
Cyber-physical systems with autonomous machine-to-machine communication: Industry 4.0 and its particular potential for purchasing and supply management

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Abstract: The number of publications on the fourth industrial revolution (Industry 4.0, short: I4.0) has increased exponentially. Likewise, significant investments by firms are planned. However, the link between purchasing and I4.0 is largely lacking even though procurement managers have high expectations. The fourth industrial revolution – which refers to the use of cyber-physical systems (CPSs) with autonomous machine-to-machine communication – could have several implications for purchasing processes. Support systems for purchasers are being developed, such as contract analysis software, and the possibility of digital negotiations has emerged and could revitalise e-marketplaces. Operative processes can act autonomously, with automated demand identification in CPSs. To support the development of I4.0 strategies in purchasing, this paper contributes by clearly defining I4.0, distinguishing it from the third industrial revolution, structuring the potential development paths of I4.0 in purchasing and by presenting the result of a project to develop a I4.0 maturity model for purchasing.

Keywords: purchasing; procurement; Industry 4.0; maturity model; supply management; cyber-physical systems.

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1 Introduction: purchasing’s central role in digital supply chains contrasting with a lack of specific research

The steam engine became a symbol for the transition from manual to mechanical labour and thereby the key technology of the first industrial revolution. Since that time, two industrial revolutions have followed: mass production enabled by electric power and automation advancements enabled by information technology. Now, a fourth industrial revolution [Industry 4.0 (I4.0)] has been envisioned: the merging of the physical and digital worlds by means of cyber-physical systems (CPSs) and autonomous machine-to-machine communication.

The expectations of I4.0 are high, but purchasing’s contribution to its realisation remains unclear. For instance, a study conducted by PricewaterhouseCoopers among German industrial firms show that in the next five years, companies plan to invest 3.3% of their annual turnover in I4.0 applications (Koch et al., 2014). In addition, the Boston Consulting Group has estimated a 5–8% increase in productivity from the adoption of I4.0 (Rüßmann et al., 2015), and the Fraunhofer Society expects a cumulative added value potential of 23% between 2013 and 2025 (Bauer et al., 2014).

Similar to industry, academia regards I4.0 as a key research topic. Since 2012, the number of publications on I4.0 has rapidly increased each consecutive year. A similar trend is observed for terms related to I4.0 (smart industry, smart manufacturing, industrial internet, and CPSs). Currently, digitisation takes place in business processes throughout the entire value chain, which differs from the role of back-office support that information technology once had (El Sawy et al., 2010). Despite its increasingly important role, however, firms tend to lack knowledge regarding their level of digitisation (Leyh et al., 2016).

Even stronger and surprisingly, while I4.0 is flourishing in many streams of operations literature, research publications discussing the implications of I4.0 for

purchasing seem to be largely absent from the literature. This is not, because industry would not expect any influence of I4.0 on purchasing, as a recent survey among 260 purchasing managers revealed: For instance, one third of the responding purchasing managers strongly expect (and another quarter moderately expect) technological support for risk management and market analysis to develop, with a consequence of a change in supply markets, while about a fifth strongly expect (and another fifth moderately expects) automated negotiations to become common (Bogaschwesky and Müller, 2018). These would be substantial changes which could alter the way sourcing and procurement processes are conducted. Lacking research in this field is a substantial gap in academic literature. Hence, firms, researchers and educators benefit from discussing the possible scenarios of I4.0 in purchasing.

The intention of this paper is to, generally, provide insight into the fourth industrial revolution and its distinction from the third industrial revolution and to, specifically, explore the relevance of I4.0 for purchasing for academics as well as its practical relevance for purchasing managers. This paper aims to contribute to the current literature by means of a literature review, deriving a definition for I4.0, a presentation of the results from more than 15 recent workshops on I4.0 in purchasing, and a design project that summarises the findings in the form of an actionable purchasing I4.0 maturity model. We suggest answers to the following questions:

- 1 What is I4.0, actually, and how does it differ from I3.0, the third industrial revolution?
- 2 Which fields of purchasing could benefit from I4.0 applications?
- 3 How could firms prepare and what would be a research agenda for academia?

First, to answer question one, this paper describes the three preceding industrial revolutions and explores the technical and organisational aspects. Then, the distinctive characteristics of the fourth industrial revolution are compared to those of the third industrial revolution (digitalisation), which will serve as input for the I4.0 definition. Without clearly distinguishing I4.0 from I3.0 practitioners and academics alike are in danger of presenting ‘old wine in new bottles’ and achieving no real progress. Next, in order to answer research question two, the paper focuses specifically on purchasing with I4.0 and supportive applications. Then, finally and to answer question three, maturity models in general, those tailored to I4.0 and our own proposed maturity model are outlined. With the help of the maturity model purchasing departments can derive an I4.0 roadmap of their own. Finally, an agenda for future research on purchasing and a conclusion are presented to summarise the findings of this study.

2 Four industrial revolutions: technological drivers are transformed into a revolution by organisational changes

Thus far, the industrial revolutions have been characterised:

- a by being ignited by new pacemaker technology
- b initially showing only slow productivity gains
- c emerged only after reorganising business.

However, innovation has not commonly occurred throughout human history, and the first industrial revolution took a long time to materialise.

The Roman Empire, for instance, was characterised by enduring technological stagnation (Cipolla, 1994). The medieval era introduced some more innovations – such as the heavy plow, the three-field system, the introduction of the horseshoe and, notably, windmills – but few agree with Gimpel's (1975) claim that there was an 'industrial revolution of the medieval times'. Instead, the literature is quite unanimous about dating the (first) industrial revolution around the mid-18th century. Presumably, the coincidence of rationality-seeking enlightenment (which occurred in several places in Europe) and a favourable institutional context (mainly in England, with the coincidence of the enforcement of property rights, competition through abolishment of monopolies, patents, risk reducing social care through the old poor law and others) started the profound transformation of our economy and the way we live (Mokyr, 2005; Acemoglu and Robinson, 2012). Since that time, several industrial revolutions have taken place, although authors disagree on the exact number of them: Perez (2010), for instance, distinguishes five revolutions; Greenwood (1999), Tien (2012) and Jensen (1993) identify three; and a fourth has recently been added (Kagermann et al., 2013). Authors usually agree that industrial revolutions are typically technology induced but lead to and require fundamental economic and societal changes (Perez, 2010; Brynjolfsson and Hitt, 2000). Evangelista and Vezzani (2010) empirically show how firms become successful when they implement technological and organisational changes at the same time.

It has been argued that the pacemaker technology of the first three industrial revolutions was the steam engine, electricity and microprocessors, respectively. Much has been written about the first industrial revolution. Steam engine technology is considered to be at the core of the first industrial revolution, even though it took a long time to establish. In the beginning, a watt steam engine produced as much power as 500 horses. At that time these horses, however, would only evoke costs less than a third of the steam engine (Greenwood, 1999). It is important to analyse the resulting changes in business systems after the disappointing beginning of the first industrial revolution. The slow progress of the first industrial revolution can be deduced from the observation that the standard of living started to grow substantially only approximately 50 years after its beginnings (Voth, 2003).

Because of the steam engine, one central power source became the centre of each work environment – and the first real factories emerged. Industrial cities formed as a consequence of economies of agglomeration (Perez, 2010). Business models had to change. For example, in textiles, instead of decentralised craft production, large centralised mills emerged. It is important to remark that only after these organisational changes taking place, could economic actors fully benefit from the technical possibilities. The technology alone did not make up for the revolution, but only the coincidence of technological innovation and organisational innovation. It took decades to create this coincidence of technical and organisational improvements.

The second industrial revolution is typically considered to have started in the 1860s with the advent of electricity and electric motors (Tien, 2012). Again, the progress was slow in the beginning, for the following reason: "thus, in the early stages, electricity tended to be overlaid onto existing systems. In particular, the mechanics of steam- and

waterpower favored having a single power drive a group of machines, and early electric motors retained the group-drive system of belts and shafting...” [Greenwood, (1999), p.9]. That is, in its first application, firms tried to use the electrical motor as just a better steam engine. It was almost 1920 when the electrical motor surpassed the steam engine as the main mechanical source of energy (Devine, 1983). Near the turn of the 20th century, firms started to realise that a large productivity gain would result from changing the layout of the factory, having many decentralised power sources, and organising production rather than following power transmission rules by following the sequential logic of assembling a product. The assembly line was the result. The mass production of standardised products became possible, with economies of scale favouring large enterprises (Perez, 2010). Again, the technological innovation of the electrical motor could only lead to a real industrial revolution once the organisational innovation of the assembly line and a new factory layout emerged.

As before, the third industrial revolution relied on new pacemaker technology, microprocessor-enabled information technology, which is sometimes differentiated into computers and robots. The third industrial revolution is called the ‘digital revolution’ (Schuh et al., 2014). Typically, the start of the third revolution is considered to end in the 1960s or during the first oil price shock in 1974, which was a turning point in many aspects, for example, by marking a shift in the spread of income (Greenwood, 1999; Jensen, 1993). One organisational consequence of digitalisation was a reduction in variable costs. A globally accessible computer program literally costs the same regardless of whether one or one hundred people use it. As a consequence of reduced variable costs, a winner-takes-all economy emerged (Brynjolfsson and McAfee, 2014). Subsequently, the premium paid for skills increased with a spread in salaries (Liu and Grusky, 2013). However, at first, a productivity paradox occurred, i.e., the expected productivity gains often did not result from the substantial IT investments undertaken (Brynjolfsson, 1993). This development was similar to the introduction of the electrical motor: business must be reorganised for technological novelties to have the potential to cause an industrial revolution.

We are currently at the beginning of the fourth industrial revolution, and firms are challenged by the new organisational forms made possible by new pacemaker technologies.

Table 1 Industrial revolutions and key technologies

<i>Revolution</i>	<i>Pacemaker technology</i>	<i>Organisational transformation</i>
First	Steam power	From decentralised manufacturing to a centralised factory
Second	Electric power (engine)	From power transmission by shafts and bolts to assembly line-based production
Third	Microprocessor-enabled digitalisation (computers and robots)	From distributed production to winner-takes-all platform monopolies due to reduction in variable costs
Fourth	Sensor-enabled cyber-physical systems and autonomous machine-to-machine communication	?

3 Anatomy of the fourth industrial revolution: connecting the physical world to cyberspace

It is important to identify the pacemaker technologies of I4.0, define I4.0 and distinguish the fourth revolution from the third. There is no clear agreement on which is the most important I4.0 technology, yet, although an analysis of the literature has shown that CPSs clearly receive the most attention in publications. In addition, a widely accepted definition of I4.0 is still lacking in academia (Brettel et al., 2014). Interestingly, it has been argued that the data indicate a decrease in the productivity gains afforded by digitalisation (Cette and de Pommerol, 2018), which would mean that there is a substantial business need to embrace the fourth industrial revolution.

Several definitions of I4.0 have been proposed. For example, Thoben et al. (2017, p.5) provide the following definition: “Industry 4.0 comprises a paradigm shift from automated manufacturing toward an intelligent manufacturing concept.” It remains unclear, though, what ‘intelligent’ refers to. Kiel et al. (2017, p.673) define I4.0 as “a novel manufacturing paradigm ensuring flexibility and adaptability of production systems and value chains in order to maintain the future global competitiveness of manufacturing enterprises.” Here, there is a narrow focus on manufacturing, and there is no clear distinction on what actually ensures flexibility, something that has long been sought. Stork (2015, p.21) provides a detailed definition of I4.0, which in the context of purchasing studies is important, by including the supply chain and suppliers: “the term Industry 4.0 [...] refers to the ‘fourth industrial revolution’ or the introduction of internet technology in the manufacturing industry [...] and integrates customers more closely into the product definition stage as well as business partners into the value and logistic chains.” A problem with this definition, however, is the assumption that internet technology is to be used rather than other, more proprietary connectivity technologies. For data security reasons, there are some serious doubts whether the relatively open internet would be the most feasible technological solution.

Ultimately, these definitions remain unclear in two aspects, namely, they do not clearly describe the constitutional elements of the fourth industrial revolution, and they do not clarify how it differs from the third industrial revolution of digitalisation and automation. If the distinction between the third and fourth revolutions is not made clear, then I3.0 applications may be simply relabelled, and no progress is made at all. To differentiate between the industrial revolutions, we define I4.0 as follows:

“Industry 4.0 is characterized by cyber-physical systems with autonomous machine-to-machine communication.”

This definition does not narrow down applications by predefining the relevant technologies (such as claiming that the internet would be the connecting technology or that it would refer only to manufacturing); however, it very clearly refers to the novel aspects of the development inducing the next industrial revolution, such as CPSs. Based on this definition, three key questions can be applied as a checklist to assess the completeness of a vision or of any solution provided in terms of clarifying its progress from Industry 3.0:

- 1 CPSs, which refer to “transformative technologies for managing interconnected systems between its physical assets and computational capabilities” [Lee et al., (2015), p.21], are at the core of I4.0. The particularly new feature is the connection

between the physical and digital world through sensors and actuators (Monostori, 2014). The third industrial revolution introduced digital systems, which, however, did not directly connect to the physical world. A purchasing example would be an electronic catalogue, which is a digital device requiring a human purchaser to enter the desired products. In a CPS, on the other hand, the demand is detected by sensors, which observe that a specific material needs to be ordered, without the need for direct human intervention.

- 2 Autonomy is the second element of I4.0 (Hwang, 2016), meaning that the system can ‘decide’ for itself. Whether these decisions are based on predefined algorithms, expert systems, or artificial intelligence (AI), they do not require additional human intervention to function. An example would be smart machines, which make decisions regarding their own maintenance (Xu, 2017). In the third industrial revolution, automated systems were installed. The difference is that an automated system cannot react to novel situations, whereas an autonomous system reacts without external help. For purchasing, a simple application would allow a material to decide when it needs replenishment. In an automated system (I3.O), the replenishment would follow a predefined plan, e.g., the first day of every month, whereas an autonomous system decides when to replenish materials based on information obtained from the outside world, namely the material’s depletion.
- 3 Finally, machine-to-machine communication is another element of I4.0 and is critical because it requires safe communication to function (Sung, 2018). Instead of focusing on the human-machine interface, as in I3.0, now the novelty is that interconnected machines communicate with each other without requiring human interaction. A classical case at hand is the availability of self-organised production environments, in which machines communicate with each other and make decisions regarding production instead of leaving this activity to a central planner. For purchasing, machine-to-machine communication can mean, for example, that the computer of the buying firm negotiates prices with the computer of the supplier without a direct intervention from a human procurement agent.

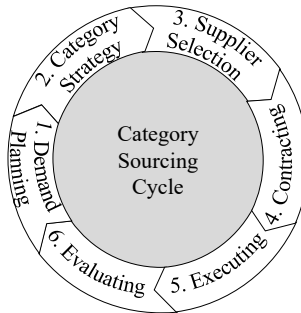
One thing is worth noting: While the origins of I4.0 lie in manufacturing, there is no reason that these principles should not apply to the entire supply chain (Tjahjono et al., 2017). However, it is also clear that new technology implementations are mainly driven by efficiency gains, not by mere ‘legitimacy’, i.e., following others (Zhongzhi et al., 2016). Therefore, the potential implications of I4.0 for the purchasing field constitute a topic worth thoroughly exploring, but with a clear focus on its potential to contribute to efficiency gains, but also to ensure contribution to competitive advantage (Ramsay, 2001) (this may even be imperative).

4 The fourth industrial revolution in purchasing

To systematically start a discussion on the impact of I4.0 on purchasing, it is helpful to first briefly summarise purchasing activities and then, as a second step, verify the impact of I4.0 based on the sequence of purchasing activities.

Regular purchasing activities are depicted in the ‘purchasing year cycle’ (Figure 1). This cycle can serve as the basis for systematically assessing the impact of I4.0 technologies on purchasing (Schiele, 2019).

Figure 1 Purchasing year cycle



Based on corporate planning that reflects the firm’s strategy, the purchasing function plans the supply for materials and services and selects and contracts with suppliers (strategic sourcing, which refers to steps 1–4 in the category sourcing cycle depicted in Figure 1.). Subsequently, these plans are executed (operative procurement, which is step 5), and purchasing performance is evaluated (step 6).

I4.0 applications supporting the purchasing year cycle

To implement I4.0 in purchasing, the following paths can be suggested for each step of the typical purchasing year cycle:

- 1 *Demand identification and planning:* demand planning in purchasing requires accurate sales planning, for which AI-based algorithms are being developed (Bohanec et al., 2017). Therefore, one possibility is relying on the use of big data analysis and AI to improve or complement sales prognoses or to anticipate operative planning decisions (Dutta and Bose, 2015; Hofmann et al., 2017).
- 2 *Category strategy:* defining a category strategy follows the typical strategic management approach, requiring both internal and external analyses. The external analysis in the case of a purchasing strategy refers to the supply market, which could be analysed using big data techniques (Moretto et al., 2017). The expectations are that AI agents might be able to support a supply market analysis. A data engine would collect information, while AI would filter out information that is relevant and present it to the strategic sourcer. The challenge lies in the learning process. Two questions remain: how can relevant information be defined? How can sufficient cases be created so that AI can be instructed to develop its capabilities of distinction?
- 3 *Supplier identification and selection:* in this process step, substantial achievements could be expected because of the ability to engage in sophisticated text mining or the ability of AI to analyse the data available on suppliers (Hofmann et al., 2017). In the preparation of a request for quotation (RFQ), it would be helpful to know all the parameters of past offers, which may contain parts similar to those that are required. Currently, such systems fail because of challenges in data classification. If this

process can be automatised through text mining, it would represent a breakthrough. Based on better knowledge of past projects, the purchaser could create a superior RFQ. Typically, suppliers may need some clarification regarding how to respond. Here, the hope is that interactive bots could manage to answer many of these questions. Once the requirements are clarified, a considerable challenge for the purchaser arises: analysing the offers that have been submitted. Considering that offers for industrial components can easily exceed 100 pages, it becomes clear that, currently, a preselection process must occur, and only a selective few offers can thoroughly be analysed. The more that a text mining system and AI can help to analyse offers and preselect them, the more offers can be collected and seriously considered, thus creating competition. Recently, the use of multi-agent technology has been proposed to support supplier selection (Ghadimi et al., 2019).

- 4 *Negotiation and contracting*: there are indications that electronic negotiations outperform physical negotiations in terms of a buyer achieving savings (Wu and Kersten, 2017). Cyber-negotiations would be the logical next step. In this case, the parties would instruct their negotiation avatars, which would then – through thousands of iterated steps – realise the actual negotiation. Initially, this process resembles automated negotiation, as the electronic agents follow the predefined instructions (Cao et al., 2015; Idrus et al., 2017). There are two steps for this process: first, the involved parties instruct their negotiation avatars by establishing rules and giving clear instructions. It should be noted, though, that such an expert system is not truly autonomous in its decision making, which would be the final stage of development (Baarslag et al., 2017). Then, predefined algorithms would optimise themselves. This process has at least four advantages:
 - a Both the selling and buying firms have to very clearly define their expectations in order to be able to provide instructions for the avatar.
 - b Not only does the price become negotiable, but other criteria, which have traditionally been disregarded due to complexity, can be negotiated as well. Even fraud detection could be improved (Zhang and Liu, 2016). Different aspects of the negotiation process can be optimised (e.g., price, diverse quality and delivery criteria, terms and conditions, liabilities).
 - c An optimum solution can be found instead of just satisficing.
 - d There is much less risk of damaging the relationship as a consequence of difficult negotiations.

Based on a cyber-negotiation it could even be hypothesised that buyer-supplier relations could improve as a consequence of avoiding inter-personal fights and misunderstandings during negotiation. One unique challenge to overcome here is of a legal nature. For example, who should own the data that are generated?

- 5 *Executing*: CPSs could play a pivotal role in the execution phase by automatising the demand generation of e-procurement systems, which are widely available (Zunk et al., 2014). Here, the connection between the physical world and the digital world needs to be introduced, for example, through devices such as smart bins or sensor-driven shelves, which recognise the depletion of a store of physical objects. The expectation is that automated e-procurement will be introduced for not only

production materials through continuous storage monitoring but also maintenance, repair and overhaul (Oks et al., 2017).

In the execution phase, though of a completely different nature, AI-driven systems offer risk management support. Similar to the expectation for market analysis, a risk management system would identify and assess supply chain risks by relying on accessible data, for example, from internet resources. Another form of risk reduction could result from blockchain technology, which may have beneficial application in operative supply chains because of the creation of transparency (Tapscott and Tapscott, 2017). In this case, every legitimised member of a chain can access the chain data, potential delays or quality failures can already be detected early on in the process, and corrective action can be taken.

- 6 *Supplier evaluation*: finally, for supplier evaluation, an old dream of automated data analysis that can be used for evaluation may be closer at hand. On the other hand, a more limited change may occur because such systems not only rely on data extracted from the enterprise resource planning (ERP) system but also require subjective evaluations made by interface partners (such as, next to purchasing, quality, logistics and engineering). These subjective evaluations, by nature, cannot be conducted by digital systems. However, third-party information could be included to complement the supplier evaluation (Moretto et al., 2017).

Some of the above elements could be combined, such as automatic demand generation through CPSs and cyber-negotiations. This combination could revitalise the idea of electronic marketplaces, which failed during the ‘dot.com hype’ in the early 2000s, presumably because as long as a human-machine interface is required for entering demand into the system, an electronic marketplace could not offer very much more than a more comfortable paper catalogue with invoicing function. However, if demand is generated automatically and cyber-negotiation takes place – every pencil could be negotiated, if it is electronically managed – then, e-markets could have a new role, fulfilling the promise from the early 2000s, when the expectation was that e-market places would become dominant.

So far, however, it is unclear how to systematically assess whether a firm can potentially profit from I4.0. To make such an assessment, it would be helpful to have a maturity model, which allows a firm to define the target to be achieved and to develop a stepwise roadmap to reach that goal. To develop this model, we started a research journey.

5 Operationalisation: a maturity model for purchasing

5.1 Method: design case, workshops and an extensive literature review

This study originated from the aspiration to discover how purchasing can progress and benefit from the fourth industrial revolution. Several procedures were followed to ensure that an academically sound scenario can be made for the future of purchasing with I4.0. Aiming to achieve both academic and practical relevance, this research draws on several constructive elements: an extensive literature review resulting in theoretical considerations. This is the central point of content input, also because in practice very

little I4.0 installations already running can be found. On top, 15 workshops on I4.0 applications for purchasing were conducted, too. Finally, a design case integrates all the preceding elements in the form of a maturity model.

First, an exploratory approach was applied to gain familiarity with the topic of I4.0. A systematic literature review was conducted, starting with terms including 'I4.0', 'internet of things', 'smart industry', 'CPSs', and 'machine-to-machine communication'. The results from Scopus were analysed in depth to gain an understanding of the subject areas, geographical dispersion, frequently cited articles and authors, and the development of the number of annual results. This approach contributed to the foundation on which the design project was built and contributed to the first attempt to identify potential I4.0 applications for purchasing. The information required for this part was acquired from both the academic literature as well as operational experience in the industry. It also became clear that the term 'I4.0' was most widely used.

Because the aim was to explore the future of purchasing, a total of 15 one day workshops on I4.0 in purchasing targeted at procurement managers were organised in Switzerland, Austria, France, Germany and Finland. Typically, attendants were either CPOs of smaller companies, who themselves strive at upgrading their organisation for I4.0 readiness or, in the case of larger corporations, the employees from the 'purchasing methods, systems and strategy' departments who were put in charge of coordinating their firm's digitalisation strategies. Altogether, more than 250 purchasers and purchasing managers attended these workshops, revealing their firms' (limited) I4.0 applications and discussing future potentials. In each of these workshops participants were asked to explain their firm's current activities on I4.0.

Finally, before the maturity model was constructed, alternative existing maturity models for I4.0 were analysed and compared to identify their focus areas. The instrument was then evaluated by purchasing managers during the last two workshops. The feedback from the purchasing managers helped us determine how advanced the first two stages of the maturity model should be.

5.2 Eight layers of I4.0: strategy, process, physical properties, purchase-to-pay (P2P) capabilities, key performance indicators (KPIs), sourcing, suppliers and human readiness

In the literature, there is no universally accepted definition of a maturity model (Bititci et al., 2015). In general, a maturity model is a tool used to identify the level of sophistication and the status of current practices for specific organisational areas. Such a tool is embedded in a matrix that includes many questions and potential answers that are subdivided into categories. During semiformal interviews, these questions form the basis for a discussion on the current state of practices to determine which stage the organisation is in.

Several maturity models that have been published. Regarding purchasing, a recent study identified 16 proposed maturity models, although they are all of a general nature (Andreasen and Gammelgaard, 2018). Next to ours, two purchasing digitalisation models have been proposed, one in a book (Kleemann and Glas, 2017) and another as a conference contribution (Kosmol et al., 2018).

A comparison of the existing I4.0 maturity models (see Table 2) reveals that most models have two limitations: they either assess only a few items or lack descriptions of

each stage, i.e., they do not offer anchor phrases describing the levels, but rely on subjective Likert scales. The assessment of a large number of items categorised by different topics adds value by making the maturity model more specific and thus more adaptable to situations that occur in practice.

Table 2 Existing I4.0 maturity models

<i>Model name</i>	<i>Institution/source</i>	<i>No. of topics</i>	<i>No. of items assessed</i>	<i>Description of every stage</i>
The connected enterprise maturity model	Rockwell Automation (2014)	4	N.A. ¹	N.A.
IMPULS – Industrie 4.0 readiness	Lichtblau et al. (2015)	6	17	Yes
Empowered and implementation strategy for Industry 4.0	Lanza et al. (2016)	N.A. ²	N.A.	N.A.
Industry 4.0/digital operations self-assessment	Geissbauer et al. (2016)	7	7	Yes
Reifegradmodell Industrie 4.0	Jodlbauer and Schagerl (2016)	3	7	No
System integration maturity model Industry 4.0	Leyh et al. (2016)	5	5	Yes
Reifegradmodell: 4.0-readiness	Kleemann and Glas (2017)	8	24	No
Procurement 4.0 model	Kosmol et al. (2018)	8	31	No
Model presented here		8	26	Yes

Notes: ¹This white paper presents a maturity model that applies a five-stage approach to realise four dimensions of I4.0. No details were provided regarding the assessed items. ²This document is not publicly available. The reference does not provide any details about the items or the development process.

Source: Expansion based on Schumacher et al. (2016)

In the development of a maturity model, a fundamental issue is determining the categories that can describe maturity. To construct an I4.0-focused maturity model, one approach involves using the previously described purchasing year cycle and developing a scheme for each step. However, the problem with this approach is that, often, one implementation of an I4.0 tool includes several steps along the year cycle. Instead, it has been shown to be more operational to update a model originally conceived by Hazelaar (2016), who developed an I4.0 roadmap for indirect materials at a leading Dutch technology company and identified several layers requiring attention.

The result of the preliminary research on implementing an I4.0 strategy in purchasing is the design of a maturity model that includes eight layers:

- 1 strategy
- 2 processes and systems
- 3 physical properties
- 4 P2P capabilities

- 5 control structures for purchasing processes
- 6 sourcing capabilities
- 7 supplier involvement
- 8 human readiness.

These layers show some similarity to those used in the model of Kosmol et al. (2018), who, on top, also included ‘leadership’, which refers to top management commitment, and split processes and systems into two categories, while neglecting supplier involvement and failing to mention a specific physical aspect. It could be argued that top management commitment is an antecedent rather than a maturity layer. Instead, our inclusion of a supplier layer reflects the observation of I3.0, where digitalisation was often hindered by supplier reluctance. The importance of physical properties is derived from our definition of I4.0 as a CPS. Hence, the explicit ability to assess the links to the physical world seems to be valuable for taking the step from the third industrial revolution to the fourth. Kleemann and Glas (2017) in their I4.0 purchasing model further highlight connectivity and commodity strategies, emphasising the purchase of, for example, 3D printed products, though this may be very much a detailed level of analysis.

Within our eight layers, each assessed item is described for the maturity levels, hence creating a matrix to be filled in. Level one refers to the premature stage of I4.0, in which I4.0 concepts have not yet been adopted. Level four represents world-class performance, which refers to a profound adoption of I4.0 concepts fulfilling all three constitutional criteria defined above (cyber-physical properties, autonomous systems and machine-to-machine communication), and the concepts are aligned at a strategic level of the organisation. We suggest to distinguish a four-stage approach, which is the design logic used in the empirically validated general purchasing maturity model proposed by Schiele (2007). For a more detailed overview of the maturity model including the anchor phrases for the extreme levels, see the Appendix.

- 1 *Strategy*: before firms can start adapting to the fourth industrial revolution, a strategy is required to prioritise the focus areas of the organisation before moving toward the future desired state (Geissbauer et al., 2016). For this reason, strategy is the first layer of our maturity model. A distinction is made between an I4.0 strategy, determining the requirements and priorities for the entire firm, and ultimately, an I4.0 strategy that is tailored to purchasing processes (Kleemann and Glas, 2017). The latter is an important refinement because strategic purchasing positively effects the financial performance of firms. For example, firms have to ask whether they have an I4.0 strategy for purchasing processes.
- 2 *Process and systems*: a model that describes how to overcome the challenges of I4.0 and how to reach organisational targets is incomplete if it does not include processes that arise from the adopted strategy. At the beginning of the previous decade, the expected potential of e-procurement systems increased due to technological progression and the increasingly important role of procurement (Presutti, 2003). As the role of procurement shifted from reducing costs to creating value, modern e-procurement systems facilitated many operational tasks, including reducing transaction costs and increasing contract compliance, thereby allowing purchasing personnel to have more time to concentrate on strategic, value-creating tasks.

I4.0 offers improved capabilities for gathering and sharing information in real-time, and thus, new opportunities arise for improving purchasing processes.

I3.0 e-procurement processes, often catalogue based, are the basis for the further development of I4.0 processes by enhancing machine-to-machine communication and changing interfaces to CPSs. A hierarchy has emerged: first, processes have to be standardised and then digitalised, and then they can be made autonomous and cyber-physical, i.e., connected to the physical world. Hence, the fundamental question for firms is to ask the following: have they fully implemented I3.0 (software) systems, and if so, has it been extended into the physical world and autonomous connectivity? A combination of process improvement and software implementation is needed. These two aspects should not be separated into two different layers in order to better comply with the requirement discussed above, that a technological update must lead to an organisational change to generate a productivity enhancing revolution. Otherwise, a case of technology adoption paradox may occur, similar to what occurred during the beginning of the 1990s (Brynjolfsson, 1993).

- 3 *Physical layer*: while CPSs are inseparable from the fourth industrial revolution (Kagermann et al., 2013), the existing maturity models either only briefly mention CPSs or omit the physical aspect altogether. Regarding I4.0 as digitisation solely thriving on IT systems, the cloud, or big data would not do the fourth industrial revolution justice. Hence, the maturity model presented here explicitly includes a physical level. It is expected that a fusion of real and virtual systems is likely better suited to operational purchasing, for example, through self-filling systems equipped with a machine-to-machine communication functionality used to order goods without human intervention (Fukui, 2016). In the third layer, hence, the main question firms may want to ask themselves is the following: where does a connection to the physical world make sense with our firm, and how can it be implemented? Please note that, here, a wide array of possibilities exist, starting with the simple replenishment of small items in an office or for production, but may also extend to things such as autonomous maintenance tasks.
- 4 *P2P capability*: preventing or reducing purchases made outside available contracts, or ‘maverick buying’, is often mentioned as an incentive for firms to adopt e-procurement systems (Angeles and Nath, 2007; De Boer et al., 2002). The increased analytic and communicational capabilities associated with I4.0, such as big data analysis, are expected to enhance contract compliance and increase the automation of payment processes. Eventually, by applying blockchain technology, the P2P process could be simplified: after the final bill of goods is settled, the payment to all chain members is also settled. The diverse array of intermediaries (banks) becomes largely though probably not completely obsolete. The guiding question here is the following: how many of the P2P processes of the firm can become fully automatised and able to autonomously solve problems?
- 5 *Controlling structures for purchasing processes*: to stay in business in fast-moving industries, it is critical to make the right decisions. With I4.0, the end-to-end transparency of KPIs in real-time becomes possible (Kagermann et al., 2013), which allows purchasing managers to intervene directly, but only, when needed. Due to the large impact of data on decisions, they should be carefully collected, stored,

analysed, shared and archived and essentially treated as an asset by organisations (Wee et al., 2015). Nonetheless, the extended possibilities of retrieving and analysing data also include risks related to cyber security, for example, preventing the unauthorised access or modification of data. Advanced analytics, for example, those based on self-learning AI, come into play. Here, it is important for the firm to determine whether it uses I4.0 capabilities to collect and analyse purchasing data.

- 6 *Sourcing*: data analyses based on data on the traffic to online stores are already used by companies to predict demand. When strategic purchasing is adopted, firms are expected to benefit more from data analyses when the results are shared within the organisation via connected systems; however, this transition requires a significant effort (Geissbauer et al., 2016). Despite the expected increasing importance of data analytics, firms should aim to highlight the useful information in the data to generate insights instead of generating as much data as possible (Lee et al., 2013). To provide guidance for the beneficial use of data for strategic purchasing, our model assesses sourcing by addressing predictive demand, conducting a market analysis, determining specifications, and contracting, including cyber-negotiations. Firms may want to assess and plan the application of I4.0 technologies, mainly through data analysis, to support strategic sourcing. Firms should also consider that I4.0 requires the purchase of new goods and services, for example, if the digital twin of a product allows for its life-long supervision.
- 7 *Supplier involvement*: for supply chains to become fully integrated, collaboration with suppliers is needed, so the willingness of suppliers to adopt I4.0 practices should be assessed in an early stage (Kagermann et al., 2013). A noticeable difference between the literature and experiences in practice is the desired level of supplier involvement. During discussions at several of our I4.0 workshops, purchasing managers indicated that they were cautious about sharing data with supply chain partners. Conversely, the literature deems collaborative networks as essential for achieving I4.0 (Brettel et al., 2014; Geisberger and Broy, 2012). The fundamental issue regarding this layer is whether the suppliers of a firm – or which ones – are ready to collaborate with the focal firm, as some I4.0 installations may include substantial costs and increase competition. Without supplier readiness, limited I4.0 applicability occurs. Here, buying firms may need to strategically prepare I4.0 integration steps by identifying key suppliers with whom the buying company achieves preferred customer status and hence can expect them to be ready to invest into this common journey (Schiele, 2012).
- 8 *Human readiness*: the final layer of the model measures whether employees are ready to adopt I4.0. Other models highlight the importance of training personnel to help them obtain the necessary skill set (Lichtblau et al., 2015; Geissbauer et al., 2016; Schumacher et al., 2016; Jodlbauer and Schagerl, 2016). In our model, a distinction is made between the expected required capabilities of employees and the degree of involvement of employees during the change process. Here, an important question is the following: How have employees in the purchasing function been prepared and trained to use the new technologies?

Based on these eight layers, a systematic managerial and academic discussion can be started. Firms can draft an I4.0 implementation roadmap by defining the desired level to

be achieved in a selected time period, comparing this to the current status of maturity and using the gap analysis to define implementation projects, including software requirements, strategic preparation of the supply base and training of employees. From an academical perspective, each of the eight layers define targeted research fields, since in virtually all of them science is still relying on an embryonic body of knowledge.

6 Conclusions: contributions and a research agenda that will help the purchasing function join the ongoing industrial revolution

In this paper, we have analysed the potential impact of the fourth industrial revolution on purchasing and developed a maturity profile that can help firms develop an I4.0 strategy. By doing so, this paper contributes in at least five ways:

- 1 Thus far, the literature has largely ignored purchasing as an object or subject of the fourth industrial revolution. This paper contributes to the literature because it is the first attempt to systematically analyse potential opportunities and challenges and integrate purchasing and supply management into the discourse on I4.0.
- 2 In terms of a managerial contribution, an actionable tool is proposed here: the maturity model. Using this tool, practitioners – but also academics – can structure their approach to grasping and understanding the implications of I4.0 for purchasing.
- 3 This paper contributes to fields outside the purchasing domain by providing a systematic and actionable definition of I4.0 that includes three constitutional elements – cyber-physical properties, autonomy and machine-to-machine communication. This definition can be used to check whether a potential application is truly an I4.0 application and can serve as guideline to develop such applications. For firms we suggest not to hesitate to start with applications, even if they only fulfil two out of the three criteria and add the missing element later in an evolutionary path.
- 4 One obstacle to the progress of I4.0 is the lack of a clear differentiation from digitalisation, the third industrial revolution. Often, “old wine is served in new bottles.” This paper clearly differentiates I3.0 and I4.0 and clarifies their definitions, which enables research progress.
- 5 Finally, this study considers the history of industrial revolutions and thus contributes by pointing to the need to not only implement new technologies in existing processes but also change these processes in order to increase productivity. We hope to contribute by shortening the unproductive investment paradox phase, which has been typical for the beginning of each industrial revolution.

If the decision to call the recent development ‘I4.0’ and hence embed it into the tradition of industrial revolutions had not already happened, this paper would have made another point regarding the use of this term, as a historical review makes the concept much richer than the use of competing terms, which are much more difficult to define and to make actionable. A revolution only occurs after the coincidence of technologic advances which are made actionable through organisational and business models.

However, this study has also shown that research on I4.0 in general and I4.0 in purchasing in particular is still in its infancy. Before the fourth industrial revolution truly

reaches its productive phase, much research remains to be done, in particular: concerning the operationalisation of the eight layers developed for the maturity model; a stepwise analysis of the I4.0 technologies and their applicability for purchasing; the impact of I4.0 on the skills needed for the purchaser of the future; strategic implications and possible business model changes induced.

- 1 Concerning the need of research on the eight layers, in terms of the P2P process, the operationalisation and assessment of automated demand generation through CPSs are strikingly important. In combination with cyber-negotiations, this feature could lead to a revitalisation of the idea of electronic marketplaces, which would be a fruitful path for future research. In the context of autonomous negotiations, it also becomes clear that, next to actionable tools, we need much a better understanding of negotiation theory and empirics, which have been neglected in the past.
- 2 Considering the pacemaker technologies of I4.0 and their impacts on supply management, blockchain technology needs to be better understood, as it has the potential to create the transparency in the supply chain that purchasers have long dreamed of Foerstl et al. (2017). Transaction costs would decrease, trade without trust could become possible, and hence, a profound transformation of purchasing could take place. Likewise, the application of AI, for example, as a source that can provide purchasers with a series of supportive tools, such as supply risk analysis or market analysis, is an important field in need of more research. Finally, the emerging digital twin technology – the digital representation of a physical system, to which it is permanently and often immediately linked (Tao et al., 2018) – could prevent products from being sold once and then disappearing from the sight of the producer; instead, these products could stay connected through their entire life-cycle. In this case, new contracts would have to be developed, for example, to include liability issues resulting from a life-long perspective. Purchasing needs to adopt to these novel sourcing situations, for which further research could be very fruitful. Green procurement and cradle-to-cradle concepts may become revitalised. 3D printing, also called additive layer manufacturing, refers to the process of producing a physical product based on digital plans by depositing layers of material to form a solid object. It could reduce the importance of global sourcing.
- 3 All of these processes and changes are unlikely to leave the role and hence the skill requirements of purchasers untouched. There is a great need for further research to determine what competences will be needed and how change processes should be changed in alignment with this new role. If digital and autonomous negotiations are incorporated, the task of purchasers would no longer focus on direct face-to-face negotiations but would rather involve the thorough and cross-functional preparation of tenders and negotiation processes. Competition would increase, and firms would need to develop a better understanding of their buyer-supplier relations. In order to prepare electronic negotiations and run their negotiation avatar, the purchaser of the future may need more market design knowledge and hence a better education in its economics background (Schulze-Horn et al., 2018).
- 4 All of these changes may have strategic implications. Fruitful research focused on purchasing should analyse the implications of I4.0 for supply chain configuration and business models. Two extreme scenarios can be imagined: global e-markets

versus closely integrated supply chains linked to each other by productivity enhancing but costly to implement technology. Are traditionally closed supply chains disintegrating? Are electronic market places with constantly changing partners taking over? Or, opposing, are closer supply chains developing – maybe even without costly software integration?

Finally, some limitations of this study and its conclusions have to be acknowledged. The novel nature of I4.0 makes any assertion concerning its impact almost intrinsically vulnerable to errors in judgment. For example, the assumptions underlying the maturity model will have to be checked empirically in the future. No formal assessment of its effectiveness is provided, because in the absence of a large set of already implemented best practices, the prognostic success accuracy of the maturity model cannot yet empirically be tested. Even though, with rare exceptions, all maturity models in purchasing lack an empirical validation (Schiele, 2007), this is an obvious limitation to be taken into consideration. This calls for future research in a few years to take this model, confront it with installations and, if necessary, propose adjustments. In addition, it has also been commented that the fourth industrial revolution is the first revolution announced beforehand. As a consequence of not presenting a piece in business history, only the future will show which technologies will actually prevail and coin the fourth industrial revolution. Our study could also have a bias, as most of the attendees of the many I4.0 workshops we conducted joined because they felt uncertain about the future. Perhaps more knowledgeable purchasers and their insights have thus escaped our attention. Additional case studies of I4.0 in purchasing should be conducted, but eventually, quantification of the findings needs to take place, once a sufficiently large empirical base has been established with firms. Finally, and considering the issue of increasing ‘factor-market rivalry’ (Ellram et al., 2013; Pulles et al., 2016), there is a question on how the competition for supplier resources could shift through the I4.0 technologies. Which influences would the scenario of a digital global market, made possible in the case of autonomous negotiation, have on accessing suppliers? This is a question of considerable strategic importance for firms.

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Appendix (continued) (see online version for colours)

PP1	Invoice to pay (i2p) Maverick buying	Is the payment process automated? Is buying from suppliers outside existing contracts, so-called maverick buying, defined? For example through a restriction by technology to deviate from agreed procedures.							Maverick buying is prohibited as a company policy.	The ordering processes are not automated when the organisations, or pilot projects have started.		Due to seamless machine-to-machine communication it is impossible to order goods outside current procedures. The process of ordering a requisition, from requisition to purchase order, is automated without human intervention. Artificial intelligence is used as a self-learning system. Suppliers are fully automated and the system itself is capable to solve problems, except for very complicated problems.
PP2	Ordering	Is the process of initiating a requisition, approving it, and raising an order automated? (Focus is on the process as opposed to question P1)										
PP3	Monitoring	Is the processing of invoices, invoices and payments, and the checking whether orders meets their agreed conditions automated? Is the derived information shared internally and with supply partners, and included in future purchases?										
CO1	Controlling / KPI	How have companies used data transparency? To which degree can the analytical capabilities of the firm? To which degree does monitoring and data processing take place? Is there a central business intelligence system?							Data analysis takes place on the level of demand prediction. Decisions are made by employees on the basis of KPIs.			
CO2	Data analytics	Is predictive analysis used in real time? Are decision support systems standardised? Are self learning algorithms present?							Manual extraction of data with limited analytic capabilities (limited in either usefulness or data).			Autonomous decision making is implemented (with Artificial Intelligence). Data analysis is outsourced to a central business intelligence system that allows for central use of predictive analytics in real-time assisted by decision support systems and improved by self learning algorithms.
CO3	Security of data	How are data and services in digital systems protected against misuse (e.g. unauthorised access, modification or destruction)? How is the privacy of data guaranteed (e.g. with usage analytics or confidential information)?							The firm has little knowledge on cyber-security. There is no collaboration with partners to face this challenge.			Data and services in digital systems are strictly protected by the firm and they provide openness on how this is done. Cyber safety is regularly checked by independent organisations.
SC	Sourcing	Is the strategic purchasing process supported?										
SC1	Predictive demand	To which degree can future demand be predicted and how fast can the organisation react upon changes of supply and demand?							Demand is predicted on the basis of data analysis of an online catalogue/web shops.			Predictions for future demand are based on both monitoring and data analysis with Artificial Intelligence. Predictions are updated immediately through cyber-physical systems.
SC2	Market analysis	To which degree is market analysis (e.g. the identification of new suppliers, goods or services) automated? Are electronic market places used?							Digitalisation is limited only to the online process of identifying the customer, but not for communication between any of the factories' elements.			Digital marketplace platforms are used to increase the gaps between processes in the supply chain supported by Cyber-physical Systems and Machine-to-Machine communication.
SC3	Specification	Is the determination of requirements supported by data analytics? For example related suggestions for alternative goods or services based on data analytics.							Requirements are determined manually based on experience and earlier purchases.			Information details from product specifications are available for collaborative supply chain. Requirements are determined, and improved compared to past purchases, fully by data-analysis according to a standardised procedure.
SC4	Contracting	How much per cent of the total purchasing volume is handled by e-procurement systems? Is the organisation ready to outsource negotiations to intelligent digital assistants 'avatars' that operate autonomously?							E-procurement systems are known, but not adopted by the organisation.			Negotiations are outsourced to avatars, which make decisions autonomously.
SU	Supplier involvement and integration	Are the suppliers prepared and willing? Does your organisation have a concept for digital integration with suppliers/integrated supply chains? Are suppliers willing to collaborate? To which degree are suppliers involved in setting up integrated supply chains? Who takes the lead in this process?							The organisation is cautious towards digital integration with suppliers and/or integrated supply chains.			Close collaboration with suppliers, realised through integrated supply chains. Full involvement of all parties.
SU2	Supplier capacity	Does your organisation have the capabilities to join the digital transformation process of purchasing? If capacity is lacking, who is responsible for a transfer of the required knowledge?							Suppliers are currently lacking the capabilities to join the digital transformation process of purchasing. No clear division of responsibilities for a transfer of knowledge.			Suppliers with world class digital capabilities take the responsibility for transferring the required knowledge to less capable suppliers in the supply chain. The excessive sharing of purposeful data with suppliers. The exchange of information is fully transparent within the supply chain and takes place in real time.
SU3	Exchange of data	Which data is shared with suppliers and how transparent is this exchange of information? Does the sharing of data take place in real time?							Sharing of data with suppliers occurs occasionally when this is explicitly requested and/or necessary.			
US	Employees / Users	Are the employees prepared and willing? Do your employees possess the required capabilities (willingness to learn, holistic thinking, proactivity, inventiveness) to undergo the transition towards the digitalisation of purchasing? Is learning and development stimulated by management?							The organisations provides employees the opportunity to follow courses in their free time, but the courses are not necessarily linked to digitalisation.			Learning and development is not only actively stimulated by management, but also regular assessments and evaluations are used to ensure that the knowledge of employees keeps up with current developments.
US2	Involvement	To what extent are employees involved in the digitalisation of the purchasing function?							Employees are sometimes invited to team meetings and receive bits of information every now and then.			Employees are structurally involved in the development in the digitalisation of the purchasing function with regular meetings and direct influences.