IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received 3 May 2024, accepted 13 May 2024, date of publication 17 May 2024, date of current version 24 May 2024.

*Digital Object Identifier 10.1109/ACCESS.2024.3402259*

RESEARCH ARTICLE

# Design AMT, Manufacturing AMT, and Product Innovation Performance (PIP)–The Contingent Effect of Organizational Culture and Environmental Turbulence

**GUILIAN WANG[1] AND YI LI[2]**
[1]Development Center for Innovation and Entrepreneurship, Tianjin Sino-German University of Applied Sciences, Tianjin 300350, China
[2]Department of Faculty Affairs (Personnel Office), Tianjin Sino-German University of Applied Sciences, Tianjin 300350, China

Corresponding author: Guilian Wang (wgl20043168@163.com)

This work was supported in part by Tianjin Education Scientific Planning Project under Grant HJE210417.

**ABSTRACT** Although extant studies have extensively investigated the association between advanced manufacturing technology (AMT) and product innovation performance (PIP), the influence of AMT on PIP is not an isolated event. In order to play an effective role, AMT needs to adapt to both external- and internal contextual factors. Prominently, design and manufacturing AMTs represent two crucial types emphasizing advanced manufacturing technology. Nevertheless, the effect of manufacturing AMT, design AMT, and the synergistic impact of these two AMTs on PIP is moderated by internal culture and external environment. However, the proposed influence has not yet been explored in the existing literature. Therefore, this paper analyzed 302 Chinese equipment manufacturing enterprises, and the study findings indicated that on the one hand, the higher the degree of flexibility-oriented culture, the higher the turbulence of the environment, and the more significant the improvement impact of design AMT on PIP; while, on the other hand, the higher the degree of flexibility-oriented culture, the more significant the improvement impact of manufacturing AMT on PIP. However, the moderate impact of environmental turbulence on the correlation between manufacturing AMT and PIP is insignificant. Further study findings highlighted that the high environmental turbulence can still support design- and manufacturing AMTs to play a synergistic role in supporting PIP when exploring the synergistic effect of design- and manufacturing AMTs on PIP. Nonetheless, a flexibility-oriented culture is not conducive to the synergy between design AMT and manufacturing AMT. In specific, the synergy between design AMT and manufacturing AMT can promote PIP only in a control-oriented culture. In this study, factors that influence the effect of AMT from both design AMT and manufacturing AMT are combined to discuss, which makes a comprehensive understanding of how to create better conditions and environment for PIP. Chinese enterprises should emphasize both design AMT and manufacturing AMT and integrate the two AMT styles through organizational culture and environmental recognition.

**INDEX TERMS** Design AMT, manufacturing AMT, organizational culture, environmental turbulence, product innovation performance (PIP).

## I. INTRODUCTION

In the process of the fourth industrial revolution, AMT carries the historical mission of technological innovation and economic efficiency's convergence; thereby, shouldering the significant responsibility of redesigning the competitiveness of the national manufacturing system. As a result, AMT has triggered a substantial deal of attention from the policymakers of the major economies [1]. For instance, Made in China 2025 (National Action Program), the High-Tech Strategy for Germany (2020), the US National Strategy for Advanced Manufacturing (2018), and Japan's Manufacturing White

The associate editor coordinating the review of this manuscript and approving it for publication was Parul Garg.

Paper (2018) all point to breakthroughs and innovations in cutting-edge technologies for advanced manufacturing. Consequently, a growing number of manufacturing firms are emphasizing and excessively investing in AMT, in order to not only make them more responsive to the market but also improve innovation performance. As two distinct types of AMT, manufacturing- and design AMTs exert a profound influence on PIP. In practice, design AMT, for example, can employ digital design tools to rapidly implement creativity, iterative design, and design validation, in order to pace up the cycle of product development; Manufacturing AMT in the presence of increased uncertainty in the mass customization production process, The enterprise takes advantages of the flexibility of the manufacturing system to develop organizational knowledge resources flexibly and instantly to generate products for intermediate testing, in order to ensure that the product can be realized for production.

There is a common consensus among numerous scholars that AMT demonstrates a profound effect on innovation. However, these studies cannot elucidate why there also exist companies that have not considerably improved their innovation performance despite having implemented AMT. As a result, the moderating role of contextual factors outside and inside the organization has been neglected by the research scholars. Moreover, researchers have focused only on the influence of design or manufacturing AMT on innovation in the few empirical studies that have been conducted on AMT, while ignoring the examination of interaction between design AMT, manufacturing AMT on innovation. Therefore, systematically analyzing the moderating role of contextual factors both within and outside the organization on design AMT, manufacturing AMT, and their synergistic effect on PIP is of vital significance but an unproven issue in the sphere of AMT management.

The present study serves as an exploratory research endeavor on the aforementioned issue based on contingency theory. Specifically, contingency theory underscores that nothing is static and advocates that organizational systems should be adjusted in accordance with various contingency factors such as the external environment, technology, culture, size, and strategy [2]. Firstly, effective implementation of AMT warrants adequate cultural fit within the organization, as AMT typically challenges organizational norms. In contrast to traditional single-species; high-volume production centered on production equipment, AMT is capable of realizing multi-species; low-volume production by changing physical setups and operating procedures in response to market demand. As a result, the type of organizational culture adopted may eventually influence the application level of the technology, as compared to the traditional internal environment of the organization [3]. Consequently, the first purpose is to investigate the moderating effect of organizational culture on the performance of manufacturing AMT, design AMT, and their synergistic and innovative performance.

In addition to the internal forces of the organization, the characteristics of the organization's external competitive environment may hinder the effectiveness of AMT implementation. Meanwhile, the environmental turbulence requires flexibility to support [4]. Similar to other digital manufacturing technologies, the value of AMT predominantly lies in its ability to add flexibility to the organization. The proposed flexibility can be defined as the ability to respond to uncertainty in the external environment. Thus, flexibility helps enterprises cope with the rate of change and unpredictability of technologies and markets. Moreover, the effect of AMT implementation not only depends on the technology itself but also on its capability to continuously adapt and match with the external environment faced by the enterprise [5]. As a consequence, the second purpose is to explore the contingency influence of environmental turbulence on the correlation between design AMT, manufacturing AMT, and their synergies with PIP.

Therefore, various research scholars have studied the impact of design AMT and manufacturing AMT on PIP. while this paper essentially studies and expects to resolve the problem at hand, that is, based on the research data of the national equipment manufacturing enterprises, this study attempts to systematically analyze how the moderating influences of environmental turbulence and organizational culture impact the design AMT, manufacturing AMT, and their synergistic effects on PIP, in the context of contingent effect, with an outlook to offering insights for innovation theory and practice.

## II. LITERATURE REVIEW

### A. RELEVANT LITERATURE

#### 1) AMT

Researchers have classified AMT in a variety of ways, and this research study centers on emphasizing AMT usage and manufacturing performance. In particular, AMT is conceptualized as design AMT, manufacturing AMT, and administration AMT [6], [7], [8]. Based on the two critical reasons, this research paper restricts the analysis to design AMT and manufacturing AMT. Firstly, the study's focus is on the application of AMT in product development activities instead of business operations. Secondly, flexible information systems such as enterprise resource planning are perceived as tools for organizational management [9]. As a result, the inclusion of administration AMT in this study may be mistaken with the organizational culture.

On the one hand, design AMT refers to the advanced technology that can shorten the product design cycle, gain business opportunity and reduce the design cost, particularly including CAD, CAPP, and CAE.

On the other hand, manufacturing AMT refers to the control of manufacturing processes and the generation of process-relevant IT in factory workshops, involving FMS, CNC, CIM, robotics, cloud computing, new materials, rapid prototyping, and industrial big data.

Empirical studies report that both manufacturing- and design AMT exhibit a significantly positive association with PIP. Explicitly, design AMT with its design and analysis functions, can reduce product development costs and some programming time [10]. Further, manufacturing AMT is not subject to economies of scale related to traditional manufacturing, whereas the "flexibility" gained allows for the production of customized products on demand; thereby, minimizing the chances of wastage and overstocking of raw materials [11]. Nevertheless, extant studies have only scrutinized their effect on innovation performance, without taking into account the moderating role of environmental turbulence and organizational culture.

#### 2) ORGANIZATIONAL CULTURE

Organizational culture presents a culture developed in practice by an organization over a long period of time through its business practices. Further, organizational culture stands for the shared perception and vision of the values, beliefs, and vision of the organization by its members. According to Quinn, Quinn and Rohrbaugh [12], [13], [14] organizational culture is categorized into a flexibility-oriented culture and control-oriented culture, based on the "flexibility-control" perspective of the competitive value framework, with the control-oriented value system stresses centralization and integration whereas the flexibility-oriented value system emphasizing decentralization and differentiation. On the one hand, the group and development cultures lay emphasis on cooperative participation and risk-taking, respectively, aligned with the characteristics of flexible cultural orientation; while, on the other hand, the hierarchical and rational cultures emphasize operational efficiency and goal orientation, respectively, consistent with the characteristics of control culture orientation.

Ajmal and Koskinen [15] infer that a flexibility-oriented culture stresses decentralized decision-making, a flat organizational structure, and a small division of labor. This culture attempts to resolve issues as they occur by delineating the uncertainties related to AMT operations. Meanwhile, a flexibility-oriented culture drives the expertise and information down to lower levels; thereby, allocating discretionary power to operators. Such a model of control and coordination supplements the pace and flexibility of the organization in responding to hidden opportunities and problems.

In comparison to flexibility-oriented culture, control-oriented culture puts emphasis on centralized decision-making, various specializations, and hierarchical organizational structures [16]. This culture impulses information and knowledge to higher levels of the organization, with middle-level management and technical experts making operational decisions.

Certainly, organizational culture not only serves as a pivotal factor in implementing technology but also plays an imperative role in various areas of organizational management. Since the organizational culture can either facilitate or impede the implementation of AMT, it is of vital significance to explore what type of organizational culture extends the most suitable conditions for AMT [17].

#### 3) ENVIRONMENTAL TURBULENCE

Environmental turbulence refers to the degree of change of external environment in terms of technological innovation, competitor behavior, and user behavior [18], [19]. Past scholars have divided environmental turbulence into two main aspects, namely: market turbulence and technological turbulence [20]. Explicitly, technological turbulence denotes the pace of technological change and the amount of uncertainty in technological development [21]. Contrary to this, market turbulence refers to the degree of change in product demand and customer preferences [22]. Presently, researchers have carried out extensive research on environmental turbulence; consequently, verifying that environmental turbulence exerts a significant impact on the application of technology [23]. This study proposes that environmental turbulence may disrupt the application of AMT by enterprises and thus may moderate the influential mechanism of manufacturing AMT and design AMT on PIP.

#### 4) RELATIONSHIP BETWEEN AMT AND PIP

AMT relates to a range of product innovations. AMT not only communicates and collaborates on innovative product concepts and ideas, but also integrates the ability to calculate, store and process critical product information to meet customers' individual and diversified needs in the modern marketplace, improving product quality and product functionality. For example, additive manufacturing allows for more customization opportunities and activates new innovation ecosystems. Furthermore, AMT also supports the optimised planning of resources that allow companies to use digital technologies to improve the efficiency of processes. This can be associated with fundamental manufacturing techniques, such as Computer Integrated Manufacturing Systems (CIMS) or Automated Guided Vehicle (AGV) [24].

In recent years, the adoption of AMT and its impact effects in the manufacturing industry has become more prominent, and the research on the key influencing factors of AMT adoption has become increasingly rich. They mainly focus on the existing technological capability [25], firm size [8], and product export [26], etc. The methodology to assess AMT adoption includes technology-organization-environment framework (TOE) [27], fuzzy comprehensive evaluation model [28], etc.

Research scholars have investigated the association between AMT and innovation directly and concluded that AMT serves as the core driving force behind innovation. For instance, Hewitt Dundas examined the role of AMT in devising innovation strategy choices in small enterprises; thereby, establishing a significant correlation between AMT adoption and innovation strategies. In specific, corporations that incorporate AMT are more inclined to employ "complex" strategies, including market innovation and product innovation strategies [29]; furthermore, Bourke and

Roper stress AMT adoption can yield innovation benefits, i.e., AMT shall exert destructive influences on innovation performance in the short run, but beneficial influences in the long term [30]. Subsequently, Altuntas et al. scrutinized the correlation between AMT, innovation, exports, and corporate performance, and their results indicated that there existed a substantial positive connection between AMT and innovation [31].

Additionally, foreign and domestic researchers have followed the paradigm of organizational change theory, in order to study the influential mechanisms between AMT and PIP. Cao explored the relationship between AMT and enterprise innovation capability, empirically verified the mediating role of human resource management practices between AMT and technological innovation capability, while the relationship between human resource management practices in AMT and management innovation capability has not been verified [32]; Chen and Huang found that there is a partial mediating effect of technological learning between AMT and product innovation through empirical research [33]; Kong et al. examined the role of internal collaboration in relation to the specific types of AMT and two dimensions of green innovation, and confirmed the important mediating role of internal collaboration [34].

## B. THEORETICAL ANALYSIS AND RESEARCH HYPOTHESIS

### 1) THE MODERATING EFFECT OF ORGANIZATIONAL CULTURE AND EXTERNAL ENVIRONMENT IN THE RELATIONSHIP BETWEEN DESIGN AMT AND PIP

Prominently, organizational culture is a soft constraint that enhances the breadth and depth of AMT applications; further, the deep integration of AMT and organizational culture assists effective collaboration and linkages among business units to realize competitive advantage. For instance, Ungan [35] reported that organizational culture exerted a positive effect on the successful implementation of manufacturing best practices; thereby, effectively contributing to improved performance. In the same manner, design AMT not only broadens the sources of innovation, but also fosters the ability to rapidly design products using digital design tools. In the meantime, a flexibility-oriented culture can effectively decentralize management decision-making to front-line employees and expand the employee responsibility requirements; resultantly, triggering employee creativity and initiative. With Design AMT, front-line designers are able to instantly implement digital product design, feedback, and adjustments, in order to address the individualized and diverse needs of customers in the marketplace. Such flexibility allows enterprises to quickly launch new products and better respond to changes in the market; hence, achieving an edge in the competition [36]. Furthermore, a control-oriented culture in which management control is augmented by decreasing the discretionary power of production employees is not conducive to effective adaptation to unstable market preferences by corporations employing design AMT. At the same time, a control-oriented culture not only obstructs the further transformation of external knowledge and information into concrete actions but also demonstrates an inhibitory effect on PIP. Based on this, the following hypotheses are postulated in this study.

H1a Control-oriented culture negatively moderates whereas the flexibility-oriented culture positively moderates the correlation between design AMT and PIP.

Organizations are influenced by the richness, volatility, and complexity of the environment [37]. The effects of technological turbulence and market turbulence in the external environment are more significant in the information age, where industrial technologies witness rapid development. Thus, high turbulence implies greater uncertainty in the technological paradigm of product design and market demand. Meanwhile, design AMT facilitates enterprises to adopt digital design tools, in order to rapidly simulate and adapt designs to diverse demand information related to customers in the context of mass customization; consequently, improving the ability of organizations to instantly respond to changing market conditions and product requirements. Therefore, environmental turbulence has a positive moderating effect between design AMT and PIP. As a result, this paper puts forward the following hypotheses:

H1b Environmental turbulence positively moderates the association between design AMT and PIP.

### 2) THE MODERATING EFFECT OF ORGANIZATIONAL CULTURE AND EXTERNAL ENVIRONMENT IN THE RELATIONSHIP BETWEEN MANUFACTURING AMT AND PIP

Manufacturing AMT can utilize software programs to automatically change processing tools and processes and to execute such operations without excessive time and cost in the conversion process. This enables business firms to manufacture multiple products for rapid manufacturing. Nonetheless, a control-oriented culture is not conducive to dealing with the uncertainty and complexity associated with AMT operations, although it is beneficial for productivity but not for PIP. In particular, Zammuto and O'Connor [17] put forward that the more the organization emphasizes control orientation, the higher the failure probability of AMT application; the more emphasis on flexible orientation, the higher the success probability of AMT application Consequently, a control-oriented culture shall inhibit the stimulating influence of manufacturing AMT on PIP. Thus, the following hypotheses are proposed in this paper.

H2a Control-oriented culture negatively moderates (flexibility-oriented culture positively moderates) the linkage between manufacturing AMT and PIP.

Typically, manufacturing AMT with flexible production systems permits corporations to adopt more sophisticated innovation strategies. The manufacturing AMT increases the uncertainty of the production process under mass customization in a highly volatile technological and market environment. By taking advantage of the flexible attributes of the manufacturing system, companies can quickly and flexibly promote the efficient use of new knowledge, develop organizational knowledge resources, conduct intermediate tests on creative products using technologies such as 3D printing, as well as customize or change their products rapidly than their competitors, in order to react to technological trends and market innovations. On this basis, the following hypotheses are hypotheses in this study.

H2b Environmental turbulence positively moderates the relationship between manufacturing AMT and PIP.

#### 3) THE MODERATING EFFECT OF ORGANIZATIONAL CULTURE AND EXTERNAL ENVIRONMENT IN THE SYNERGISTIC RELATIONSHIP BETWEEN DESIGN AMT AND MANUFACTURING AMT ON PIP

In general, enterprises do not adopt one-dimensional AMT in isolation, but incorporate multi-dimensional AMT in sequential order (incremental model) or concurrently (discontinuous model) [38]. Accordingly, Gomez and Vargas [39] asserted the interrelationships of certain AMTs and suggested that the implementation and use of these technologies not be analyzed in isolation. The authors' previous findings reflect that multi-dimensional AMT must complement each other and coordinate to support business firms to bolster innovation and effectively translate new external technological knowledge into PIP rather than one-dimension of AMT adoption [40]. Though, design AMT and manufacturing AMT are different, whether the two types of AMT can effectively collaborate is constrained by internal and external environmental conditions. Therefore, organizations need to comprehend and ascertain whether the design and manufacturing AMTs can coordinate, in order to improve PIP, in accordance with external and internal environmental factors.

Apparently, a control-oriented culture can guide the collaboration between design AMT and manufacturing AMT by emphasizing predictability, direction, and efficiency; thereby, enhancing the efficiency and effectiveness of converting knowledge resources into creative ideas. Based on this, this research study holds that a control-oriented culture also positively impacts the connection between the synergy of design AMT and manufacturing AMT and PIP. On the one end, the interaction of a control-oriented culture with the synergy of design AMT and manufacturing AMT lowers task or process conflicts within the organization and enhances knowledge exchange and collaboration among departments [41]. This accelerates the transformation of ideas into products. On the other end, the synergy of design AMT and manufacturing AMT can be regarded as a design and manufacturing integration mechanism in enterprises characterized by a control-oriented culture, which can promote implicit knowledge exchange between product design and manufacturing processes. In short, the synergy of design AMT and manufacturing AMT can also be more effective in fostering PIP when control-oriented culture is enhanced. Resultantly, the following hypotheses are proposed by the authors.

H3a: The higher the degree of control-oriented culture (the lower the degree of flexibility-oriented culture), the positive interaction between design AMT and manufacturing AMT on PIP; the higher the degree of control-oriented culture (the lower the degree of flexibility-oriented culture), the positive interaction between design AMT and manufacturing AMT on PIP.

Environmental turbulence may affect the linkage between this behavior and PIP when firms engage in complementary synergies between design AMT and manufacturing AMT [5]. Meanwhile, organizations operating in highly uncertain environments may be coerced to innovate at a higher rate. In such scenarios, business organizations must strive to expand functional boundaries and shorten product life cycles through the synergy of manufacturing- and design AMT, leading to more diversified and multilayered products and services that are successfully adapted to unstable market preferences and technological change in an externally volatile environment [42], [43]; consequently, optimizing the PIP. As a result, the researchers put forward that environmental turbulence positively moderates the connection between the complementary of design AMT, manufacturing AMT and PIP. Thus, the following hypotheses are proposed in this research paper.

H4a: There is a positive interaction between design AMT and manufacturing AMT on PIP at higher levels of environmental turbulence.

Based on the aforementioned theoretical analysis and research hypotheses, the conceptual model of this study is depicted in Figure 1.

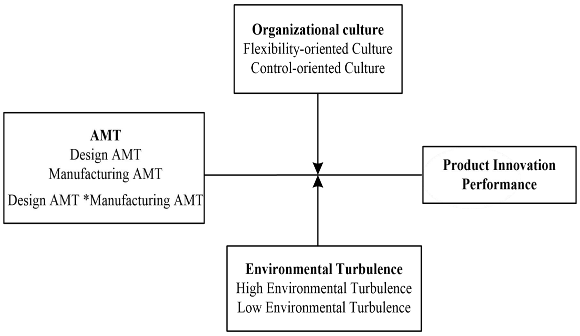


**FIGURE 1.** Conceptual model.

## III. METHODOLOGY

### A. DATA COLLECTION

Noticeably, the study object is equipment manufacturing enterprises in China. In addition, sample selection criteria are as follows: (1) Geographical division: four major economic zones in China are selected, namely: North China(Beijing, Tianjin, Jilin, Heilongjiang and Liaoning), East China (Zhejiang, Jiangsu and Shanghai), South China (Hubei, Hunan, Henan, Fujian and Guangdong), and West China (Chongqing, Shanxi and Sichuan). (2) Industry division: reference to "National Economic Industry Classification" (GB/T4754-2017), including 7 categories of equipment manufacturing companies. As per the chosen industries and regions, the distribution of the sampled enterprises in each industry is relatively balanced, whereas the geographical distribution is fundamentally aligned with the actual situation in China.

Explicitly, only one respondent questionnaire is gathered for each firm. Further, related criteria are introduced to ensure that the respondents are undeniably qualified to offer the requested information: a. involved in the development of a new product; b. implemented AMT in product design, production, and other associated processes; c. the survey firm has been set up for over 3 years since the application of AMT acts is a combination of technological and innovative factors. The official study period was initiated in Dec 2020 and ended in May 2021. In the meantime, the respondents of the questionnaire survey are the managers of the R&D department or in charge of the product development project and possess a holistic perception of AMT, cultural orientation, product innovation, and external environmental turbulence. The questionnaire filled out by them reflects the actual circumstances of the firm to a certain extent.

In this study, the chosen scale chosen is predominantly designed based on the mature scales extracted from the foreign literature. First, the original English scales were translated into Chinese, and English proficient researchers were requested to correct the original English scales, so as to they were consistent with each other. Second, prior to the final questionnaire being developed, preliminary survey >100 companies was conducted in Hebei and Tianjin. Third, in light of the survey outcomes and feedback retrieved from the enterprise personnel, inappropriate questions were deleted whereas ambiguous statements were modified to develop the measurement scales.

Reportedly, the total number of recovered questionnaires was 339 out of the 1,200 questionnaires sent out to respondents, with a recovery rate of 28.3%. Besides this, 302 questionnaires stood valid, with a valid recovery rate of 25.2%. In terms of the individual characteristics of the respondents, middle-level personnel accounted for 44.0%, grass-roots personnel accounted for 40.4%, and senior personnel were reported to be 15.6%. Furthermore, 119 enterprises were sampled from mechanical engineering and other important basic machinery, accounting for 39.4% of the study sample. Similarly, 61 enterprises were engaged in critical mechanical and electronic basic components such as instruments and cultural office machinery, accounting for 20.2%. Further, 122 companies were chosen from the transportation equipment manufacturing and other major complete sets of enterprises, accounting for 40.4%. From the perspective of firm size, 500 individuals, 500∼999 individuals, and more than 1,000 individuals account for 54%, 18.2%, and 27.8% respectively. Subsequently, in terms of the distribution of geographic regions, East China, North China, West China, and South China accounted for 36.1%, 27.8%, 12.3%, and 23.8% respectively. Finally, in the context of firm age, corporations with 5 years or less, 6 to 10 years, and 11 years or more accounted for 7.3%, 23.5%, and 69.2% respectively. The basic characteristics are shown in Table 1.

**TABLE 1.** Descriptive statistics of sample companies.

| | Firm characteristics | Frequency | Percentage |
|---|---|---|---|
| Industry type | Metal products | 38 | 12.6 |
| | Ordinary machinery | 73 | 24.2 |
| | Electrical machinery and equipment | 57 | 18.9 |
| | Electronic and communication equipment | 46 | 15.2 |
| | Instrumentation, cultural and office machinery | 23 | 7.6 |
| | Transportation equipment manufacturing | 65 | 21.5 |
| Number of workers | <149 | 55 | 18.2 |
| | 150~249 | 45 | 14.9 |
| | 250~499 | 63 | 20.9 |
| | 500~999 | 55 | 18.2 |
| | >1000 | 84 | 27.8 |
| Firm area | East China | 109 | 36.1 |
| | North China | 84 | 27.8 |
| | West China | 37 | 12.3 |
| | South China | 72 | 23.8 |
| Firm age | <5 | 22 | 7.3 |
| | 6~10 | 71 | 23.5 |
| | 11~15 | 77 | 25.5 |
| | 16~20 | 69 | 22.8 |
| | >20 | 63 | 20.9 |

The owner's subjective judgment may be biased since there is only one respondent in each enterprise. Therefore, it is essential to perform Harman's one-factor test for homogenous data. The relevant results indicated that the first factor explained 29.791% of the variance (less than 40%). As a consequence, the findings are not significantly influenced by the homogenization of the data.

### B. MEASURES

In this study, the items scaling different dimensions of AMT are majorly sourced from Boyer et al. [7], Swamidass and Kotha [8], and Zhou and Yao [44]. On the one hand, design AMT is estimated by 3 measurement items; while, on the other hand, manufacturing AMT is gauged by 14 measurement items.

Organizational culture measurement items are borrowed from variables proposed by Quinn and Spreitzer [45]. Meanwhile, the Competing Values Model scale focuses on the two functions of organizational culture, namely: control-oriented culture and flexibility-oriented culture. The present study was benchmarked against the control culture orientation. Control-oriented culture comprises 2 dimensions of hierarchical and/or rational values of culture, with 8 measurement items.

Technological turbulence measurement items are adapted from Jaworski and Kohli [18]. Evidently, this scale contains 4 measurement items. Moreover, the market turbulence measures are mainly derived from Jaworski and Kohli [18];and

**TABLE 2. Reliability and validity tests for the scale.**

| Variables | Item | Factor loading | Cronbach's α | CR | AVE |
|---|---|---|---|---|---|
| Design AMT | AMT1-Computer-aided design(CAD) is used | 0.824 | 0.800 | 0.882 | 0.714 |
| | AMT2-Computer-aided engineering (CAE) is used | 0.847 | | | |
| | AMT3-Computer-aided process planning (CAPP) is used | 0.864 | | | |
| Manufacturing AMT | AMT9-Flexible manufacturing systems (FMS) are used | 0.763 | 0.900 | 0.920 | 0.589 |
| | AMT10-Automated material handling systems (AMH) are used | 0.785 | | | |
| | AMT12-Robotics are used | 0.777 | | | |
| | AMT13-Computer integrated manufacturing systems (CIMS) are used | 0.794 | | | |
| | AMT14-Industrial internet of things （IIOT） are used | 0.761 | | | |
| | AMT15-Rapid prototyping methods are used | 0.720 | | | |
| | AMT16-Industrial big data （TBD） is used | 0.743 | | | |
| | AMT17-Cloud computing (CC) is used | 0.793 | | | |
| Product Innovation Performance | PIP1-Overall technology innovation performance | 0.846 | 0.710 | 0.841 | 0.639 |
| | PIP3-Market share from innovative products or services | 0.735 | | | |
| | PIP4-Growth in new products or services | 0.813 | | | |
| Control-oriented Culture | COC1-Control, centralization | 0.707 | 0.758 | 0.858 | 0.431 |
| | COC2-Routinization, formalization, structure | 0.618 | | | |
| | COC3-Stability, consistency, order | 0.802 | | | |
| | COC4-Predictable, performance, results | 0.678 | | | |
| | COC5-Mission priorities, accomplishment, achievement | 0.664 | | | |
| | COC6-Direction, target setting, target clarification | 0.722 | | | |
| | COC7-Efficiency, productivity, profitability | 0.767 | | | |
| | COC8-Outcome, excellence, quality | 0.608 | | | |
| Environmental turbulence | ET1-The industry's technology is changing fast | 0.848 | | | |
| | ET2-Technological revolution is a huge opportunity for our industry | 0.860 | 0.923 | 0.940 | 0.721 |
| | ET3-Technological breakthroughs in our industry have made many new product/service ideas possible | 0.829 | | | |
| | ET4-The technological revolution in our industry are substantial | 0.858 | | | |
| | ET5-In our business, our customers are always looking for new products and services | 0.849 | | | |
| | ET6-In our business, customers' preferences for products and services have changed over time | 0.851 | | | |

Olson et al. [46]. In addition to this, the scale includes 2 measurement items.

The PIP measurement items are adapted from Reinartz et al. [47]. This statistical scale contains 4 measurement items.

Firm size (SIZE). Firm size may be associated with the corporate ability to adopt new technologies. Additionally, firm size may also be related to the level of synergies warranted between the design AMT and manufacturing AMT. In any case, these two functions may be performed by the same person in a very small firm. As obvious, this variable is classified into 5 ascending levels (1=under 149, 2=150 to 249, 3=250 to 499, 4=500 to 999, and 5=over 1000)

Firm age (AGE). Long-term enterprises have more time to absorb knowledge, therefore such corporations may demonstrate a higher degree of synergy between design AMT and manufacturing AMT [48]. Correspondingly, this variable is divided into five different levels (1=1 to 5, 2=6 to 10, 3=11 to 15, 4=16 to 20, and 5=over 20)

Firm area (AREA). Divergences and differences in geographic cultures, innovation environments, and geographic policy may directly impact corporate innovation [49]. Hence, geography is treated as a control variable in this paper whereas geographical locations are divided into four separate regions. At last, the geographic measures are operationalized as 3 dummy variables, with the western zone as the benchmark.

### C. DATA ANALYSIS

#### 1) RELIABILITY AND VALIDITY

From the standpoint of scale reliability, this research analysis was estimated by Cronbach's $\alpha$ and combined reliability (CR). As illustrated in Table 2, the values of Cronbach's $\alpha$ are over 0.7 [50], and CR coefficients exceeded 0.6 [51]. These results indicate that the sample data have good consistency. In this paper, two validation indexes are chosen to test the structural validity. Until the optimal level of reliability values is reached, items below a specific threshold are removed from the measurement model. Additionally, 6 items from AMT and 1 item from PIP were not assumed in the analysis as these items did not fulfill this criterion. Correspondingly, the Appendix demonstrates the entire scale in Chinese and English used in the paper [52]. As depicted in Table 1, all the thresholds of the factor loadings of each variable are higher than 0.6 [50]. Based on this, there is a sound convergent validity of the scale. In addition to this, the AVE and correlation coefficients of each variable are compared and analyzed in this research. As evident from Table 3, the square root of AVE is larger than the correlation coefficients between other variables. Hence, the discriminant validity is considered to be good [51].

#### 2) DESCRIPTIVE STATISTICS OF VARIABLES

The results are presented in Table 3, which reflect that there exist significant correlations among design AMT, manufacturing AMT, PIP, control-oriented culture, and environmental turbulence, with Pearson correlation coefficients of less than 0.6, and VIF of less than 2. This implies that the issue of multiple covariance is not severe, and it can be analyzed by further regression analysis. Besides, the study variables are standardized when constructing the quadrature terms, in order to effectively minimize the multicollinearity among the explanatory variables.

**TABLE 3. Descriptive Statistics of Each Variable and Pearson's Correlation Coefficient.**

| Variables | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Design AMT | 0.845 | | | | |
| Manufacturing AMT | 0.556** | 0.767 | | | |
| PIP | 0.355** | 0.376** | 0.799 | | |
| COC | 0.431** | 0.418** | 0.513** | 0.715 | |
| ET | 0.403** | 0.408** | 0.106** | 0.174** | 0.849 |
| Mean | 11.914 | 28.235 | 12.338 | 33.752 | 23.149 |
| S.D. | 2.481 | 7.205 | 1.826 | 3.694 | 5.579 |

### D. HYPOTHESIS TESTS

Using SPSS.26, this research article verifies the postulated hypothesis by performing the hierarchical regression analysis on the sample data [53]. Gefen et al. [54] report that regression analysis is appropriate for exploring the specific mechanisms of action in models. Especially for the testing of moderating influences, hierarchical regression analysis represents a wide range of applications, which can avoid estimation errors that disrupt statistical significance and multi-collinearity [55].

#### 1) TEST OF HYPOTHESIS H1

In Table 4, Model 1 only takes into account the influences of control variables such as firm size, firm area, and firm age on the PIP; afterward, Model 2 adds the independent/explanatory variable design AMT; subsequently, Models 3 and 4 add the moderating variable (organizational culture) and the interaction term between the two, respectively; thereafter, Models 5 and 6 add the moderating variable (environmental turbulence) and the interaction term between the two, respectively. Parallel to this, in Table 5, variable settings for each model are the same as those in Table 4, except that the explanatory variable is replaced with the manufacturing AMT.

When design AMT is taken as an explanatory variable, hypothesis H1 is tested against the results in Table 4. Explicitly, Model 2 exhibits that the regression coefficient of design AMT on PIP is positive and significant ($\beta = 0.377$, $p<0.01$). Further, Model 4 demonstrates that the interaction term of design AMT and control-oriented culture exerts a significant impact on the PIP ($\beta = -0.105$, $p<0.05$), and control-oriented culture negatively moderates the correlation between design AMT and PIP. Therefore, H1a stands valid in this study. Subsequent to this, Model 6 highlights that the interaction term of design AMT and environmental turbulence has a significant impact on PIP ($\beta = 0.128$, $p<0.05$). Consequently, hypothesis H1b is also verified in this paper.

#### 2) TEST OF HYPOTHESIS H2

When manufacturing AMT is incorporated as an independent variable, hypothesis H2 is tested against the results in Table 5. Obviously, Model 2 illuminates that manufacturing AMT ($\beta = 0.388$, $p<0.01$) exerts a significant influence on PIP. Additionally, Model 4 reflects that the product of manufacturing AMT and control-oriented culture shows a significant effect on PIP ($\beta = -0.113$, $p< 0.01$), whereas control-oriented culture negatively moderates the association between manufacturing AMT and PIP. Based on this, H2a is also supported in this study. Moreover, Model 6 illustrates that the interaction term between manufacturing AMT and environmental turbulence is positively but not significantly associated with PIP ($\beta = 0.063$, $p>0.1$), and hypothesis H2b is not tested. This implies that environmental turbulence does not exert a significant effect on manufacturing AMT and PIP, as firstly when environmental turbulence is high, firms attempt to adapt to external pressures through flexibility [56]. This is achieved by customers using 3D printing to make rapid prototypes; thereby, contributing to PIP. Secondly, the high environmental turbulence makes the existing knowledge system and production specifications of the enterprise gradually lose their value [57]. Manufacturing AMT can no longer play a supportive role in innovation practices. The positive moderating effect of environmental turbulence is somewhat neutralized by the aforementioned factors; thus, making the moderating influence less significant.

#### 3) TEST OF HYPOTHESIS H3

Based on the degree of flexibility of organizational culture, the sample is categorized into two groups, the enterprises with higher flexibility are termed as employing flexibility-oriented culture, while the enterprises with lower flexibility are termed as incorporating control-oriented culture, and stepwise regressions are carried out on the samples of the two groups separately. Accordingly, the specific results are populated in Table 6.

In the control culture-oriented organization, both manufacturing AMT ($\beta = 0.168$, $p<0.05$) and design AMT ($\beta = 0.138$, $p<0.05$) have a significant effect on PIP, with a higher coefficient for manufacturing AMT. The positive interaction between design AMT and manufacturing AMT

**TABLE 4.** The moderating role of organizational culture and environmental turbulence in the relationship between the effect of design AMT on PIP.

| Variables | Product Innovation Performance | | | | | |
|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 | M6 |
| Firm size | 0.085 | 0.019 | -0.010 | -0.027 | 0.017 | 0.029 |
| Firm age | -0.004 | -0.056 | -0.020 | -0.014 | -0.056 | -0.060 |
| East China | 0.055 | 0.024 | 0.026 | 0.046 | 0.024 | 0.001 |
| North China | 0.134 | 0.150* | 0.101 | 0.104 | 0.153* | 0.134 |
| South China | -0.014 | -0.035 | -0.005 | -0.004 | -0.036 | -0.045 |
| Design AMT | | 0.377*** | 0.186*** | 0.170*** | 0.373*** | 0.459*** |
| Organizational culture (control-oriented culture COC) | | | 0.426*** | 0.375*** | | |
| Environmental turbulence (ET) | | | | | 0.011 | 0.040 |
| Design AMT x COC | | | | -0.105*** | | |
| Design AMT x ET | | | | | | 0.128*** |
| F | 1.340 | 8.833*** | 17.529*** | 16.559*** | 7.551*** | 8.257*** |
| $R^2$ | 0.022 | 0.152 | 0.294 | 0.311 | 0.152 | 0.184 |
| Adjusted $R^2$ | 0.006 | 0.135 | 0.278 | 0.293 | 0.132 | 0.162 |

Notes: N=302;*p<0.10;**p<0.05;***p<0.01

**TABLE 5.** The moderating role of organizational culture and environmental turbulence in the relationship between the effect of manufacturing AMT on PIP.

| Variables | Product Innovation Performance | | | | | |
|---|---|---|---|---|---|---|
| | M1 | M2 | M3 | M4 | M5 | M6 |
| Firm Size | 0.085 | -0.030 | -0.040 | -0.063 | -0.030 | -0.026 |
| Firm age | -0.004 | 0.023 | 0.021 | 0.031 | 0.024 | 0.023 |
| East China | 0.055 | 0.040 | 0.033 | 0.053 | 0.040 | 0.028 |
| North China | 0.134 | 0.128 | 0.090 | 0.086 | 0.125 | 0.123 |
| South China | -0.014 | -0.033 | -0.006 | -0.012 | -0.033 | -0.035 |
| Manufacturing AMT | | 0.388*** | 0.213*** | 0.215*** | 0.391*** | 0.413*** |
| Organizational culture (control-oriented culture COC) | | | 0.420*** | 0.350*** | | |
| Environmental turbulence (ET) | | | | | -0.009 | 0.010 |
| Manufacturing AMT x COC | | | | -0.113*** | | |
| Manufacturing AMT x ET | | | | | | 0.063 |
| F | 1.340 | 9.434*** | 13.053*** | 17.257*** | 8.063*** | 7.331*** |
| $R^2$ | 0.022 | 0.161 | 0.304 | 0.320 | 0.161 | 0.167 |
| Adjusted $R^2$ | 0.006 | 0.144 | 0.287 | 0.302 | 0.141 | 0.144 |

Notes: N=302;*p<0.10;**p<0.05;***p<0.01

on PIP ($\beta = 0.142$, p<0.05) implies that design AMT andmanufacturing AMT can promote each other and work synergistically to a certain extent when the enterprise is in the control culture orientation. In the flexible culture-oriented organization, the effect of design AMT ($\beta = 0.359$, p<0.1) on PIP is relatively significant, whereas the effect of manufacturing AMT (B=0.039, p>0.1) on PIP is insignificant; additionally, there exists a certain negative (insignificant) interaction between design AMT and manufacturing AMT ($\beta = -0.028$, p>0.1). This indicates that it is difficult to

**TABLE 6. The moderating role of organizational culture in the relationship between the synergistic effect of design AMT and manufacturing AMT on PIP.**

| Variables | Product Innovation Performance | | | | | |
|---|---|---|---|---|---|---|
| | Control-oriented culture | | | Flexibility-oriented culture | | |
| | M1 | M2 | M3 | M1 | M2 | M3 |
| Firm Size | -0.069 | -0.107* | -0.104* | 0.573** | 0.379 | 0.375 |
| Firm age | 0.029 | 0.011 | 0.006 | -0.140 | -0.141 | -0.132 |
| East China | 0.119 | 0.095 | 0.068 | -0.026 | -0.114 | -0.115 |
| North China | 0.160** | 0.174** | 0.178** | -0.047 | -0.116 | -0.124 |
| South China | 0.041 | 0.024 | 0.027 | -0.092 | -0.185 | -0.188 |
| Design AMT | | 0.138** | 0.190*** | | 0.359* | 0.318 |
| Manufacturing AMT | | 0.168*** | 0.191*** | | 0.039 | 0.021 |
| Design AMT x Manufacturing AMT | | | 0.142*** | | | -0.028 |
| F | 1.552 | 4.049*** | 4.809*** | 1.884 | 2.201* | 1.883* |
| $R^2$ | 0.030 | 0.103 | 0.136 | 0.183 | 0.278 | 0.279 |
| Adjusted $R^2$ | 0.011 | 0.078 | 0.107 | 0.086 | 0.152 | 0.131 |

Notes: N=302;*p<0.10;**p<0.05;***p<0.01

**TABLE 7. The moderating role of environmental turbulence in the relationship between the synergistic effect of design AMT and manufacturing AMT on PIP.**

| Variables | Product Innovation Performance | | | | | |
|---|---|---|---|---|---|---|
| | Low environmental volatility | | | High environmental volatility | | |
| | M1 | M2 | M3 | M1 | M2 | M3 |
| Firm Size | 0.127 | 0.012 | 0.004 | 0.029 | -0.012 | 0.002 |
| Firm age | -0.066 | -0.047 | -0.026 | -0.002 | -0.037 | -0.036 |
| East China | -0.213 | -0.143 | -0.127 | 0.137 | 0.082 | 0.079 |
| North China | 0.366* | 0.365* | 0.361* | 0.020 | 0.014 | 0.039 |
| South China | -0.109 | -0.120 | -0.119 | -0.015 | -0.028 | -0.011 |
| Design AMT | | 0.189 | 0.133 | | 0.304*** | 0.431*** |
| Manufacturing AMT | | 0.202 | 0.131 | | 0.163** | 0.140** |
| Design AMT x Manufacturing AMT | | | -0.068 | | | 0.216*** |
| F | 3.230** | 3.373*** | 2.998*** | 1.497 | 7.822*** | 9.196*** |
| $R^2$ | 0.165 | 0.228 | 0.233 | 0.035 | 0.210 | 0.264 |
| Adjusted $R^2$ | 0.114 | 0.160 | 0.155 | 0.012 | 0.183 | 0.235 |

Notes: N=302;*p<0.10;**p<0.05;***p<0.01

synergize design AMT and manufacturing AMT in a flexible culture orientation, to a certain extent. In contrast to the previous conclusion, which takes into account the effect of design AMT and manufacturing AMT on PIP separately, the synergy between design AMT and manufacturing AMT can only be realized when the organization is in a control culture orientation. Thus, the researchers test the hypothesis H3.

#### 4) TEST OF HYPOTHESIS H4

Under the degree of environmental turbulence, the sample is classified into two groups. On the one hand, enterprises with lower environmental turbulence are regarded as being in a more stable environment. On the other hand, enterprises with higher environmental turbulence are regarded as being in a more turbulent environment. Subsequent to this, stepwise regressions are performed on the two groups of samples separately, and the results are presented in Table 7.

In a relatively stable environment, the impacts of design AMT ($\beta = 0.189$, p>0.1) and manufacturing AMT (B=0.202, p>0.1) on PIP are not significant. Further, manufacturing AMT and design AMT demonstrate some negative interactions with PIP ($\beta = -0.068$, p>0.1), but they are not significant. Meanwhile, this reveals that it is difficult to synergize design AMT and manufacturing AMT in a more stable environment to a certain extent. In a more turbulent environment, both manufacturing AMT ($\beta = 0.163$, p<0.05) and design AMT ($\beta = 0.304$, p<0.05) exert a significant impact on PIP. However, the impact coefficient of design AMT is higher. Besides this, design AMT and manufacturing AMT exhibit a positive interaction on PIP ($\beta = 0.216$, p<0.05). Additionally, design AMT and manufacturing AMT can synergistically affect PIP when the environmental turbulence is high. Thus, hypothesis H4 is tested.

## IV. CONCLUSION

On the basis of a research sample of 302 equipment manufacturing enterprises in China, this paper empirically investigated how the moderating influences of organizational culture and environmental turbulence affect manufacturing AMT, design AMT, and their synergistic effects on PIP. Consistent with this, the major findings of this study are as follows.

First, the influence of design AMT on PIP - the moderating effect of organizational culture and environment turbulence: the higher the degree of flexibility-oriented culture (the lower the amount of control-oriented culture), the more dynamic the organization's external environment is, and the more prominent is the contribution of design AMT to PIP. Consistently, the high volatility of the external environment mirrors that organizations require the ability to promptly design products using digital design tools in response to fluctuating external technology paradigms and market demands. To be specific, a flexibility-oriented culture empowers employees to operate autonomously and respond quickly and accurately to customer needs; thus, utilizing design AMT to attain agile product development and positively support PIP.

Second, the effect of manufacturing AMT on PIP - the moderating effect of organizational culture and environment turbulence: the higher the amount of flexibility-oriented culture (the lower the extent of control-oriented culture), and the positive effect of manufacturing AMT on PIP is more significant. Certainly, flexible culture orientation provides front-line production employees with appropriate decision-making power, which encourages employees to be multi-skilled and highly trained, capable of rapidly diagnosing and troubleshooting production-related problems and proposing practical and economic solutions, which uplifts the potential for flexible application of manufacturing AMT. In terms of the volatility of the external environment, the diversification of customer demands necessitates corporations to utilize the flexible production system of manufacturing AMT, in order to adapt to the requirements of mass customization. Therefore, the proposed flexible production system also plays a positive moderating effect on PIP, which is in line with the expectation of this study. Nonetheless, the derived results are not significant since other factors brought about by environmental turbulence, including the high environmental turbulence that makes the enterprise's current production specifications and knowledge system gradually lose their value, which may, to some extent, neutralize their original positive impacts on the PIP by manufacturing AMT.

Third, the potential impact of synergy between design AMT and manufacturing AMT on PIP-the moderating effect of organizational culture and environment turbulence: in organizations with higher external environment dynamics and stronger control culture orientation, the synergy between design AMT and manufacturing AMT reports a positive interaction effect on PIP. In contrast to the finding that design AMT and manufacturing AMT individually moderated the positive interaction of design AMT and manufacturing AMT were more significant, from the perspective of control culture orientation. In control culture-oriented companies, design AMT and manufacturing AMT synergy can be declared as a design-manufacturing integration mechanism, through which new product design and manufacturing can be transformed into interdependent tasks; the mismatch between possible errors and functionality is minimized, the resource allocation efficiency is optimized, and the digital innovation process is boosted. As a result, design AMT and manufacturing AMT can facilitate each other to improve PIP in a highly control-oriented corporate culture. In flexible culture-oriented enterprises, the synergistic influence of design AMT and manufacturing AMT on PIP is insignificant and negative as in this case, the difficulty of integration of design and manufacturing leads to an increase in iteration times, resulting in increased collaboration time and resource consumption; thereby, leading to the cost of innovation exceeding the benefit. Therefore, it is not possible to effectively integrate to support innovation [58]. In line with the finding that design AMT and manufacturing AMT individually perform their moderating roles, the synergistic influence of design AMT and manufacturing AMT is more significant in the more volatile environment. Both design and manufacturing AMTs have a positive effect on PIP in highly volatile environments, and corporations tend to strongly rely on the synergistic effects of design- and manufacturing AMTs in volatile environments. Since the synergistic effects of design and manufacturing AMTs determine, to some extent, the extent and pace with which external knowledge and information can be transformed into new products, the value of design AMT and manufacturing AMT synergies uplifts significantly in terms of the volatile environments; whereas the adoption of established and more cost-effective manufacturing methods shall be more beneficial in a relatively stable and low volatile environment, due to low changes in external technological paradigms and market demand.

## V. PRACTICAL AND ACADEMIC CONTRIBUTIONS

### A. ACADEMIC CONTRIBUTIONS

First, this paper expands the extant literature on AMT. Prior AMT studies have most often elucidated the effect of manufacturing AMTor design AMT on the PIP from a1-dimensional standpoint. This article studies the influence of and manufacturing AMT or design AMT and the synergistic effect of the two on PIP from both multi-dimensional and 1-dimensional viewpoints; thus, verifying the positive impact of multi-dimensional and 1-dimensional AMT on PIP. The proposed finding expands the relevant studies on the influence of multidimensional AMT on PIP [24], [25], which is conducive to the development and improvement of the AMT theoretical system.

Second, this study enriches the moderating influences of environmental turbulence, explores and illuminates the analysis of environmental turbulence's effect on the AMT and PIP, and proposes that there exist differences in the moderating mechanisms of environmental turbulence on the manufacturing AMT, design AMT, and the synergistic effect of the two and PIP. Prominently, enterprises are experiencing a special situation of rapid technological, institutional, and market changes, as well as a substantial degree of uncertainty. Concurrently, the turbulence and changes in the environment in which corporations operate present key factors that should be taken into account, in order to accelerate product innovation. In line with this, the study conclusion confirms the positive moderating impact of environmental turbulence on the association between design AMT and PIP, as well as the synergy between design AMT and manufacturing AMT and PIP. Thus, the study findings validate Candi and Beltagui's [59] argument which holds that 3DP is more effective in supporting innovation performance when utilized in highly volatile environments; consequently, further enriching the role of environmental turbulence in PIP.

Third, the value of organizational culture for enterprise-oriented performance has been recognized in previous studies [3], although few empirical works have been reported in the existing literature that associate organizational culture with the domains related to product innovation. Nevertheless, this study investigates the differences and similarities in terms of their moderating impacts on the design AMT, manufacturing AMT, and the synergy between the two and PIP in the context of competing value frameworks. The proposed research findings validate the positive moderating influence of flexibility-oriented culture on PIP when manufacturing- or design AMT is adopted, while control-oriented culture positively contributes to the PIP only when the two are synergized. On the basis of competitive value framework theory and creativity process perspective, this article extends and enriches the research analysis of Zammuto's [17] by empirically studying the role of moderating impact of cultural orientation in the correlation between AMT and PIP.

### B. PRACTICAL CONTRIBUTIONS

First, to improve PIP through the application of AMT, equipment manufacturing enterprises should pay attention to two types of AMTs: design AMT and manufacturing AMT. Technological innovation is the only way for equipment manufacturing enterprises to improve PIP. Improving PIP for equipment manufacturing enterprises requires simultaneous efforts in product design and manufacturing, and cannot be achieved without applying two types of AMTs. By implementing these two types of AMTs, equipment manufacturing enterprises can achieve product design optimization and manufacturing optimization, thereby better enhancing PIP.

Second, Equipment manufacturing enterprises should focus on leveraging the ''soft power'' role of organizational culture when applying design AMT and manufacturing AMT. When using only one type of AMT, considering that the promotion effect of flexibility-oriented culture on PIP is more obvious than that of control-oriented culture, more attention should be paid to flexibility-oriented culture, advocating the spirit of exploration, embracing change, and continuous change, giving employees more and greater work autonomy to quickly and accurately adapt to and meet customer product design and manufacturing needs, and positively regulating PIP. When applying both design AMT and manufacturing AMT simultaneously, considering that a control-oriented culture can better reduce the costs of adaptation, coordination, and communication in different application stages or departments, promote and ensure the effective coexistence and better synergy of the two different types of AMTs, it is necessary to consciously strengthen the control-oriented culture, advocate for strong execution and collaborative spirit, maximize the promoting effect of simultaneously applying two types of AMTs on PIP.

Third, in the process of simultaneously applying design AMT and manufacturing AMT to improve PIP, equipment manufacturing enterprises should consider the turbulence and changes in the external environment as positive factors rather than negative factors to improve PIP. They should actively embrace and respond to changes, achieve accurate identification, scientific adaptation, and proactive pursuit of change. AMT (such as CAD and 3DP) is more suitable for turbulent environments. In highly volatile environments, rapid product innovation is crucial. However, in less volatile environments, production capacity and costs are crucial [60]. In the context of the digital economy, industrial transformation drives the rapid transformation of technological paradigms and the increasingly fierce market competition in the knowledge economy era has become the norm. However, the rapid

**TABLE 8.**

| Variables | Code | 汉语量表改编版 | Original Scale |
|---|---|---|---|
| Design AMT | AMT1 | 计算机辅助设计（CAD） | Computer-aided design (CAD) |
| | AMT2 | 计算机辅助工程（CAE） | Computer-aided engineering (CAE) |
| | AMT3 | 计算机辅助工艺及规划（CAPP） | Computer-aided process planning (CAPP) |
| Manufacturing AMT | AMT4 | 计算机数控机床（CNC） | Computerized numerical control (CNC) |
| | AMT5 | 计算机辅助制造（CAM） | Computer-aided manufacturing(CAM) |
| | AMT6 | 环境控制系统 | Environmental control systems |
| | AMT7 | 条形码/自动识别 | Bar coding/automatic identification |
| | AMT8 | 实时过程控制系统 | Real-time process control systems |
| | AMT9 | 柔性制造系统（FMS） | Flexible manufacturing systems (FMS) |
| | AMT10 | 自动化物料搬运系统（AMH） | Automated material handling systems (AMH) |
| | AMT11 | 成组技术（GT） | Group technology (GT) |
| | AMT12 | 机器人技术 （PR） | Robotics |
| | AMT13 | 快速成型技术 | Rapid prototyping methods |
| | AMT14 | 计算机集成制造系统（CIM） | Computer integrated manufacturing systems (CIM) |
| | AMT15 | 工业物联网（IIoT） | Industrial internet of things（IIOT） |
| | AMT16 | 工业大数据（IBD） | Industrial big data（IBD） |
| | AMT17 | 云计算 （CC） | Cloud computing (CC) |
| Product Innovation Performance | PIP1 | 技术创新取得的整体绩效 | Overall technology innovation performance |
| | PIP2 | 新产品或新服务的可盈利性 | Profitability of innovative products or services |
| | PIP3 | 新产品或新服务取得的市场份额 | Market share from innovative products or services |
| | PIP4 | 新产品或新服务的增长 | Growth in new products or services |
| Control-oriented Culture | COC1 | 控制，集中化 | COC1-Control, centralization |
| | COC2 | 常规化，形式化，结构 | COC2-Routinization, formalization, structure |
| | COC3 | 稳定性，连续性和秩序 | COC3-Stability, consistency, order |
| | COC4 | 可预测的绩效结果 | COC4-Predictable, performance, results |
| | COC5 | 方向，目标设定，目标清晰 | COC5-Mission priorities, accomplishment, achievement |
| | COC6 | 关注任务重点、成就 | COC6-Direction, target setting, target clarification |
| | COC7 | 效率，生产力，盈利能力 | COC7-Efficiency, productivity, profitability |
| | COC8 | 追求卓越、品质 | COC8-Outcome, excellence, quality |
| Environmental turbulence | ET1 | 我们行业的技术日新月异 | ET1-The industry's technology is changing fast |
| | ET2 | 技术变革为行业发展带来无限机遇 | ET2-Technological revolution is a huge opportunity for our industry |
| | ET3 | 通过行业技术突破，衍生大量的新产品服务理念 | ET3-Technological breakthroughs in our industry have made many new product/service ideas possible |
| | ET4 | 我们行业的技术发展是巨大的 | ET4-The technological revolution in our industry are substantial |
| | ET5 | 在我们开展的业务中，客户对产品和服务的偏好随时间改变 | ET5-In our business, our customers are always looking for new products and services |
| | ET6 | 在我们开展的业务中，客户总是不断寻求新产品和服务 | ET6-In our business, customers' preferences for products and services have changed over time |

updating and iteration of the technological environment and the ever-changing market environment not only pose challenges for enterprises to catch up with technology, but also bring new opportunities for enterprises, and amplify the role of AMT in promoting new product development. Therefore, application design AMT and manufacturing AMT enable enterprises to better adapt to changes and demands in the external environment.

## VI. LIMITATION AND FUTURE RESEARCH

First, this study employs cross-sectional data, which is not completely consistent with the logical order of possible effects. Since design AMT, manufacturing AMT, and their synergistic effect on PIP need to be implemented for a time period before these variables can play a role, in order to overcome this point, this research study chooses the PIP of the sample of enterprises "established more than three years" and "current", which lessen the cross-sectional data to a certain extent. Future research can undertake a long-term tracking study, from a longitudinal viewpoint, in order to yield more robust conclusions.

Second, the sample data of companies covers 7 industries of equipment manufacturing industry, based on the different characteristics of firms, firm age, firm size, and firm location. However, the empirical part of this paper in the number of questionnaires have certain deficiencies due to the limitations of the actual situation. Although the number of questionnaires fulfills the requirements of large-sample empirical analysis, the resource constraints make the overall sample size relatively small, therefore the generalizability of the research conclusions needs to be further tested in future studies.

Third, this paper discusses the mechanism of design AMT, manufacturing AMT, and the synergy between the aforementioned variables and PIP in the context of organizational culture and environmental turbulence as the amount of external and internal situational factors. Nevertheless, the degree of employee participation within the organization, and the pace of internationalization outside the organization may also be significant factors impacting the PIP. Therefore, this phenomenon should be further expanded in future research, in order to upgrade the existing theoretical framework.

## APPENDIX

See Table 8.

## REFERENCES


[1] D. L. M. Nascimento, V. Alencastro, O. L. G. Quelhas, R. G. G. Caiado, J. A. Garza-Reyes, L. Rocha-Lona, and G. Tortorella, "Exploring industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal," *J. Manuf. Technol. Manage.*, vol. 30, no. 3, pp. 607–627, Apr. 2019.

[2] D. J. Hickson, C. R. Hinings, C. A. Lee, R. E. Schneck, and J. M. Pennings, "A strategic contingencies' theory of intraorganizational power," *Administ. Sci. Quart.*, vol. 16, no. 2, p. 216, Jun. 1971.

[3] G. N. Stock and C. M. McDermott, "Organizational and strategic predictors of manufacturing technology implementation success: An exploratory study," *Technovation*, vol. 21, no. 10, pp. 625–636, Oct. 2001.

[4] W. J. Orlikowski, "Using technology and constituting structures: A practice lens for studying technology in organizations," *Org. Sci.*, vol. 11, no. 4, pp. 404–428, Aug. 2000.

[5] S. Uwizeyemungu, P. Poba-Nzaou, and J. St-Pierre, "Assimilation patterns in the use of advanced manufacturing technologies in SMEs: Exploring their effects on product innovation performance," *J. Inf. Syst. Technol. Manage.*, vol. 12, no. 2, pp. 271–288, May 2015.

[6] P. S. Adler, "Managing flexible automation," *California Manage. Rev.*, vol. 30, no. 3, pp. 34–56, Apr. 1988.

[7] K. K. Boyer, P. T. Ward, and G. K. Leong, "Approaches to the factory of the future. An empirical taxonomy," *J. Oper. Manage.*, vol. 14, no. 4, pp. 297–313, Nov. 1996.

[8] P. M. Swamidass and S. Kotha, "Explaining manufacturing technology use, firm size and performance using a multidimensional view of technology," *J. Oper. Manage.*, vol. 17, no. 1, pp. 23–37, Dec. 1998.

[9] S. R. Tiller, "Organizational structure and management systems," *Leadership Manage. Eng.*, vol. 12, no. 1, pp. 20–23, Jan. 2012.

[10] J. Sauer, B. Zimolong, and S. Ingendoh, "Maintaining production quality in advanced mechanical engineering organizations: The compensatory function of the CNC-machine operator," *Hum. Factors Ergonom. Manuf.*, vol. 10, no. 4, pp. 465–480, 2000.

[11] H. Singh and R. Mahmood, "Aligning manufacturing strategy to export performance of manufacturing small and medium enterprises in Malaysia," *Proc.-Social Behav. Sci.*, vol. 130, pp. 85–95, May 2014.

[12] R. E. Quinn, *Beyond Rational Management*. San Francisco, CA, USA: Jossey-Bass, 1988.

[13] R. E. Quinn and J. A. Rohrbaugh, "Competing values approach to organizational effectiveness," *Public Productiv. Rev.*, vol. 2, no. 2, pp. 122–140, May 1981.

[14] R. E. Quinn and J. Rohrbaugh, "A spatial model of effectiveness criteria: Towards a competing values approach to organizational analysis," *Manage. Sci.*, vol. 29, no. 3, pp. 363–377, Mar. 1983.

[15] M. M. Ajmal and K. U. Koskinen, "Knowledge transfer in project-based organizations: An organizational culture perspective," *Project Manage. J.*, vol. 39, no. 1, pp. 7–15, Mar. 2008.

[16] D. R. Denison and A. K. Mishra, "Organizational culture and organizational effectiveness: A theory and some preliminary empirical evidence," *Acad. Manag. Proc.*, no. 1, pp. 168–172, Aug. 1989.

[17] R. F. Zammuto and E. J. O'Connor, "Gaining advanced manufacturing technologies' benefits: The roles of organization design and culture," *Acad. Manage. Rev.*, vol. 17, no. 4, pp. 701–728, Oct. 1992.

[18] B. J. Jaworski and A. K. Kohli, "Market orientation: Antecedents and consequences," *J. Marketing*, vol. 57, no. 3, p. 53, Jul. 1993.

[19] R. Calantone, R. Garcia, and C. Dröge, "The effects of environmental turbulence on new product development strategy planning," *J. Product Innov. Manage.*, vol. 20, no. 2, pp. 90–103, Feb. 2003.

[20] P. Anderson, "Organizational environments and industry exit: The effects of uncertainty, munificence and complexity," *Ind. Corporate Change*, vol. 10, no. 3, pp. 675–711, Aug. 2001.

[21] U. Lichtenthaler and H. Ernst, "Developing reputation to overcome the imperfections in the markets for knowledge," *Res. Policy*, vol. 36, no. 1, pp. 37–55, Feb. 2007.

[22] A. K. Kohli and B. J. Jaworski, "Market orientation: The construct, research propositions, and managerial implications," *J. Marketing*, vol. 54, no. 2, p. 1, Apr. 1990.

[23] C.-N. Chiu and C.-L. Yang, "Competitive advantage and simultaneous mutual influences between information technology adoption and service innovation: Moderating effects of environmental factors," *Struct. Change Econ. Dyn.*, vol. 49, pp. 192–205, Jun. 2019.

[24] X. Chen, S. Liu, J. Zhao, H. Wu, J. Xian, and J. Montewka, "Autonomous port management based AGV path planning and optimization via an ensemble reinforcement learning framework," *Ocean Coastal Manage.*, vol. 251, May 2024, Art. no. 107087.

[25] G. P. Yin and Y. Chen, "An empirical study of corporate IT capabilities and their impact on informatization success—Based on the RBV theory perspective," *Nankai. Bus. Rev.*, vol. 12, no. 4, pp. 152–160, Apr. 2009.

[26] A. Nair, C. Ataseven, and P. M. Swamidass, "An examination of the use of manufacturing technologies and performance implications in U.S. plants with different export intensities," *Int. J. Prod. Res.*, vol. 51, no. 11, pp. 3283–3299, Jun. 2013.

[27] M. Darbanhosseiniamirkhiz and W. K. Wan Ismail, "Advanced manufacturing technology adoption in SMEs: An integrative model," *J. Technol. Manage. Innov.*, vol. 7, no. 4, pp. 112–120, Dec. 2012.

[28] X. Chen, S. Liu, R. W. Liu, H. Wu, B. Han, and J. Zhao, "Quantifying Arctic oil spilling event risk by integrating an analytic network process and a fuzzy comprehensive evaluation model," *Ocean Coastal Manage.*, vol. 228, Sep. 2022, Art. no. 106326.

[29] N. Hewitt-Dundas, "The adoption of advanced manufacturing technology and innovation strategy in small firms," *Int. J. Innov. Technol. Manage.*, vol. 1, no. 1, pp. 17–36, Mar. 2004.

[30] J. Bourke and S. Roper, "AMT adoption and innovation: An investigation of dynamic and complementary effects," *Technovation*, vols. 55–56, pp. 42–55, Sep. 2016.

[31] S. Altuntas, O. Cinar, and S. Kaynak, "Relationships among advanced manufacturing technology, innovation, export, and firm performance: Empirical evidence from Turkish manufacturing companies," *Kybernetes*, vol. 47, no. 9, pp. 1836–1856, May 2018.

[32] Y. D. Cao, D. T. Yang, and J. Z. Yang, "An empirical study on the relationship between advanced manufacturing technology application, human resource management, and innovation capability: A case study of Jiangsu manufacturing industry," *Sci. Technol. Prog. Policy*, vol. 28, no. 11, pp. 51–54, May 2011.

[33] Y. Chen and Z. D. Huang, "The relationship between advanced manufacturing technology and innovation capability: An empirical study based on manufacturing enterprises in Jiangsu province," *Enterprise Economy*, vol. 10, no. 11, pp. 52–56, Nov. 2015.

[34] T. Kong, T. Feng, and C. Ye, "Advanced manufacturing technologies and green innovation: The role of internal environmental collaboration," *Sustainability*, vol. 8, no. 10, p. 1056, Oct. 2016.

[35] M. Ungan, "Factors affecting the adoption of manufacturing best practices," *Benchmarking, Int. J.*, vol. 11, no. 5, pp. 504–520, Oct. 2004.

[36] A. Fayolle, O. Basso, and V. Bouchard, "Three levels of culture and firms' entrepreneurial orientation: A research agenda," *Entrepreneurship Regional Develop.*, vol. 22, nos. 7–8, pp. 707–730, Nov. 2010.

[37] R. C. May, W. H. Stewart, and R. Sweo, "Environmental scanning behavior in a transitional economy: Evidence from Russia," *Acad. Manage. J.*, vol. 43, no. 3, pp. 403–427, Jun. 2000.

[38] K. K. Boyer, "Evolutionary patterns of flexible automation and performance," *Manage. Sci.*, vol. 45, no. 6, pp. 824–842, Jun. 1999.
[39] J. Gómez and P. Vargas, "Intangible resources and technology adoption in manufacturing firms," *Res. Policy*, vol. 41, no. 9, pp. 1607–1619, Nov. 2012.
[40] G. Wang and L. Zhang, "Simulation analysis of dynamic feedback correlation between advanced manufacturing technology (AMT) and product innovation performance," *IEEE Eng. Manag. Rev.*, vol. 50, no. 1, pp. 113–131, 1st Quart., 2022.
[41] T. Büschgens, A. Bausch, and D. B. Balkin, "Organizational culture and innovation: A meta-analytic review," *J. Product Innov. Manage.*, vol. 30, no. 4, pp. 763–781, Jul. 2013.
[42] G. Ahuja and C. M. Lampert, "Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions," *Strategic Manage. J.*, vol. 22, nos. 6–7, pp. 521–543, Jun. 2001.
[43] X. Xing and D. Liang, "Antecedents and consequences of exploitative, exploratory and balanced innovation: Environmental turbulence and start-up firm performance," *Sci. Technol. Manage. Res.*, vol. 36, no. 13, pp. 1–7, Jul. 2016.
[44] J. J. Zhou and X. F. Yao, "Advanced manufacturing technology and the new industrial revolution," *Comput. Integr. Manuf. Syst.*, vol. 21, no. 8, pp. 1963–1978, Aug. 2015.
[45] R. E. Quinn and G. M. Spreitzer, "The psychometrics of the competing values culture iinstrument and an analysis of the impact of organizational culture on quality of life," *Res. Organizational Change Develop.*, vol. 10, no. 5, pp. 115–142, Jan. 1991.
[46] E. M. Olson, S. F. Slater, and G. T. M. Hult, "The performance implications of fit among business strategy, marketing organization structure, and strategic behavior," *J. Marketing*, vol. 69, no. 3, pp. 49–65, Jul. 2005.
[47] N. Azad and F. Ahmadi, "The customer relationship management process: Its measurement and impact on performance," *Uncertain Supply Chain Manage.*, vol. 3, no. 1, pp. 43–50, 2015.
[48] J. B. Sørensen and T. E. Stuart, "Aging, obsolescence, and organizational innovation," *Administ. Sci. Quart.*, vol. 45, no. 1, pp. 81–112, Mar. 2000.
[49] J. Song, J. Chen, and Y. Sun, "The effect of network search on collaborative innovation performance under different geographic cultures," *Manage. Sci.*, vol. 27, no. 3, pp. 39–49, May 2014.
[50] J. F. Hair, W. C. Black, B. J. Babin, and R. E. Anderson, *Multivariate Data Analysis: A Global Perspective*, 7th ed. Upper Saddle River, NJ, USA: Pearson, 2010.
[51] R. P. Bagozzi and Y. Yi, "On the evaluation of structural equation models," *J. Acad. Market. Sci.*, vol. 16, no. 1, pp. 74–94, Jan. 1988.
[52] B. A. Çallü and L. Çallü, "Relationships between digital maturity, organizational agility, and firm performance: An empirical investigation on SMEs," *Bus. Manage. Stud., Int. J.*, vol. 9, no. 2, pp. 486–502, Jun. 2021.
[53] H. J. Arnold, "Moderator variables: A clarification of conceptual, analytic, and psychometric issues," *Organizational Behav. Hum. Perform.*, vol. 29, no. 2, pp. 143–174, Apr. 1982.
[54] D. Gefen, D. Straub, and M.-C. Boudreau, "Structural equation modeling and regression: Guidelines for research practice," *Commun. Assoc. Inf. Syst.*, vol. 4, pp. 1–78, Jan. 2000.
[55] J. R. Busemeyer and L. E. Jones, "Analysis of multiplicative combination rules when the causal variables are measured with error," *Psychol. Bull.*, vol. 93, no. 3, pp. 549–562, 1983.
[56] M. Candi, J. V. D. Ende, and G. Gemser, "Organizing innovation projects under technological turbulence," *Technovation*, vol. 33, nos. 4–5, pp. 133–141, Apr. 2013.
[57] R. Li and Q. Tao, "Three-dimensional intellectual capital linkage role and business model innovation," *Lanzhou. Acad. J.*, vol. 10, no. 3, p. 15, Mar. 2019.
[58] C. A. Rusinko, "Exploring the use of design-manufacturing integration (DMI) to facilitate product development: A test of some practices," *IEEE Trans. Eng. Manag.*, vol. 46, no. 1, pp. 56–71, Feb. 1999.
[59] M. Candi and A. Beltagui, "Effective use of 3D printing in the innovation process," *Technovation*, vols. 80–81, pp. 63–73, Feb. 2019.
[60] M. Baumers, P. Dickens, C. Tuck, and R. Hague, "The cost of additive manufacturing: Machine productivity, economies of scale and technology-push," *Technol. Forecasting Social Change*, vol. 102, pp. 193–201, Jan. 2016.

**GUILIAN WANG** received the Ph.D. degree in management science and engineering from Tianjin University of Finance and Economics, Tianjin, China. She is currently a Lecturer with the Department of Development Center for Innovation and Entrepreneurship, Tianjin Sino-German University of Applied Sciences, Tianjin. Her research interest includes technological innovation and management.

**YI LI** received the Ph.D. degree in management from Tianjin University of Finance and Economics, Tianjin, China. She is an Associate Professor with the Department of Faculty Affairs (Personnel Office), Tianjin Sino-German University of Applied Sciences, Tianjin. Her research interest includes innovation management and education.