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Evolving manufacturing mobility in Industry 4.0: The case of process industries

Purpose – This paper presents an approach to incorporating mobility into continuous manufacturing following the advent of Industry 4.0 (I4.0).
Design/methodology/approach – The investigation is based on a year-long canonical action research into a paper-manufacturing company implementing core I4.0 technologies.
Findings – The findings show how to: classify manufacturing mobility strategy based on the dimensions of team, task, and control; design business processes enabled by mobile cyber–physical resources; involve different stakeholders in modelling mobility; and create a comprehensive guide to assist in implementing the mobile digitalization required by I4.0.
Research limitations/implications – Despite the complexity, richness, and depth of the insights obtained in this research for mobility management in process industries, this inquiry was conducted in a single organization.
Practical implications – As the fourth industrial revolution encourages decentralization and increased interaction between humans and machines, this paper presents a model to capture the mobility potential in manufacturing. The tools proposed in this research can be used to steer investments in industry transformations that fuse the physical and digital worlds, overcoming mobility constraints.
Originality/value – Theoretically, this paper expands the concept of manufacturing mobility in I4.0. In practice, it proposes a participative roadmap to assist technology management in increasingly decentralized environments, identifying the intertwined network of cyber–physical actors, processes, and services.

Keywords: Manufacturing mobility, Mobile strategy, Organizational fluidity, Industry 4.0, Go to manufacturing mobility (Go2M).

Paper type: Research paper

Introduction

Mobility is a key component of the fourth industrial revolution (I4.0) and the use of mobile devices in business is expected to continue to grow at rate of 6.9% until 2022 (Mearian, 2017). Processes and production lines are being decentralized all over the world. The context in which organizations compete is changing at unprecedented rates due to technological advances, especially with mobile devices and cloud computing. Mobility is now the norm in many areas of society (Middleton *et al.*, 2014), leading manufacturing managers to include mobile connectivity in their strategic agendas that recognize "the inevitability of IT consumerization" (Harris *et al.*, 2011, p. 110) and the need to proactively embrace it. Companies around the world are implementing technological changes to achieve horizontal, vertical, and end-to-end digital integration in distributed supply chains (Wang *et al.*, 2016). However, the major challenges and requirements for I4.0 are not purely technological, but rather point to standardization, work organization, new business models, and the importance of design principles for the new scenarios offered (Acatech, 2013; Hermann *et al.*, 2016; Lasi *et al.*, 2014; Smit *et al.*, 2016).

I4.0 can be defined as "the organisation of production processes based on technology and devices autonomously communicating with each other along the value chain" (Smit *et al.*, 2016, p. 7). There are several technological innovations in I4.0, including mobile devices, cloud computing, and the internet of things (Oesterreich and Teuteberg, 2016) that require the creation of strategic roadmaps tailored to each type of industry and competitive context (Ghobakhloo, 2018). Mobile information systems (MobIS) are pillars of I4.0. For example, in the aeronautical industry, mobile systems can be found in the critical maintenance repair process (Koornneef et al., 2017). However, despite the general use of mobile technologies for personal use, the adoption of mobile systems in manufacturing is still in its early stages of evolution (Moffitt *et al.*, 2016), requiring additional research and the development of prototypes (Bankosz and Kerins, 2014). Much has changed since 1997, when Puuronen and Savolainen (1997) published an executive view of mobile information systems (MobIS), but one aspect appears even more critical nowadays, namely “the flexibility and tailorability of the mobile IT service platforms and applications. Each organization should have a chance to tailor their mobile information systems …” (p. 18).

To be successful, mobile strategy implementation requires addressing a three-pronged challenge: “(1) selecting system capabilities that align with and enable the strategic intent; (2) implementing the systems successfully within the organization and (3) producing the necessary organizational change to allow the strategic intent to be realized” (Arvidsson *et al.*, 2014, p. 56). However, process industries have specificities that make mobility a challenge, for example:

- continuous production lines that require a great deal of fluidity, agility, and flexibility to align with company strategy (Chatterjee *et al.*, 2017; Esturilho and Estorilio, 2010);
- reduced geographic mobility of production; and
- rigid job roles within the production lifecycle.

Failure to implement the strategic intent of mobility can lead to what Arvidsson *et al.* (2014) referred to as strategic blindness. The above insights lead to the following research question:

> How can manufacturing mobility be developed in process industries so that it adheres to I4.0 strategy?

The remainder of this paper is organized as follows. The next section explains the motivation for this research, which is particularly inspired by the work of Chatterjee *et al.* (2017), relating to organizational fluidity enabled by mobile technologies. Their work suggests that future research is needed on "design principles for mobile ICTs supporting mobile work, and the design of the processes (…) that capture such fluidity, by properly appropriating the mobile ICTs" (Chatterjee *et al.*, 2017, p. 9). Following this, the research approach, i.e. canonical action research (CAR) as described by Susman and Evered (1978), is detailed. Subsequently, the literature review is presented, focusing on papers that can shed light on three main areas: the conceptualization of MobIS; how to go mobile; and the organizational challenges for mobility in process industries. This followed by a description of a year-long action research cycle in a multinational paper manufacturing industry. A discussion of the findings ensues and the paper concludes by presenting the study's limitations and avenues for future research.

Motivation of the study

The authors' interest in manufacturing mobility surfaced during a visit to a traditional ceramic factory, where tablet-computers were found all over the production line. According to the chief information officer (CIO), the reasons for their use were quite obvious: tablets are cheaper and smaller than laptops, they resist open air, heat, and dust well; it is easier to train users because the interfaces are simple; wireless networks are readily accessible; and they facilitate the recording of important data and/or associated photographs, for example, when problems occur with machines or with product quality. This case motivated conversations with industry colleagues and researchers, and the authors conducted six exploratory interviews into this topic (Myers and Newman, 2007) (averaging 1.5 hours each) with continuous process industry experts in ceramics (two), metalworking (two), and food (two). To gain diverse insights, the interviewed companies were selected from the authors' contacts from past projects, based on conceptual fit (Burton-Jones *et al.*, 2015) and their need for mobility. During these interviews, the authors posed questions regarding how the traditional definition of manufacturing mobility ["leading to the system's swift transfer and quick response of strategic dispersion" (Shi, 1998, p. 204)] could be applied to the increasing interactions between disperse cyber–physical systems in I4.0.

One of the maintenance managers of a leading food company that is evolving towards I4.0 stated that "you can take away my laptop computer and all the paper you want, I would really appreciate that … the only thing that I really can't get rid of is my smartphone … so I would be most grateful if you could transform it into my main link to the company, including machines, corporate data, requests …". The authors were surprised in another situation (within a global metalworking company) when a senior manager stated, "we have already been using mobile technologies in our three continuous lines for quite a while now; one tablet in each". Yet, when visiting the installation, the tablets were found to be fixed to the wall (for security reasons; as explained by the manager) and being used as mere machine operation guides. It became clear that the acquisition of mobile technology is not enough to ensure strategic mobility in manufacturing contexts as illustrated by the contradiction of wall-mounted tablets that cannot be moved.

Mobility in I4.0 cannot be reduced to the mere use of mobile devices such as smartphones and tablets to access information. Nor is it confined to the quick transport and operation of manufacturing equipment in distinct locations (which is not even a priority for process industries such as petrochemical, paper, or oil production). I4.0 mobility must integrate aspects such as users, machine, and process mobility. Therefore, industry managers need new models with the potential to assist in the early stages of identifying priorities for mobile transformation, according to the organizational strategy. The six industrial experts interviewed were enthusiastic about an approach to assist in the design of their mobile strategy, the priorities for development, and the requirements for digital transformation: digital infrastructure and digital services (Andersen and Ross, 2016).

This recent study and past research in 15 process industries <*removed for refereeing*> strengthened the authors' our conviction that mobility in industrial contexts is still in its infancy. Considering the potential advantages of mobile devices described above, their spread to "less mobile" areas such as production should be included in their strategic plans.

Research objectives and approach

The aim of this research is to propose an approach to improve mobility in process industries. Accordingly, CAR was selected (Susman and Evered, 1978) as the method to guide intervention in two medium-sized units of a paper production factory. CAR has the dual aim of contributing to science while also solving a real organizational problem (McKay and Marshall, 2001). It is both rigorous and relevant, fitted to understanding complex situations in their real setting (Baskerville, 1999; Davison *et al.*, 2004). The CAR in the present research was developed based on the following five steps (Susman and Evered, 1978):

(1) *Diagnosing:* identifying or defining the situation. The participants interpret the phenomenon and formulate working hypothesis to be used in the subsequent phases of the CAR cycle.

(2) *Action planning:* specifying courses of action to improve the problematic situation.

(3) *Action taking:* causing change to occur and trying to create improvements.

(4) *Evaluating* the consequences of the actions, involving a critical analysis of the results.

(5) *Specifying learning:* documenting and defining the outcomes that will add to the body of knowledge.

The authors followed the principles recommended by Davison *et al.* (2004) to ensure rigor and validity of the CAR project, namely researcher–client agreement, cyclical process model, theory, change through action, and learning through reflection. These principles will be used later in this paper to guide the discussion.

To prepare a theoretical frame of reference for action research (Lau, 1999), the authors surveyed existing literature using the keywords: "mobile information system" and "mobile manufacturing" in EBSCO Discovery, ScienceDirect, Google Scholar, Web of Science, and IEEE Xplore. First, the authors screened titles and abstracts to identify the applicability to the scope of the research and possible paper categories. The inclusion criteria were papers in the English language that addressed mobile development at the organizational (enterprise mobility), project (design and implementation), or process (examples, experiments, and case studies) level. Papers describing mere technological aspects (e.g. tools and mobile apps) or addressing non-manufacturing settings were excluded. Backward and forward reference searches were conducted; for example, Chatterjee *et al.* (2016) emerged from the forward reference search in Overby (2008). A total of 43 articles were annotated using Mendeley's reference management tool. The next section summarizes the literature review.

Literature review

The authors identified three overlapping categories of papers:

1. *conceptual*, including studies that describe the definitions and nature of information systems in support of mobility;
2. *operational*, aiming at putting mobility in practice; and
3. *organizational*, including studies about enterprise mobility and associated challenges for manufacturing contexts.

Conceptualization of Mobile information systems (MobIS)

MobIS can be defined "as information systems in which access to information resources and services is gained through end-user terminals that are easily movable in space, operable no matter what the location, and, typically, provided with wireless connection" (Pernici, 2006, p. 4). Therefore, it is necessary to identify:

- a shared organizational view of the strategy for manufacturing mobility and digital business (Bharadwaj *et al.*, 2013; Chen *et al.*, 2010; Scornavacca and Barnes, 2008);
- the mobility potential of business processes (Graham *et al.*, 2005);
- the user requirements, including the social, task, personal, environmental, informational, and spatiotemporal context (Göker and Myrhaug, 2008; Krogstie, 2001; Perry and Brodie, 2006); and
- the supporting mobile applications (Unhelkar and Murugesan, 2010) and supporting devices.

Mobile systems differ from traditional information technologies in the personalization capability and focus on users' needs, supporting technology and methodologies for development and operations (Krogstie *et al.*, 2004). Shiau *et al.*'s (2016) literature review concluded that MobIS have specific characteristics in the following areas: technology acceptance; success; the value of continued mobile usage; adoption; user behaviour; the measurement and evaluation of mobile commerce;

innovation in, and usage of, mobile commerce; and opportunities and challenges presented by mobile technology. However, there is a gap in the literature concerning guidelines to assist industry managers in the development of the above-mentioned characteristics.

Despite the clear definition (Pernici, 2006) and strategic value of IT for mobility (Barnes and Scornavacca, 2006; Scornavacca and Barnes, 2008), the authors were unable to find any study that focused on process industries. These industries are facing challenges of I4.0 (European Commission, 2016), including the decentralization of production processes (Brettel and Friederichsen, 2014) and mobile supply chains. Although there are obvious difficulties in moving complex equipment used in continuous production (such as paper and chemicals), new technologies can be implemented to improve the mobility of functions [e.g. identify preventive maintenance plans using quick response (QR) codes in the manufacturing line], processes (e.g. decentralized sampling and quality inspections), or information (e.g. augmented reality to assess manufacturing dashboards and procedures). New information channels must be implemented to increase mobility in process industries.

Going mobile with information technologies

MobIS can be used to identify the presence and behaviour of the local and remote workforce using geolocation capabilities (Ríos-Aguilar and Lloréns-Montes, 2015). Potential applications include: the estimation of task execution according to the employee location in the plant; replacing existing control presence; and in emergency situations, e.g. when it is necessary to abandon specific industrial areas for safety reasons. New tools have been proposed to develop mobile applications, e.g. MARPLE (Pryss *et al.*, 2010), which is a development framework and light-weight process engine. There remain, however, shortcomings in the methods that involve stakeholders in the enhancement of mobility. Moreover, despite extensive examples in specific economic sectors [for example, in medicine (Choi *et al.*, 2006), construction (Chen, 2013), tourism (Riebeck *et al.*, 2008), and agriculture (Liopa-Tsakalidi *et al.*, 2013)], there is a lack of examined cases in the production phases of manufacturing units.

The multi-phase framework for mobile transformation considers four phases: mobilization; enhancement; reshaping; and redefinition (Basole, 2005). Organizations face different barriers when moving from the initial phase of enabling existing information to become mobile, creating new processes supported by mobile technology, shaping new business models and strategies, and redefining industries and markets (Basole, 2005; Basole and Rouse, 2007). Therefore, it is necessary to evaluate enterprises' readiness for mobility and promote a culture of innovativeness (Basole and Rouse, 2007). Enterprises' readiness for mobility is a multi-dimensional challenge. Therefore, the context for mobility must include the user (e.g. emotional state, category, preferences, history, activity, location, orientation), the environment (e.g. time, sensor readings), the system (e.g. device characteristics, network conditions, privacy, security, energy consumption), social aspects (e.g. relationships, interactions, groups), and the service (Emmanouilidis *et al.*, 2013). The literature provides models for mobile readiness, mobile transformation, and mobile distributed work (Barnes, 2004) with the potential to be adapted and tested in empirical studies.

Organizational challenges for mobility in process industries

Mobility requires organizational actions to achieve optimal connectivity and an individualized approach "recognizing that each employee will have personal responses to the management of work and non-work to meet personal and organizational requirements" (Dery and MacCormick, 2012, p. 171). Moreover, there are "very practical constraints that arise from the nature of the technology, the sorts of work that they [mobile workers] are doing, the environment that they are working in, and the broader context of the work (including temporal, social and political contexts)" (Perry and Brodie, 2006, p. 98).

To successfully overcome the challenges of mobility, new solutions should be "aligned with the overall business strategy and support enterprises current and future business objectives (…) have a common vision, leadership support, and a strategic path to implementing enterprise mobility (…) [deal with] resistance to change" (Basole, 2005, p. 1938). Mobile systems are critical to achieve organizational fluidity (team, task, and control fluidity), allowing mobility, connectedness, interoperability, identifiability, and personalization (Chatterjee *et al.*, 2017). It is necessary then to address the process virtualization level that is affected by sensory requirements, relationship requirements, synchronism requirements, and identification and control requirements (Overby, 2008). The mere use of tablets, smartphones, or other types of mobile technologies is not enough to develop manufacturing mobility. It is necessary to consider different interrelated dimensions that include the manufacturing context, people, process, information technologies, and information/data.

Mobility is a top priority for the industrial supply chain. According to Mourtzis *et al.* (2016, p. 693) "the general set of supply chain problems are ideal candidates for mobile solutions". Process industries, however, have specificities. Herterich *et al.*'s (2015) systematic review identified two motivational factors leveraging mobile technologies in manufacturing industries: the complexity of plants and machines; and shortcomings in IS integration. These authors concluded that, despite the frameworks for industrial mobility, "only isolated practical challenges are addressed" and "a unified architecture is still missing" (Herterich *et al.*, 2015, p. 141). Some authors have explored the possibility of reusing manufacturing capabilities in different projects to overcome barriers of geographic and organizational distances (Benama *et al.*, 2017; Stillström and Jackson, 2007). However, the notion of the "transportability" of traditional manufacturing mobility capabilities that are quickly operational across different locations (Benama *et al.*, 2017, p. 112) does not translate well to continuous process industries, which have severe challenges and limitations with regard to equipment mobility. Other authors have suggested potential benefits in different sectors, including adopting mobile services in the utilities industry, for example, to record energy and maintenance data and reduce errors (Jain, 2003) or exploring the potential of mobile technologies in manufacturing supply chains (Coursaris *et al.*, 2008). These studies strengthen the present authors' motivation to contribute to research on the strategic development of mobility in process industries where little is understood.

Developing mobility in continuous production

The following sub-sections provide detail on the case company, the action plan, and the results of field intervention. The authors initially conducted a joint diagnosis with practitioners.

Case setting and diagnosing

The paper manufacturing company studied (hereafter referred to as "PC") was founded in 1989 and, using recycled paper as a raw material, the company is exclusively dedicated to the customised production of packaging for consumer goods, such as eggs and fruit. The company has a print-line to customize the packaging according to customer requirements, such as personalising various colour combinations. The productive capacity of the company is such that it is a market leader in supplying the majority of the national poultry market. Exports to Europe and Africa represent about 60% of the company's production. PC is certified according to ISO 9001 (Quality) and

ISO 14001 (Environment). Their future challenges relate to providing improved service to the market (namely achieving the required response capacity to customer solicitations) and evolving through the means of technology so that they are able to provide reliable products, while respecting environmental issues.

The CAR diagnosis started with semi-structured interviews (Myers and Newman, 2007) with the top manager and the integrated systems manager of PC. The authors used different data-gathering techniques for document collection and observation (Myers and Newman, 2007) to understand the organizational processes, existing models, and the company strategy. The joint diagnosis started simultaneously with the systematic literature review outlined in previous sections.

PC does not use mobile technologies, but their adoption is a strategic priority due to: the need to stem the increase of bureaucracy resulting from certification standards; the European priority for industry digitalization and digital market (Brettel and Friederichsen, 2014); and their wish to improve fluidity (Chatterjee *et al.*, 2017). The authors evaluated this company's expectations according to the mobile work model (MWM) (Barnes, 2004), presented in Figure 1.

<Figure 1 about here >

MWM considers three axes: mobility (geographic independence of the workers); process (change in work configuration); and value proposition of implementing mobile services. Each axis is graduated from lowest (level 0) to highest (level 3). According to managers, the ultimate objective is to introduce changes in job roles (level 3 - transformation) to improve efficiency and empower employees with real-time information to support decision making. Due to the restrictions of the process industry, mobility is expected to achieve the transient state (level 1), although geographic independence (level 2) could be considered in the medium-term for specific functions in the company (such as quality management). I4.0 and the internet of things could make level-3 mobility possible (employees almost completely removed from the production location) in the long term. Finally, value proposition is scored as 1 (mobile channel access in MWM) because this company is introducing mobile technologies for the first time.

Despite being a paper manufacturing company, “paper is not welcome” in the company processes. The managers “want to recycle all our paper”, including not only their raw materials but also their colossal amount of production records. According to the top manager, industrial indicators are difficult to obtain, and the records have several errors that affect information quality and, consequently, decision quality. Concerns were raised from managers about process information and workflow control. Their enterprise resource planning (ERP) and enterprise asset management (EAM) systems are not integrated and do not provide support for production, quality, and customer relationship management (CRM). A major investment in equipment did not improve manufacturing as expected, with the production context (type of equipment, facility conditions, heat, labour organization, employee digital literacy, and so on) resulting in some restrictions. First, most of their production workers must move around different (long) pieces of equipment, requiring mobility to record information in different parts of the production processes. Second, their production line presents difficulties for using computers, caused by space restrictions and environmental conditions. Third, it is important to have information available in different parts of the production process, for example, for maintenance, order management, and quality control. Fourth, the company is not merely interested in defining requirements for new mobile platforms, but also in preparing itself for the challenges of I4.0 that require mobility and rethinking their business processes, job roles, and digital services. A key priority is regulatory compliance, as evidenced by excessive paper records and non-conformity highlighted by external audits from customers and assessors.

Action planning

The overall plan for action research aimed to create a model that could assist companies in their mobile strategy and test it in a pilot case. The authors followed the recommendations to analyse the *as-is* situation, define courses of action, and then model the *to-be* situation (Sandkuhl *et al.*, 2014). Most team members were familiar with the ISO 9001 quality standard and certification requirements, so the authors decided to adopt a process-oriented approach. Informed by multiple document analyses in the case organization, the initial draft began with priorities for mobile transformation in quality management. However, the authors soon realized that this did not take into account the company strategy for I4.0 in an integrated manner; for example, new technologies for quality management and augmented reality could also be important for other processes in the organization, such as maintenance and production. After some discussion, the authors drew inspiration from the well-known strategic grid proposed by McFarlan (1984), which categorizes solutions in terms of their level of relevance both in the present and in the future. It was also agreed that it was important to go beyond the "strategic geometry" and consider different perspectives in aligning strategy and technology in complex human contexts (Ciborra, 1997). The plan, therefore, considered four stages:

1. model the mobility strategy to achieve team fluidity, task fluidity, and control fluidity (Chatterjee *et al.*, 2017);
2. evaluate mobile readiness and define priorities at the business process level;

3. define the new mobile services to develop and prototype one mobile service to test the model in practice; and
4. propose a comprehensive approach for manufacturing mobility in process industries based on lessons learned, subsequently named “Go to manufacturing mobility” (Go2M).

Action taking

The first stage of the plan was “to define manufacturing mobility strategy”, involving the creation of strategic grids for team, task, and control fluidity (see Figure 2).

<Figure 2 about here >

According to McFarlan (1984), strategic solutions (on the top left of each matrix) are important to the company’s future, critical ones (bottom left) are important in the present, and high-potential ones (top right) may be important in the future. Support systems provide marginal contribution to the company strategy.

Three matrices are created for team, task, and control fluidity. As explained by Chatterjee *et al.* (2017, p. 3), “team fluidity captures the phenomenon of compositional fluidity”, where teams exist for the duration of a specific project. Task fluidity represents the variation of actions required, the inputs, sequence of task, and outputs. Finally, control fluidity “captures the phenomenon of ‘free control’ where human agents are flexible, autonomous, and mobile, yet tied to the organization by being part of an information network, which implements organizational norms that are cocreated by the human agents in the first place” (Chatterjee *et al.*, 2017, p. 3).

The participants in this CAR project included researchers, company staff, and a mobile development team adopting agile software development (ASD) practices. When starting to build the strategic matrices for mobility, the authors complemented the IT with strategic aspects, including company policies and requirements and visions for future applications of I4.0 (e.g. RFID and QR codes), encouraging reflection around two main aspects: *information to provide* (for example, what production data must be recorded in each section and which tool could be used to assist users in proper classification of quality problems to minimize data-quality issues); and *information to obtain*. The first perspective challenges the designers to think about services that cyber–physical elements (employee or machine) must provide to each other (e.g. maintenance details provided to production), while the latter promotes thinking about the required knowledge to empower mobile workers.

At this point in the research, the authors were in a position both to identify the key strategies for mobility and the priorities for IS development. The decision was to focus on the critical and strategic needs represented in the left-most columns of Figure 2. The information included in the strategic grid clearly pointed to production processes and the employees at the production lines. It was also found necessary to include maintenance and quality interfaces.

The authors then proceeded to the business-process level of analysis, adopting a qualitative approach for this purpose, in the form of workshops that involved managers and production staff. The authors considered developing criteria and weights to support decisions but company managers wanted to test a more flexible and informal selection of priorities. Figure 3 presents one of the resulting outputs regarding these two approaches, involving production, maintenance, quality, and the CFO.

<Figure 3 about here >

Figure 3 uses a simplified process model to identify the most strategic mobile processes and tasks (darker shaded boxes) and a wireless icon to represent the mobile potential (considering three levels of mobility: low; medium; and high). The starting point was the popular process maps described by PC's ISO 9001 certification to identify touch points in different processes and within each process.

Production is a process with low mobile potential, but it must be assessed as it includes three darker shaded activities (most strategic mobile processes and tasks) due to information quality issues and the need for the use of tablets and smartphones by employees instead of non-mobile hardware. The mobile potential was gauged by consensus between project participants considering a multidimensional analysis that included the system conditions, employee mobility and training, empowerment needs, and sensors (Basole, 2005; Basole and Rouse, 2007; Emmanouilidis *et al.*, 2013). The result was a graphical representation of interrelated tasks that can be performed by one or more actors and that can be automated with mobile technologies.

The organization did not want to buy new IT or change the existing enterprise systems during this research; therefore, the authors developed mobile prototypes in-house, enabling an evaluation of different stages of mobility improvement. The subsequent phase of the approach was to represent the mobile landscape; a comprehensive representation of the main processes and activities (each one with specific mobile potential), actors (humans and machines) and their interactions (according to the processes in which they participate), and the mobile services that needed to be developed by the software development team (see Figure 4).

<Figure 4 about here >

Figure 4 is a comprehensive model that represents the:

- team (cyber–physical actors and their relationship with processes and IT);
- task (including the strategic relevance and mobile potential of each process / activity); and
- control fluidity, supported by an information network of mobile services (Chatterjee *et al.*, 2017).

The actors are represented by their roles in the organization (e.g. maintenance actor on the left) and they *create* information that is related to one or more processes. For example, the line connecting the pulp moulding actor to “mobile service #1”, where mobile service #1 represents a mobile application. Based on the connecting lines, it is possible to identify which actors *use* mobile services or the knowledge source.

There are two forms of IT represented in this model: mobile service, representing data inserted by the actor (may have inputs from devices such as sensors, or tablet camera); and knowledge source, representing information that is necessary to empower the actor and allow control fluidity [in this example, it is represented as a procedure produced by the quality manager that must be followed by the thermoforming (machine) actor]. The authors did not want to create an overly detailed model or one that was too technical and, therefore, not useful as a communication tool for fostering participative improvement of manufacturing mobility.

The mobile potential (low, medium, or high) of each landscape element (consisting of people, process, and technology) is the result of the manufacturing strategy and the supporting technologies, i.e. the mobile services (e.g. mobile apps supporting quality inspections) and knowledge sources (e.g. electronic manuals) that support the integration of each element. The landscape model can be helpful in identifying digital information requirements for cyber–physical elements and the cooperative work or impact of each function and piece of equipment in the overall system. The landscape model is dynamic as the organization invests in new socio-technical resources or changes the process configuration (which are aligned with ISO 9001 process modes in this case). An internal ISO 9001 quality audit allowed the authors to confirm that the developed tool was:

- accessible to experts with different backgrounds;
- potentially helpful in quality audits to identify the inputs, outputs, participants, and resources needed for each process;
- representative of improvement initiatives (e.g. new mobile services implemented); and
- useful to implement risk-based thinking, particularly in the identification of risks that emerge from process integration (e.g. data-quality issues).

The Go2M approach incorporates Tuckman and Jensen's (1977) stages to assist the users' participation in mobility tailored to the characteristics of process industries, fostering a culture of innovativeness in manufacturing. Figure 5 illustrates the steps for incorporating mobility in process industries.

<Figure 5 about here >

The topmost line in Figure 5 presents the purpose that an organization should pursue in order to improve mobility. The second line represents the well-known stages of group development. According to Tuckman and Jensen (1977), the maturity of groups evolves through these stages of forming (orientation), storming (confronting options), norming (share a common goal), and performing (decision-making process). The third line includes the proposed outcomes associated with the artefacts in Figures 2–4. At the bottom, key references are included that inspired the author's proposal and the field work with practitioners.

Discussion

There was a joint reflection between the authors and PC to ensure that the results would be relevant for the scientific body of knowledge and also help to improve the client's mobility strategy. The authors learned about the difficulties of incorporating mobility in the process industry, the benefits of a Go2M approach, and the challenges raised in this process. The authors received enthusiastic feedback from company managers and end users of the developed solution. According to them, it was useful to identify improvements and process changes that avoided "converting paper bureaucracy to technological bureaucracy". The software-development team considered the models simple enough to be used in the context of agile practices (iterative development cycles), while maintaining a holistic vision of the entire system, particularly in the identification of the development cycles and potential evolution according to the strategic priorities.

In this company, each IT element presented in Figure 4 (mobile services and knowledge sources) was integrated in separated development cycles. Therefore, the authors' approach for manufacturing mobility supports an iterative process involving stakeholder interaction throughout to develop a product that meets customer expectations. The resulting system assists the user in their current tasks and empowers them to undertake other tasks (e.g. data validation, required fields, and quality control on-site). Curiously, the less IT-equipped part of the factory turned into the most digitalized one, using small and low-cost devices such as tablets.

The authors benefited from considering the three dimensions of organizational fluidity as recommended by Chatterjee *et al.* (2016) to focus the strategic analysis. The contribution of this research mitigates the risks of narrowing the mobility discussion around mobile technologies and wireless communication benefits. Although the authors agree that it is necessary to reach the process level of analysis as presented by Graham *et al.* (2005), risks were found in assessing processes during the initial stages. There are potential risks in narrowing the reflection about "what is done" when we should be asking first "why it is done". In the proposed strategic evaluation, some processes may disappear, others may change, and it is hoped that new mobile processes will emerge.

I4.0 requires a new vision of fluidity in mobile industries. For example, during this cycle, the authors merged production, quality, and maintenance tasks that were previously included in different business processes. The resulting mobile process is also multidimensional, because it is not merely a "production process"; it involves team fluidity (employees from multiple departments as well as equipment suppliers), task fluidity (composite tasks supported by mobile technologies that serve different processes), and control fluidity, decentralizing data collection within product lines and empowering users with information to assist decision-making related to quality issues that need immediate corrective measures.

Go2M representations assists managers in identifying priorities for mobile technology developments. The priority in this organization was given to activities with high strategic mobility (dark green) and potential (e.g. inspections activities in maintenance and quality).

Evaluating rigour and validity

The following sub-sections provide more detail regarding the five principles suggested by Davison *et al.* (2004) follows to evaluate the CAR project.

Researcher–client agreement

Both researchers and practitioners agreed to adopt CAR and study the development of holistic manufacturing mobility within a real situation, supported by I4.0 core technologies. The company made a formal agreement to implement the project because of their commitment to implement I4.0 technologies and level of priority attached to this commitment. Data collection included interviews, field observations, and document collection.

Cyclical process model

The research followed the five stages of CAR as described by Susman and Evered (1978). The frame of reference for CAR was created with exploratory contacts and a systematic literature review. Next, the authors made a diagnosis of the current situation. Data sources and users' perspectives were constantly contrasted to minimize threats to validity. The initial CAR cycle was considered sufficient to outline the approach for incorporating mobility strategies in process industries; however, the authors also found opportunities for future research.

Theory

The theoretical frame of reference was created with a systematic literature review. Inspiration was also found in important models for IS strategy (McFarlan, 1984), enterprise mobility literature, and organizational fluidity. This approach can support fluidity by:

- fostering the foundations of cultural change needed for manufacturing mobility and users' empowerment;
- promoting task fluidity with mobile systems, holistically considering the process map; and

- integrating control fluidity in the data obtained by the socio-technical system in the process industry.

Change through action

Change occurred in a number of situations. First, the authors created a new way of modelling mobility in continuous process industries. Several artefacts were created and routines promoted (Pentland and Feldman, 2008) to guide the team. The organizational situation and context were evaluated before, during, and after the intervention, ensuring that ongoing changes were analysed and documented. This approach assisted managers in the identification of potential developments and also in establishing priorities according to the company's strategy and the mobile potential of its landscape.

Learning through reflection

Project reports were provided to the paper-manufacturing company. Learning occurred as a joint activity between researchers and practitioners in different stages of CAR. The researchers learned that manufacturing mobility must consider the strategic intentions of the organization in the models. It is not enough to evaluate mobile readiness and potential mobile functionalities at the process level of analysis. According to company managers, the models proposed by the authors provided a valuable tool for communicating with IT providers and establishing priorities for the development phases of *going mobile*. Moreover, these models shifted the mobile analysis from mere IT adoption to the global needs of team, task, and control fluidity in production. The authors argue that these three perspectives are necessary to include mobility in the agenda of production in process industries.

Implications for theory

In their recent work, Hofmann and Rüsch (2017, p. 23) stated that "the concept of [I4.0] still lacks a clear understanding and is not fully established in practice yet" and concluded that it is necessary to create frameworks that guide companies "on their road to [I4.0]". The present work contributes to this purpose, suggesting that it is necessary to assess mobility for team, task, and control. The authors followed Hofmann and Rüsch's (2017) suggestion that each company must define a customized strategy for I4.0.

The authors suggest adopting a comprehensive approach to manufacturing mobility in I4.0. The reasons are as follows: the increasing adoption of mobile technologies in businesses; the adoption of bring your own device (BYOD) and choose your own device (CYOD) for professional and private use; and improving communication of the mobile strategy in the organization. I4.0 is a complex transformation process that must include organizational partners to improve integration and different technological suppliers. Consequently, the concept of "going mobile" in I4.0 is not restricted to the traditional transportability of manufacturing equipment, nor is it a result of adopting mobile technologies such as PDAs and mobile apps. Manufacturing mobility in I4.0 should be the result of profound socio-technical changes that occur at strategic, tactical, and operational levels.

Implications for practice

Mobile systems are at the core of industrial transformation. For managers, the present work provides tools to define a mobility strategy and model a mobile landscape for their processes and services. The mobile landscape can be used to communicate with I4.0 suppliers when implementing technological transformations. A multidimensional analysis is necessary for process-technology improvements. That is the case for “minerals and metals, pulp and paper, food and beverages, chemicals and petrochemicals and pharmaceuticals [which] constitute a large part of all manufacturing industry” (Lager *et al.*, 2010, p. 699), but the team are not necessarily mobile in all phases of the process. Go2M can assist managers in the creation of tailored I4.0 strategies that fit the particularities of their sector and competitive context; it was found useful in the regulatory context of quality and environmental certification, which suggests a process-oriented approach to management and evidence of improvement actions.

The interaction between humans and machines will be one of the major challenges for manufacturing in the coming years. Digitalization is key in this transformation effort as it “combines the knowledge, data, and processes of diverse physical machines that were previously disconnected” (Yoo *et al.*, 2012, p. 1401). Therefore, mobility strategies are crucial to fully explore the decentralization of manufacturing. However, there is a lack of methods for manufacturing companies to explore the full potential of industry 4.0 (Xu *et al.*, 2018). The present research contributes to filling this gap by showing how to create digitalization strategies that overcome the paradox in industry 4.0 to interconnect humans and machines in increasingly decentralized environments. The authors highlight a particular aspect raised by a team element that is essential for I4.0: “the artefacts force us to think about data integration opportunities during the entire process of system design and to identify opportunities to communicate in real-time between humans and machines, wherever they are”.

Conclusion

The present paper presents an approach to improving mobility in process industries. It starts with the definition of manufacturing mobility strategy using McFarlan's (1984) grids for each fluidity dimension, as suggested by Chatterjee et al. (2016): team; task; and control. It then identifies priorities at the process level and intertwines social and technical elements in a coherent and simplified model that can assist mobile-system designers and process users in developing the mobile manufacturing context: the mobile landscape. I4.0 removes the traditional barriers of location and offers a new vision for manufacturing mobility via cyber–physical integration.

The proposed approach was developed and successfully tested in a real situation, assisting the company's investments in mobile technologies and preparing their structure for I4.0 decentralization (Brettel and Friederichsen, 2014; Lasi *et al.*, 2014). Nevertheless, there are several limitations that must be stated. First, this is an initial cycle of a CAR project and, despite its representativeness of continuous manufacturing, it is necessary to refine the results in other process industries. The paper-manufacturing company was selected from the authors' previous contacts regarding I4.0 development projects, but it is only one among many other examples of manufacturing industries. Moreover, it is possible to test the approach in other type of industries, e.g. make-to-order production or new processes that include additive manufacturing, simplifying the mobility of physical systems. Second, Go2M assists communication between different stakeholders but it does not include sufficient detail to assist technological developers (e.g. mobile-app developers) in the identification of all the operational requirements of identified mobile services (Nysveen *et al.*, 2015). Nevertheless, the company considered the approach essential for the definition of their new mobility strategy and decision support in process redesign and technology requirements. Third, the benefits of the proposed approach were only assessed by the researchers and the company users, omitting, for now, external quality auditors, partners, suppliers, and customers. Finally, due to the focus in developing Go2M in a real situation, the authors could not fully explore the productivity improvements (e.g. decrease in quality defects or machine availability due to maintenance improvements) using this approach. Although the authors gathered positive feedback from managers and developers in this case, most of the integration advances were internal to the organization, so it was not possible to fully explore the opportunities for inter-organizational horizontal integration. One possible case to explore in the future involves co-production in different plant locations, using similar manufacturing processes (e.g. partners producing the same product) or distinct processes (e.g. a composite product requiring different processes in parallel).

Several opportunities for future research are revealed. Studies investigating how mobile strategies will reshape the production processes of organizations to increase I4.0 readiness and to create digital ecosystems that explore mobility in process industries are potential avenues for further research. Additional research is needed to improve the mobility of cyber–physical configurations in I4.0 and address these challenges, e.g. security issues, safety, operational performance, and the profound social and organizational implications. The authors hope that these results may inspire researchers to propose new tools and methods that assist manufacturing managers and teams in the emergent mobility required by I4.0.

References

Acatech (2013), "Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0", Acatech, Frankfurt, available at: https://www.acatech.de/wp-content/uploads/2018/03/Final_report__Industrie_4.0_accessible.pdf (accessed 27 April 2019).

Andersen, P. and Ross, J.W. (2016), “Transforming the LEGO Group for the digital economy”, CISR Working Paper No. 407, available at: https://ctl.mit.edu/sites/ctl.mit.edu/files/attachments/MIT_CISRwp407_TheLEGOGroup_AndersenRoss_0.pdf

Arvidsson, V., Holmström, J. and Lyytinen, K. (2014), “Information systems use as strategy practice: A multi-dimensional view of strategic information system implementation and use”, Journal of Strategic Information Systems, Vol. 23 No. 1, pp. 45–61.

Bankosz, G.S. and Kerins, J. (2014), “Mobile technology-enhanced asset maintenance in an SME”, Journal of Quality in Maintenance Engineering, Vol. 20 No. 2, pp. 163–181.

Barnes, S.J. (2004), “Wireless support for mobile distributed work : A taxonomy and examples”, Proceedings of the 37th Hawaii International Conference on System Sciences, pp. 1–10.

Barnes, S.J. and Scornavacca, E. (2006), “Wireless applications in New Zealand businesses: A strategic assessment”, Journal of Computer Information Systems, Vol. 47 No. 1, pp. 46–55.

Baskerville, R. (1999), “Investigating information systems with action research”, Communications of the Association for Information Systems, Vol. 2 No. 3, pp. 1–32.

Basole, R. (2005), “Transforming enterprises through mobile applications: A multi-phase framework”, Proceedings of the Americas Conference on Information Systems (AMCIS), pp. 1935–1939.

Basole, R.C. and Rouse, W.B. (2007), “Mobile enterprise readiness and transformation”, in Basole, R. (Ed.), Encyclopedia of Mobile Computing and Commerce, IGI Global, Hershey, PA, pp. 481–486.

Benama, Y., Alix, T. and Perry, N. (2017), “Framework definition for the design of a mobile manufacturing system”, In Eynard, B., Nigrelli, V., Oliveri, S., Peris-Fajarnes, G. and Rizzuti, S. (Eds), Advances on Mechanics, Design Engineering and Manufacturing. Lecture Notes in Mechanical Engineering. Springer, Champagne, IL, pp. 111–118.

Bharadwaj, A., El Sawy, O., Pavlou, P. and Venkatraman, N. (2013), “Digital business strategy: Toward a next generation of insights”, MIS Quarterly, Vol. 37 No. 2, pp. 471–482.

Brettel, M. and Friederichsen, N. (2014), “How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective", International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering, Vol. 8 No. 1, pp. 37–44.

Burton-Jones, A., McLean, E.R. and Monod, E. (2015), "Theoretical perspectives in IS research: From variance and process to conceptual latitude and conceptual fit", European Journal of Information Systems, Vol. 24 No. 6, pp. 664–679.

Chatterjee, S., Sarker, S. and Siponen, M. (2017), "How do mobile ICTs enable organizational fluidity: Toward a theoretical framework", Information & Management, Vol. 54 No. 1, pp. 1–13.

Chen, D., Mocker, M., Preston, D. and Teubner, A. (2010), "Information systems strategy: Reconceptualization, measurement, and implications", MIS Quarterly, Vol. 34 No. 2, pp. 233–259.

Chen, X. (2013), "Web service based mobile worker supporting system for construction industry applications", Telecommunication Systems, Vol. 54 No. 3, pp. 277–286.

Choi, J., Yoo, S., Park, H. and Chun, J. (2006), "MobileMed: A PDA-based mobile clinical information system", IEEE Transactions on Information Technology in Biomedicine, Vol. 10 No. 3, pp. 627–635.

Ciborra, C.U. (1997), "Deconstructing the concept of strategic alignment", Scandinavian Journal of Information Systems, Vol. 9 No. 1, pp. 67–82.

Coursaris, C., Hassanein, K. and Head, M. (2008), "Mobile technology and the value chain: Participants, activities and value creation", International Journal of Business Science and Applied Management, Vol. 3 No. 3, available at: https://doi.org/10.1109/ICMB.2006.35

Davison, R., Martinsons, M.G. and Kock, N. (2004), "Principles of canonical action research", Information Systems Journal, Vol. 14 No. 1, pp. 65–86.

Dery, K. and MacCormick, J. (2012), "Managing mobile technology: The shift from mobility to connectivity smartphone", MIS Quarterly Executive, Vol. 12 No. 4, pp. 159–174.

Emmanouilidis, C., Koutsiamanis, R.A. and Tasidou, A. (2013), "Mobile guides: Taxonomy of architectures, context awareness, technologies and applications", Journal of Network and Computer Applications, Vol. 36 No. 1, pp. 103–125.

Esturilho, C.G. and Estorilio, C. (2010), “The deployment of manufacturing flexibility as a function of company strategy”, Journal of Manufacturing Technology Management, Vol. 21 No. 8, pp. 971–989.

European Commission (2016), "The Fourth Industrial Revolution", available at: https://ec.europa.eu/digital-single-market/en/fourth-industrial-revolution (accessed 27 April 2019).

Ghobakhloo, M. (2018), “The future of manufacturing industry: a strategic roadmap toward Industry 4.0”, Journal of Manufacturing Technology Management, Vol. 29 No. 6, pp. 910–936.

Göker, A. and Myrhaug, H. (2008), “Evaluation of a mobile information system in context”, Information Processing & Management, Vol. 44 No. 1, pp. 39–65.

Graham, V., Köhler, A. and Klawes, R. (2005), “Mobile process landscaping by example of residential trade and industry”, Proceedings of the Thirteenth European Conference on Information Systems, pp. 1400–1409.

Gubisch, M. (2014), “Flydubai opts for Boeing’s MRO mobile information system”, Airline Business, Vol. 30 No. 2.

Harris, J., Ives, B. and Junglas, I. (2011), “IT consumerization: When gadgets turn into enterprise IT tools”, MIS Quarterly Executive, Vol. 11 No. 3, pp. 99–112.

Hermann, M., Pentek, T. and Otto, B. (2016), “Design principles for Industrie 4.0 scenarios”, Proceedings of the 49th Hawaii International Conference on System Sciences (HICSS), pp. 3928–3937.

Herterich, M.M., Peters, C., Uebernickel, F., Brenner, W. and Neff, A. (2015), “Mobile work support for field service : A literature review and directions for future research”, Internationale Tagung Wirtschaftsinformatik, No. 2015, pp. S134–S148.

Hofmann, E. and Rüsch, M. (2017), “Industry 4.0 and the current status as well as future prospects on logistics”, Computers in Industry, Vol. 89 No. 2017, pp. 23–34.

Jain, R. (2003), “Enterprise mobile services: framework and industry-specific analysis”, AMCIS 2003 Proceedings, Paper 254.

Koornneef, H., Verhagen, W.J.C. and Curran, R. (2017), “Contextualising aircraft maintenance documentation”, International Journal of Agile Systems and Management, Vol. 10 No. 2, pp. 160–179.

Krogstie, J. (2001), “Requirement engineering for mobile information systems”, paper presented at the Seventh International Workshop on Requirements Engineering: Foundations of Software Quality: REFSQ'01, Interlaken, Switzerland, 4–5 June.

Krogstie, J., Lyytinen, K., Opdahl, A.L., Pernici, B., Saiu, K. and Smolander, K. (2004), “Research areas and challenges for mobile information systems”, International Journal of Mobile Communications, Vol. 2 No. 3, pp. 220–234.

Lager, T. and Frishammar, J. (2010), “Equipment supplier/user collaboration in the process industries: In search of enhanced operating performance”, Journal of Manufacturing Technology Management, Vol. 21 No. 6, pp. 698–720.

Lasi, H., Fettke, P., Kemper, H.G., Feld, T. and Hoffmann, M. (2014), “Industry 4.0”, Business & Information Systems Engineering, Vol. 6 No. 4, pp. 239–242.

Lau, F. (1999), “Toward a framework for action research in information systems studies”, Information Technology & People, Vol. 12 No. 2, pp. 148–175.

Liopa-Tsakalidi, A., Tsolis, D., Barouchas, P., Chantzi, A.-E., Koulopoulos, A. and Malamos, N. (2013), “Application of mobile technologies through an integrated management system for agricultural production”, Procedia Technology, Vol. 8, pp. 165–170.

McFarlan, F.W. (1984), “Information technology changes the way you compete”, Harvard Business Review, May–June, pp. 98–103.

McKay, J. and Marshall, P. (2001), “The dual imperatives of action research”, Information Technology & People, Vol. 14 No. 1, pp. 45–59.

Mearian, L. (2017), “Your next company computer may be a 2-in-1 laptop”, Computerworld, available at: http://computerworld.com/article/3211051/mobile-wireless/your-next-company-computer-may-be-a-2-in-1-laptop.html (accessed 27 April 2019).

Middleton, C., Scheepers, R. and Tuunainen, V.K. (2014), “When mobile is the norm: researching mobile information systems and mobility as post-adoption phenomena”, European Journal of Information Systems, Vol. 23 No. 5, pp. 503–512.

Moffitt, K., Richardson, V.J., Snow, N.M., Weisner, M. and Wood, D.A. (2016), “Perspectives on past and future AIS research as the Journal of Information Systems turns thirty”, Journal of Information Systems, Vol. 30 No. 3, pp. 157–171.

Mourtzis, D., Doukas, M. and Vandera, C. (2017), “Smart mobile apps for supporting product design and decision-making in the era of mass customisation”, International Journal of Computer Integrated Manufacturing, Vol. 30 No. 7, pp. 690–707.

Myers, M.D. and Newman, M. (2007), “The qualitative interview in IS research: Examining the craft”, Information and Organization, Vol. 17 No. 1, pp. 2–26.

Nysveen, H., Pedersen, P.E. and Skard, S.E.R. (2015), "A review of mobile services research: Research gaps and suggestions for future research on mobile apps", SNF Working Paper No 01/15, Centre for Applied Research at NHH, Bergen, Norway.

Oesterreich, T.D. and Teuteberg, F. (2016), “Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry”, Computers in Industry, Vol. 83, pp. 121–139.

Overby, E. (2008), “Process virtualization theory and the impact of information technology”, Organization Science, Vol. 19 No. 2, pp. 277–291.

Pentland, B.T. and Feldman, M.S. (2008), “Designing routines: On the folly of designing artifacts, while hoping for patterns of action”, Information and Organization, Vol. 18 No. 4, pp. 235–250.

Pernici, B. (Ed.) (2006), Mobile Information Systems: Infrastructure and Design for Adaptivity and Flexibility, Springer, Berlin.

Perry, M. and Brodie, J. (2006), “Virtually connected, practically mobile: Mobile technology and mobile work”, in Andriessen, J.H.E. and Vartiainen, M. (Eds.), Mobile Virtual Work - A New Paradigm?, Springer-Verlag, Berlin, pp. 97–127.

Pryss, R., Tiedeken, J., Kreher, U. and Reichert, M. (2010), “Towards flexible process support on mobile devices”, Proc CAiSE’10 Forum, pp. 150–165.

Puuronen, S. and Savolainen, V. (1997), “Mobile information systems - executives’ view”, Information Systems Journal, Vol. 7 No. 1, pp. 3–20.

Riebeck, M., Stark, A. and Modsching, M. (2008), “Studying the user acceptance of a mobile information system for tourists in the field”, Information Technology & Tourism, Vol. 10 No. 13, pp. 189–199.

Ríos-Aguilar, S. and Lloréns-Montes, F.-J. (2015), “A mobile business information system for the control of local and remote workforce through reactive and behavior-based monitoring”, Expert Systems with Applications, Vol. 42 No. 7, pp. 3462–3469.

Sandkuhl, K., Stirna, J., Persson, A. and Wißotzki, M. (2014), Enterprise Modeling - Tackling Business Challenges with the 4EM Method, Springer, Berlin.

Scornavacca, E. and Barnes, S.J. (2008), “The strategic value of enterprise mobility: Case study insights”, Information Knowledge Systems Management, Vol. 7, pp. 227–241.

Shi, Y. (1998), “International manufacturing networks—To develop global competitive capabilities”, Journal of Operations Management, Vol. 16 No. 2–3, pp. 195–214.

Shiau, W., Lin, B. and Yan, C. (2016), “The intellectual core knowledge of the mobile information system”, PACIS 2016 Proceedings, Paper 255, pp. 1–11.

Smit, J., Kreutzer, S., Moeller, C. and Carlberg, M. (2016), Industry 4.0 - Study for the ITRE Committee, available at: http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf (accessed 27 April 2019).

Stillström, C. and Jackson, M. (2007), “The concept of mobile manufacturing”, Journal of Manufacturing Systems, Vol. 26 Nos 3/4, pp. 188–193.

Susman, G.I. and Evered, R.D. (1978), “An assessment of the scientific merits of action research”, Administrative Science Quarterly, Vol. 23 No. 4, pp. 582–603.

Tuckman, B.W. and Jensen, M.A.C. (1977), “Stages of small-group development revisited”, Group & Organisation Management, Vol. 2 No. 4, pp. 419–427.

Unhelkar, B. and Murugesan, S. (2010), “The enterprise mobile applications development framework”, IT Professional, Vol. 12 No. 3, pp. 33–39.

Wang, S., Wan, J., Li, D. and Zhang, C. (2016), “Implementing smart factory of Industrie 4.0: An outlook”, International Journal of Distributed Sensor Networks, Vol. 12 No. 1, available at: https://doi.org/10.1155/2016/3159805

Xu, L. Da, Xu, E.L. and Li, L. (2018), “Industry 4.0: State of the art and future trends”, International Journal of Production Research, Vol. 56 No. 8, pp. 2941–2962.

Yoo, Y., Boland, R.J., Lyytinen, K. and Majchrzak, A. (2012), “Organizing for innovation in the digitized world”, Organization Science, Vol. 23 No. 5, pp. 1398–1408.

Figures

Figure 1. Diagnosing manufacturing mobility with MWM.

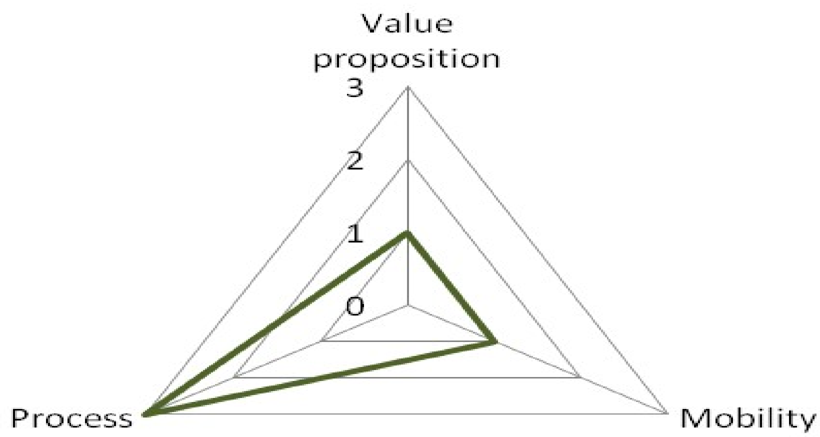


Figure 2. Defining the Go2M strategy.

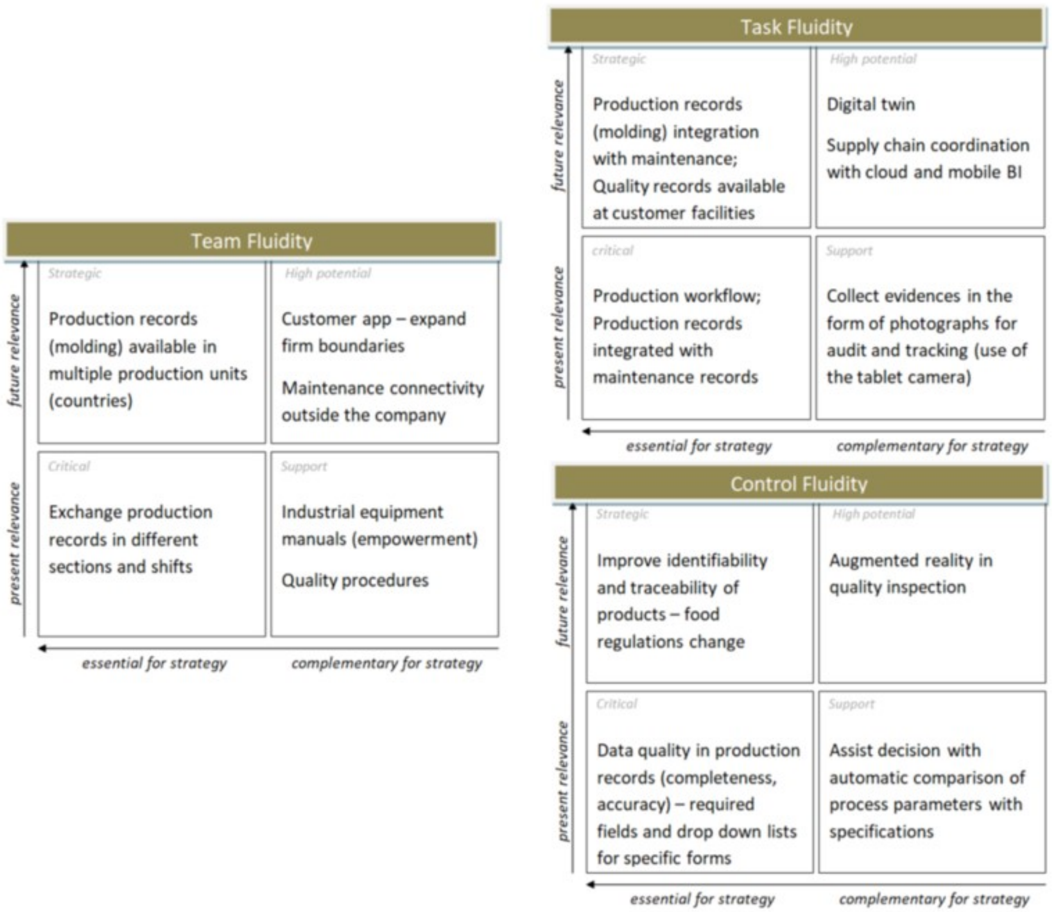


Figure 3. Go2M mobility assessment.

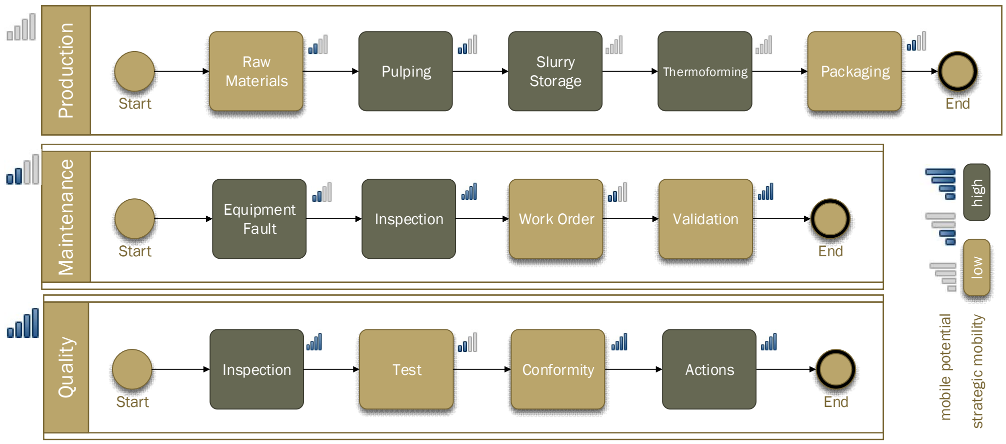
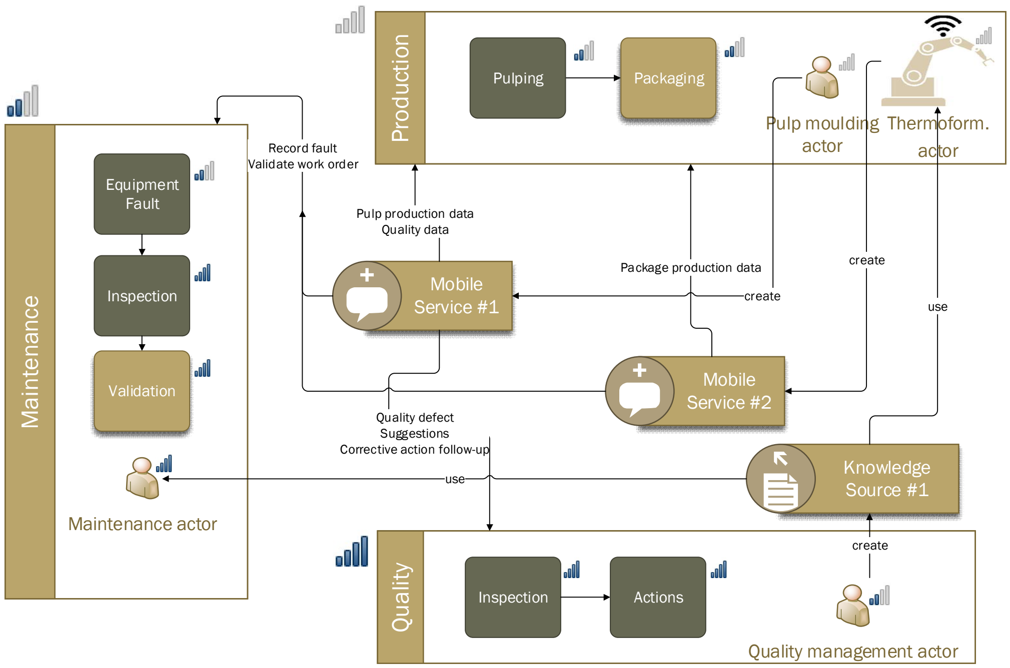


Figure 4. Go2M Mobile landscape (extract for production, maintenance, and quality).



Notes: The three levels of mobility considered are: low ; medium ; and high .

High strategic mobility is represented by the darker shaded boxes.

Figure 5. Go2M steps: define strategy, assess readiness, model landscape, go mobile.