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- a critique of the AMT construct as basis for research

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Published in:
Proceedings of the 4th Production and Operations Management Conference / 19th International Annual EurOMA Conference : Serving the World

Publication date:
2012

Document Version
Accepted author manuscript, peer reviewed version

Theorizing about technological development of manufacturing companies - a critique of the AMT construct as basis for research

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Abstract

The paper applies metatriangulation and theory building to strengthen our theorizing on technological development of manufacturing firms. AMT literature is reviewed and by means of bracketing, the paper identifies a set of problematic assumptions embedded within traditional AMT research. A case study is used to emphasize how a process perspective enriches the traditional structural perspective. Finally, through first attempts at theory building, a set of propositions is suggested in order to overcome long-standing problems found in AMT research.

Keywords: Theory building, AMT, technological development

Introduction

Although it is widely accepted that the term technology has many different interpretations (see e.g. Gaynor 1996), the most widely used operationalization of technology in the context of manufacturing found in the academic literature only reflects some narrow interpretations of technology. ”Advanced Manufacturing Technologies” as a construct has several weaknesses impacting the possibility to advance our knowledge and theorizing on manufacturing technology and technological development of manufacturing. The most apparent weaknesses are i) the many, small variations of research models that is applied in research using this construct, ii) the mixed results that empirical studies using this construct has resulted in, and iii) the failure to convert the mixed results into new theorizing about manufacturing technology and technological development. These issues will be substantiated in the following.

Variations over a research model

In spite of numerous publications on the topic, to date, no systematic review has been brought forward. Systematic reviews are aimed at gathering and combining the empirical results from a field in order to develop evidence based theorizing (Kitchenham, Dybå & Jørgenson 2004). Instead, a *meta-analysis* of research models has been found in the Scopus database: Heine et al (2003) review a selected set of 16 different studies from 1989 to 2001. They find that each source applies its own, distinct research model promoting variations of the covariance model. These variations concern the technology constructs, performance measures, and the set of moderators hypothesized to affect the relationship between these constructs. They conclude that results are incomparable due to this variation in research models.

Mixed results
Overall the findings in the AMT literature are inconsistent (Heine et al, 2003). E.g. Swamidass & Kotha (1998) found no direct correlation between AMT use and company performance when the results were controlled for the effects of company size. It appears that the problem of identifying general relationships between investments in technology aimed at factory automation and possible derived company effects is generic in its nature and has spurred the development of a long list of appraisal and justification methods. See e.g. the review by (Rafaat 2002) listing 231 sources in the area.

Lacking theorizing
Very few sources define the AMT construct theoretically; instead the empirical studies tend to jump straight to operationalization as a mix of various technical assets (CAD, CNC, AGV and many more). Some define AMT as "*computer-controlled or micro-electronics-based equipment used in the design, manufacture or handling of a product*" (OECD 1993, Annex 2, paragraph 35, p117). Later studies also add an infrastructural component related to information and planning, see Swamidass & Kotha (1998). One problem related to the weak definition combined with the apparently standard operationalization of the construct, is the term "advanced" combined with the continued use of now well-known and widely used technologies (Boyer & Pagell, 2000). While each technology may be technically advanced, the assets cannot by themselves be considered to have sufficient discriminating power in regards to advanced versus less advanced manufacturing systems or technically versus less technically competent organizations. Therefore there appears to be a lack of theorizing about the role of advanced technology in relation to the technological development of manufacturing companies and their performance.

Theoretical background
This paper is concerned with the quality of our theorizing about technological development of manufacturing firms. Several sources address how to conduct quantitative survey studies within operations management, see e.g. Forza (2002), Malhotra & Grover (1998). These sources provide useful insights on how to perform rigorous research. However, they give little guidance as to how to develop good theory and good constructs. A common request within OM is the need for applying "*common terminology concerning the meaning of variables and their operationalisation*" (cited in Forza 2002, p154). This is a call for rigor in methods, however, as briefly outlined above, rigor in research does not necessarily lead to good theorizing. E.g. it appears that research into technological development of manufacturing companies do not benefit from the rigorous application of an AMT operationalization that could be outdated. One of the quality measures typically applied within quantitative research is *internal validity*. Internal validity ("the quality of evidence for causal relationships") may be dealt with from within the functionalist paradigm through path analytic approaches (Malhotra & Grover, 1998) and statistical significance limits. However, such quality measures apply to the individual studies and, as pointed out above do not guarantee quality in the field. Beyond statistical maneuvers, there is little guidance available as to how to ensure internal validity. Malhotra & Grover (1998) e.g. state that: "*in the absence of experimental designs, [OM researchers] should try to justify internal validity ... through a discussion of ... why alternate explanations are unlikely*" (p414). Such discussions are rarely seen in AMT research although numerous extraneous variables are known to impact firm performance. Rather than developing new statistical maneuvers, this paper will be concerned with the issue of theory building (Wacker,

1998). In qualitative research the term theoretical validity is concerned with the extent to which theory and data matches. Several strategies can be applied in order to address this issue: Extensive fieldwork, theory triangulation, pattern matching, and peer review. It appears that Filippini's concerns could be addressed by adopting notions of quality (specifically theoretical validity) from the qualitative paradigms.

Theory building

Wacker (1998) suggests that in the first stage of theory building research, the conceptual definitions used in analytical research should match the definitions operationalized in the empirical methods. Since some drawbacks of the AMT construct and its empirical operationalization has already been pointed out above, analytical research should not progress based on the empirical traditions related to AMT research alone. In a field lacking good concepts, metatriangulation (Lewis & Grimes, 1999) and construction of metatheory (Wallis, 2010) may be useful approaches. Metatriangulation is an approach to building theory based on multiple paradigms. It is proposed by Lewis & Grimes (1999) as a combination of three approaches to multiparadigm inquiry: Multiparadigm reviews, multiparadigm research, and metaparadigm theorizing. Multiparadigm reviews make use of bracketing - a means for highlighting differences in assumptions – and bridging – a means for identifying areas where paradigms overlap and common grounds could be established. Multiparadigm research make use of a set of studies conducted either in parallel or sequentially, each grounded within one paradigm. Finally, metaparadigm theorizing is aimed at neither synthesis nor conflict; instead it "*requires the ability to comprehend paradigmatic differences, similarities, and interrelationships*" (Lewis & Grimes, 1999, p675). This process may be informed by metatheory which is concerned with the analysis of theory and theorizing. The subject of analysis is theory, the data for the field is texts conveying the content of theory, and the methods rely on interpretation. As such, metatheoretical analysis may be seen as a hermeneutic approach. It entails critical analysis build on e.g. categorization, applying norms of correspondence (theory and data), coherence in comparison to other theories, and pragmatic norms related to applicability, investigations of causal structures and analysis of relationships between propositions. (Wallis, 2010)

Research aims

The objective of this paper is to show how the process of metatriangulation and metatheoretical analysis can be used to strengthen our theorizing on the role of advanced technology in relation to technological development of manufacturing firms by addressing the question: *How can we theorize about and research between factory performance differences related to technological development?*

Methodology

In light of problems in the empirical research of AMT, this paper will aim to combine analytical research with new, empirical research. A range of literature on AMT and other genres of technology studies have been studied in parallel with a case study, 15 smaller case-visits and discussions with an expert panel consisting of senior researchers and practitioners in the field of automation and production development. This process lead to a critical understanding of drawbacks related to the AMT literature. This understanding has subsequently been systematized and elaborated by following part of the process suggested by Lewis & Grimes (1999). This paper documents the outcomes of these first steps in metatriangulation and theory building. The work reported here consists of a critical reading of AMT literature, case studies and attempts at metaparadigm theorizing.

Bracketing AMT assumptions

A thorough reading of a broad range of AMT studies has been conducted in order to identify characteristics and assumptions found in the typical AMT research. Surprisingly, many of these general characteristics and assumptions have actually been addressed in individual studies and conceptual writings on the topic. Yet it appears that these individual findings cannot penetrate the broad field of AMT research. This paper takes the perspective that it is the very nature of AMT research questions, constructs, and research models that hinders this development. Therefore these individual findings that go against the general AMT research approaches are taken as important indicators of aspects that needs to be considered in an attempt to build the foundation for better theorizing about technological development of manufacturing companies.

Performance frontiers and input / output scales

A widely applied research model creates a direct link between AMT and performance benefits. Mediators are rarely used. This implies that ”more AMT” is modeled as a lever for ”more benefits”. Organizational practices are seen as moderators of this link. This research model is in line with the notion of performance frontiers as described by Schmenner and Swink (1998). In their conceptual writing, Schmenner and Swink distinguish between theoretical asset frontiers and operating frontiers where organizational capabilities determine the gap between these. One problem with this model as a basis for empirical research is that in practice we only study operating frontiers (based on perceptual mappings of AMT usage (Boyer & Pagell, 2000)) but not theoretical asset frontiers. For this reason, we do not know to what extend the input variables chosen are relevant and sufficient to explain different performance levels. The risk of “intermediate” variables is high and continuously spurs research to test new input variables (moderators) affecting operational performance. E.g. Small (2007) identifies 19 critical implementation activities based on 40 sources. Another potential problem is the operationalization of technological assets as discrete technologies – in literature no discussion about the appropriateness of such an input measure has been found although lately, attempts have been made to identify portfolios of AMT with distinct characteristics, see e.g. Small & Yasin (2003).

Immediate effects of scale versus potentially realizable and contingent effects of scope

The use of discrete technologies may be a poor measure of scale and in fact, scale may be a poor measure of input. Boyer (1999) as well as Hannah (1993) argue that some benefits from AMT investments are achieved through economies of scope – i.e. not only scale or quantity. Different ways of studying aspects of scope have been implemented in some studies: As technology consistency (Small 2007); technological complementarities (Das & Jayram 2007); and as organizational practices supporting integration and leveraging complementarity effects (Nair & Swink 2007). Boyer describes integration as a process of linking different technologies electronically. This implies that in order to unlock the potential benefits of scope, investments in AMT need to be followed up with investments in adaptation. Such need for adaptation may delay the realization of some benefits related to AMT investments. Along this vein, Boyer (1999) found that while AMT investment was not positively associated with performance in a cross-sectional analysis, longitudinal analysis of data collected two years later did reveal a relationship. This potential delay is poorly reflected in the common cross sectional survey approach.

Unit of analysis and system effects

One hurdle to successful financial justification of AMT that has been mentioned in literature is the strategic value of AMT and the assessment of the economical value of flexibility (Swamidass & Waller, 1990). But more fundamentally there may be flaws in the way we conceptualize the establishment of benefits at various system levels. Hannah (1993) argues that just having the machine level flexibility inherent in AMT does not guarantee plant level manufacturing flexibility. Pyoun & Choi (1994) distinguish between potential and realizable flexibility – the latter also depending upon internal capabilities, company strategy, and market knowledge. A reactive way of dealing with the difficulties of tracing cross level effects is to only link AMT directly to manufacturing performance; see e.g. Swink & Nair (2007). But in the words of Swamidass and Waller (1990) "*it is not clear what justification of NMT accomplishes in the absence of a well defined manufacturing strategy.*" Parthasarthy & Yin (1996) found that investments in CIM are associated with higher firm performance if investments and adjustments are also made at other levels. Their study also showed that higher levels of investments in CIM are associated with decreased firm performance if these additional investments and adjustments are not made. They argue that this is because the expensive assets are underutilized.

Strategic benefits are achieved at the business systems level in which the manufacturing system is only one subsystem among others. From system dynamics we know that the impact of a subsystem can have nonlinear effects in the wider system depending on how these systems are linked. Although empirical studies of AMT investments usually treat the technologies as discrete entities that can be either adopted or not adopted, they are usually elements of broader manufacturing and business systems with different characteristics. These broader systems are open to further development; they are not discrete units but can be modified in numerous ways to match the peculiar needs of the specific organization and market and this modification may go on over a number of years, see e.g. Ettlie & Khazanchi (2010).

Acquisition as an independent, linear process versus company learning

AMT is governed by weak appropriability regimes (Nair & Swink, 2007), this calls for research into less imitable mechanisms through which AMT can play a role on strategic performance. In addition to scope and system effects, learning may also play a role. Boyer (1999) found that plants invest in technology in an incremental fashion over time. Sohal et al (2006) found evidence of a dynamic accumulation of both technical assets and human assets for technology indicating a learning process affecting the tendency to acquire more AMT. Apparently the effect of external pressures for AMT adoption is mediated through these human assets for AMT. This implies that there is a need for a process perspective that goes beyond the notion of AMT adoption as an independent, linear process; existing portfolios and experience affect future projects.

Insights from AMT assumptions

A critical reading of a range of AMT literature highlights some embedded assumptions: Adoption is considered a linear, path independent process; AMT is modeled as having linear, path independent, and immediate performance effects; discrete technical components are used as indicators of highly complex manufacturing and business system characteristics; heterogeneous systems are compared on the basis of a weak description of a select set of technical components and organizational practices. These assumptions are contrasted by various research findings emphasizing that: Performance effects of individual technologies depends on the system in which they are integrated; potential, cross level effects cannot be associated with individual technical components but are properties of the entire system; insertion of discrete technologies into complex systems results in system effects rather than linear, independent effects; broader technological systems are – unlike some discrete components – open to ongoing adaptation; technological development is an incremental, dynamic process in which human and technical assets co-evolve. These alternative views point to *the need for adopting a process and systems perspective* to the study of technological development of manufacturing firms. They furthermore point to weaknesses associated with the AMT construct as a research construct.

Technological development in practice - input from case examples

Here insights from the case study are reported along with a set of illustrative case examples selected from the set of company visits. Two (C & D) of the case examples were small smith companies with job-shop production. One (B) was a medium sized company with batch production. And the case study (A) was conducted in a factory that is part of a large company with high-volume repetitive manufacturing.

In case A, a completely new, fully automated production line with extensive use of robotics had recently been introduced and the study focused on the processes leading to implementation as well as post implementation experiences. The company has many years of experience with automated production in a range of different factory setups and product as well as process technologies are key competences for the company. The organization has its own technology center in charge of experimenting with, and maturing new technologies. But where older production lines were characterized by semi-automation – automation mixed with manual assembly stations, the aim of the new project had been to establish a line with so low variable costs that it would be competitive against manual manufacturing in low cost countries. A large cross-functional project team, mainly consisting of engineers, was devoted to conduct the project within the stage gate model and the ambitious target led to several new realizations during the project. The project started off on the basis of a fully developed product design but with mandate to redesign the product alongside the development of a production line. This degree of design freedom helped the team overcome the types of issues that had earlier led to the use of manual stations mixed with automation. The team realized that the fully automated line needed to be able to produce with lot size one so as to fully exploit the benefits of the flexible supply stations. A new ”design for automation” concept was developed which captured many of the existing production experiences along with new realizations. This resulted in a new product architecture and more than 20 smaller product design changes. Another lever was the availability of commercial bin pickers combined with newly developed vision capabilities that enabled the feeding of the lines to be fully automated as well. Subsequently also the acquisition, implementation and ramp-up resulted in significant new insights. The project entailed adopting technologies that were still at the R&D stage. To counter the risks of unstable processes, the technology suppliers were engaged in testing the equipment on-site and demonstrate stable operation. This test scenario only entailed low volume production. However, when all the equipment was integrated, a range of new problems was uncovered. In the previous mix of automation and manual stations, assemblers could remedy various quality issues but these became evident as the fully automated line was in full operation in high-volume production. On one hand surface flaws went undetected; on the other hand issues related to tolerance stack-up were uncovered. The engineering team had been unaware of these old quality issues. Thereby the ambition to develop competitive technology based production rather than offshoring resulted in both significant new manufacturing performances (in terms of substantial cost, quality, delivery service, and lead time benefits) and in significant new insights to be embedded in future technology projects. Interviewees reported that the nature of the project worked to levitate existing experiences. As such, the project is best understood in light of the technological development history of the organization and is itself a part of the ongoing development of the company's resources and capabilities for technological development.

Case C is a small job shop mainly producing custom made stair cases but also other metal products requiring cutting and welding. The production is characterized by low volume and a large manual input. The company has demonstrated capabilities for internal technology development and had also experimented with a welding robot. But since the robot required ongoing supervision, the productivity gains were insignificant. Especially in light of the recent years of experience with establishment of production facilities in Eastern Europe. Therefore the robot had been taken out of use again, instead the components were being produced in the facility abroad. The example illustrates that in light of existing experiences, technology portfolios, and layout the main benefits associated with automation was replacement of manual labor for productivity gains.

Case D is similarly a small job shop producing similar types of products as company C but with a broader product range. Company D had through the years acquired some CNC equipment and linked these to an ERP system so that work orders and machine settings could be directly pulled from a job schedule. These types of systems appear to be available and manageable for even the smallest shop. In addition, the company had acquired a welding robot and was in the process of building up in-house competences for programming. But in contrast to company C, which mainly evaluated robotic welding in light of current layout and product program, company D was in the process of insourcing welding tasks from neighboring companies in order to better exploit equipment and skills. The reason for adoption was stated to be "*the need to stay tuned with the ongoing development*".

Case B is a medium sized factory with a functional layout producing a narrow product line in a medium volume. CNC equipment was employed in most processes and the most recent developments were not technological but rather organizational. The company had worked on reducing WIP levels and lead times by implementing small lot sizes in machining as well as in transport processes. Integration between CNC and ERP system was the enabler for this approach. The new concept implied that components for the same product were cut in the same sheet and that these components were kept together during transport and subsequent processing. This in turn facilitated significantly improved process control in the rolling process where sheet characteristics could now easily be identified and offset in the rolling of components from the same sheet. As such a combination of AMT acquisitions and new work practices had spurred additional innovations in the production system. These however where yet to be exploited at the business level; a mass customization paradigm with matching process layout seemed to be a way of exploiting new capabilities and support additional productivity gains and automation. The company was yet to realize the benefits of such transition from skill based to standardized production.

Insights from case examples

The case examples demonstrate the *varied nature of technological development* of manufacturing companies. Some of the variation is related to volume; especially larger technology projects can function as vehicles for converting experience into learning by gathering sufficient resources to address longstanding problems, find solutions and potentially develop new understandings (production / product architecture / business paradigms) within the organization. This is in contrast to minor projects primarily aimed at replacing manual labor with machines through the adoption of standardized technologies. While such small-scale projects eventually may provide the organization with the foundation (in terms of technological portfolios) for more wide-ranging changes, in themselves, each of them may have little *impact on the organization's capabilities and paradigms*. It appears that smaller companies with fewer human as well as technical manufacturing assets may be *locked in* to a paradigm in which the only justification for automation is related to direct labor cost. This may hinder the growth of the company's *technological portfolio from reaching a critical point* at which additional automation effects can be achieved through *leverage mechanisms* such as integration and other types of organizational development. While small portfolios may be more economical in the short term, there is a risk that the company stuck at this level looses out on some of the more advanced automation effects, including learning effects associated with technological development. Under the right circumstances, even (or perhaps especially) the most technologically advanced organizations can use *technology projects as a springboard for learning and development* as the many issues related to solving technical problems challenge the organization and attract focused attention.

Metatheory and theory building

While the bracketing of AMT assumptions was conducted in order to investigate the content of AMT research, this section will be concerned with metatheory. The aim is to suggest a metaparadigmatic perspective in order to span AMT research on structure and insights from a process perspective on technological development. From a theory evaluation perspective, the most critical issue related to AMT research may not be the usual suspects (definition and operationalization, reliability and construct validity) but rather the very way the construct is used. Overall, the aim of AMT research is to investigate the impact of structural decisions on firm performance. This implies a conceptual understanding of the construct as "something that has a unique role in promoting firm performance". Intuitively this should apply to advanced technologies. However, when the construct (advanced technologies) is defined as "*computer-controlled or micro-electronics-based equipment*", a causal link is suggested between discrete components and manufacturing or firm performance. In light of the overall research aims, this definition may especially be criticized for excluding all other "advanced technologies" (such as e.g. integration and controls technologies, process technologies, digitalization) that play a significant role in firm performance in combination with the discrete equipment and software elements. Earlier criticisms have been concerned with the dynamic nature of the pool of AMTs, which is not always addressed in the static AMT operationalization; see e.g. Boyer & Pagell (2000). It appears however, that more profoundly, the context in which these elements are embedded has changed significantly since early AMT studies. The technological systems of advanced manufacturers are becoming ever more advanced and the research community is yet to identify, label, and communicate the breadth of these. As indicated by the case examples, AMTs may once / in the individual company have provided the platform for the establishment of more wide-spanning technological solutions. But today, this type of equipment and packaged software may more appropriately be considered tip of the iceberg types of artifacts of potentially broader technological manufacturing and business systems with systemic features hidden deep inside. A few quotes from other types of technology studies are cited to support these claims: "*with rare exceptions, technological knowledge is not marketed or even marketable, as such. ... in most cases, new knowledge is utilized internally to increase the productivity of the labor and capital assets of the firm*" (Ayres & Warr, 2009 p45). "*Because the computing power is now embedded in the capital, only field research of specific machines under the guidance of experts in these technologies can identify the IT features of new CNC machines [in combination with CAD and ERP systems]*" (Barel et al, 2005, p4). As indicated by the case examples, the adoption of "tip of the iceberg" elements such as e.g. CNC may have limited systems effects. Therefore justification is limited to direct labor cost under the "replacement" paradigm found within smaller companies lacking the foundation for leveraging isolated technical assets with additional technological, organizational, and business related developments.

Conclusion

Through the process of metatriangulation the need for a process and system perspective has been identified alongside the role of technical portfolios, technological projects, organizational capabilities, and paradigm innovations. Also the changed context for AMT adoption since early AMT studies has been outlined. These issues need to be taken into account in order to develop better research and theorizing in the field. A set of illustrative propositions are suggested here to summarize the points made throughout the text:

1. *The effect of discrete, commercial AMTs is determined by the production and business systems in which they are inserted (system as mediator).*
2. *Certain levels or portfolios of technical assets are prerequisites for integration and other system effects.*
3. *Below these levels, AMTs may impact isolated subsystems only (e.g. labor cost).*
4. *In 2012, technologically advanced companies embed AMTs in advanced technological systems.*
5. *AMTs are poor indicators of technologically advanced system features.*
6. *Technological systems are not discrete and fixed; they can be configured, developed and exploited in countless ways through ongoing development processes.*
7. *Paradigm innovations can leverage the potentials embedded in technological systems.*
8. *Technological projects are different in nature and it is relevant to distinguish between acquisitions aimed at "replacement" and system projects aimed at leveraging system effects.*
9. *System projects can be the driver for development of organizational capabilities and resources required to perform paradigm innovation.*
10. *Without system projects and paradigm innovation, technical assets can be underutilized.*

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