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International Journal of Production Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tprs20

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INTERNATIONAL JOURNAL OF PRODUCTION RESEARCH
https://doi.org/10.1080/00207543.2022.2146228

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A framework for agility improvement projects in the post mass customisation era

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ABSTRACT
Changing customer requirements and turbulent markets require suitably adapted capabilities to proactively cope with rapid changes. Agile manufacturing emerged in the late 1990s as a competitive concept to respond to these business challenges. While several seminal research works address agility in terms of concept definition, drivers and strategic capabilities, there is a lack of implementation frameworks of agile manufacturing. The current paper is concerned with the question of how to improve the agility of manufacturing companies. To address this question, a framework is iteratively developed with the aim of supporting decision makers in planning and implementing agility improvement projects. To this end, Design Science Research (DSR) methodology is used in conjunction with CIMO-logic (Context, Intervention, Mechanism, Outcome). The iterative development of the framework relies heavily on insights from case studies and from practitioners in the broad manufacturing sector. The paper provides evidence of the validity of the framework as well as outlining further research perspectives.

ARTICLE HISTORY
Received 17 February 2022
Accepted 3 November 2022

KEYWORDS
Agile manufacturing; lean; mass customisation; project; quality; design science research

1. Introduction

The ever-evolving business environment in the manufacturing and service sectors consistently raises new challenges for companies to remain competitive. Increasing customer requirements, market volatility, turbulence and complexity are among the key features of such a business environment (Stettina and Hörz 2015; Conforto et al. 2016; Brandl et al. 2021; Troise et al. 2022). Leading concepts grounded in theory and practice have helped industry keep up with the pace of these evolutions. Examples of these include lean manufacturing and mass customisation. These concepts have enabled companies to achieve significant economies of scale and economies of scope and thus improve their competitiveness (Womack, Jones, and Roos 1990; Pine 1993; Liker 2004). Mass customisation inherits some principles from mass production and lean, enabling both customer-centricity and cost-efficiency. In the face of changing business environments, agile manufacturing emerged in the late 1990s as a competitive strategy (Duguay, Landry, and Pasin 1997; Gunasekaran 1999). Agility capabilities and attributes encapsulate a range of aspects related to customer and stakeholder requirements, including products, services, processes, information system, and governance (Bottani 2010; Stettina and Hörz 2015; Conforto et al. 2016).

In today's ever-changing business environment, agility has become an inescapable challenge for manufacturing and service companies. This requires not only well-defined strategic capabilities but also guidance in order to implement these capabilities progressively and iteratively. The literature uncovers a persistent need for research into how to implement and improve agility (Zhang and Sharifi 2007; Abrahamsson, Conboy, and Wang 2009; Bottani 2010). While several seminal research works address agility in terms of concept definition, drivers and strategic capabilities, there is a notable lack of implementation frameworks of agile manufacturing. Previous research has been more concerned with strategic capabilities for agility adoption, how to move from the long-term strategic level to a tactical level where mid-term actions can be implemented is yet to be addressed. Decision makers at different levels within a company, need decision support on where to start from (justification), how to proceed (process) and how to close the loop (capitalise/sustain) to implement and improve agility (Abrahamsson, Conboy, and Wang 2009; Conboy 2009; Bottani 2010; Stettina and Hörz 2015; Conforto et al. 2016).

In line with these requirements, the objective of this study is to develop a framework to support agility improvement projects in manufacturing companies. The aim is to support decision makers to opt for an agility

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path through a structured approach. The framework supports projects aiming to enhance customer (and stakeholders') value and improve a company's (or companies') responses to change by focusing on one or more of the following study areas: products, services, processes, information system and governance.

The remainder of the paper is organised as follows: Section 2 provides a literature review of agile manufacturing as well as Design Science Research (DSR) methodology. Section 3 offers an overview of the methodology used to develop a framework for agility improvement projects. Section 4 reports on the data collection, including case studies, interviews and survey. Section 5 addresses results analysis and covers building, refining and evaluating the framework. Section 6 discusses the paper's contribution and research perspectives, with a conclusion presented in Section 7 of the paper.

2. Literature review

2.1. Agile manufacturing

Changing customer requirements and turbulent markets require suitably adapted capabilities to proactively cope with rapid changes. Unsurprisingly, manufacturing paradigms are shifting in order to keep up with the pace of these evolutions. In the late 1960s, US industrial productivity decreased by 0.8%, which uncovered several limitations in the theory and practice of mass production. Examples of these limitations include intra and inter-firm parochialism, excessive development time and failure to co-operate with customers (Duguay, Landry, and Pasin 1997). Consequently, mass production focusing mainly on cost reduction and productivity started to give ways to other paradigms such as lean manufacturing, mass customisation and agile manufacturing (Pine 1993; Duguay, Landry, and Pasin 1997). Lean manufacturing, as a predecessor of mass production, emphasises the reduction of resource use through waste elimination or minimisation as well as other practices such as Just In Time (JIT) (Womack, Jones, and Roos 1990). Lean origins are rooted in the Toyota production system, which is driven by customer orders in the way that cars are produced on demand rather than on a mass production basis (Liker 2004). As such, lean is more adapted to stable production and products with similar characteristics. Therefore, in high-variety and turbulent environments the benefits of lean are difficult to achieve (Duguay, Landry, and Pasin 1997). The concept of mass customisation is intended for high-variety environments as it aims to meet individual customer needs with near mass production efficiency (Pine 1993). This can be enabled by strategies such as differentiation postponement and technologies such as product configurators. Salvador, de Holan, and Piller (2009) put forth three capabilities for following a mass customisation path: solution space development, choice navigation, and robust process design. Implementing these capabilities concurrently enables an increased diversity in the offer without a significant increase in related complexity and costs.

Yet changing customer requirements and turbulent markets require not only (mass) customisation but also the proper capabilities to cope with rapid changes. Agile manufacturing emerged in the late 1990s as a competitive concept to respond to these business challenges (Duguay, Landry, and Pasin 1997; Gunasekaran 1999; Yusuf, Sarhadi, and Gunasekaran 1999). The need for agile manufacturing is reinforced by the lack of flexibility in automation defining the mass production era, the widening of customer choices, and ongoing product development and marketing activities (Yusuf, Sarhadi, and Gunasekaran 1999). While agility inherits several principles from its successor paradigms such as efficiency and customer centricity, it places more emphasis on the responsiveness to changes of all kinds (Vinodh et al. 2009). The term was first coined by Iacocca Institute in their two-volume report published in 1991 and sought to outline key features of a more competitive manufacturing industry (Iacocca Institute 1991). The leading figures in industry and academia who contributed to the report assumed that agile manufacturing was the key for U.S. industry to regain leadership.

Adopting agile manufacturing means acquiring capabilities for *responding to the fast-changing market needs and manufacturing demands of a global economy*. Since its emergence in the late 1990s, several publications have attempted to define the concept of agile manufacturing. In a relatively comprehensive overview published by Yusuf, Sarhadi, and Gunasekaran (1999), the authors define agility as "the successful exploration of competitive bases (…) through the integration of reconfigurable resources and best practices in a knowledge-rich environment to provide-customer driven products and services in a fast changing market environment". This definition concurs with previous ones on many points, in particular responsiveness and customer-centricity. In a more recent study, Bottani (2010) builds on previous research work to define agility as the ability of companies to respond quickly and effectively to changes in market demand with the aim of meeting varied customer requirements in terms of price, specification, quality, quantity and delivery. This definition reflects the most common features of agility reported on in previous studies. However, as highlighted earlier, there is a lack of implementation frameworks of agile manufacturing (Abrahamsson, Conboy, and Wang 2009; Conboy 2009; Stettina and Hörz 2015; Conforto et al. 2016). This conclusion is in line with previous reviews of the literature which determine that most of the publications addressing agility focus on theoretical frameworks and that implementation procedures are not sufficiently covered (Ramesh and Devadasan 2007; Sherehiy, Karwowski, and Layer 2007). Moreover, Zhang and Sharifi (2007) and Bottani (2010) highlight the need for identifying practices and tools to address agility capabilities. Generally, these research works concur on the fact that further methodological support is still needed for agility implementation and improvement within companies.

2.2. Review of DSR and relevance to current research

The goal of DSR is to create innovative artefacts for addressing unsolved problems in organisations. These artefacts can take different forms such as constructs, models, methods, languages, and design methodologies. DSR research projects aim to *extend the boundaries of human and organisational capabilities by designing new and innovative artefacts represented by constructs, models, methods, and instantiations* (vom Brocke, Hevner, and Maedche 2020). DSR has been dealt with in several seminal research works addressing issues such as artefacts, DSR processes and theory building (March and Smith 1995; Hevner 2007; Hevner and Chatterjee 2010; Peffers et al. 2007; Gregor and Hevner 2013). A common understanding shared in the literature is that DSR is very useful in interdisciplinary research contexts, which is a key characteristic of the subject at hand. In fact, agile manufacturing improvement projects touch upon various stakeholders and processes within and across companies. The reviews conducted by Yusuf, Sarhadi, and Gunasekaran (1999) and Sherehiy, Karwowski, and Layer (2007) illustrate the various dimensions shaping agility in their conceptualisation of its related components (e.g. drivers, attributes and capabilities).

Scholars' contributions to DSR tend to emphasise different features of this approach depending on the lens from which they perceive DSR, e.g. design thinking, problem-solving or knowledge building. The current study aligns with Hevner's perspective highlighting the problem-solving feature of DSR. Hevner (2007) introduced a three-cycle view to better understand DSR and improve research quality. DSR is therefore seen as an embodiment of *relevance cycle*, to determine opportunities and problems in actual application environment, *rigour cycle*, to provide past knowledge to the research project, and *design cycle* consisting of generating design alternatives and evaluating them. Gregor and Hevner (2013) defined four main contributions of DSR projects depending on problem maturity and solution maturity, *invention* (new solutions for new problems), *exaptation* (extended known solution to new problems), *improvement* (new solutions for known problems) and *routine design* (known solutions to known problems). The current paper offers an *improvement* contribution by addressing agility improvement projects, for which there is a lack of implementation procedures and commonly shared practices.

3. Research methodology

The framework is developed following the DSR methodology as shown in Figure 1. The *rigour* cycle of the methodology relies on literature analysis focusing on seminal research works enabling the development of an understanding of agility philosophy based on its definitions, its related concepts and identified enablers as well as the DSR methodology. The *relevance* cycle is supported by a multiple case study approach. Case study method is usually used to contribute to knowledge by answering the questions of *how* and *why* based on an analysis of a real-life context (Yin 2003).

The *design cycle,* which is the heart of DSR, consists of an iterative building and evaluation of the artefact(s) based on the *rigour* and *relevance* cycles. Artefact building follows CIMO-logic (Context, Intervention, Mechanism, Outcome) which allows the formulation of rigorous, general design propositions rather than solutions to specific problems (Denyer, Tranfield, and van Aken 2008). These design propositions are structured into a general framework for agility improvement projects, which is the designed artefact. The *design cycle* involves two iterations; the first one allows an initial version of the artefact to be built by using CIMO-logic while the second allows for further refinement.

The current study uses analytical evaluation for the two design iterations in order to obtain an appraisal of whether the artefacts *work and do what they are meant to do*, which is referred to as validity (Gregor and Hevner 2013). The analytical evaluation is implemented through a mixed method relying on interviews and a survey (Hollstein 2014). The first iteration allowing the formulation of a draft of the artefact relies on interviews with selected senior experts in order to obtain detailed feedback on the validity criterion. This helps carry out a refinement of the artefact during the second iteration, during which the evaluation uses a survey among practitioners from the manufacturing sector. The survey generates quantitative data and provides further evidence on the validity of the artefact.

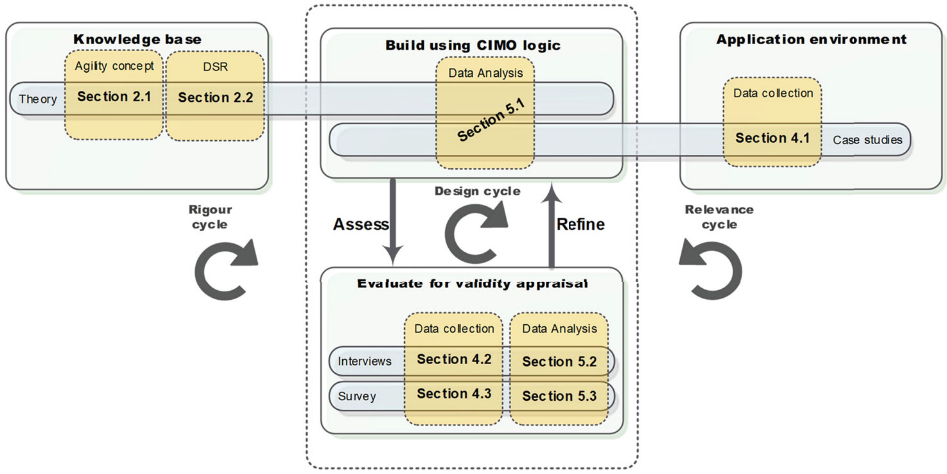


Figure 1. Framework development methodology.

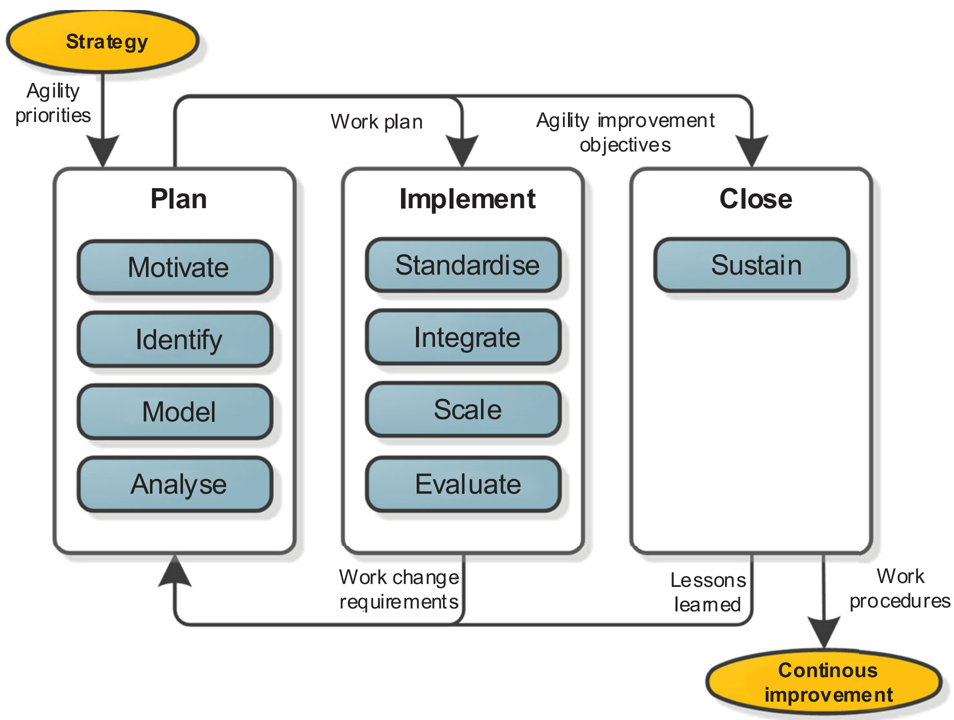


Figure 2. Initial framework overview.

The interviews and the survey are based on a simple questionnaire consisting of three sections namely, introduction and presentation, design propositions (DPs) evaluated individually (cf. section 5.1), and design propositions evaluated collectively as a framework (cf. Figure 2). Table 1 provides an overview of the questionnaire. A Likert scale was used to assess respondents' agreement with the DPs and with the validity evaluation criteria of the framework. These criteria include *intelligibility* (i.e. the extent to which the framework is clear and its related vocabulary is understandable), *practicality* (i.e. the extent to which is the framework easy to apply), *complementarity with existing practices, tools and methods* (i.e. the potential of filling a gap and of reusing existing, practices methods and tools), and finally, *agility improvement potential* (i.e. the potential of the framework to contribute to agility improvement).

4. Data collection

4.1. Case studies data for framework building

The unit of analysis of the case studies is development and improvement projects related to agility. Seven cases out of 13 shortlisted ones meet this requirement. However, some of these cases support the same conclusions.

Table 1. Questionnaire.

Questions topic	Answer
Respondent profile	
Job category	Senior manager, middle manager, first line manager, consultant, other
Years of experience	0–5 years, 6–10 years, 11–20 years, 21–30 years, > 30 years
Activity sector	Drop menu (national database)
Company size	Small, Medium, Large
Country	Drop menu (country list)
Activities for improving agility in manufacturing companies	
DPs are referred to as activities for the sake of readability. They are listed in this section to allow the respondent to judge their level of agreement with each of them.	
Please indicate to which extend you agree with each of the following statements	1 = strongly disagree; 3 = neither agree nor disagree; 5 = strongly agree
General framework evaluation	
The framework as a set of structured and logically linked DPs is presented to the respondent through a figure and a short overview to allow him/her judge a set of validity criteria.	
Intelligibility	Likert scale
Practicality	Likert scale
Complementarity with existing practices, tools and methods	Likert scale
Agility improvement potential	Likert scale
General ramp-up improvement options	Open question
General comments	
Please add any comment about positive aspects, improvement areas, etc.	Open ended question

Therefore, it was decided to remove redundancy for the sake of readability and simplicity. This is in line with the principle of case study analysis supporting mainly qualitative rather than quantitative analysis (conclusions are not based on the number of responses). Both SME (Small and Medium-sized Enterprises) and large companies are included since the priority is the unit of analysis, namely development and improvement projects regardless of company size. In total, five case studies are selected for the subsequent analysis. The insights drawn from these case studies rely on primary data collected through semi-structured interviews conducted with several project stakeholders, and secondary data obtained from companies' internal reports and project documents. Table 2 provides a summary of the case studies as well as their respective contexts. For reasons of confidentiality, companies' names as well as other details are omitted.

Case study 1 involves a large co mpany from the energy sector, which is seeking a more sustainable service for the supply of safety clothing. The project involves both the suppliers of the clothing (solution providers) and the company as well as a group of researchers and one consultant. The strategy of the company is to foster pull innovation for more sustainable solutions. To this end, the management of the company arranged several internal meetings with the help of facilitators including researchers, to explain the strategy. The ultimate aim was to motivate the teams belonging to several departments and increase their awareness of the need for innovation in response to both customer expectations and national regulation requirements in relation to sustainability. Case study 2 involves an SME in the meat processing industry, a robotic solutions provider whose main expertise is system integration, a battery system supplier, and a group of researchers. The project is focused on the development of a solution for autonomous cleaning which is adapted to customer requirements (hygiene regulations in the food sector, limited space for traditional cleaning equipment involving operators, etc.). Ultimately, the project is expected to improve both cleaning quality and productivity by limiting production department intervention in cleaning activities. In the long run, the ambition of the project is to be extended to other customers and market segments such as car parks and airports. Therefore, there is a need to diversify the offering and managing the induced complexity. Case study 3 relates to a mass customising SME in the furniture sector. The company offers a broad range of luxury and customisable kitchens, which results in high complexity within the production system. Among the challenges raised by this context, key issues include production and supply chain management policies, production ramp-up management and integrating economic and environmental considerations in the management of offering variety. Environmental considerations are driven by both the CEO (Chief Executive Officer) and by the customers of the SME. This work is part of a European project involving several partners from three manufacturing sectors as well as a group of researchers and consultants. Case study 4 involves a large company with a complex global supply chain, providing tubular solutions for oil industry. In order to focus on customers and on business priorities, the company launched a pilot project to align its information system with business processes across one of its global supply chains. Several challenges are identified such as lack of supply chain visibility, heterogeneity of information system components across company's subsidiaries, and heterogeneity of business processes. The project involves the IT Governance officer, an IT consultant and one research engineer. Case study 5 relates to an SME in the cycling industry in the process of developing its business. More specifically, the project involves production ramp-up of a newly created production unit to meet fast-growing customer demands, in particular during the COVID-19 pandemic. However, this requires the company to address several challenges beforehand, such as definition of work procedures, quality assurance, information system integration and planning for production

Table 2. Summary of the case studies.

Case study	*Context*	*Sector*	*Company size*	*Agility related project goals*
Case study 1 – Customer-driven safety clothing service supply	National collaborative project	Energy	Large	Shift safety clothing supply model to a more sustainable one considering economic, environmental, social and customer perspectives.
Case study 2 – Customised autonomous industrial cleaning solution	Regional collaborative project	Industrial cleaning	SME	Develop a service for autonomous cleaning for the meat processing industry tailored to customers' expectations and manage offering variety by product and service modularisation.
Case study 3 – Customised kitchen furniture	European project and bilateral collaboration	Kitchen furniture	SME	Improve operational performance in high-variety context and support the selection of suitable strategies for production ramp-up.
Case study 4 – Information system alignment	Bilateral industrial collaboration	Tubular solutions for oil industry	Large	Focus on customer value and align information system with business processes using enterprise architecture.
Case study 5 – Bicycle production ramp-up	Bilateral industrial collaboration	Cycling industry	SME	Plan for and manage production ramp-up of a newly created assembly unit.

ramp-up. The project involves a small team including company CEO, production department head and a group of researchers. The author was involved in project teams within all five case studies.

4.2. Interviews with experts for framework refinement

After building the DPs (section 5.1), these are evaluated separately in terms of relevance to agile manufacturing and then collectively as a framework for agility improvement projects.

Evaluation relies on interviews with practitioners and consultants. The questionnaire presented in section 3 (Table 1) was used as a guideline for collecting experts' feedback. Interviews allow access to detailed feedback, help convey the interviewer's message more easily and may uncover possible inconsistencies in the way questions are asked. A panel of 10 experts was selected with an average of 25 years of experience in the areas of manufacturing, supply chain management, operations management and innovation management. The aim is to obtain qualitative and detailed feedback on the design artefact (i.e. the framework) in order to adjust as per the DSR philosophy (Gregor and Hevner 2013).

In total 10 experts were interviewed, the average duration of the interview was 40 min, evenly distributed among the questionnaire sections. The discussions provided complementary insights with the case studies.

4.3. Survey for framework evaluation

The refined version of the framework (based on interviews) is evaluated using a survey among practitioners. Alongside the first iteration, which relied mainly on qualitative analysis, the current iteration is designed to obtain more quantitative results on the validity of the research results. The survey was based on the questionnaire presented in section 3.

The questionnaire was sent to a large panel of practitioners and consultants in the manufacturing sector (between 500 and 600 recipients located mainly in Europe). The questionnaire was intentionally sent to respondents from various manufacturing sectors and different company sizes. The targeted respondents' roles include senior managers (Chief Executive Officer, Chief Operations Officer, etc.), middle managers (Head of Department, Director, etc.), first line managers (Assistant Manager, Section Chief, etc.), team leaders and consultants. This allows the evaluation of the framework from the perspectives of most of the involved stakeholders in its promotion and implementation within companies.

The survey took around two weeks during which a total of complete answers were collected. The responses came in two main waves with around 70% resulting from the initial dissemination campaign. The second dissemination campaign consisted of sending reminders and extending the panel consistently with the targeted profiles.

5. Data analysis

5.1. Building the framework

This section elaborates on a set of DPs based on the identified case studies (cf. section 4.1) as well as scientific literature (cf. section 2.1) and following the CIMO logic. Each of the next paragraphs highlights the main insights

Table 3. Cases mapping to design propositions.

Case study	*DP1*	*DP2*	*DP3*	*DP4*	*DP5*	*DP6*	*DP7*	*DP8*	*DP9*
1	X								
2		X			X				
3			X	X					
4						X		X	X
5							X		

from a given case study, then reports on related scientific literature, and finally presents the related DP. Table 3 provides a summary of the mapping of the DPs to the case studies.

Engaging in any project related to agility improvement requires communication with and motivation of various stakeholders involved in the project. Case study 1 perfectly illustrates this requirement, with the major part of the project being dedicated to interviews with suppliers and employees from various departments. The aim is to explain and share the vision and motivate the team and external stakeholders. Consequently, adherence to the project increased progressively throughout the interviews and brainstorming sessions.

Stathakopoulos et al. (2019) highlighted motivation and performance enhancement among the key traits of middle management in an effective market-driven strategy implementation. This is also in line with the required competencies of project managers identified by the Project Management Institute, namely leadership, ability to motivate and business management (Project Management Institute 2017). Furthermore, according to agile manufacturing philosophy, all stakeholders including workers assume higher responsibilities, and therefore, need to be aware of the strategy implications (Duguay, Landry, and Pasin 1997).

> **DP 1 – Motivate.** In order for a manufacturing company to engage in an agility improvement project, internal and external stakeholders should be motivated by explaining the strategy and the meaningfulness of the project. This allows to gain stakeholders to buy-in and to increase project success chances.

In case study 2, the project was divided into (1) needs analysis and scenario identification, and (2) assessment for service delivery. The first part helped identify the expectations of the meat processing company, which were not clear from the beginning. The project team including industrial stakeholders and researchers, conducted intensive work meetings and interviews to collect data about their specific needs. In parallel, the researchers used visual representation of an extended version of the value chain to build a common understanding of the envisioned value creation and service delivery scenarios.

The iterative definition of value proposition and stakeholders' roles in service delivery helped to focus the project mainly on stakeholders' requirements rather than on technological solutions. This is one of the core principles of agile manufacturing aiming *to meet varied customer requirements* (Bottani 2010). The literature is rich in papers addressing requirements engineering through conceptualisation frameworks, methods and tools (Medini et al. 2020). A major challenge at this point is how to balance customer requirements with company performance (Gunasekaran 1999; Lyons et al. 2012). Proper needs identification and requirements definition is a key to avoid uncontrolled expansion of the development or improvement project scope (Project Management Institute 2017).

> **DP 2 – Identify.** In order to for a company to focus on agility priorities, regular needs identification and requirements definition is required. This enables the avoidance of scope creep and ensures the project is aligned with stakeholders' requirements throughout the project.

In case study 3, an integrated product-process-supply chain approach is adopted to define efficient ways to manufacture and deliver customised kitchens. This induced a high degree of complexity since the SME involved in the project does not have a clear understanding of all the required manufacturing processes. Moreover, the link between customisation attributes and processes' characteristics was difficult to establish. To this end, a huge amount of collected data was used to create an iterative model incorporating product families, processes and supply chains and to assess the performance of alternative configurations. This helped to establish a basis for discussing the best scenarios with regard to indicators related to agility and sustainability.

This is in line with previous research highlighting the role of visualisation techniques and of modelling in the context of development projects of customer-driven solutions (Bertoni, Bertoni, and Isaksson 2013; Project Management Institute 2017; Medini and Boucher 2019). Modelling is also consistent with the practices promoted for implementing agility, such as cross-functional teams and concurrent engineering, which allow significant compression of development time (Bottani 2010; Vernadat 2020).

> **DP 3 – Model**. In order for a project team working on implementing actions related to agility to communicate with each other and with external stakeholders, it is important to model and visually represent the context and (re)designed artefacts. This allows for a mitigation of the complexity induced by customisation and interdisciplinary teams.

A key question underpinning case study 3 is how to improve company's agility while adopting mass customisation, through concurrent design of products, processes and supply chains. The as-is value chain was modelled and a set of interviews were conducted in order to define alternative to-be scenarios. In order to assess these alternatives, project stakeholders could only provide general qualitative assessment. This helped refine alternative scenarios, though further analysis was still needed. To this end, indicators measuring sustainability and customisation where selected and validated by the project team. Simulation was used to calculate these indicators and assess improvements brought by alternative-to-be scenarios.

Quality management methods and tools are suitable for the as-is analysis, e.g. root cause analysis, Pareto analysis (Soltanmohammadi, Ardakani, and Dion 2021). Performance measurement literature provides a reasonable foundation for conducting an assessment of various alternatives, in the sense that it allows linking the indicators to the objectives of the project. This is particularly important to focus improvement actions on agility priorities (Nudurupati, Garengo, and Bititci 2021). Moreover, various tools for project planning can be used to address, cost, quality, time and risk perspectives (Project Management Institute 2017).

DP 4 – Analyse. Project teams working on implementing actions related to agility improvement, need to plan for the envisioned actions by analysing the as-is scenario and identified improvement scenarios. This allows a prioritisation of the envisioned actions within the project and to increase its chances of success.

One of the objectives of the project conducted in case study 2 involved the extension of the company offer to other sectors and market segments. This naturally leads to higher variety and therefore increases the complexity within the production system. The complexity is heightened by two main factors, the embodiment of products (robotic system) and services (remote performance monitoring, maintenance, etc.) within the offer, and the involvement of several stakeholders with different core businesses. To address this issue, the project team, with the support of two researchers, conducted a sub-project for modularising the offer and related resources. Components and modules supporting same functions and using same resources are grouped into aggregate modules.

This process is in line with previous research works supporting the idea that modularity is an effective means for mitigating complexity and improving agility (Gunasekaran 1999; Zhang and Sharifi 2007; Bottani 2010; Medini 2015; Ezzat et al. 2022). Modularity supports also delayed differentiation, which is one of the enablers of agile manufacturing (Bottani 2010). More generally, broadening product portfolio, reinforcing modularity and commonality and flow rationalisation are complementary enablers of economies of scale and economies of scope (ElMaraghy et al. 2013).

DP 5 – Standardise. In high variety contexts, companies needs to promote standardisation as much as is feasible while maintaining a satisfactory level of product variety to meet customer requirements. This allows the mitigation of internal complexity and the generation of economies of scale and economies of scope.

Within case study 4, the aim was to reinforce agility and focus on customer value. However, the challenge is the complexity and lack of visibility of the multinational company's global supply chain. A pilot project led by the IT governance officer was launched involving business processes re-engineering across the supply chain of one business unit. To this end, an Enterprise Architecture approach was adopted to enhance customer value and focus on business priorities, re-engineer business processes and align the information system accordingly. This helped identify heterogeneity areas and derive recommendations on how to improve interoperability and integration across the internal supply chain.

Unsurprisingly, integration, interoperability and collaboration have been put forth in the scientific literature as enablers of enterprise agility. These complementary practices have been widely addressed in the literature in the context of enterprise modelling and concurrent engineering (Gunasekaran 1999; Bottani 2010; Medini and Bourey 2012; Gunasekaran et al. 2019; Vernadat 2020).

DP 6 – Integrate. In order to drive company's capabilities towards agility, projects should involve enterprise integration and interoperability. This improves intra- and inter-enterprise collaboration and therefore company's responsiveness.

The COVID-19 pandemic uncovered several challenges for the manufacturing industry and engendered new market trends. In case study 5, there have been major issues with supply activities since some of the suppliers are located abroad. Conversely, the demand for bicycles has experienced a significant increase since the end of the first COVID wave in 2020. The case company is faced with high and unpredictable demand volumes over several months. The response promoted by the CEO was to define sales targets considering a tactical horizon, and to invest in a new assembly unit. This involves working on forecast and on sales and operations planning (S&OP). However, with the launch of a new assembly unit, the company recognised the need to establish well-defined work procedures, standardise business processes, integrate the information system and finally plan for production ramp-up. An incremental increase of production seemed the most appropriate strategy given the limited resources and difficulties in hiring additional operators.

These insights are in line with the literature, which recognises the importance of production ramp-up management including planning the ramp-up project and selecting suitable strategies. Unlike series production, ramp-up reflecting the transition from prototype to high-volume production is challenged by high uncertainty, lack of process maturity and strong likelihood of quality problems (Schmitt et al. 2018; Medini, Romero, and Wuest 2021). Therefore, the selection of a suitable ramp-up and ramp-down strategy is key to ensuring agility (APICS 2017).

> **DP 7 – Scale**. In order for a company to scale up or scale down a solution, a suitable strategy needs to be selected and the entire scaling project should be carefully planned for. This enables quicker and more effective responses to a variety of customer and market demands.

In case study 4, the progressive standardisation and integration of information systems components had several implications. Examples of these include business process re-engineering, staff training and software applications benchmarking. Therefore, the impact of the implemented actions was measured in order to assess their effectiveness. A maturity model was used as reference for this activity, covering several areas such administration, planning, blueprint and integration.

The evaluation can also be supported by existing frameworks and indexes from the agility literature. Ren, Yusuf, and Burns (2009) developed a multi-criteria decision method to support agility partner selection. Lin, Chiu, and Chu (2006) introduced an aggregate measure of supply chain agility based on several attributes such as responsiveness, competency, flexibility and speed. New metrics can also be developed as per company requirements. In this line of research, based on two case studies and on literature insights, Bottani (2010) determined that existing metrics do not cover all agility aspects. From a project management perspective the evaluation allows the monitoring of project work and the identification of any required changes (Project Management Institute 2017).

> **DP 8 – Evaluate**. In order for a manufacturing company to assess the effectiveness of agility improvement projects, evaluation should be conducted using existing or newly developed metrics. This helps the monitoring of the project and refining its scope.

The last activity of the project conducted as part of case study 4 was a series of meetings with several stakeholders from other business units (not involved in the pilot project). The aim was to present the pilot project's results and show the benefits in terms of integration, interoperability and agility. While some participants have shown interest in the project, overall adherence was very low. The reluctance of participants is mainly due to the large scope of the project, which implies changing some of the roles, information system tools and business processes.

Agility improvement projects and practices should be rooted in the company culture. This is in line with the literature highlighting continuous improvement as one of the attributes of agility and agile manufacturing (Lin, Chiu, and Chu 2006; Ren, Yusuf, and Burns 2009; Bottani 2010). Lin, Chiu, and Chu (2006) reported on a case company, which made tremendous improvement in its overall company agility over a two-year period of continuous improvement. Furthermore, defining comprehensive and straightforward procedures and drawing lessons learned helps capitalise knowledge and know-how and paves the way for continuous improvement (Project Management Institute 2017).

> **DP 9 – Sustain.** In order for a company to sustain the results from agility improvement projects, the project team and the project sponsor should promote project results, define procedures and conduct change management. This allows an enhancement of the culture of continuous improvement and the facilitation of similar future projects.

Consistent with the objective of providing operational support, the DPs are structured following a process approach to obtain the initial version of the framework (Figure 2). As highlighted by the scientific literature, agility philosophy shifts the improvement focus from long-term projects controlled by managers to more frequent improvement activities giving more responsibility to employees. In this sense, agility projects involve top management, operational management and workers, and most importantly middle management (Duguay, Landry, and Pasin 1997; Lin, Chiu, and Chu 2006; Ren, Yusuf, and Burns 2009; Bottani 2010; Stathakopoulos et al. 2019). The proposed framework is rooted in this continuum in the way that it is driven by enterprise strategy providing agility priorities, supporting the enhancement of continuous improvement culture.

Figure 2 shows the identified activities arranged in three main groups, Plan, Implement and Close. The first group includes *Motivate*, *Identify*, *Model* and *Analyse* activities, which support the initiation and planning of the project based on identified agility priorities. Second group includes the following activities, *Standardise*, *Integrate*, *Scale* and *Evaluate*, which ensure a structured way of implementing and monitoring agility-related actions based on the work plan. During these activities and based on the evaluation, change requests may be generated to plan for corrective actions or to refine the definition of requirements. The third group covers a single but very important activity, *Sustain,* which is intended for the assimilation of lessons learned (which can also be used for (re)planning activities), and work procedures to ensure continuous improvement.

Figure 2 presents the activities in a linear way, however they are iterative in nature and some of them are conducted in parallel, i.e. *Evaluate* and *Standardise*, *Integrate*, *Scale*. Iterations ensure more stakeholder involvement and the periodic incorporation of required changes. This allows for a closer control of the project performance via the loop Plan – Implement. Closing the project or project phase will depend on the validation of agility improvement objectives. This arrangement of the framework activities is known as iterative project life cycle, which exhibits a potential to address changing and turbulent environments (Ramesh and Devadasan 2007; Project Management Institute 2017).

5.2. Refining the framework

The refinement of the framework relied on interviews with 10 selected experts (cf. section 4.2). Generally, the respondents concur with the statements listed in the design propositions and with the fact that they are relevant to agile manufacturing and agility in general. In particular, they *definitely agree* with the motivation as a key for gaining stakeholder buy-in and integration representing a means to achieve agile manufacturing. They assume that scaling, evaluating and sustaining are also of major importance for succeeding in agility improvement projects. The experts see requirement identification, modelling and analysis as relevant activities to agility improvement projects. However, some of them assume that these activities are also required in other kinds of projects. This does not contradict the rationale of the developed framework, which inherits several practices from existing paradigms. Some of the respondents also raised the need for testing before moving to implementation. Therefore, it was decided to further highlight the role of implementation through a specific activity, which allows the deployment of actions related to *standardise*, *integrate* and *scale* activities.

While some of the respondents consider standardisation as an inescapable challenge to improve agility, others assume it may represent an obstacle to achieving agility. According to DP5, standardisation aims to reduce unnecessary variety which is not (positively) perceived by either the customer or other stakeholders. Such variety is referred to as *harmful variety, which* is generally a source of complexity and customer confusion (Perona and Miragliotta 2004). The basic enabler of standardisation is modularisation following the principle of Lego construction toys, which allows different combinations meeting various needs based on elementary standard modules to be obtained (Garud, Kumaraswamy, and Langlois 2002; Salvador, de Holan, and Piller 2009). Several experts among the respondents are aware of this principle.

The respondents are also in favour of framework intelligibility, complementarity with existing tools, relevance to agile manufacturing and practicality. However, they emphasised the fact that its practicality will also depend on the application context. Furthermore, some of the respondents highlighted the need to establish a framework that is as simple as possible in order for *Chief Executive Officers to adhere to it and deploy it*. Conversely, they uncovered another issue concerning overly simple agility tools, which are *very difficult to implement* because of the lack of a structured approach. Therefore, intelligibility, practicality and relevance to agile manufacturing should be balanced to ensure that the framework is *made as simple as possible, but no simpler* (a quote from Albert Einstein).

More general and interesting discussions were triggered by the interviews about how the framework could evolve. Three main profiles of the respondents can be identified, *radical innovation promoters*, *lean promoters*, and *project management promoters*. Radical innovation promoters are aware of the relevance of framework but think it should enhance customisation, innovation rather than standardisation. Lean promoters assume that activities supporting process stabilisation can be reinforced. Project management promoters fully adhere with the framework and assume motivation and planning are the backbone of the framework. This is in line with the framework positioning, i.e. building on lean and mass customisation and integrating agility requirements.

Based on the discussions conducted during the first iteration, the activities are arranged in a way to clearly highlight the iterative approach and distinguish between activities categories. Figure 3 summarises the framework including the activities and examples of supporting enablers.

Standardisation, integration and scaling represent the scope (i.e. the *what*) of the planned actions within agility improvement projects. The priority of each of the scope activities depends on overall project objectives, which are in turn derived from agility priorities. Generally, the sequence *standardise*, *integrate*, *scale* should be followed; however these activities can be conducted concurrently. In this vein and in line with the insights from the first iteration, a new activity named *implement* is introduced. It defines how to support a smooth and sustainable implementation of the improvement actions. This relies on practices such as change management, knowledge management and team management (Project

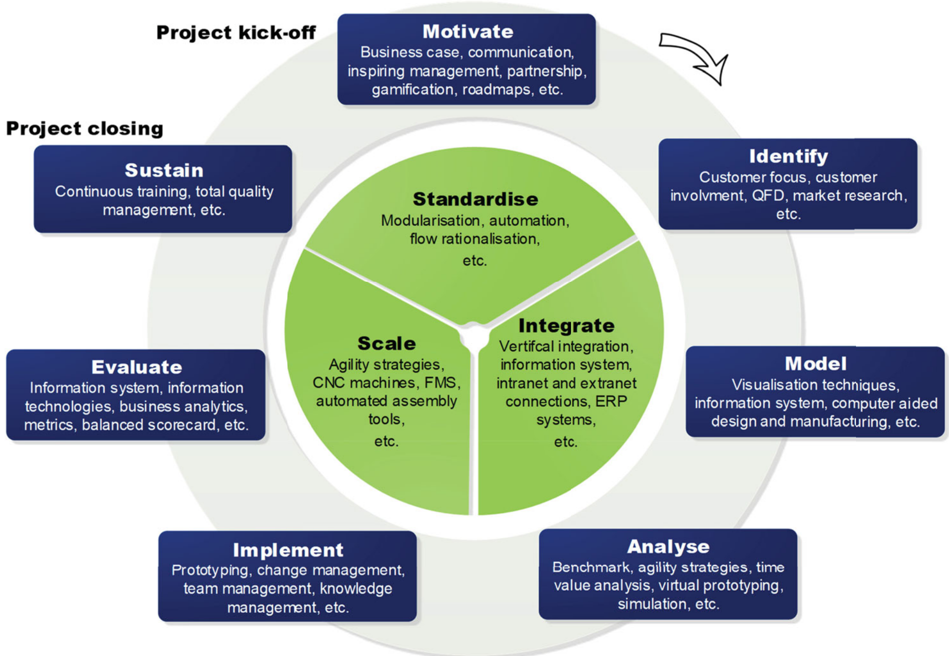


Figure 3. Updated framework summary.

Management Institute 2017). Improvement of standardisation, integration and scaling is ensured by the iterative activities related to planning, i.e. *motivate*, *identify*, *model*, *analyse*, implementation, i.e. *implement*, and sustainment, i.e. *evaluate*, *sustain*. These activities represent the *how* to plan and execute the project. The activities are briefly defined as follows:

- *Motivate*: motivate the stakeholders by explaining the strategy and engaging them in the project.
- *Identify*: identify needs and define requirements on a regular basis.
- *Model*: model and visually represent the context and the design system.
- *Analyse*: plan for the envisioned actions by analysing the as-is scenario and identified improvement scenarios.
- *Implement:* support a smooth and sustainable implementation of the improvement actions.
- *Evaluate*: evaluate actions/systems using existing or newly developed metrics.
- *Sustain*: promote project results, define procedures and conduct change management.
- *Standardise*: promote standardisation while maintaining a satisfactory level of product variety to meet customer requirements.
- *Integrate*: work on enterprise integration and interoperability.
- *Scale*: define a suitable and flexible strategy and plan for the scaling project.

5.3. *Evaluating the framework*

Figure 4 provides a summary of the survey respondents' information. Respondents' affiliations are evenly distributed between large companies and SMEs, with small companies representing 29%, medium companies representing 21% and large companies representing 50% of the total panel. This provides a solid basis for the subsequent analysis due to a reasonably well-balanced representativeness of different company sizes. The information on the specific activities of these companies was not exhaustively completed although they all relate to manufacturing sector, e.g. metal products, machinery, consumer goods, pharmaceutical products, automotive, textile, etc.

Respondents' job categories are quite well-balanced relative to their roles in promoting or implementing the proposed framework. In fact, the main job categories responsible for ensuring full understanding and implementation of the framework are consultants and middle managers and to some extent first line managers, team leaders and senior managers. The share of consultants and middle managers amounts to 46% of the total respondents. Senior managers represent 21% of the total respondents, which is quite satisfactory since they are likely to be the sponsors/promoters of agility improvement projects. First line manager and team leaders represent 33% of the respondents, which can be considered sufficient given the expected level of their involvement.

Interestingly, 58% of the respondents have less than 10 years of experience, which could be partly explained by

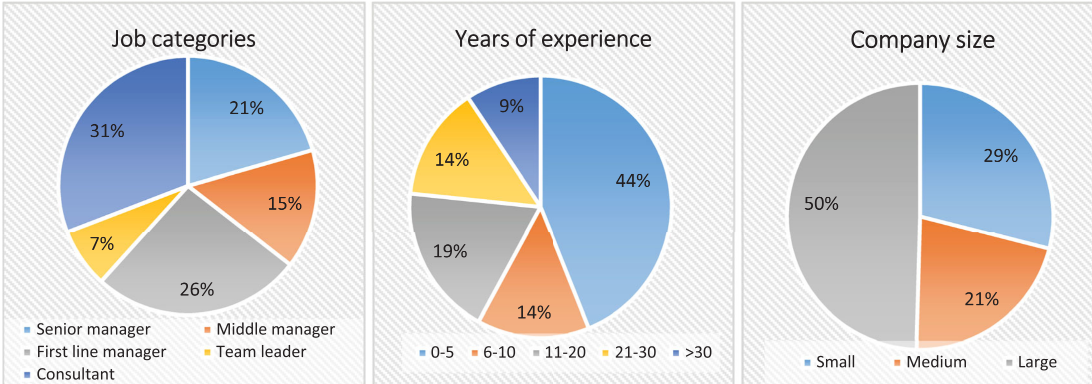


Figure 4. Respondent information.

the distribution of seniority among the targeted respondents. One further explanation could be the growing awareness of agility in recent years leading to an increased receptiveness among the younger generations to agility-related concepts. 9% of the respondents have more than 30 years of experience which is also of interest, as they will have experienced various trends throughout their professional careers. Having such senior practitioners answering the survey could witness the importance of the current research in the spectrum of project and operations management trends. In order to establish a broader overview of respondents' feedback, some basic descriptive statistics were applied to the 107 answers. The results are shown in Figure 5, which represents the average values and standard deviations of the rates given by the respondents to the activities and to the overall framework.

The average rates are above 4.08 for all activities except *model* whose average rate is 3.85. This reflects the relevance of these activities to agility improvement projects. This observation is generally shared by the respondents, which is reflected by a standard deviation below 1 for all activities, once again except in the case of *model* (1.01).

The three scope activities, *standardise, integrate*, and *scale* are seen as important for agility improvement projects. The fact that standardisation has relatively the lowest average of 4.08 may be explained by the apparent contradiction with agility seen by some of the respondents (as raised by some of the interviewees during the first iteration). However, a point of interest is that respondents are aware of the positive impact of standardisation, some of them stating that "the best results emerge when there are standard processes, yet significant flexibility allowed". This is key in the post mass customisation era, in the sense that agility inherits from lean practices while going beyond by identifying change requirements and responding to them. The respondents also agree with integration being a key to support agility. This is reflected by an average rate of *integrate* amounting to 4.19. Some of the respondents also highlighted the need for interoperability and information sharing within and between

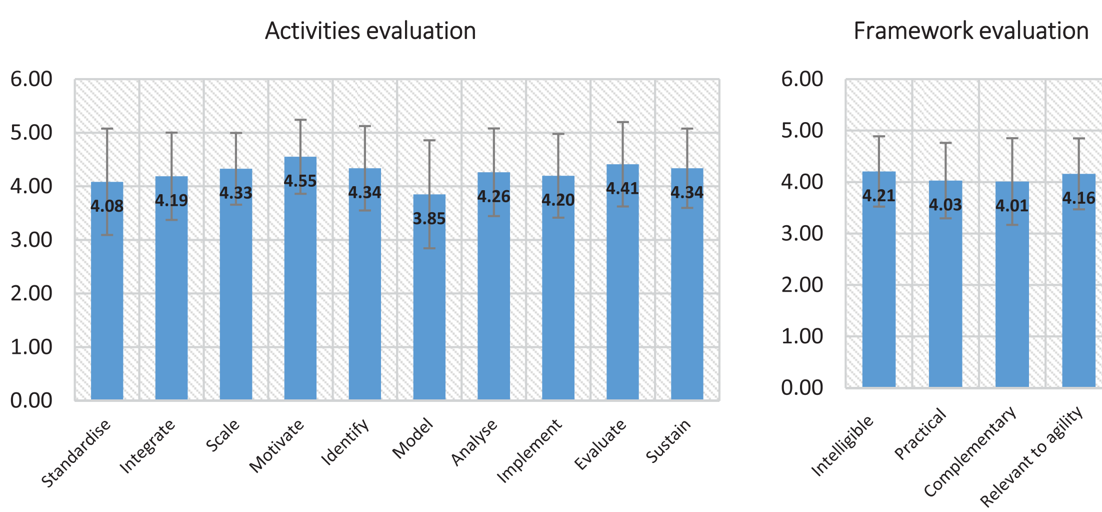


Figure 5. Average rates and standard deviations of activities and framework evaluations.

companies. They assume that *the more information is shared the more likely people will collaborate*. *Scale* is also seen as backbone of agility improvement projects with an average rate of 4.33.

The activities related to the *how* to plan and execute the project are generally well rated. Motivating the stakeholders is seen to be a key activity (4.55). Some of the respondents, mainly from the middle manager and consultant categories, consider that it is part of their job "to explain objectives and why they are important and meaningful". The respondents are also in favour of the fact that identification of requirements, evaluation and sustainment are among the pillars of agility improvement projects. This is reflected in their respective average rates of 4.34, 4.41 and 4.34. Similarly, analysis and supporting implementation are positively evaluated with average rates of 4.36 and 4.20, respectively.

Curiously, many of the respondents are impartial regarding the need for modelling to support agility improvement projects. This observation aligns with some of the discussions which took place with some of the experts during the first iteration interviews. These experts originally have a technical background in specific engineering areas or have been working with domain-specific experts for several years (e.g. mechanical engineering). Therefore, they might think that projects do not necessarily require general purpose modelling in order to communicate and support decision-making. Interestingly, first-line managers represent 30% of the respondents who rated *model* 4 or 5 and only 9% of those who rated this activity less than 3. This could be related to the fact that first line managers are more aware of the complexity underpinning projects planning and implementation and therefore they recognise the need for modelling to mitigate such complexity. Consultants are evenly distributed between these two groups. That said, the average rate of *model* remains above 3 and close to 4. Therefore, we consider it as still among the key activities of the framework, the insights from the survey will further help the identification of which modelling approach is appropriate for which context.

The overall evaluation of the framework is very positive with average rates ranging from 4.01 for complementarity with existing tools criterion, to 4.21 for intelligibility of the framework criterion. Respondents assume that the framework "is very clear and well detailed" which explains the highest rate given to intelligibility criterion. Practicality is judged based on respondents' experience and on the description of the framework. This resulted in a good average rate of 4.03. One of the reasons for this positive perception of its practicality is the fact that the framework is "organised according to the project steps". Such project perspectives ensure smooth iterative planning and execution of the actions for agility improvement. Overall, the respondents concur with the complementarity of the framework with existing practices. Some stated that they are "globally in phase with all the key factors proposed". However many of them cannot *easily judge* without diving deeper into feasibility studies and even implementation. In this vein, a more in-depth analysis of the suitable tools for each of the activities could be a perspective for extending the current research.

Relevance of the framework to agility improvement is widely recognised among the respondents whose average rate for this criterion is 4.16, while the standard deviation is the lowest (0.69) among all other criteria and activities except *scale* (0.67). This is a particularly encouraging result as it shows an agreement among the respondents. For instance, 85% of the respondents rated this criterion 4 or above and only 15% rated it 3 (15respondents) or below (only 1 respondent rated it 2). Some of the respondents stated that they *like the concept and the visual* (in reference to the pie chart).

6. Discussion

The adopted research methodology helped to build and refine the framework in a structured way. During framework building, CIMO logic was the backbone for the combination of the insights from practice and from scientific literature. The discussion with practitioners during the interviews lead to significant improvements of the framework. A quantitative evaluation through the survey provided further evidence of the framework validity.

The proposed framework supports the operationalisation of agility enablers identified in previous research (Gunasekaran 1998; Dowlatshahi and Cao 2005, 2006; Bottani 2010; Zhang and Sharifi 2007; Gunasekaran et al. 2018; Gunasekaran et al. 2019) thanks to a project management approach (Project Management Institute 2017). This allows key questions such as which point to start from (strategy and motivation), how to proceed (plan, implement) and how to close the loop (sustain) to be addressed. Consistent with agile manufacturing theory, development and improvement projects should be part of a culture of continuous improvement (Duguay, Landry, and Pasin 1997). This is in line with the idea that agility, as a successor of mass customisation and lean manufacturing, is a path rather than a final destination (Gardner and Piller 2009). The proposed framework provides a framework to plan, implement and sustain a set of actions to ensure an incremental but sustained progress along the agile manufacturing path. These actions are organised into projects whose objectives are driven by agility priorities. In this sense, the current research contribution is complementary to the existing literature in the sense that it addresses the tactical decision horizon for agility improvement and therefore builds on the works addressing the strategic level (Abrahamsson, Conboy, and Wang 2009; Bottani 2010; Zhang and Sharifi 2007). By supporting smooth project planning and implementation the paper also complements the findings of the study conducted by Conforto et al. (2016) which highlights the role of rapid project planning and active customer involvement as core elements of agility construct.

The paper brings one more element of managerial added value by equipping middle management with a framework for a smooth implementation of the enterprise strategy in agile manufacturing. This complements previous research works highlighting the key role of middle management in market-driven strategies (Stathakopoulos et al. 2019). Transformational leadership, self-confidence and commitment are among the traits of an effective middle-level employee according to Stathakopoulos et al. (2019). The proposed framework is expected to have a positive impact on these traits as it provides a framework for motivating, taking more informed decisions and following a clear course of actions to achieve results.

The framework places itself in the continuum of agility developments, which inherit from both lean and mass customisation paradigms. In fact, economies of scale and economies of scope are considered as relevant objectives to ensure competiveness in agile manufacturing. The proposed framework is in line with this requirement as it promotes standardisation, for instance, through practices such as modularisation and flow rationalisation. However, standardisation is subject to (useful) variety requirements, which allows the definition of a minimum level of variety, the bottom line to meet customer requirements. The framework also considers agility requirements in terms of iterative project management and the necessity of continuous change detection to define appropriate responses. In this sense, the framework is inspired by the logic of agile methods, which stem from the agile manifesto. However, unlike most existing lean and agile methods, the framework is more specific and provides closer guidance to implement and sustain enterprise strategy. The limitations of continuous improvement methods such as DMAIC (Define-Measure-Analyse-Improve-Control) have been highlighted in the literature. One major obstacle to the application of these methods is their generality (Mast and Lokkerbol 2012). One of the consequences of this hurdle is the implementation complexity of these methods due to the broad spectrum of possible interpretations.

The paper provides several promising research outlooks for reinforcing agile manufacturing in the post-mass customisation era: value concept extension, information systems and digitalisation synergies, and the development of agility strategies.

As highlighted in this paper, agile manufacturing is inherently an interdisciplinary concept. This also requires shifting the value concept from a mere cost perspective to a multidimensional perspective accommodating sustainability and multi-stakeholders requirements (Fearne, Martinez, and Dent 2012). In this sense, tools such as value chain configuration analysis can be more easily used to plan for agility improvement projects. Works by Stabell and Fjeldstad (1998) and Fearne, Martinez, and Dent (2012) can provide a methodological foundation for this orientation. A perfect illustration of how to address some of the agility objectives from a value chain perspective can be found in the work of Colldén, Hellström, and Gremyr (2021).

Among the interesting insights provided by a survey conducted by Sharifi and Zhang (1999) is the key role of information systems in improving agility confronted by the poor adoption of related methods and tools. Following this observation researchers investigated information system as a driver for agility through empirical evidence or building on theoretical insights (Wang 2009; Bottani 2010; Abdelilah, El Korchi, and Balambo 2018). The case studies addressed in the current paper are in line with this premise. In particular, substantial time and cost savings can be generated during the modelling activity if the information system is well maintained. Furthermore, standardisation and integration depend heavily on the flexibility of information systems and on the heterogeneity of applications. A promising perspective in this direction is to investigate the synergies between information systems development and digitalisation opportunities (Teubner and Stockhinger 2020; Ardolino et al. 2022; Dohale et al. 2022). In a recent work, Gunasekaran et al. (2018) discussed the role of big data and business analytics in implementing agile manufacturing enablers. They determined that *harmonious* development of several agility enablers lead to better performance of the company.

The improvement of agility also depends on the selection of suitable strategies for product, project and operations management (Lin, Chiu, and Chu 2006; Agarwal, Shankar, and Tiwari 2007; Bottani 2010). For instance, case study 5 uncovered the need to carefully plan for production ramp-up to meet the increasing demand. In this vein, the SCOR model (Supply Chain Operations Reference) highlights the seminal role of quick production ramp-up and ramp-down in ensuring agility (APICS 2017). The appropriate strategy definition is even more critical in high-variety contexts, where the complexity is also high and therefore the impact of management decisions is difficult to anticipate (Slamanig and Winkler

2011). An illustration of this orientation can be found in the recent work by Balaji et al. (2021) addressing agility improvement while considering the weighted effect of several factors. Simulation and mathematical modelling are among the strong candidates for addressing this problem (Glock and Grosse 2015; Doltsinis et al. 2020).

7. Conclusion

The current paper uses a structured approach to identify a set of design propositions for improving agility in manufacturing companies. The approach relies on scientifically sound methods that have proved to be efficient in similar contexts. The development of the research relies on theory and on case studies conducted in several sectors. Two iterations have been conducted in line with DSR methodology leading to the establishment and refinement of a framework for agility improvement projects, which has been evaluated using a mixed method. As such, the paper offers a step forward in efforts to concretise agile manufacturing. Research is still needed in order to test and evolve the proposed framework taking opportunities raised by the post-mass customisation era into consideration.

Acknowledgements

The author would like to thank all the interviewed experts and the respondents to the questionnaire for their valuable input, the representatives of the companies involved in the case studies conducted over the past few years, and finally, the researchers who contributed to the maturation of this research work.

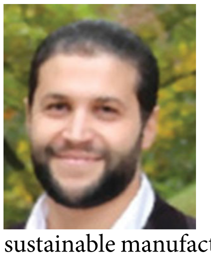
Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work is partly supported by the German-French Academy for the Industry of the Future (GFA) through RAMP-UP project and by Région Auvergne Rhône Alpes (AURA) through VARIETY project.

Notes on contributor



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Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

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