Implementation of Industry 4.0 Technologies: What Can We Learn from the Past?

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Abstract. The fourth industrial revolution ("Industry 4.0") promises a multifaceted paradigm shift in manufacturing. This study aims to gain an in-depth understanding of what the transition to Industry 4.0 may involve. We do so by looking for, and learning from, experiences of similar shifts in the past. Specifically, we conduct a structured literature review of the rich operations management literature on Advanced Manufacturing Technologies (AMTs). AMTs were arguably central in the shift from the second to the third revolution in the second half of the 20th century. A review of the existing AMT literature allows us to infer relevant observations, theories, and findings for the emerging shift into Industry 4.0. We employ the review process defined by Tranfield et al. (2003).

Keywords: Industry 4.0, Advanced Manufacturing Technology (AMT), Literature Review

1 Introduction

The fourth industrial revolution ("Industry 4.0") promises a multifaceted paradigm shift in manufacturing [1]. Industry 4.0 deals with the applications of intelligent products and production processes [2]. To date, studies of Industry 4.0 have encompassed three interrelated trends. The first aspect is related to the advanced and expanding technologies in manufacturing industries, which allow for the digital transformation of products and production systems into fully integrated and automated settings. Examples are the Internet-of-Things, big data, cloud computing (and cyber security), virtual reality and augmented reality, robotics and artificial intelligence, and additive manufacturing (3D printing) [3]. The second aspect is concerned with the implementation process and use of such technologies in manufacturing industries. In this regard, Industry 4.0 is defined as an enabler for communications in the form of Cyber-Physical-Systems [2, 4]. The third aspect deals with the impact of creating these digital ecosystems on organizations, industries, environment, and societies [5]. For instance, it is argued that implementation of Industry 4.0 can yield productivity gains, as well as other benefits, namely, quality improvement and greater flexibility of manufacturing industries [6].

In retrospect, it is clear that manufacturing underwent a similar shift in the second half of the 20th century, the third industrial revolution. More specifically, a generation of computing and automation opened up a new source of competitive advantage for manufacturing settings to move toward automated factories [7]. In this regard, Advanced Manufacturing Technologies (AMTs) were arguably central in the shift from the second to the third revolution.

An AMT can be broadly defined as "an automated production system of people, machines, and tools for the planning and control of the production process, including the procurement of raw materials, parts, and components, and the shipment and service of finished products" [8]. AMTs encompass a group of technologies that are hardware-based (e.g., computer numerical control, flexible manufacturing systems, and industrial robots) and software-based (e.g., computer-aided design, material requirements planning, and manufacturing resource planning), linked through advanced computing technology called computer-integrated manufacturing (CIM) [9, 10].

On the one hand, AMTs represent a number of advanced computer-based technological innovations, consolidated as a system, which can mainly enhance design, manufacturing, and administrative processes in production systems [11]. Such an integrated system of physical assets, software packages, and planning methods fits perfectly with the attributes of Industry 4.0.

On the other hand, organizations aim at creating competitive capabilities, namely price, quality of products, product line breadth, delivery capabilities, and flexibility, by implementing AMTs, ultimately resulting in high levels of performance [12, 13]. Several studies investigate the implementation aspects of AMT and what contributes to its successes and failures [9, 14-17]. Other studies deal with the effect of AMT on performance [18-21]. Implementation of AMT and its resulting effects have been widely investigated in the extant literature.

Thus, examining the literature of AMT and existing theories provides a reliable basis for gaining a deeper understanding of the dynamics of Industry 4.0. More importantly, this allows us to infer relevant observations, theories, and findings for the emerging shift into Industry 4.0. In other words, we learn from the past to prepare for the future of manufacturing [22]. Therefore, the objective of this study is twofold:

1. To summarize the body of research on AMT;
2. To discuss what can be learned from the AMT research for Industry 4.0.

2 Methodology

This research is based on a systematic review of the AMT literature. A systematic literature review is defined as "a written document that presents a logical argued case founded on a comprehensive understanding of the current state of knowledge about a topic of study" [23]. In conducting this review, we employ the review process defined by Tranfield, Denyer [24].

2.1 Identification of keywords and search terms

This review is based on a journal search. Conducting a review based on a journal search ensures a certain level of quality [25]. In doing so, we develop a list of journals based on our preliminary research and journal rankings (see [26, 27]). Conference proceedings are not included in this review. The search keyword is "advanced manufacturing technolog*", and "AMT." The search field is mostly constructed from a combination of abstract (AB), title (TI), and keywords (KW). The primary result is 285 papers. In the following, we employ a round of selection criteria based on checking the scope relevance by title and abstract review, as well as evaluating access to the full manuscript. In that selection process, we do not apply any criteria for the number of pages, year of publication, or number of citations. The secondary result that is the focus of this review comprises 208 papers (see Table 1).

Table 1. List of journals, results, and fields of search

Title	Final Selection	Field of Search
International Journal of Operations & Production Management (*IJOPM*)	34	AB
Journal of Manufacturing Technology Management[1]	28	AB
International Journal of Production Economics (*IJPE*)	17	AB, TI, KW
International Journal of Production Research (*IJPR*)	16	AB, TI, KW
Journal of Operations Management (*JOM*)	16	AB, TI, KW
International Journal of Advanced Manufacturing Technology	13	AB, TI, KW
Technovation	11	AB, TI, KW
Industrial Management and Data Systems	10	AB
Journal of Engineering and Technology Management	8	AB, TI, KW
Computers and Industrial Engineering (*CIE*)	8	AB, TI, KW
Management Decision	7	AB
International Journal of Industrial Ergonomics	6	AB, TI, KW
International Journal of High Technology Management Research	6	AB, TI, KW
Journal of Manufacturing Systems (*JMS*)	5	AB, TI, KW
Decision Sciences	4	AB
Production Planning and Control	4	AB, TI, KW
Production and Operations Management (*POM*)	4	AB, TI, KW
Strategic Management Journal (*SMJ*)	3	AB
Harvard Business Review (*HBR*)	2	AB
Research Policy	2	AB, TI, KW
Academy of Management Journal (*AMJ*)	1	AB, TI
Academy of Management Review (*AMR*)	1	AB or TI
European Journal of Purchasing & Supply Management	1	AB, TI, KW
Organization Science	1	TI or KW

[1] Previously known as *Integrated Manufacturing Systems* (*IMS*) and *World Class Design to Manufacture* (*WCDM*) [http://www.emeraldinsight.com/loi/wcdm].

As recommended by Tranfield, Denyer [24], we employ data-extraction forms that include general information (e.g., title, author, and publication details), study attributes (e.g., objectives or research questions, context of the study, methods), and core contributions (findings, links to other concepts, information on growing themes, key results, and additional information). This process requires a clear documentation of all steps.

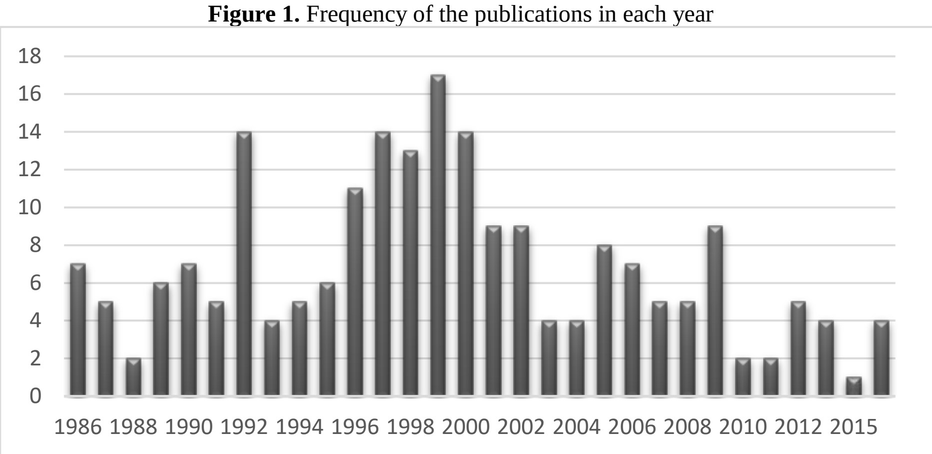
In doing so, we develop a simple coding system to classify the areas of prior research on AMT. Consequently, we classify 208 papers into four main clusters of AMT evaluation, AMT implementation, AMT results, and AMT contingency. Moreover, we have some papers that combine these classes. In the following, we assign each paper with two codes based on its core contributions. The first code relates to the overall contribution of the paper, which allows us to adopt a descriptive analysis, whereas the second code reflects other details about the papers, allowing us to portray the overall scheme of the AMT literature.

3 Findings

3.1 Descriptive analysis

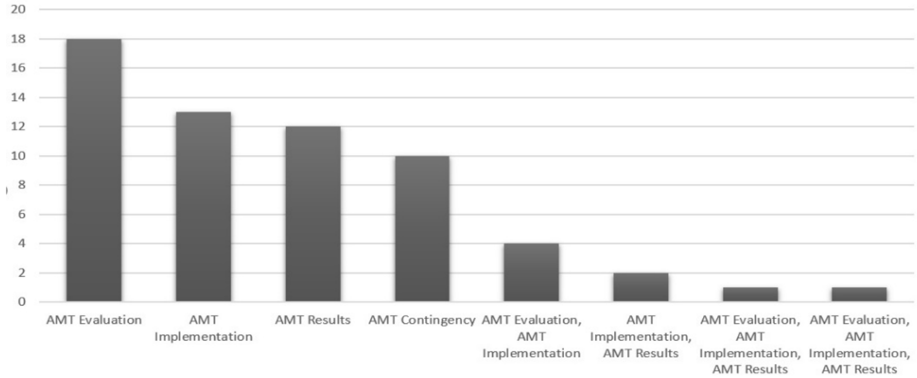
We first report on the frequency of the 208 publications from 1986 to 2016. Figure 1 shows that the publications on AMT are not evenly distributed, indicating a plethora of research during the late 1990s. In order to gain a detailed understanding of the trends and the focus of publications in the past, we classify our descriptive analysis into three decades: 1986–1995, 1996–2005, and 2006–2016.

Figure 1. Frequency of the publications in each year



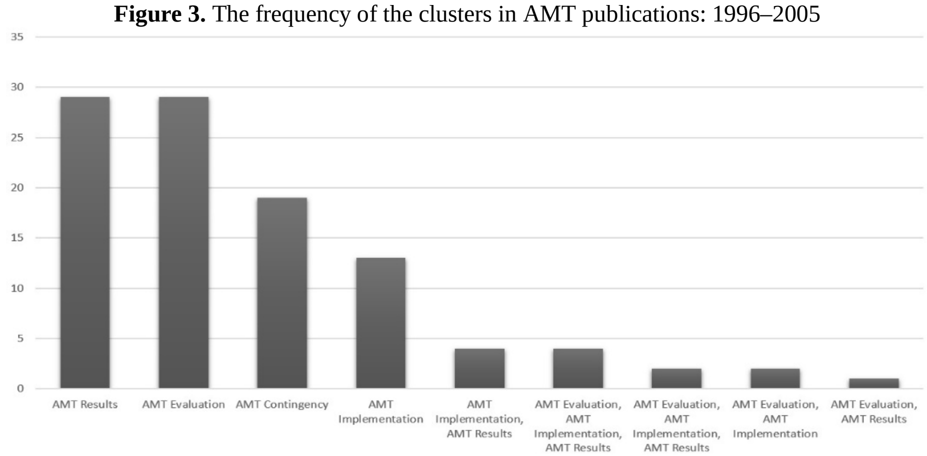
The first decade: 1986–1995. This decade shows that most of the publications were focused on AMT evaluation and AMT implementation (see Fig. 2). For instance, the results show high focus on the evaluation of investment, justification, and decision making, as well as elaboration on implementation issues.

Figure 2. The frequency of the clusters in AMT publications: 1986–1995



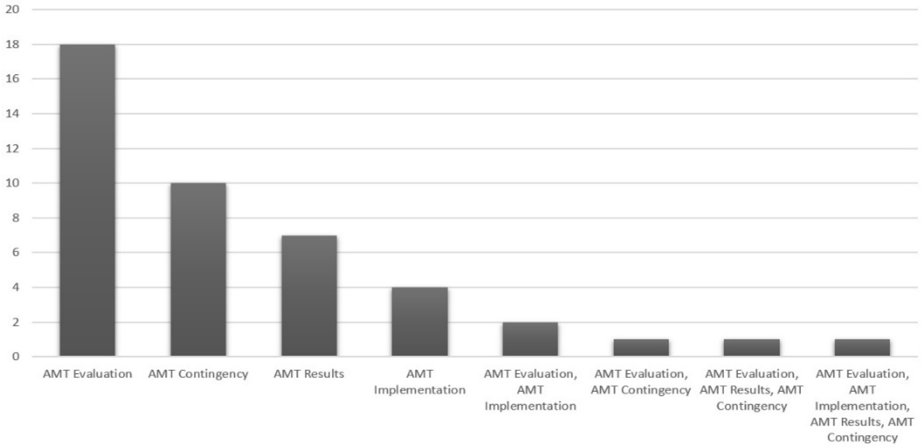
The second decade: 1996–2005. This decade shows significant attention to AMT results, although AMT evaluation still dominates (see Fig. 3). During this decade, scholars were elaborating on manufacturing and business performance, assessment mechanisms, success factors, and the gaining of competitive advantage.

Figure 3. The frequency of the clusters in AMT publications: 1996–2005



The third decade: 2006–2016. This decade represents attention by scholars to AMT contingency, although AMT evaluation remains most frequent (see Fig. 4). Examples of AMT contingency are size of the company, organizational characteristics, and implementation issues in developed versus developing countries and in the public versus private sectors.

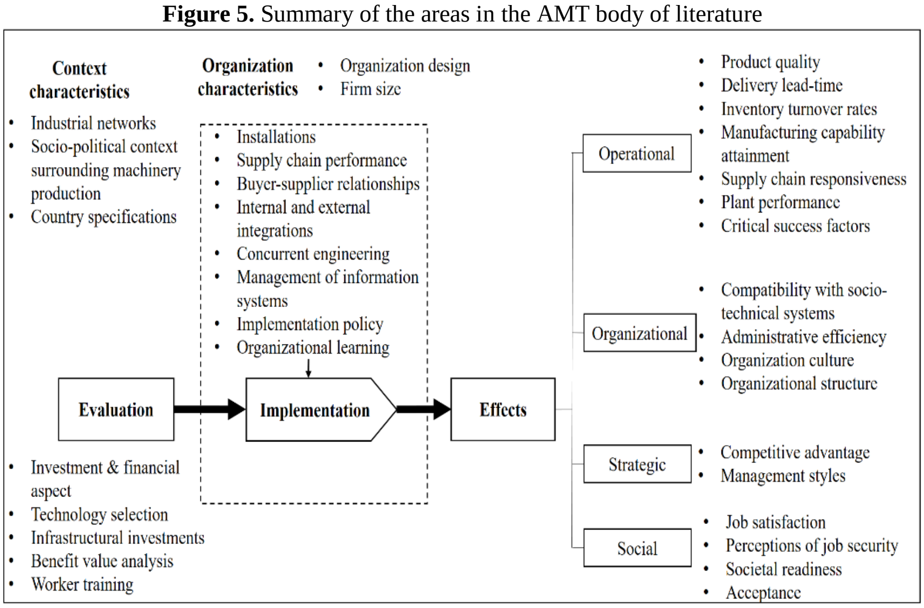
Figure 4. The frequency of the clusters in AMT publications: 2006–2016



3.2 Thematic analysis

Our literature review allows us to summarize the wide-spanning areas of prior research on AMT (see Fig. 5). This framework illustrates a brief summary of the results of the second code in our review. It represents an overview of the key parameters during the evaluation and implementation phases. Moreover, it classifies possible outcomes of implementing new manufacturing technologies and shows the context variables that may influence this process.

Figure 5. Summary of the areas in the AMT body of literature



4 Conclusion

The fourth industrial revolution is evolving, yet it has many similarities to its antecedent phenomenon, AMT. An examination of three decades of publications on AMT shows that the evaluation of new technologies, regardless of their maturity, has always been central to industries that plan to implement them. More specifically, analyzing the first decade implies that industries need to justify their decisions and carefully evaluate their investment in implementing new technologies. The second decade illustrates growing concerns about AMT results, mainly performance improvement, measurement issues, competitive advantage, and success factors. The third decade of AMT literature shows that some outcomes are likely to be influenced by contingent factors, such as organizational and national characteristics. Therefore, it is worthwhile for industries that are planning to implement new Industry 4.0 technologies to examine similar attributes in terms of AMT evaluation, implementation, outcomes, and contextual variables. To the best of our knowledge, the areas of investigations identified are potentially viable in the context of Industry 4.0 and to a certain extent can set the scene for the emerging industrial revolution.

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