# Rediscovering the Forgotten Field of Industrial Applications in Information Systems Research: A Literature Review of Industry 4.0

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Keywords: Industry 4.0, Industrial Information Systems, Digital Transformation, Fourth Industrial Revolution, Smart Factory, Manufacturing, Business Process Management.

Abstract: This paper is a literature review to determine if industrial applications are appropriately represented in information systems (IS) scholarship. The field of Industry 4.0 was used as a representative sample of industrial information systems and the Association for Information Systems (AIS) Senior Scholars' Basket of Journals was used as a representative, albeit highly ranked, sample of IS literature. Keywords representing the eleven recognised technologies of Industry 4.0 were chosen and used to search the eight IS journals over a time period corresponding with the lifecycle of Industry 4.0. This resulted in 1305 papers being discovered. After calibrating the search terms, a second search yielded 770 papers. These were screened for relevance to Industry 4.0 and for use of a manufacturing application. The resulting 20 papers were queried in detail to establish the concepts used and a concept centric matrix was produced. The analysis shows that industrial information applications are rarely used to undertake IS research in the academic field. The dominant concept revealed was digital transformation resulting in changes to business processes. The contribution to the literature is to highlight that substantial research studies can be conducted in the industrial manufacturing arena, but very few have been conducted in the last decade. Therefore, it is an area worth exploring for future IS research.

## 1 INTRODUCTION

When comparing a computer scientist to an information system researcher, it has been written that the computer scientist stands in front of the technology and looks in, while the IS researcher stands in the same place and looks at the world at large (Avison et al., 2001). A similar comparison can be drawn between the control and automation engineer and the industrial information systems (IIS) researcher. In this case the control and automation engineer is standing in the factory and looking at the technology while the industrial information researcher is looking at the enterprise at large. This paper, therefore focuses on industrial information systems within the enterprise setting and assesses the breadth and extent of research within the IS field.

Chiasson and Davidson have written that industry "provides an important contextual "space" to build new IS theory and to evaluate the boundaries of existing IS theory" (Chiasson & Davidson, 2005). While Chiasson and Davidson searched only two IS journals (MIS Quarterly and Information Systems Research), this paper searches all eight journals of the AIS Senior Scholars' Basket of Journals and defines industry as the narrower manufacturing sector.

Industry is a significant part of the world economy and fertile ground for IS research. In the EU, in 2017, the manufacturing sector had a turnover of €7,230bn and employed 28,531,906 persons (Eurostat). In the same year in Ireland, an open economy with a large exposure to foreign direct investment, industry accounted for a turnover of €239bn (33% of the business economy) while employing 242,966 persons (only 14% of the persons engaged in the total business economy) (CSO). Industry 4.0 and automation enables this leverage of turnover. The motivation of this research is to establish if the manufacturing

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industry is a valid arena in which to conduct IS research.

This paper is structured as follows, with section 1.1 examining prior research. Section 2 gives the background and definitions of Industry 4.0. In section 3, a methodology is designed and used to perform a literature review. In section 3, the results of the search and screening are presented. The emerging themes or concepts of the literature are presented in section 4, the literature review, containing section 4.1, synthesis, or what do we know from the literature. The methodological and quality state of the literature is also presented in section 4.2, analysis, or how do we know what we found in the literature. These results are discussed in section 5 and future literature review and research opportunities are outlined.

### 1.1 Previous Research

In their 2005 paper, titled 'Taking Industry Seriously in Information Systems Research' (Chiasson & Davidson, 2005), Mike Chiasson and Elizabeth Davidson "consider various ways industry influences IS activities". They analysed two journals, MIS Quarterly and Information Systems Research over eight years from 1997 to 2004. It should be noted that while they accepted that the Webster Dictionary definition of industry is "any particular branch of productive, especially manufacturing, enterprise", they take the "broad colloquial sense" of the word to be synonymous with socio-economic sectors, e.g., retail industry and airline industry.

They posited that "increased attention to industry" (or industries by their definition) "will extend and refine IS knowledge". They claim the advantages for the IS field include:

- diffusing IS theory into other disciplines
- attending to the IS artefact embedded in its social and technical context
- fostering new customers for IS knowledge
- and increasing the practical relevance of IS research

This paper revisits this theme by replicating the essence of the study and determining if there has been any significant uptake in industry focused studies in the period since 2011.

In this paper, the Webster Dictionary definition is applied and the term "industry" is used to define the manufacturing sector. It searches in the current Basket of Eight journals, which expands on the two used by Chiasson and Davidson, and searches from 2011 to 2020, a nine year period comparable to the eight years of the other paper.

In their paper, Chiasson and Davidson present a table of industry sectors returned in their search (Table A-1, p. 605). In this paper, while screening papers for relevance to Industry 4.0 and manufacturing, the industry sectors were recorded so that a comparable table could be presented. See Table 2, where it is evident that IS research in the industrial manufacturing arena is declining.

## 2 INDUSTRY 4.0 BACKGROUND

Industry 4.0, or the fourth industrial revolution, is meant to signify that we are experiencing a step in capability equivalent to the previous industrial revolutions. The first industrial revolution is described as the advent of steam power in the late eighteenth century which led to the textile industries and railways (Duarte et al., 2018). The electrification of the second industrial revolution at the turn of the last century led to mass manufacturing, the assembly line and household appliances (Klein & Crafts, 2020). The third industrial revolution was born out of the electronics industry and led to the automation of manufacturing since the 1980s (Vasilash, 1995). The essence of the fourth industrial revolution is the interconnection of machines and cyber physical systems (Lasi et al., 2014).

Industry 4.0 is a term that was first defined by the German federal ministry of education and research (Bundesministerium für Bildung und Forschung) (BMBF, 2020) in 2011 and outlined in a research agenda by the German Academy of Engineering Sciences (Deutsche Akademie der Technikwissenschaften) (Acatech, 2020), in 2013. The synonymous term "fourth industrial revolution" was first published by Klaus Schwab, Founder and Executive Chairman of the World Economic Forum (Schwab, 2012). Industry 4.0 has application-pull and technology-push factors driving it. The pull factors include short development periods, individualisation on demand ("batch size one"), flexibility, decentralisation and resource efficiency. The push factors include automation, digitalisation, networking and miniaturisation (Lasi et al., 2014).

### 2.1 Industry 4.0 Definition

Industry 4.0 is an all-encompassing term, which envelops a number of existing and emergent technologies and techniques. While there is a lack of an agreed upon definition, academic, government and consulting companies have attempted to define it and the "definitional dimensions and sub-dimensions characterizing Industry 4.0 in its technological and non-technological aspects" (Culot et al., 2020). The OECD has outlined the nine key technologies enabling digital transformation as additive manufacturing, autonomous machines and systems, human machine integration, simulations, artificial intelligence, system integration, big data, cloud computing and the internet of things (OECD, 2017). The Boston Consulting Group have outlined an overlapping nine pillars of technological advancement which also include augmented reality and cybersecurity but not human machine integration nor artificial intelligence (Lorenz et al., 2015). Figure 1 shows the specific terms used in each publication and how the two lists overlap.

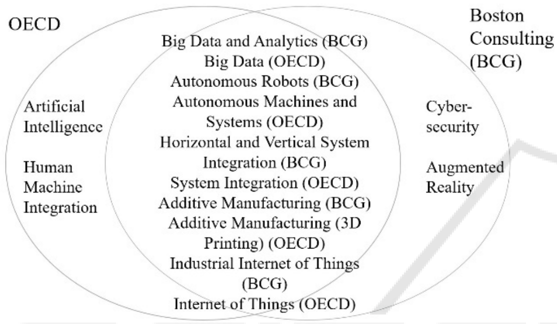


Figure 1: OECD's nine key technologies enabling digital transformation and the Boston Consulting Group's nine pillars of technological advancement.

Some of the seven shared terms have synonyms, such as additive manufacturing and 3d printing, and autonomous machines and autonomous robots. Other terms have hypernyms, such as internet of things and industrial internet of things, and big data and big data analytics. Well known synonyms for artificial intelligence and simulation; machine learning (Samuel, 1962) and digital twin (Zhang et al., 2018) respectively, are also included.

A comprehensive list of keywords was developed from these definitions with which to search the literature.

# 3 METHODOLOGY

## 3.1 Methodology Development

The literature review methodology was developed from seminal IS literature review methodology papers, and more recent papers (as examples for specific steps and/or how to present the analyses). After the pre-requisite of asking a research question, the first task is the identification of the literature to be searched (Webster & Watson, 2002). Within this task, predetermined filters are chosen, i.e., the field of research, the timescale of publications and sources, such as journals, databases or conference proceedings. The first iteration of keywords, combination of keywords or phrases to be used in the search are also listed. The overall structure of define, search, select, analyse and present (Wolfswinkel et al., 2013) is employed and modified.

In the select phase the researcher's judgement is used to further refine the sample obtained. In the analyse phase, the quantitative data is collected and the qualitative data is organised in content analysis tables (dataset). After removing duplicate spurious papers the flow of the filtration process is documented (Pereira & Serrano, 2020). After screening for relevance and applicability, the final selection of papers is queried for research motivation, objective, and method. The concepts in each paper are established. The methodologies used in the final resulting papers are presented and the papers are assessed for quality.

This represents the overview of the analysis process (Sammon, 2020). The data is organised with the number of concepts, either by existence or frequency. The other two analysis processes, synthesis (compressing and presenting results (Petersen et al., 2015)) and critique (highlighting research deficits and future research directions), are presented. Theoretical development involving the development of a conceptual model with supporting propositions (Webster & Watson, 2002) and the evaluation of such a theory is beyond the scope of this paper, but could be applicable for an expanded literature review, or a separate coding paper.

### 3.1.1 Identify the Research Question

The research question is an explicit statement of what the researcher wants to know about and phrasing it as a question "forces the researcher to be more explicit about what is to be investigated" (Bell et al., 2019). The larger research question currently being investigated is:

"How are industrial information systems topics being reviewed, researched and communicated in the IS body of peer-reviewed academic literature?"

To reduce the scope of the literature review for this paper, the area of Industry 4.0 was chosen as a sample of industrial topics and the AIS senior scholars' basket of journals (hereafter called the "basket of eight") was chosen as a well-respected and highly ranked sample of IS academic literature (AIS, 2020) (Table 1). The refined and reduced research question is:

"How are the topics of Industry 4.0 in a manufacturing setting being used for IS research in the basket of eight?"

### 3.1.2 Identify the Relevant Literature

The research question limited the field of study to Industry 4.0 and limited the relevant literature to the basket of eight.

The timescale of the search was contemporaneous with the lifecycle of Industry 4.0; from 2011 to date. Industry 4.0 as a general topic and all eleven identified sub-topics outlined in section 2.1 were included in the search. Some terms outside the OECD and Boston Consulting Group list, identified during unstructured searching, such as nanotechnology (Duarte et al., 2018) and edge computing (Collett, 2020) were excluded.

Table 1: AIS Senior Scholars' Basket of Journals.

| AIS Senior Scholars' Basket of Journals |
|---|
| European Journal of Information Systems |
| Information Systems Journal |
| Information Systems Research |
| Journal of AIS |
| Journal of Information Technology |
| Journal of MIS |
| Journal of Strategic Information Systems |
| MIS Quarterly |

Based on the terms identified, the following keywords and keyword combinations were chosen:

High Level: "industry 4.0" OR "industrie 4.0" OR "fourth industrial revolution" OR "smart factory"
"digital transformation"

Detail Level: "additive manufacturing" OR "3d printing"
"artificial intelligence" OR "machine learning"
"augmented reality"
"autonomous machine" OR "autonomous robot"
"big data" OR "big data analytics"
"cloud computing"
"cybersecurity" OR "cyber security"
"human machine interface"
"internet of things" OR "industrial internet of things"
"simulation" OR "digital twin"
"system integration"

### 3.1.3 Search

Online tools and resources, which have access to all the relevant journals and databases, were selected for the search ("UCC Library," 2020).

The search method was to use the journal search function and to enter each of the thirteen search terms above into each of the basket of eight journals individually. The following data was to be recorded for each search: number of results per journal and number of results per search term. The data was to be recorded in a Microsoft Excel spreadsheet.

The citation of each resulting paper was also saved to a reference management software package (Zotero, 2020).

### 3.1.4 Select

After the first search, using the search terms above, it was determined that the search terms were too broad and the results could have non-industrial applications. The search terms were then amended to include the terms "industrial" and "manufacturing". The search was re-run with the new terms.

### 3.1.5 Analyse

The full dataset of all 1305 papers returned in the search is available on request.

Duplicate papers, editorials and spurious papers (e.g., "about the authors") were eliminated.

At this stage, the abstract of every paper was read, i.e. content-based analysis was conducted (Alhassan et al., 2016). Introduction and conclusion were also read, if necessary. Whether the paper covered the topic in substantive manner or just in passing was recorded. Whether the topic was covered with reference to an industrial manufacturing application was recorded. For each of these questions, a negative resulted in elimination, i.e., two "yes" results were required for the paper to proceed.

In some cases, the terms are misinterpreted or misunderstood as they have alternative meanings. e.g., the search term "system integration" is meant to return results for the interconnection of technology systems but results for mergers and acquisitions were also returned. These were eliminated by the relevance criterion.

The remaining papers were read in detail and queried for research objective, motivation and method. The particular manufacturing application was also recorded. They were conceptualised and a concept centric matrix was created (not displayed but described in section 5.1). The methodologies used in the final resulting papers were presented and the papers were assessed for quality.

# 4 RESULTS

The result of the first search returned 1305 papers. After the second search run, this was reduced to 770, or 59.1% of the first run.

The number of results is reduced in all cases after the second run. The next reduction in results was as a consequence of removing duplicate and spurious papers.

## 4.1 Content Analysis and Screening

To establish pertinence to the research question, the dataset was queried for relevance to the search term, i.e., is the term central to the paper, dealt with in a comprehensive manner or just mentioned in passing. A significant number of papers appear in multiple search results and were eliminated as duplicates on their second and subsequent appearances. The searches in which they were analysed and the searches in which they were eliminated were purely artefacts of the order in which the searches were presented. For that reason, when a paper was reviewed for relevance, it was reviewed against all the search topics.

The papers were also, more importantly, checked to establish if the term covered is related to the manufacturing industry. For these two questions, two “yes” answers were required for the paper to proceed. If manufacturing was included as one sector among other industry sectors, the paper was included.

With a view to continuing the research agenda as proposed by Chiasson and Davidson (2005), the industry sector covered in the paper, if any, was recorded.

Editorials, spurious papers, e.g. “About the Authors” and duplicate papers were removed from the total. 770 papers remained. After duplicates, editorials and spurious papers were removed, 459 papers remained. After reading the abstracts, and further sections if required, papers that were not substantively relevant to Industry 4.0 were removed and 94 papers remained. Of these, only papers that used an industrial manufacturing application were allowed though the screening process. Thus 20 papers remained. See Figure 2.

## 4.2 Content Analysis

The results, after screening, contain papers that address one or more of the Industry 4.0 topics and use an industrial manufacturing application. The resulting 20 papers were queried. The questions asked of each paper, based on the six honest serving men (Sammon, 2020), are as follows: Who: Author(s), When: Year of publication, What: Title, Where: Journal, What: Research objective, Why: Research motivation, How: Research method, What: Manufacturing application.

Of the 20 papers resulting, the plurality (six) were from the European Journal of Information Systems. The next most numerous source was the Journal of MIS (four).

# 5 LITERATURE REVIEW

## 5.1 Synthesis

In the synthesis section, we examine what we know from the literature. Each of the 20 papers was read in full and a number of findings emerged.

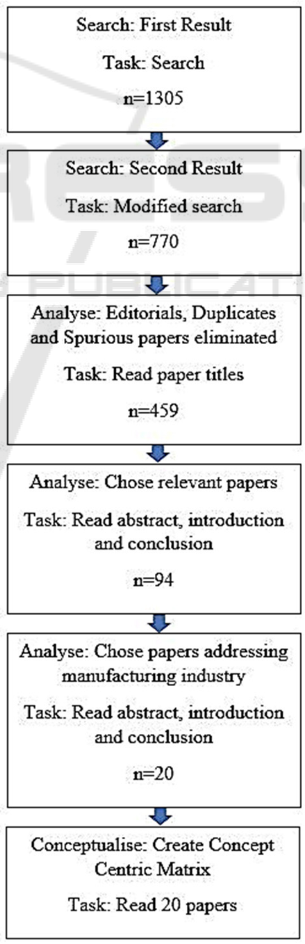


Figure 2: Process flow of search, filtration, screening, content analysis and conceptualisation.

These studies have examined data management and usage, business processes, CIO practices, and education. Within data management, one paper each covered the topics of democratisation of information (Clemons et al., 2017), external knowledge driving innovation (Trantopoulos et al., 2017), blockchain securing IOT data (Chanson et al., 2019), big data stories (Boldosova, 2019) and information completeness in tracking (Bardaki et al., 2011). In the area of people, a paper covered the role of CIOs (Kappelman et al., 2018) and another covered the education required for virtual and augmented reality adoption (Steffen et al., 2019). Under processes, the following concepts were covered: modularity of product design (Henfridsson et al., 2014), using big data (Woerner & Wixom, 2015), how environment affects cloud decisions (Kung et al., 2015), boundary objects as socio-material linkages (Doolin & McLeod, 2017) and blended approach to security needs (Niemimaa & Niemimaa, 2019). The most common concept was that of digital transformation resulting in changing business processes (Baiyere et al., 2020), (Kathuria et al., 2018), (Sandberg et al., 2020), (Wamba & Chatfield, 2017), (Huang et al., 2014), (Grover & Saeed, 2014), (Lee et al., 2020), (Lyytinen et al., 2016).

Each paper was read in full and the following concepts were extrapolated from the papers.

In Clemons et al. (2017), information flows between four entities who create value: consumers, producers, markets and society. The interaction is determined by viability, networks and agency. The information strategies of all entities are changing. For consumers it is changing from ownership to a sharing model. For

producers it is changing from push production to customisation. For markets it is becoming more disintermediated. This all results in a society that values fairness as opposed to a 'winner takes all' model. The framework is one of democratisation of information.

Trantopoulos et al., (2017) say that innovation in firms is dependent on external knowledge (e.g. customer, competitors, universities and consultants). Information technology and network interconnectivity moderate how a firm's external knowledge search benefits innovation.

For a firm undergoing digital transformation, Baiyere, Salmela and Tapanainen (2020) explain that the existing three logics associated with business process management (BPM), process, infrastructure and actors, experience tensions and should be modified. Process should be modified from modelled to light touch, infrastructure should be modified from aligned to flexible and actors should change behaviour from procedural to mindful.

European Chief Information Officers perform both IT and business roles and are evaluated on their performance in both spheres. Kappelman et al. (2018) explain that there are differences in emphasis between the USA and Europe. While the US CIOs spend more on cloud computing, cybersecurity issues are more in focus in Europe.

Design science research (DSR) was used to instantiate a blockchain-based sensor data protection system for IOT and two other projects were ex-post evaluated by Chanson et al., (2019) suggesting that the design successfully ensures tamper-resistant gathering, processing and exchange of IOT data.

Storytelling patterns and types of stories can be developed from big data analytics implementation according to Boldosova (2019).

Henfridsson, Mathiassen and Svahn (2014) outline how adopting and complementing two architectural frames, network of parts and hierarchy of patterns, allows modularity and decoupling, leading to flexibility of redesign of digitised industrial products.

Woerner and Wixom (2015) explain that big data is not the solution to firms' problems but used within existing structures and processes, it can extend a firm's strategic toolbox.

Implementation of cloud computing must be deployed in a hierarchical manner aligned with business processes. Kathuria et al. (2018) consider two options, cloud integration capability (internal) and cloud service portfolio (external facing).

Sandberg, Holmström and Lyytinen (2020) say that waves of digitisation can lead to product platform transitions which can lead to organisational outcomes, e.g. changed boundaries of platform scope, scale and sources of value creation and extraction.

Radio frequency identification (RFID) technology can be used as part of an IT system to provide business benefits taking in to account five contingency factors: environmental upheaval, leadership, second-order organisational learning, resource commitment and organisational transformation. This is described in Wamba and Chatfield (2017).

Boundary objects, e.g. a prototype device, can, according to Doolin and McLeod (2017), act sociomaterially to link diverse groups across knowledge domains, cultures, languages and locations.

Kung, Cegielski and Kung (2015) explain that environmental factors, including mimetic pressure (to copy other organisations) and perceived technological complexity influence firms' intentions to adopt cloud technology, e.g. software as a service (SaaS).

Operational agility is achieved through an information processing network and organisational control. Huang, Pan and Ouyang (2014) explain that the information processing network depends on three capabilities: information sensitivity, synergy and fluidity.

Information received after implementation of an integrated inter-organisational system (IOS) must be used to make adjustments based on the information. Grover and Saeed (2014) believe that if not, the implementation has no benefit.

IOS integration results in manufacturer-supplier flexibility, explain Lee, Wang and Grover (2020). This aligned with IOS-enabled analytical ability results in manufacturer agility.

Information security policy can be implemented using abductive innovation, involving deductive adoption, inductive adjustment and synthetic innovation. This, according to Niemimaa and Niemimaa (2019), blends best practices (top down) and participatory development (bottom up).

Lyytinen, Yoo and Boland Jr. (2016) explain that organisations can innovate using a framework of four innovations networks: project, clan, federated, and anarchic innovation networks.

Object tracking information 'completeness' is not increased by increasing the number of capture points. Rather, as found by Bardaki, Kourouthanassis, and Pramatari (2011), it depends on the size (capture points), breadth (location of capture points) and depth (capability of capturing different objects).

Educating users on the affordances offered by virtual reality (VR) and augmented reality (AR) would result in greater adoption, as found by Steffen et al.(2019).

## 5.2 New Insights into Industry Sector Coverage in IS Research

While papers were screened for relevance, the industry sector being covered in each paper was recorded so that Table A-1 (Chiasson and Davidson, 2005, p.605) (2005) could be updated. The original table covered eight years from 1997 to 2004 and analysed only two papers: MIS Quarterly and Information Systems Research. They "tallied the number of articles in which empirical data were drawn from a particular industry, using the industry labels (e.g. manufacturing) used by the article authors" (Chiasson & Davidson, 2005). This paper covers nine years from 2011 to 2020 and analyses all eight journals in the AIS Senior Scholar basket. This paper also filters and screens the papers for relevance to Industry 4.0. The number of articles referencing industry sectors were tallied.

The papers specifying "Various" or "Various Services" were excluded from the percentage calculations of both papers to avoid discrepancy of classification, i.e., the percentages for the original table were recalculated without the "Various" entries.

The comparative results are in Table 2. Comparing the percentage representation of papers from Chiasson and Davidson (2005) to this paper, the following industry sectors have increased visibility in IS research: High-Tech/ IT Consulting / Telecomms, Retail (albeit negligible increase), Health care, Government and Utility. The following industry sectors have decreased visibility: Manufacturing, Banking/ Financial, Insurance (to zero), Distribution, Education, Airline, Oil & Gas, Military, Law (negligible decrease) and Real Estate (negligible decrease), The following industry sectors were not listed in the 2005 paper but were results in this 2020 search: Media/ Entertainment, Energy and Agriculture.

The decrease in the coverage of manufacturing from 21.8% to 16.9%, despite the latter search being more focussed on manufacturing would indicate that interest in researching manufacturing in the IS field is decreasing.

## 5.3 Analysis

In the analysis section, we examine how we know what we have gleaned from the literature by reviewing the quality and methodological state of the final papers.

### 5.3.1 Quality Analysis

The final 20 papers were reviewed from a quality point of view and assessed for relevance, accessibility, quality, and research method.

All papers were deemed relevant as they were the result of a systematic search using predefined search terms. All papers were deemed accessible as they were sourced from the AIS senior scholars' basket of eight journals and were all accessible using the library OneSearch tool. All journals were deemed to be of sufficient authority for the same reason. The authority of the authors was judged using their Google Scholar citation count and h-index. The authority of paper was judged by its Google Scholar citation count. The quality of each paper was reviewed and assessed for organisation, completeness and accuracy.

Based on the quality analysis above, all papers were deemed to be of sufficient quality and none were discarded.

#### 5.3.2 Methodology Analysis

Case studies have been the most common type of methodologies, accounting for twelve, or over half, of the papers. Three papers proposed frameworks. Two papers used ethnography. Design science research, commentary and literature review accounted for one paper each.

## 6 FUTURE RESEARCH

Eight of the final 20 papers covered the concept of digitalisation causing changes to business processes. A particular example in Sandberg et al. (2020) outlines how digitalisation of a product platform results in changes to organisational logic and raises two interesting avenues for a future research agenda:

- “a more fine-grained classification of (digital) platform types is essential for advancing understanding of digitization’s impact on product platforms.”
- “digitization covered substantial parts of ABB’s and its customers’ operations (with more significant and broader effects) and involved multiple subsystems simultaneously. This sequencing provides insights into how digitization processes are likely to unfold in product platforms and also suggests the need for future research on their path dependencies.”

Topics other than industry and manufacturing (e.g., COVID-19, social media, green IT, entrepreneurship, agile IS, cryptocurrency, smart cities) can be filtered or selected from the body of papers in the analysis phase. An extra column could be used to explicitly define the topic.

### 6.1 Comparative Analysis

The scope of the journal sources can be expanded beyond IS journals to include equivalently ranked journals in the field of Operations and Technology Management, in order to compare how industrial applications are covered in this field. These journals were identified by choosing the top eight journals ranked 4*, 4 or 3 in the Chartered Association of Business Schools (CABS) Academic Journal Guide (AJG) in the field of Operations and Technology Management (CABS, 2022). The eight chosen journals were used as a comparable sample.

Using the same search terms and the same methodology, but searching in the operations and technical management basket of journals the results were 10,464 papers. This is more than an order of magnitude more than the 770 papers found in the AIS basket of eight. Without completing this literature review, it is still obvious from the search results that industrial manufacturing topics are more frequently covered in Operations and Technology Management journals than in IS journals, as expected.

## 7 CONCLUSION

This paper is a literature review to determine the level at which industrial information systems (IIS) are studied to research information systems (IS). The field of Industry 4.0 was used as a representative sample of IIS and the Association for Information Systems (AIS) Senior Scholars’ Basket of Journals was used as a representative, albeit highly ranked, sample of IS literature. This literature review can be leveraged by future research managers to investigate the prevalence of industry and manufacturing as topic of IS research outside the basket of eight journals.

Over the search period of 2011 to 2020, 20 papers were found that include substantial reference to the topics of Industry 4.0 and cover the manufacturing arena.

The analysis shows that IIS is rarely used to undertake IS research in the academic field compared to other technical and operational fields. It was also found that, compared to previous data on IS research in industrial sectors, the coverage of manufacturing has decreased.

The dominant concept revealed was that of digital transformation resulting in changes to business processes. The contribution to the literature is to highlight that substantial research can be conducted in the industrial manufacturing arena but few have been conducted in the last decade. Therefore, it is an area worth exploring for future IS research.

The authors are advocates of the role of the researcher-practitioner, where practitioners trained and qualified as researchers, can carry out research in the industrial field and contribute to both academic and practice knowledge. This type of researcher with access to the industrial manufacturing sector has a lot to offer IS research. IS researchers in academia should encourage and advocate for the recruitment of practitioners (in this case industrial manufacturing professionals) as IS research students.

Industry in general and manufacturing in particular offers a fertile area for IS research for many reasons. The application of Industry 4.0 concepts in the real world environment offers opportunities to research the migration of data from the factory floor to the cloud, the move from owning licences to software as a service, the ability to use artificial intelligence to optimise production, and the unveiling of new information from big data sets.

The life science manufacturing sectors (pharmaceutical, biotechnology and medical device) offer the added advantage of requirement to retirement lifecycle documentation suites and traceability from a project, process and product point of view, providing copious data to the prospective researcher.

By encouraging cross pollination between manufacturing engineers and IS practitioners, but also between practitioners and researchers, the field of industrial information systems can only grow successfully in the coming years.

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# APPENDIX

Table 2: Industries Examined. Comparison of industries returned in Chiasson and Davidson (2005) and this paper. * Various/Various Services excluded.

| Industry | Count (Chiasson and Davidson, 2005) | Percent (Chiasson and Davidson, 2005) | Count (This paper) | Percent (This paper) | Increase or Decrease |
|---|---|---|---|---|---|
| Manufacturing | 30 | 21.8% | 44 | 16.9% | Decrease |
| High-Tech/ IT Consulting /Telecomm | 28 | 20.4% | 81 | 31.0% | Increase |
| Banking/ Financial | 22 | 16.1% | 30 | 11.5% | Decrease |
| Retail | 13 | 9.5% | 25 | 9.6% | Increase |
| Insurance | 9 | 6.6% | 0 | 0% | Decrease |
| Health care | 8 | 5.8% | 33 | 12.6% | Increase |
| Various/Various Services* | 7 | N/A | 61 | N/A | N/A |
| Government | 5 | 3.6% | 14 | 5.4% | Increase |
| Distribution | 5 | 3.6% | 5 | 1.9% | Decrease |
| Education | 5 | 3.6% | 5 | 1.9% | Decrease |
| Airline | 4 | 2.9% | 4 | 1.5% | Decrease |
| Oil & Gas | 3 | 2.2% | 1 | 0.4% | Decrease |
| Military | 2 | 1.5% | 0 | 0% | Decrease |
| Utility | 1 | 0.7% | 3 | 1.1% | Increase |
| Law | 1 | 0.7% | 1 | 0.4% | Decrease |
| Real Estate | 1 | 0.7% | 1 | 0.4% | Decrease |
| Media/ Entertainment | 0 | 0% | 12 | 4.6% | Increase |
| Energy | 0 | 0% | 1 | 0.4% | Increase |
| Agriculture | 0 | 0% | 1 | 0.4% | Increase |
| **Total (excluding Various/Various Services)** | **137** | **100%** | **261** | **100%** | |