Requirements and Barriers for Introducing Smart Manufacturing in Small and Medium-Sized Enterprises

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Abstract—*Bigger companies have been the main adopters of Industry 4.0. However, small- and medium sized enterprises (SMEs) are significant economic and employment contributors in the European Union and the United States. For a successful application of Industry 4.0, customized implementation strategies and approaches as well as adapted concepts and technological solutions are needed. The paper presents requirements and barriers for introducing smart manufacturing in SMEs. These items were identified throughout the research project “SME 4.0 – Industry 4.0 for SMEs” by using expert workshops with SMEs from the United States, Central Europe, and Northern Thailand. The results inform recommendations for managerial action to support an appropriate adaptation of Industry 4.0 technologies and concepts into SMEs.*

Key words: Barriers, Industry 4.0, requirements, small and medium-sized enterprises, smart manufacturing

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INTRODUCTION

INDUSTRY 4.0 aims at increasing digitization and automation of the manufacturing industry by merging information technology (IT) with production and logistics processes. Industry 4.0 has been mainly introduced by bigger companies and small- and medium sized enterprises (SMEs) are not fully able to exploit Industry 4.0's potential for efficiency improvements.

An investigation in how Industry 4.0 concepts and technologies can be appropriately applied to SMEs commenced ([Rauch *et al.*, 2019]; [Dallasega *et al.*, 2019]). Various governments have started to actively financially support SMEs in the adoption of Industry 4.0 – for example the European Commission and the Thai government.

Some studies reveal the potential for SMEs to apply Industry 4.0 to enhance their competitiveness [Rickmann, 2014]. Compared to larger companies, SMEs have the

potential to more rapidly implement digital transformations; they typically have increased flexibility in terms of process and technology changes.

Industry 4.0 still represents a special challenge for businesses in general and for SMEs in particular. SMEs are not ready due to limited organizational capability to adapt Industry 4.0. In particular, compared with bigger companies, SMEs have usually fewer financial resources for research and development and less qualified staff [Matt *et al.*, 2018].

SMEs are defined by the European Commission as having fewer than 250 employees and an annual turnover – revenue – of less than €50 million. They are considered the backbone of the European economy.

According to SME statistics from the 2015 Eurostat database in 2015, there were 23.4 million SMEs in the European Union's (EU) non-financial sector. Together they employed 91 million people and generated €3,934 billion of value. Large enterprises

represent 0.2% of all enterprises in the EU and generate 43.5% of value. These large enterprises account for around one third of the number of employees (33.7%).

Two-thirds of employees in the non-financial sector are employed by SMEs, with 29.1% in micro enterprises with less than 10 persons employed, 20.2% in small enterprises with less than 49 persons employed, and 17.1% in medium enterprises with less than 250 employees. All three sizes of SMEs are contributing nearly equally to value added in the EU with 20.3% for micro enterprises, 17.6% for small enterprises and 18.5% for medium-sized enterprises (Eurostat, 2018).

The economic contribution from SMEs is particularly apparent in Malta, Cyprus, Estonia, Greece, Latvia, Lithuania and Italy with SMEs providing more than two-thirds of the total value generated. In the overall EU, the value added generated by SMEs is 56.5% (Eurostat, 2018).

The number of EU SMEs increased by 13.8% between 2008 and 2017. SMEs represented 88.3% of all enterprises exporting goods. Most SMEs were engaged in intra-EU trade, while less than half of exporting SMEs sold to markets outside the EU [Brusselsnetwork, 2018].

Small to medium enterprises also make up the vast majority of businesses in the US. According to the U.S. Census Bureau Data from 2016, of the 5.6 million employer firms in the US, 99.7% had fewer than 500 employees, 98.2% had fewer than 100 employees and 89.0% had fewer than 20 employees.

SMEs contributed 46 percent of the private nonfarm GDP in 2008 – the most recent year for which the source data are available – making them important for economic growth, innovation, and diversity [Ward, 2018].

Small businesses in the US employed 58.9 million people, or 47.5% of the private workforce, in 2015. SMEs contribute to economic growth in the US as small businesses created 1.9 million net jobs in 2015 [SBA, 2018].

Given the importance of SMEs there is a need for further research and action plans to prepare SMEs for successful adoption and application of Industry 4.0. Successful application of Industry 4.0 to SMEs requires customized implementation strategies and approaches as well as adapted concepts and technological solutions. Otherwise, awareness-raising alone will not result in expected successful adoption.

We now delve into specific requirements, barriers and difficulties for introducing Industry 4.0 into SMEs. They were identified within the research project “SME 4.0 – Industry 4.0 for SMEs” by using expert workshops with SMEs from the Northeast part of the United States of America, Central Europe and Northern Thailand. We then provide insights for managers from these results.

METHODOLOGY

To obtain direct input from the beneficiaries of Industry 4.0 in manufacturing SMEs, we selected a primary research approach to collect specific user needs by interviewing SMEs. An explorative field study using SME workshops was used. These workshops allow for common exchange of experiences and to stimulate discussion among the participants, thus creating a deeper experiential environment.

Four SME workshops were held in Europe (Italy and Austria), the US (Massachusetts) and Asia (Thailand) to investigate specific requirements for SME. The implementation of SME workshops in different countries/continents should also help to identify

cultural or country-specific differences, thus avoiding local needs having a strong influence on the final design guidelines for the introduction of Industry 4.0 into SMEs.

The workshops had a standardized structure starting with an initial introduction and overview of Industry 4.0, then presenting some practical applications and best practice examples in SMEs.

Afterwards, the participants were asked to express their needs and requirements for introducing Industry 4.0 concepts in their companies and share their experiences with the other participants.

They were then asked about the main barriers and limitations for the implementation of Industry 4.0. The inputs were collected in the form of sticky notes on pin boards and categorized by topic.

Before starting the evaluation of the collected inputs, several company visits were carried out at participating SMEs to gain a better practical understanding of the requirements and barriers.

Table 1 illustrates the structure of the workshops, where inputs were collected in three categories defined previously by the research team: (i) Smart Manufacturing, (ii) Smart Logistics (iii) Organization and Management Models for Smart SMEs. In this paper, we concentrate on the results obtained for the smart manufacturing category.

REQUIREMENTS FOR SMART MANUFACTURING SYSTEMS IN SMEs

A total of 163 items with inputs from SME companies were collected in the workshops. These items were consolidated into 65 requirements – indicated in Table 2 – for introducing

smart manufacturing. Those 65 requirements are further subdivided into 27 Clusters.

From the requirements listed in Table 2, the following four requirements were of most interest to SME workshop participants:

- 1) *Agility in manufacturing and Mass Customization*: manufacturing systems need to be quickly adaptable, changeable and reconfigurable according to short-term changes in volume or product variant. This item allows for a profitable mass customization strategy.
- 2) *Real-time data, digitization and connectivity*: SMEs should work on vertical data integration from sales data in the ERP system over production planning and control tools to machine data on the shop floor level. Such integration is required to gain benefit from connecting machines and workstations and collecting their data in real-time. A challenge will be to convert legacy machines into “Industry 4.0 ready” ones, by installing IoT-gateways and sensors.
- 3) *Advanced Manufacturing Technologies and Automation*: with new emerging technologies

on the market like high speed and high precision machines for milling and turning as well as with the introduction of collaborative robots. SMEs can take a further step towards automation although to produce small lot sizes.

- 4) *Ease of Use and low Investment*: when introducing new technologies in SMEs, they should be easy to learn and affordable for SMEs. An example is the use of robots in SMEs. Usually SMEs do not have highly qualified staff able to program robotic systems. Therefore, robotic systems for SMEs should be easy to handle and to program, as it is the case with most of the collaborative robots on the market.

The following topic is also of high interest for SMEs, although they are aware that they are not yet well prepared for these concepts:

- 1) *Machine Learning and Smart Data Analytics*: Machine Learning will become an important topic in the next few years for developing new and intelligent approaches for smart data analytics. Such data analytic tools can be used for both optimizing production

planning and control strategies as well as to realize predictive maintenance in the shop floor.

MAIN BARRIERS AND DIFFICULTIES

The workshops also asked participants about difficulties they face. Thus an overview of the main limitations and barriers for smart manufacturing in SMEs was also determined. Table 3 summarizes the results showing 14 main limitations and barriers categorized into six Clusters.

From the limitations and barriers listed in Table 3 the following ones were discussed in detail during the workshops.

- 1) *Cultural barriers* in terms of lack of acceptance by the management and the operational level personnel were mentioned. Here, the lack of support by top management was highlighted, and confirmed by other studies (Orzes *et al.*, 2019).
- 2) Considering the *implementation* phase, the frequent lack of experience in managing and applying Industry 4.0 concepts and technologies were mentioned. Specifically, the

Table 1. Structure of SME Workshops

No.	Agenda point	Duration	Objective	Method
1	Introduce project presentation	15 min	Explanation of the project and research objectives	Opening presentation
2	Concept and origin of Industry 4.0	30 min	Introduction in Industry 4.0 for a common understanding	Opening presentation
3	Best practice examples	20 min	Awareness raising for implementation	Case studies, pictures, videos
4	Overview methodology	15 min	Understanding of the research method	Introductory presentation, examples
5	Introduction brainstorming session	10 min	Understanding of the brainstorming method	Introductory presentation
6	Brainstorming ‘Smart Manufacturing’	90 min	Creative brainstorming with sticky notes and subsequent discussion	Sticky note method
7	Brainstorming ‘Smart Logistics’	90 min	Creative brainstorming with sticky notes and subsequent discussion	Sticky note method
8	Brainstorming ‘Organization and Management Models for Smart SMEs’	90 min	Creative brainstorming with sticky notes and subsequent discussion	Sticky note method
9	Discussion and closure	30 min	Summary and impression of the day	Open discussion

Table 2. Requirements for Introducing Smart Manufacturing in SMEs

Cluster	No	Requirements for the design of smart manufacturing systems in SMEs
AGILITY	1	Build or improve production lines and work stations to be more compact
	2	Ensure flexible, scalable, customizable production systems
	3	Reduce set up time for new configurations
	4	Produce a wide variety of products and at wide range of volumes without significant re-configuration costs, and time
	5	Adapt and adjust processes autonomously
	6	Enable easy to use and change systems of new manufacturing technologies
	7	Take advantage of rapid prototyping technologies to make product development easier, and reduce requirements for stock
AUTOMATION	8	Mitigate repetitive tasks with quick payback time
	9	Customize packaging on demand
	10	Reduce labor and cost of all production and logistics processes
	11	Implement self-maintaining processes
CONNECTIVITY	12	Ensure the ability to easily and efficiently communicate on a sufficiently real time basis with internal and external customers
	13	Standardize and simplify security and interoperability of information and communication technologies
	14	Create standardized easy to use systems for connectivity, communication, and transparency
	15	Enable internal and external information connectivity to enable better forecasting, inventory management, current demand measuring, internal material requirements, etc.
CULTURE	16	Understand the culture of customers to interpret preferences for cost and quality
DESIGN FOR MANUFACTURING	17	Enable the use of advanced manufacturing technologies in the design phase
DIGITIZATION	18	Implement automation and digitization of internal workflows and report generation
	19	Reduce cost of physical prototyping
	20	Implement clear data gathering, management, analysis, and visualization to both internal and external customers
	21	Collect real-time data of machines, warehouses and facilities to keep production under control
	22	Enable data flow has to be consistent through the whole product life cycle and in the whole supply chain
	23	Enable fast measurement on-site and immediate delivery of data to production facility
	24	Provide and visualize information everywhere and every time to reduce waiting times and unnecessary delays
	25	Simplify maintenance of newly adopted manufacturing technologies
EASE OF USE	26	Lower informational barrier, complexity of entry to new manufacturing technologies
	27	Enable user-friendly robot programming for "normal" workers
	28	Manage legal and bureaucratic hurdles for introducing I4.0 technologies
IMPLEMENTATION	29	Measure the impact of I4.0 on the company's sustainable success
	30	Provide an overview of existing I4.0 instruments and their suitability for SMEs or industry sectors
	31	Gain access to knowledge needed to implement I4.0
	32	Identify a defect as early as possible with little to no worker intervention needed
INSPECTION	33	Mitigate the human element in otherwise tedious or low information content tasks, such as delicate maintenance, equipment calibration, etc.
	34	Identify defects through in line inspection of process and material to avoid non-quality at the customer side
	35	Reduce non-value adding activities in production and logistics
LEAN	36	Produce on demand and deliver just in time
	37	Move product individualization as late as possible in the value chain
	38	Automatically identify and adjust parameter deviations in the manufacturing process influenced by environmental variance
MACHINE LEARNING	39	Implement fast and automated design-based generation of tool path, part processing plan and quotation
MASS CUSTOMIZATION	40	Gain the ability to produce small lot sizes (lot size 1) without losing efficiency
NETWORK	41	Ensure that SME has a culture which includes the needs of the customer and workers through discourse and communication to enable full and productive integration of SME 4.0
	42	Communicate and/or share capacity, materials, infrastructure, and information with internal and external customers, and suppliers
PEOPLE	43	Enable ergonomic support for physically difficult tasks
	44	Manage internal knowledge and staff development for Industry 4.0
PRODUCTION PLANNING AND CONTROL	45	Enable a decentralized and highly reactive production planning and control
	46	Forecast demand changes quickly and interact with systems for planning, control, and logistics
	47	Ensure maintenance costs are minimized while maximizing value added time of machines
PREVENTIVE AND PREDICTIVE MAINTENANCE	48	Proactively maintain to ensure availability and decrease down time of machines.
	49	Predict data-based probability of machine stops or machine down time
REAL TIME STATUS	50	Digitize feedback system, and infrastructure, which monitors status of production, storage, shipping, risk, and crisis management
	51	Gather real-time status and visualize this data for operators and management
REMOTE CONTROL	52	Enable location independent control of maintenance, facilities and products

Table 2. (Continued)

Cluster	No	Requirements for the design of smart manufacturing systems in SMEs
RESOURCE MANAGEMENT	53	Monitor (data driven) material and process capability for all relevant resources
	54	Ensure machines are capable for prospective jobs, and are able to be repurposed for a variety of other jobs
	55	Reduce time investment for I4.0 implementation and throughout life cycle
SAFETY	56	Provide workers with ergonomic workplace
	57	Provide safe working environment
SUSTAINABILITY	58	Reduce energy consumption and environmental cost
	59	Measure and optimize energy, material, and time usage on processes
TRACKING AND TRACING	60	Track products easily from origin through the value chain
	61	Trace and locate products digitally along the supply chain
TRANSPORT	62	Transport material inside the plant easily and without the need of a worker
UPGRADE	63	Reuse and upgrade of existing manufacturing equipment
VIRTUAL REALITY	64	Allow user friendly 'smart' representation of systems for production, maintenance, design, and service
	65	Digitize product development, improvement, management and security to ensure product is more profitable for SME and customer through product life

difficulties in budgeting because of a lack of experience were highlighted. The uncertain return of investment because of the unclear market potential of Industry 4.0 and the relatively long implementation process were also mentioned (Orzes *et al.* 2019).

3) The scarcity of *qualified staff* in SMEs, is an important barrier to successful adaptation and application of Industry 4.0; this concern was a core issue mentioned several times.

4) Workshop participants argued that their *industrial facilities* –

buildings and infrastructure – were not designed for automating internal transports or processes or to host new manufacturing technologies.

5) Finally, *data security* was mentioned as a very important aspect, which if not assured properly is one of the principal factors that decreases the acceptance level of Industry 4.0 by top management.

IMPLICATIONS FOR MANAGERS

A number of recommendations and implications for SMEs and their

management teams exist. We summarize some of these now.

In the short term, SMEs should already try to advance digitization in the basics of everyday organizational life and start with simple activities such as paperless production. This can already be achieved with very cost-effective digital tools and devices – smartphones and tablets.

In the medium term, it is important to introduce connectivity in the shop floor. This means starting with a comprehensive enterprise resource planning (ERP) system. Machines and workstations can be connected

Table 3. Limitations and Barriers of SMEs Introducing Smart Manufacturing

No	Cluster	Limitations and barriers for the design of smart manufacturing systems in SMEs
1	CULTURE	Lack of cooperation, openness and trust between firms
2		Lack of employee acceptance of new operational processes and technologies
3		Company needs a well-entrenched top down culture which allows continual improvement and mitigation of silo syndrome
4		Regulations and culture of the sphere within which the SME and parent organization functions must be such that proliferation of I4.0 is enabled, rather than disabled
5		Lack of visibility of I4.0 among professionals who would otherwise champion the implementation of I4.0
6	IMPLEMENTATION	Lack of experience in project management and budgeting for implementation of I4.0
7	PEOPLE	Lack of training and qualification of personnel for systems to encourage communication, flexibility, education of I4.0 and soft skills
8		SMEs lack access to the financial, informational, digital, physical, and educational resources to ensure I4.0 is fully realized.
9	RESOURCE MANAGEMENT	Lack of easy access to thought leaders and talent (relative to multinational companies)
10		Buildings are not designed for automating internal transports or processes or for new manufacturing technologies
11		High financial barrier to new manufacturing technologies
12	SECURITY	Lack, and need for better, data security for operations such that potentially unforeseen dangers can be mitigated or blocked entirely
13	STRATEGY	Current lack of knowledge transfer from experts to SMEs for the implementation of I4.0
14		Lack of risk management tools for investments in new processes

with the ERP system or an underlying Manufacturing Execution System (MES) system in order to be able to exchange production data in real time.

Likewise, in the medium term SMEs should concern themselves with advanced manufacturing technologies. Technologies like high speed and high precision computer numerical control (CNC) machines, collaborative robots, or 3D printers are currently economically more feasible for SMEs.

In the long term, smaller companies will have to gradually deal with topics such as artificial intelligence and machine learning. Although the widespread use of these technologies in industrial practice will continue for some years to come, this change will also be mastered by those who adapt to it at an early stage.

Regarding the aforementioned limitations and barriers SMEs should decrease the cultural barriers by providing transparent implementation plans of Industry 4.0 in a medium-term perspective. To improve the acceptance level, especially for top management and owners, Industry 4.0 technology providers should guarantee an appropriate data security level. Employees should be trained to appropriately plan and manage the implementation phase of Industry 4.0 technologies and concepts [Dallasega, 2018].

These are not easy goals to accomplish and will require a new mindset that SMEs, to remain competitive, are in urgent need to integrate the necessary technologies. Training programs and skills development are important organizational capabilities that

require development. Policy makers who realize that SMEs are a backbone of most local and regional economies should seek to support investment and incentivize, maybe through tax breaks or other measures, supporting SME Industry 4.0 industrialization. It is not only good for the company, but many countries to make their industries more competitive.

Knowing the needs, capabilities, and barriers of for Industry 4.0 is important. These items summarized in this paper can inform companies, managers, and policy makers of many issues. Just their listing can provide some initial guidance for planning purposes.

FURTHER CONSIDERATIONS AND CONCLUSION

Bigger companies have advanced Industry 4.0 and SMEs are at risk to not fully exploit this potential for efficiency improvements and build their competitiveness. Even if SMEs have the potential to rapidly digitally transform their manufacturing more rapidly, the application of Industry 4.0 is still quite challenging.

The paper presents specific requirements, barriers and difficulties that were identified within workshops with SMEs from Europe (Italy and Austria), USA (Massachusetts) and Asia (Thailand).

The identified requirements were listed in specific clusters. The ones that received particular attention by participant included: 1) Agility in manufacturing and Mass Customization, 2) Real-time data, digitization and connectivity, 3) Advanced Manufacturing

Technologies and Automation, 4) Ease of Use and low Investment as well as 5) Machine Learning and Smart Data Analytics.

The following major barriers were highlighted: 1) Cultural barriers in terms of lack of acceptance of owners, managers and employees, 2) difficulties within the implementation phase, 3) scarcity of qualified staff and 4) the difficult assurance of an appropriate data security level. Based on the identified requirements, barriers and difficulties, we identified some recommendations for action by organizations and their managers from short, medium and long-term perspectives.

Future research consists of enhancing the validity and reliability of the presented results, by means of specific surveys and a statistical generalization to a broader population. Furthermore, specific models to assess the current level of Industry 4.0 as well as the technical and organizational readiness of SMEs will be developed and applied into practice.

These exploratory results should help SMEs and their stakeholders plan for technology that can provide them with long-term competitive advantages.

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