take	Modular, learning microservices

microservice ecosystems	reuse or interoperability. Few external APIs.	expertise emerge. Reusable libraries within ecosystems.	shape, with AI enhancing and composing service modules.	continuously evolve through usage. Embedded across the lifecycle and supporting lifelong learning.
Outcome-based business models for equipment	CapEx-heavy investments. Rare performance-based contracts.	Growing shift to OpEx. Subscription models tested by SMEs.	Mainstream success-based contracts. Risk-sharing partnerships.	Fully outcome-based production models. Performance-aligned incentives.

7 Standardisation, regulation and legislation for future MaaS

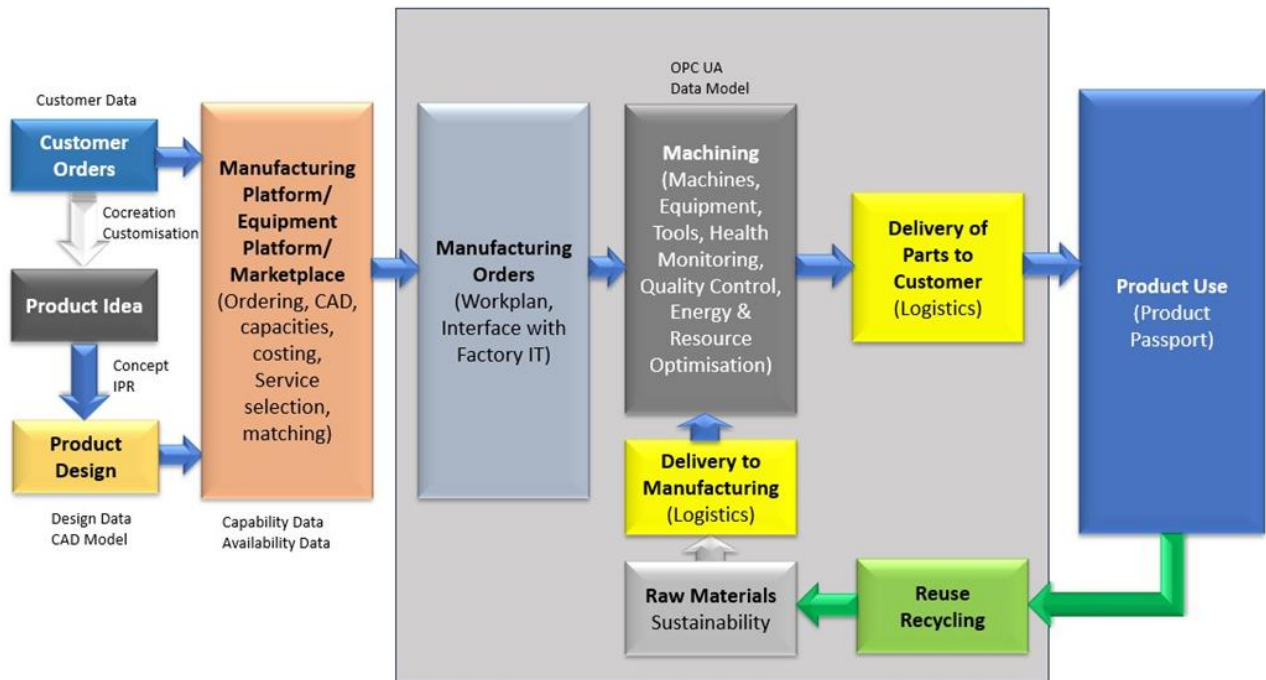


Figure 27: Key Manufacturing Activities, Data Flows and Standards Areas for MaaS

As standardisation, regulation and legislation were important aspects that were tackled during the roadmapping exercise, this chapter is dedicated to building the bridge to the follow-on phase of the MASTT2040 project which specifically targets these issues. Thus, below the main findings of the roadmapping activities regarding standardisation, regulation and legislation are briefly outlined. These will be taken up and deepened during project phase 4 in the second half of 2025.

The manufacturing of products requires a number of interacting stages including interactions with the customer and manufacturing systems as shown in Figure 28. In addition, it requires many different activities from designing a product to ordering components and raw materials, to scheduling manufacturing processes, organising and monitoring various machining and production activities through to the delivery of parts via logistics companies. This is growing ever more complex through the use of new technologies such as AI for optimising various processes and the drive towards sustainability in terms of raw material usage, energy consumption reduction and in the adoption of new circular models for recycling products. These activities and operations need to satisfy a vast amount of standards:

- Standards for Customer Data Personal Data, Engagement Data, Behavioural Data, Attitudinal Data, Privacy and Security Standards, Data Governance Act, Cyber Resilience Act and AI Act
- Standards for Product Design
- Standards for Ordering, Materials Requirements Planning, Enterprise Resource Planning and Costing
- Standards for Exchange of Product Data

- Standards for Health and Safety, Connecting Machines, Machinery Health Monitoring, Quality Management, Energy Management and Environmental Standards
- Standards relevant to Logistics, Supply Chain Risk Management, Logistics Data Interoperability and Environmental Impact of logistics
- EU Sustainable Raw Materials Standards
- Circular economy standards driven by the New Circular Economy Action Plan⁴, the Sustainable Products Initiative⁵ and Product Passports⁶.

To optimally source the potential that MaaS can bring for European industry at large, the roadmapping workshops highlighted a number of standardisation and regulation priorities for the future which are presented under the following five headlines:

Trusted Data Spaces

Secure and trusted data spaces are essential to enable data sharing across MaaS ecosystems—especially to support resilience and circularity. However, uptake is currently limited due to legal, institutional, technical, and cultural barriers, as well as insufficient data quality and capacity, particularly among SMEs.

To overcome these challenges, the following standardisation needs have been identified:

- Common standards for secure data sharing in trusted data spaces, including open data formats that ensure interoperability, safety, and data sovereignty.
- Reference architectures for MaaS that define standard interfaces, roles, and governance mechanisms for federated collaboration.
- Cybersecurity standards tailored to manufacturing networks, including support for blockchain-based solutions and secure cloud infrastructure, especially accessible to SMEs.
- EC-wide support for secure, federated cloud solutions that respect GDPR and enable scalable, trusted MaaS operations across Europe.

⁴ https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

⁵ https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Sustainable-products-initiative_en

⁶ <https://data.europa.eu/en/news-events/news/eus-digital-product-passport-advancing-transparency-and-sustainability>



Figure 28: Expected MaaS Capability by 2040 and Growing Importance of Federated Dataspaces

Interoperability

Interoperability across systems, machines, and organisations is fundamental to scaling MaaS ecosystems. However, fragmentation in formats, interfaces, and system architectures still hampers collaboration and data exchange.

To address these gaps, the following standardisation needs have been identified:

- Standards for machine-level interoperability, enabling seamless communication between diverse equipment and sensors.
- Standards for integration between machine systems and ICT platforms.
- Cross-company data exchange standards, to support collaboration and interoperability across distributed MaaS networks.
- Standardised APIs and data interfaces for open tools supporting trade-offs (e.g. between sustainability and cost), including integration with materials banks.
- Support for multilingual data formats, ensuring usability across regional and linguistic contexts.
- Development of a MaaS Reference Architecture, defining roles, data flows, and integration layers to align stakeholders on common system design principles.

Circularity

Advancing circular manufacturing in MaaS ecosystems requires harmonised standards to ensure products, processes, and data are consistently designed for sustainability and reuse.

Key priorities include:

- Eco-design standards to guide sustainable product development from the outset.
- Standards and eco-labels for sustainable and circular products, complemented by certification schemes to ensure compliance and market recognition.

- Standardised data formats for Digital Product Passports, reviewed and validated by industry associations to guarantee interoperability and transparency across value chains.

Human Centric Aspects

To ensure MaaS systems are inclusive, adaptive, and aligned with the values of Industry 5.0, dedicated standards are needed to balance technological innovation with human empowerment.

Key standardisation needs include:

- Standards for Industry 5.0 principles, such as those emerging from initiatives like Catena-X, focusing on human-machine collaboration, inclusiveness, and wellbeing.
- Trustworthy AI standards for MaaS, covering ethical deployment, transparency, explainability, and human oversight of AI systems across value chains.
- Frameworks for data and knowledge retention within companies, to safeguard human expertise, enable knowledge sharing, and maintain long-term competitiveness in increasingly automated environments.

Regulation

To unlock the full potential of MaaS and align with EU policy objectives, targeted regulatory action is needed to ensure transparency, safety, circularity, and worker protection.

Priority regulatory needs include:

- Mandatory ESG reporting (environmental, social and governance), introduced progressively across product groups, with a phased rollout over three years.
- Certification of MaaS value chains and components, covering sustainability (e.g. emissions), social and economic impact, and information security (e.g. ISO 27001).
- Product safety certification, to prevent the production and circulation of unsafe outputs via MaaS platforms.
- Zero-waste certification schemes, supporting the shift to circular manufacturing models.
- Regulation to promote the uptake of Digital Product Passports, enabling traceability, recovery of critical raw materials, and circular practices.
- Occupational health and safety regulation, adapted to increasing automation and human–cobot interaction.

Legislation

Beyond standardisation and regulation, experts also identified areas where legislation will be important for MaaS. Key concerns for the future are the handling of data and the increasing use of AI requiring extensive data gathering across supply chains. This will require updated GDPR regulation for protection of data. AI will be everywhere and AI driven automation in particular requires consideration of AI liability. Certification of MaaS networks according to goals, e.g. safety to stop people making unsafe products, sustainability, circularity, etc., is seen as core.

Specific legislation that have a direct impact on MaaS are:

- **GDPR and Data Governance Act** with respect to privacy of data, e.g. customer data for personalised products or data being collected through interactions between humans in MaaS production facilities or supply chains.
- The **Cyber Resilience Act** which is important due to the digital nature of products and increased data being recorded, e.g. Product Passports, and interconnectivity between actors in the supply chain.
- The **AI Act** which classifies AI into risk categories Prohibited AI, High Risk AI, Limited Risk AI and Minimal Risk AI. Potentially due to the nature of manufacturing machinery and cobots interacting with humans it is likely that applications will fall under the High Risk AI category. The Act also provides requirements for transparency and disclosure for generative AI.
- **Product Passports** will be a key driver for circularity requiring collection of data throughout a products life. The general requirements for digital product passports include having a data carrier on the product, its packaging or on documentation, with a unique product identifier according to ISO/IEC 15459:2015. This needs to be in an interoperable machine-readable, structured, and searchable format with information on the product model, batch, or item.

8 Concluding remarks and next steps

This document presents the outcomes of the roadmapping activities undertaken during the implementation of phase 3 of the MASTT2040 project in the first half of 2025. The roadmapping exercise was successfully conducted by way of a number of participatory workshops which took place both on-site and online. The approach was very well received by the workshop participants who were eager to contribute and participate in all activities. Thus, the results build on the insights of a large and diverse number of stakeholders.

When the final roadmap was presented during the third MASTT2040 webinar on July 8th 2025, it got very positive feedback from the participants. At the same time, the discussion confirmed that significant work remains to realise the MaaS 2040 vision—particularly regarding capability development and practical implementation.

We expect that by 2040 MaaS will mature into a trusted, resilient, and adaptive industrial backbone, enabling on-demand, high-quality, and precisely timed production making it accessible to all players from SMEs to global integrators. A key enabler will be standardisation so that machines, processes or capabilities are easily discoverable, semantically described and dynamically composable. By 2040, sustainability and resilience can be comprehensively integrated into MaaS platforms considering energy, resources and raw materials usage to optimise for low-carbon manufacturing, avoid use of virgin raw materials and implement circular approaches, making the EU's Twin Transition a reality.

To achieve this, phase 4 of the project which will run until December 2025 will take the next step following-up on the MASTT2040 roadmapping activities. Therein, the information generated during the roadmapping as well as the preceding two project phases will be utilised to recap and validate all project findings and to draft recommendations, especially regarding future standardisation needs. The Industry Strategy and Action Plan which will be submitted as D3.2 shortly after this document builds the bridge to the final project phase. It outlines general manufacturing trends and the impact MaaS approaches can have on European manufacturing and the EU's Twin Transition with a special focus on resilience, circularity and human-centric aspects. It discusses estimated costs and investment need to implement MaaS approaches in industry as well as the potential of and need for standardization and EU regulation as a starting point for related work in project phase 4 and a deepened exchange with Standards Development Organisations and policy actors.

The roadmap and its accompanying insights provide a solid foundation to support the advancement of MaaS accelerating Europe's transition toward a resilient, circular, and human-centric manufacturing future by 2040. They contribute to industry, research, policy, and societal actors with the direction and evidence needed to adequately address future needs and promising routes to action for a future-fit European industry.

9 Annex

9.1 MaaS related projects and initiatives

The following European MaaS related research projects and initiatives have been considered:

- HORIZON-CL4-2023-TWIN-TRANSITION-01-07 Achieving resiliency in value networks through modelling and Manufacturing as a Service
 - ACCURATE <https://accurateproject.eu/>
 - COGNIMAN <https://cogniman.eu/>
 - Digital Supply Chain Hub <https://digitalsupplychainhub.uk/>
 - DMaaST <https://dmaast.eu/>
 - M4ESTRO <https://www.m4estro-project.eu/>
 - MAASive <https://www.maasive.eu/>
 - MaaSiveTwin <https://maasivetwinproject.eu/>
 - NARRATE <https://project-narrate.eu/>
 - RAASCEMAN <https://www.dfki.de/en/web/research/projects-and-publications/project/raasceman>
 - Tec4MaasEs <https://www.tec4maases.eu/>
- 2024-TWIN-TRANSITION-01-03 - Manufacturing as a Service: Technologies for customised, flexible, and decentralised production on demand
 - Laders4Maas <https://lasers4maas.eu/>
 - MaaSai <https://maasai-project.eu/>
 - MEDUSA <https://medusa-maas.eu/>
 - REED <https://reed-eu.eu/>
 - UniMaas <https://unimaas-project.eu/>
- National research projects
 - Catena-X <https://catena-x.net/en/>
 - Factory-X: A sovereign data space for mechanical and plant engineering <https://factory-x.org/>
 - Manufacturing-X: <https://www.plattform-i40.de/IP/Navigation/EN/Manufacturing-X/Manufacturing-X.html>
- Circular Economy related projects
 - Alicia <https://alicia-cme.eu/>
 - CIRPASS <https://cirpassproject.eu/>
 - Greene 4.0 <https://www.interreg-central.eu/projects/greene-4-0/>
 - Plooto <https://www.plooto-project.eu/>
 - Up2Circ <https://up2circ.eu/about-the-project/>
- Data spaces
 - DFA Digital Factory Alliance <https://digitalfactoryalliance.eu/>
 - International Data Spaces <https://internationaldataspaces.org/>
 - Open DEI <https://www.opendei.eu/>
 - RE4DY <https://re4dy.eu/>
- Human-centric manufacturing
 - EARASHI <https://earashi.eu/>