Front. Eng. Manag. 2023, 10(3): 373–390
https://doi.org/10.1007/s42524-022-0237-x

RESEARCH ARTICLE

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Construction of digital 3D magic-cube organization structure for innovation-driven manufacturing

Abstract Owing to the heterogeneity between functional units and resource scarcity, manufacturing firms have been struggling with intra-organizational coordination for productivity and innovation. Traditional organizational structures, such as linear-functional and matrix, may cause responsibility division and independent goals (Shahani, 2020), and are more difficult to be adopted by large-sized innovative manufacturing firms for quantity production. This is based on a review of several new forms of organization (i.e., network organization, multiteam system, and platform organization) compared with the traditional forms of organization (i.e., linear, matrix, and business unit organization, among others). This study proposes a three-dimensional (3D) magic-cube organizational structure, considering the product dimensions, business, and administration. Moreover, the characteristics, propositions of system operation, system dynamic model, and working model of the 3D magic-cube organization are described. Finally, the 3D model is applied in a Chinese manufacturing firm to test its effectiveness. By redesigning the post and pay system, the pilot organization establishes a project-driven and cross-functional coordination mechanism, positively affecting the firm's financial profit, output value, labor productivity, and income of per capita. The proposed 3D model can be adopted by large- or medium-sized manufacturing firms for product development and innovation. The implications of both practice and theory are also discussed in this study.

Received April 13, 2022; accepted September 13, 2022

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This study is supported by the Key Project of the National Natural Science Foundation of China (Grant No. 72132001).

Keywords innovation, manufacturing, 3D magic-cube organization structure, coordination

1 Introduction

Manufacturing is the economic foundation of various countries. With the advancement of technological revolution, the deep integration of digital technology with the manufacturing industry has resulted in far-reaching industrial changes and the creation of new production modes, business models, and economic growth. Many countries have increased investments in science and technology to take further steps in the fields of Internet, big data, cloud computing, new energy, bioengineering, and new materials. China also proposed to make breakthroughs in high-end manufacturing and move from a "big manufacturing" to a "leading manufacturing". One challenge that manufacturing firms struggle with is the internal coordination activities among functional units. For example, Ghislanzoni et al. (2008) argue that cross-functional coordination has become a top concern for firms involved in product innovation. Research on multiteam system and project-based organization also found the positive relationship between intra-organizational coordination and product development (Mathieu et al., 2001; Samimi and Sydow, 2021). However, the negative effects of numerous barriers, including divergent goals and desire for autonomy among functional departments, on the performance of manufacturing firms (Zhang et al., 2008) should also be addressed.

To address the challenges of intra-coordination, manufacturing firms have been deploying various coordination strategies, such as redesigning the organization structure. For example, as the leading manufacturing firm in the United States, IBM has increased the cross-functional coordination by adopting network structure and process-based organization to be boundary open and customer-oriented for high productivity (Lawler and Worley, 2006). Organizational structure is defined as how people work together, and tasks are assigned (Mintzberg, 2007), enabling organizations to establish a formal structure, task allocation rules, and team responsibilities (Damanpour, 1991). Manufacturing firms typically use linear-functional, business units, or matrix organization structures to meet the external requirements of product innovation and market adaptability (Ren, 2005). However, traditional organizations and departments have relied on authority and hierarchical controls, allowing senior teams to be the decision-makers for the whole organization that may cause a slow information flow (Annosi and Brunetta, 2017). Moreover, traditional collaboration among different units, such as research and development (R&D), technology, and production operation, has suffered from functional separation and unclear responsibility boundaries (Mathieu et al., 2001), which can be unfavorable for the goal of an organization. Thus, management cost has increased annually (Xiang, 2015), making it difficult for organizations to match customer demands.

To address these challenges mentioned above, this study proposes a three-dimensional (3D) magic-cube organizational structure for manufacturing. The model is presented as a 3D network, with a coordination mechanism considering product traction, business support, and administrative guarantee (Xiang, 2014). This study may contribute to the existing literature in three ways. First, by reviewing and comparing prior organizational structure theories, a new cross-functional, process-based, and product-oriented organizational structure that is beneficial for intra-organizational coordination and productivity has been proposed. Second, the system operation dynamics and working mechanism of the proposed 3D model are discussed and its coordination mechanism is illustrated. This mechanism may contribute to the theory of organizational coordination (Victor and Blackburn, 1987). Finally, past research shows significant findings on organizational structure (Mathieu et al., 2001; Annosi and Brunetta, 2017); however, empirical tests to verify their effectiveness are relatively limited (Shahani, 2020). Therefore, this study conducts a field study to test the change effect of the 3D cube model and shows its positive relationship with firm's financial profit, gross output value rate, and labor productivity, among others.

2 Theoretical background

2.1 Traditional forms of organizational structure

There are six main types of organizational structures in the traditional industrial economy: Classical, linear, functional, linear-functional, matrix, and business unit structures (Li, 2000).

The classical organization is the embryonic form of organizational structure, which defines the hierarchy of managers and subordinates. Based on the classical organization, the linear organization further clarifies the responsibility and affiliation of managers and subordinates, enhancing the specialization and standardization of work. Beyond the focus on vertical management, functional organizations emphasize horizontal business connections between departments. Consequently, some organizations began to integrate "linear" and "functional" organizational structures for larger organization scales and more complex projects. Thus, the "linear-functional" organizational structure was formed (Lewin and Volberda, 1999).

In addition to the vertical structure of linear-functional organizations, there is a horizontal leadership system in matrix organizations. Members are subject to the vertical leadership of their departments and flexibly appointed by temporary project teams. Matrix organizations are more responsive because they strengthen the coordination among departments and optimize resource allocation (Turner et al., 1998). With the trend of business globalization, some large enterprises (e.g., Huawei, Haier, and General Motors) have established business units based on product classifications and different unit locations. With the decentralized management system, each business unit has an independent accounting system and a complete functional organization.

In summary, the development of organizational structure in traditional industrial economies shows two main characteristics. First, the hierarchy of organizations shift from centralization to decentralization (i.e., linear versus business unit organizations). Second, the boundaries within organizations are gradually expanded, strengthening horizontal coordination among functional departments (i.e., linear versus matrix organizations). However, traditional organizational structures primarily rely on top-down vertical decision-making (from managers to subordinates like a pyramid, see Fig. 1). Although the matrix organization enhances horizontal leadership, the members are under the dual leadership of functional departments and temporary projects, leading to vague responsibilities and separate roles (Clement and Puranam, 2018; Shahani, 2020).

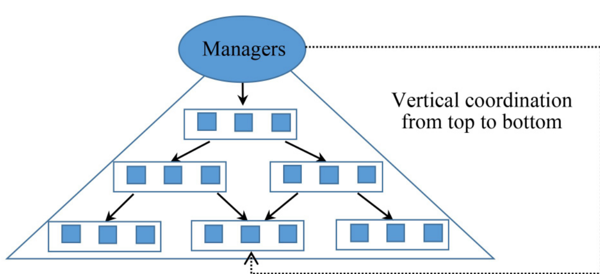

Fig. 1 Pyramid organizational structure.

2.2 New forms of organizational structure

With the volatile market and diverse demands of consumers, organizations need to be flexible and resilient to get closer to the market. New organizational forms, such as network organizations, multiteam systems, and platform organizations[1)], have gained substantial research attention (Ciborra, 1996; Sun, 2001; Porck et al., 2019). These new organization structures shifted from a "top-down" vertical management to a "bottom-up" leadership (like an inverted pyramid, see Fig. 2) (Clement and Puranam, 2018). Each empowered front team shares common performance, takes direct responsibility for customers, and collaborates cross-borderly, making the organization more responsive to the market. For example, the Amoeba management, conceived by Kazuo Inamori, involves structuring a company into small, fast-responding, and customer-focused units called "amoebas". By empowering each interdependent "amoeba" to share united goals, the Kyocera company has met outstanding financial performance over a period of years (Adler and Hiromoto, 2012; Adler et al., 2020).

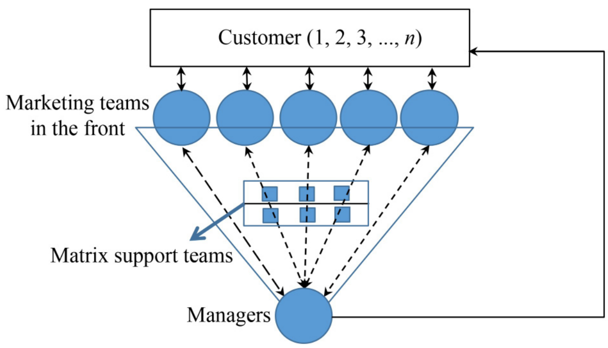

Fig. 2 Inverted pyramid organizational structure.

2.2.1 Network organization

From the perspective of the strategic network, organizations cannot exist in isolation (Podolny and Page, 1998). Network organization (Fig. 3) is an economic phenomenon dependent on strategic cooperation, division of labor, and trade among organizations, teams, or individuals. Compared with bureaucratic organizations, network organizations weaken internal boundaries and hierarchy and share external resource rather than compete for united profit goals. Moreover, network organizations also alleviate borders among sellers, users, and competitors, and activate all strategic network participants into value co-creation (Sun, 2001).

Four characteristics can be recognized for a network

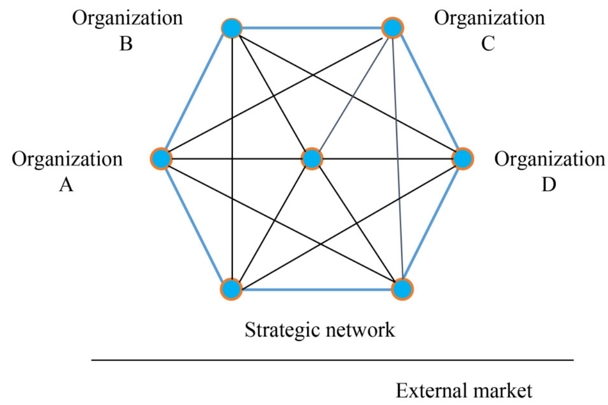

Fig. 3 Network organization.

organization. First, all participants in the strategic network share collective goals. Second, a network organization is connected by several active nodes for communication and decision-making. In addition, a network organization can be self-organizing and self-learning by the interplay of different participants. Finally, communication or digital technologies are generally used in a network organization for immediate information flow and collaborative innovation (Lin and Li, 2000).

2.2.2 Multiteam system (MTS)

A multiteam system (MTS) consists of two or more heterogeneous departments in response to complex emergencies (see Fig. 4). For example, leading by integration team, point teams in an MTS are oriented to the external market environment and take responsibilities for critical tasks. Support teams are functional with high specialization and provide expertise and technology to support the point team (Davison et al., 2012). To cope with urgent projects, all interdependent and boundaryless teams in an MTS take responsibility for collective goals, achieved by vertical and horizontal coordination among functional teams (Mathieu et al., 2001; Porck et al., 2019).

However, owing to the diverse compositions of an MTS, barriers generally impact communication and synergy among teams. Therefore, compound capabilities are needed for coordination. For example, members with experience in different functional departments can better understand work complexity, which is conducive to increasing cross-border interaction and improving team performance (de Vries et al., 2014). Furthermore, for a large-scale MTS, information communication technology can enhance collaboration by alleviating geographical distances among different departments (Steigenberger, 2016).

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1) There are many other new organizational structures and theories in this period, such as the boundaryless organization, flexible organization, and organic organization (Zanzi, 1987; Cross et al., 2000). Their common features are flattening, decentralization and boundaryless. This study compares three typical and recent theories of organizational structure.

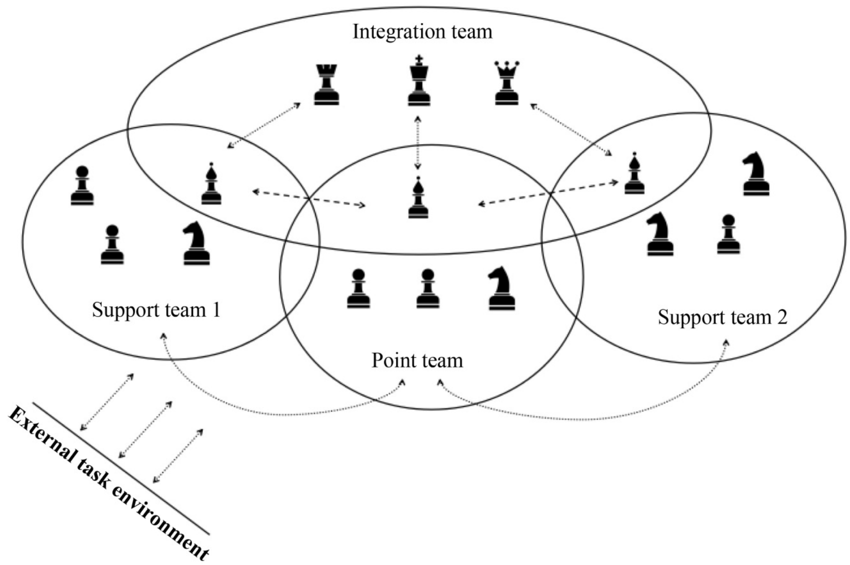

Fig. 4 Multiteam system (MTS).

2.2.3 Platform organization

The rapid development of digital or platform economy has produced the network effect of two- or multiple-sided markets, bringing about a new type of organization — the platform organization[1)] (Fig. 5). According to Cennamo and Santalo (2013), a platform organization continuously motivates co-value creation with the joint effort of multiple parties and achieves profits by meeting economies of scale. For example, Google Android provides a platform for app designers, consumers, and third-party companies, such as Samsung, and earns profit by selling advertising or other ancillary services (Cusumano et al., 2020).

Platform organizations mainly consist of three parts: Front, middle, and back platform. The front platform is responsive to consumers and is sensitive to the active market. The middle platform is responsible for resource integration and empowers the front platform with data

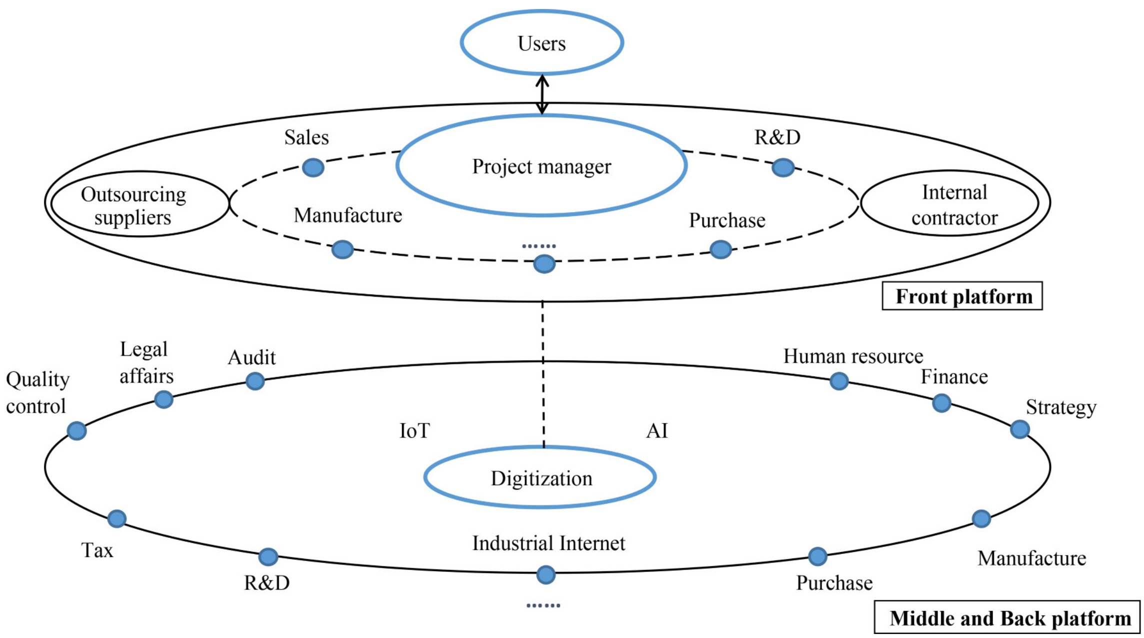

Fig. 5 Platform organization.

1) According to Gawer (2014), there are three types of platform organization: Internal platform, which serves internal production and forms a clear boundary with the external environment; supply chain platform, which matches upstream and downstream suppliers but has limited coordination capability; and industry platform, which acts as the ecological leader of the platform and fully cooperates with all participants to jointly create value. This study mainly reviews and summarizes the relevant characteristics of the industry platform.

support. The back platform generally sets rules and schedules strategic goals for the organization (Li and Yang, 2018). Digitalization makes platform organizations agile to volatile market. For example, through big data, platform organizations can accurately match products with the needs of users. Large-scale production can be achieved with artificial intelligence (AI), Internet of Things (IoT), and cloud computing, among others. Moreover, platform organizations are boundaryless and act as a "resource puddle" to gather multiple participants to create co-value (Sandhu and Kulik, 2019).

In summary, the three components of organizational structure are centralization, formalization, and integration (Duncan, 1979). Compared with traditional organizational structures, new forms of organizational structure (network, MTS, and platform) are decentralized and formed with networks. To some extent, they extend internal boundaries and alleviate information barrier and hierarchies within the organization. Moreover, new forms of organizational structure are less formalized with cross-border interaction and horizontal coordination (Clement and Puranam, 2018). Finally, using digital technology, information flow in these organizations is more dynamic and immediate, enhancing the integration capabilities of these new organizational structures.

2.3 Comparisons of organizational structures

The traditional organizational forms are found to less flat and decentralized (e.g., the horizontal leadership of a linear organization makes it more centralized and hierarchical than a matrix organization). Moreover, the organizational focus is more external-oriented in the new forms (e.g., a platform organization is more customer-focused and shares resources with platform participants for co-value creation). Table 1 compares the nine organizational structures reviewed above with their advantages/disadvantages and different application scenarios.

The rapid development of new digital intelligence technologies, such as AI, big data, and IoT, has reduced communication obstacles among organizations and users in various industries. With the increasing personalized demands of customers from different regions and ages, products provided by manufacturing firms also need to be diversified, causing product challenges. Moreover, it is still difficult for the traditional organizational forms (e.g., matrix organizational structure) widely adopted by medium- and large-sized firms to cope with the requirements of multiproduct batch production and R&D management of innovative organizations (Annosi and Brunetta, 2017; Shahani, 2020). Thus, this study proposes a 3D magic-cube organizational structure for innovative manufacturing and describes the geometric model, system dynamics model, and system working model of this organizational form. By applying the model in an innovative manufacturing firm, this study demonstrates the effectiveness of the model by addressing various batch production, resource constraints, and internal functional barriers suffered by the innovative manufacturing firm.

3 Construction of 3D magic-cube organizational structure for innovation-driven manufacturing digitalization

3.1 3D geometric model

3.1.1 Geometric model of 3D magic-cube organization structure

Previous research suggests that interactions among the product, business, and administration sectors influence

Table 1 Comparison of organizational structures

	Structure	Advantages	Disadvantages	Application scenarios
Traditional forms	Classical	Simple and effective	Lack of systematic scheduling	Small workshops
	Linear	Clear chain of command with clear authority and responsibility	Poor horizontal communication and high cost for management	Small-sized enterprises
	Functional	Professional division of labor and reasonable decentralization	Unclear authority and responsibility	Specialized enterprises
	Linear-functional	Clear authority and responsibility, professional division of labor and stable structure	Poor horizontal communication and inflated management costs	Medium- and large-sized enterprises
	Business unit	Balanced cost and control with consideration of both individual motivation and high-level workload	Internal competitive frictions and managerial redundancies	Large global enterprises
	Matrix	High flexibility and efficiency for projects	Two lines of leadership with unclear authority and responsibility	Large- and medium-sized project-based enterprises
New forms	Network	High connectivity and complementarity	Lack of business process pull	Strategic network organizations
	Multiteam system	Multi-team synergy and responsiveness	High demands for coordinators to cross boundaries	Temporary organizations responding to emergencies
	Platform	User-oriented and high degree of digitization	High demand for digital technology and resource allocation capabilities, higher risk, and uncertainty	Digital platform organizations act as intermediates of multiple sided markets

intra-organizational coordination (Annosi and Brunetta, 2017). For example, research found that trust between the business and IT sectors is positively associated with units collaboration and service quality (Mei and Xie, 2013). In addition, the project performance can be influenced by commitment between human resource managers and business managers (Li and Tao, 2016). Compared with technical control, bureaucratic control may hinder project autonomy, negatively affecting business and product development (Kellogg et al., 2020). To address the coordination barriers among traditional functional units, the 3D magic-cube organizational structure is proposed to strengthen coordination and interactions within three dimensions: Product, business, and administration. This can be beneficial for a united effort to realize product development and co-value creation.

As shown in Fig. 6, the top part of the 3D magic-cube organizational structure model is composed of the heads of each product project (or team) for resource allocation and integration. Based on the characteristics of matrix organization, network organization, MTS, and platform organization, the 3D magic-cube organization is project-based, cross-functional, and units-interdependent. The *z*-axis of the 3D magic-cube organization represents the product dimension, consisting of different types of product (i.e., research and expanded products). The *y*-axis is the business dimension (including functional units, such as strategy, R&D and technology), providing functional use for product scheduling and marketing. The *x*-axis is the administration dimension, composed of empowered lower administrative units, such as different producing departments or sub-factories, and provides resource

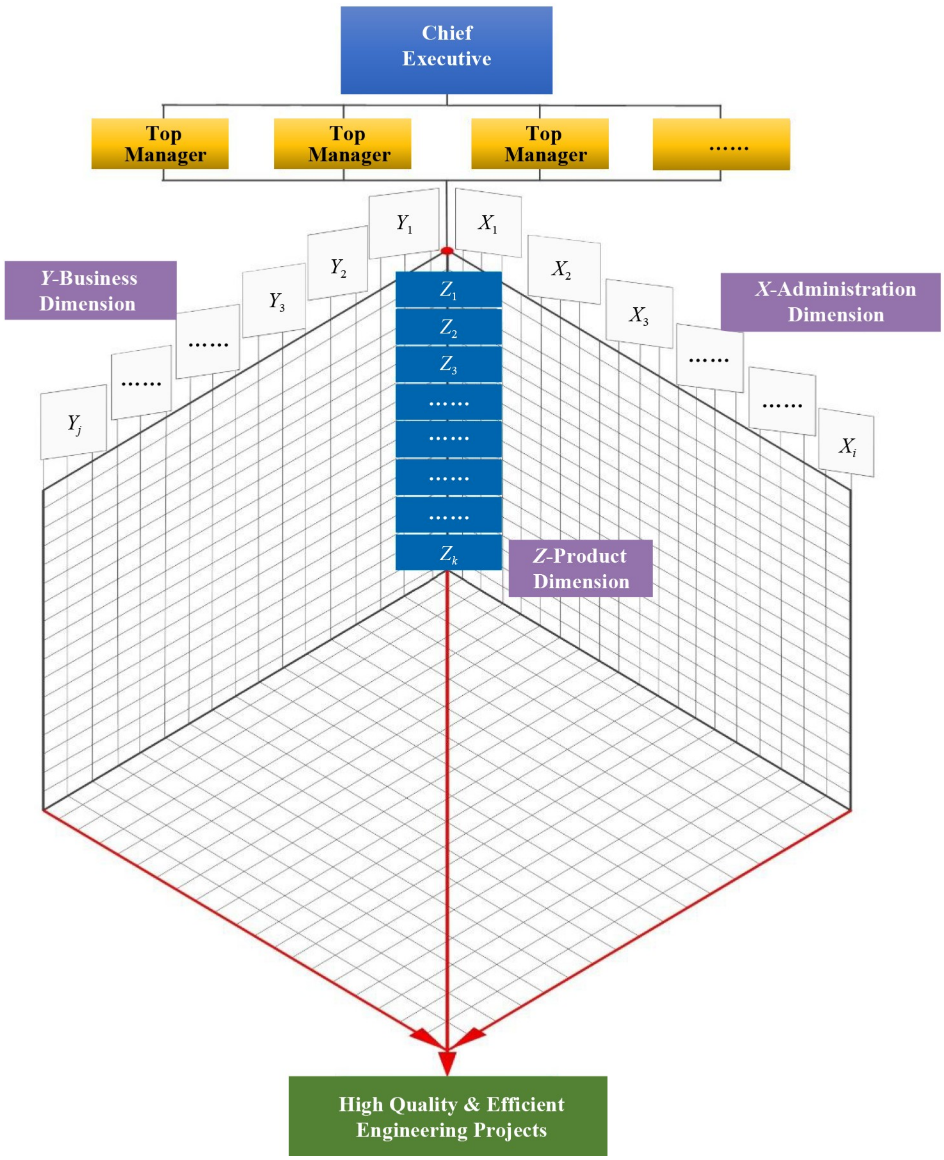

Fig. 6 Geometric model of 3D magic-cube organization structure.

guarantee for both the product and business dimensions. The administration dimension focuses on organizational decentralization and flexibility. In summary, the proposed 3D magic-cube model aims to optimize responsibility division among functional units and establish a decentralized and boundaryless organization to facilitate intra-organizational coordination and realize collective goals towards product development.

3.1.2 Characteristics of the 3D magic-cube organization structure

The 3D model has the characteristics of a matrix organization, which is project-oriented and subject to vertical coordination (e.g., top management) and horizontal coordination (e.g., engineering project managers). However, the 3D magic-cube structure builds a more flexible network structure by stripping traditional business level from the administration dimension, which is beneficial for a "de-administrative" and cross-functional business process.

The coordination mechanism of the model is similar to that of network organizations. The three dimensions of the 3D magic-cube organization share united network goals (i.e., product development and innovation) and interact with one another, forming effective communication and decision-making capabilities. Furthermore, the tightly connected network structure makes information and knowledge fully shared among dimensions, strengthening the self-learning capabilities and agility of the organization.

The team structure of the 3D magic-cube organization is similar to that of MTS. All units share the united organizational goal (i.e., engineering product goal) and focus on the coordination among the three dimensions to aggregate the scattered resource for products (Xiang, 2013b). However, the 3D model alleviates organizational control of vertical leadership; thus, it can be more project-driven and market-oriented. Finally, the organizational culture of the 3D model contributes to value co-creation, similar with industrial platform organizations. The product dimension is oriented to the market and customers, making the organization closer to external requirements, similar to the front platform. The business and administration dimensions are responsive for resource requirement from the product dimension, similar to the middle and back platform. All dimensions operate interdependently and contribute jointly to product development.

3.2 Basic propositions of 3D magic-cube organizational structure

3.2.1 Competency demand proposition — compound talent development strategy

In response to the challenges of rapid changes in the external market, the professional competencies of personnel required by the industry are becoming more comprehensive. In addition, companies have been introducing digital intelligence technologies for intra-organizational coordination. However, digital technology, such as algorithms equipped with stronger data processing, can be an alternative to people of various professions (van Laar et al., 2019). To avoid such risk, employees are demanded to master information and technologies across projects, departments, and fields, making themselves indispensable. Nonetheless, companies need to inspire talent development with complex competencies to drive agility and innovation. In the 3D magic-cube organization, although the three departmental dimensions have different functional divisions, they contribute to achieve united engineering goals. This study proposes that the compound talent development strategy is beneficial to intra-organizational coordination in 3D organization for three reasons. First, compound talents can enhance interdepartmental coordination across borders. Multiple expertise and skills can deepen the interpersonal cognitive complexity of employees and departments (de Vries et al., 2014) and can converge knowledge among teams to promote collaboration. Second, the compound talent development strategy facilitates innovation. Efficient communication between teams can consolidate social networks and operation systems in organizations (Kogut and Zander, 1992), creating an orderly knowledge exchange and driving innovation. Finally, teams with diverse and comprehensive capabilities have stronger problem-solving capability, realizing efficient human–machine cooperation and improving organizational agility (Lu and Ramamurthy, 2011). Therefore, Proposition 1 is presented.

Proposition 1: Compound talent development can enhance intra-organizational coordination in 3D magic-cube organization.

3.2.2 Technology demand proposition — connection, visualization, and intelligence

Digital technology is key for the efficient operation of the 3D magic-cube organization, enabling interdepartmental intelligent connection and collaborative production. Industrial Internet, IoT, block chain, AI, and digital twins are gradually integrated with the traditional industrial economy to integrate, coordinate, and optimize the entire production chain, significantly improving the efficiency of production and services (Thoben et al., 2017). For the network platform, digital technology can promote multi-sided collaboration within the organization, making departments more connective with each other. In addition, the integration platform and converged data provide visual support for management decisions, enhance the digitization and transparency of material supply and control, and increase the efficiency of financial use (Porter and Heppelmann, 2015). At the production end, the efficiency of manufacturing can be improved through industrial robots and intelligent production lines. Moreover, the industrial IoT applications enhance risk control of equipment and data security. Finally, the intelligent manufacturing scenario can be formed with intelligent R&D, production, supply chain, sales, security management, and operation management. Therefore, Proposition 2 is presented.

Proposition 2: Digital technology may facilitate connection between functional units, management visualization, and intelligent manufacturing, promoting intra-organizational coordination in the 3D magic-cube organization.

3.2.3 Organization culture proposition — adhocracy culture and boundary spanning

Previous studies have shown that business complexity, team heterogeneity, and individual hierarchical orientation can easily trigger interdepartmental coordination barriers (van Bunderen et al., 2018). Considering different characteristics among the three dimensions of 3D magic-cube organizations, the organizational culture development will be a guarantee mechanism for collaboration and production capability. First, organizations with adhocracy culture are oriented to external and organic focus, favoring the innovation, risk capacity, and adaptability of the members and building innovative and dynamic organizations (Wei et al., 2014). The 3D magic-cube organization with adhocracy culture gets close to the market demands. Thus, the organization focuses on innovation for purpose. Second, boundary spanning is also essential to the 3D magic-cube organizational culture. At the organizational level, the communication and collaboration barriers among departments can be broken by long-term coordination mechanisms, making each dimension focuses on product development and business processes. At the individual level, the traditional profit- or hierarchy-driven culture can also be replaced by the value of co-creation. Furthermore, employees are encouraged to overcome cognitive anxiety, benefitting long-term organizational learning and knowledge-sharing. Based on the above-mentioned theories, Proposition 3 is presented.

Proposition 3: The adhocracy culture and boundary spanning may strengthen intra-organizational coordination in the 3D magic-cube organization.

3.3 System dynamic model of 3D magic-cube organization structure

The system dynamics of the 3D magic-cube organization structure is the embodiment of internal process capability, acting as the driving force in the system operation. Through the interaction of product, business system, and administrative resource capabilities in the three dimensions, the coordination mechanism of product traction, business support, and administrative guarantee are deployed to jointly complete the project demands.

The product dimension (*z*-axis) acts as the traction of the 3D magic-cube organization structure, enabling organizations to integrate relevant administrative resources and business systems and effectively transform the resource and system capabilities to achieve the collective engineering goal.

The business dimension (*y*-axis) consists of functional units, such as R&D, technology, and quality systems, and provides specialized support for the organization to ensure maximum use of resource capability.

The administration dimension (*x*-axis) promotes the functions of personnel, finance, equipment, and facility resources of each administrative department in the organization. It ensures the availability of resources to meet the basic demands of engineering objectives and acts as the basic control of the 3D magic-cube organization structure.

In summary, the product dimension (*z*-axis) proposes product instructions and resource requirements to the business and administration dimensions, receiving resource support from the business dimension and guarantee from the administration dimension. Thus, it focuses on productivity (engineering result). Furthermore, the business dimension (*y*-axis), which contributes to product scheduling and marketing, focuses on product sale and expansion (engineering process). It performs the instructions given by the product dimension and receives the resource guarantee from the administration dimension. The administration dimension (*x*-axis) receives product and business instructions proposed by the product and business dimensions, respectively, provides resource support to the product and business dimensions, and acts as a distributor and coordinator to improve organizational efficiency.

The driving force of the product, system, and resource capabilities is enhanced through the functions of the product traction, business support, and administrative guarantee in the 3D model. Moreover, the coordination mechanism strengthens connections within the 3D magic-cube organization. The three dimensions realize the efficient use of the organization’s internal resources and system power, as shown in Fig. 7.

3.4 System operation model of 3D magic-cube organization structure

The volatile market requires manufacturing firms to be production-diversified. These projects are completed by each project team according to the operation process, and the team members have common goals in terms of cost, schedule, and quality. Therefore, the objective of 3D magic-cube organization is identical to that of project management, which shares the collective principles of

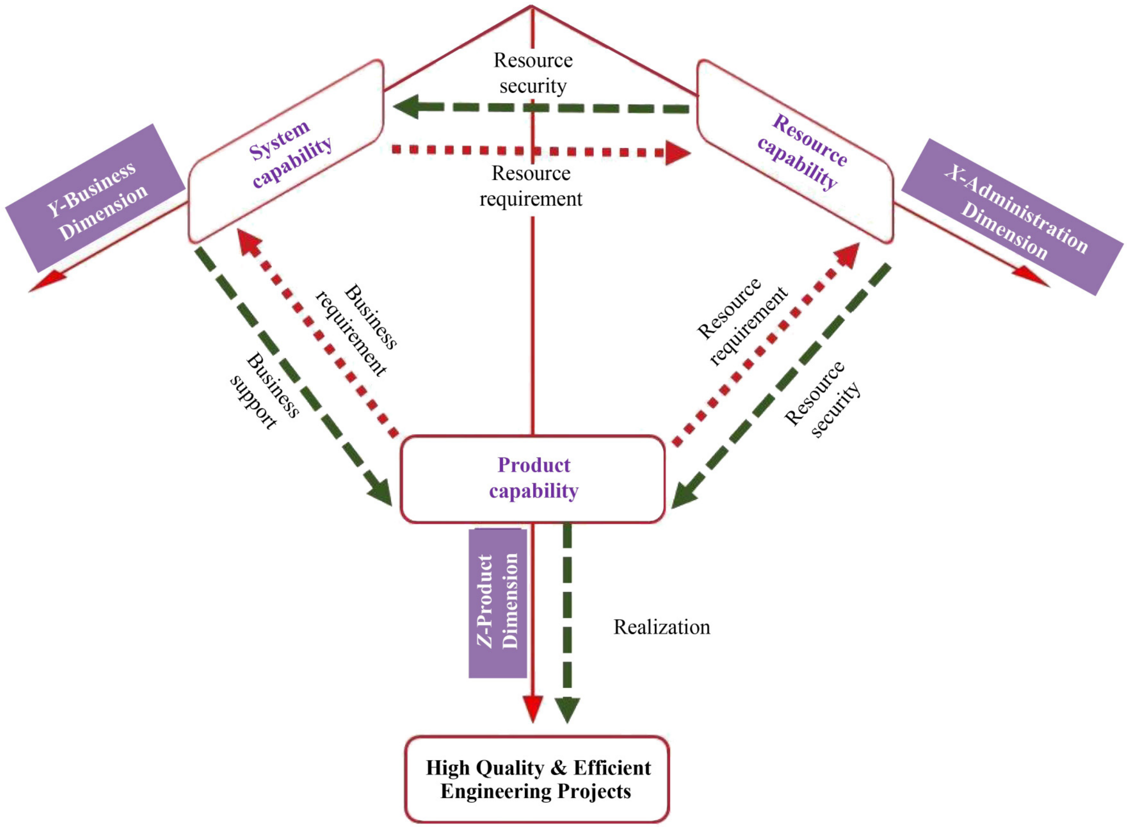

Fig. 7 System dynamic model of 3D magic-cube organization structure.

production with high efficiency among units (Xiang, 2013a).

Based on the description of the system dynamics of the 3D magic-cube organizational structure, the system operation model of the 3D magic-cube organization structure is constructed with the post system of product, business, and administration dimensions. The system work within the 3D magic-cube organization structure is decomposed into project teams led by product project managers, with business managers providing system support and administrative department managers guaranteeing resources. From the product, business, and administration dimensions, a project-based mechanism of "product traction, business support, and administrative guarantee" has been formed, as shown in Fig. 8.

From the single project perspective, the project teams quickly integrate resources guided by project goals with systematic management and division of labor. Moreover, the project teams strictly implement the product schedule and evaluate the productivity. After implementation of project management, teams draw up improvement schedules and clarify the responsibilities of all team members.

From the overall perspective of the system operation model, each team contributes to the collective engineering goals of their respective responsibility nodes within the process. The horizontal connection unifies each team to achieve a set of project objectives. It realizes the flexible sharing and project-based utilization of resources and eliminates the disadvantages of multiline leadership and unclear responsibility division in traditional matrix organizations (Shahani, 2020). Teams are not completely parallel or independent but are flexible to each project depending on the production schedule.

4 Practical applications and a field study of 3D magic-cube organization structure

The proposed 3D magic-cube structure is applied in an aeroengine manufacturing firm located southwest of China. The size of the pilot organization, consisting of 5 sub-factories and 8 functional departments, is more than 2200 staffs. To address the coordination barrier and resource scarcity among units, the 3D magic-cube organizational structure was applied in the pilot firm since 2014.

4.1 3D magic-cube organization structure transformation

To enhance intra-organizational coordination, the manufacturing firm strengthened the product responsibility across hierarchies. Based on the mechanism of product traction, business support, and administrative guarantee, the comprehensive management efficiency of products

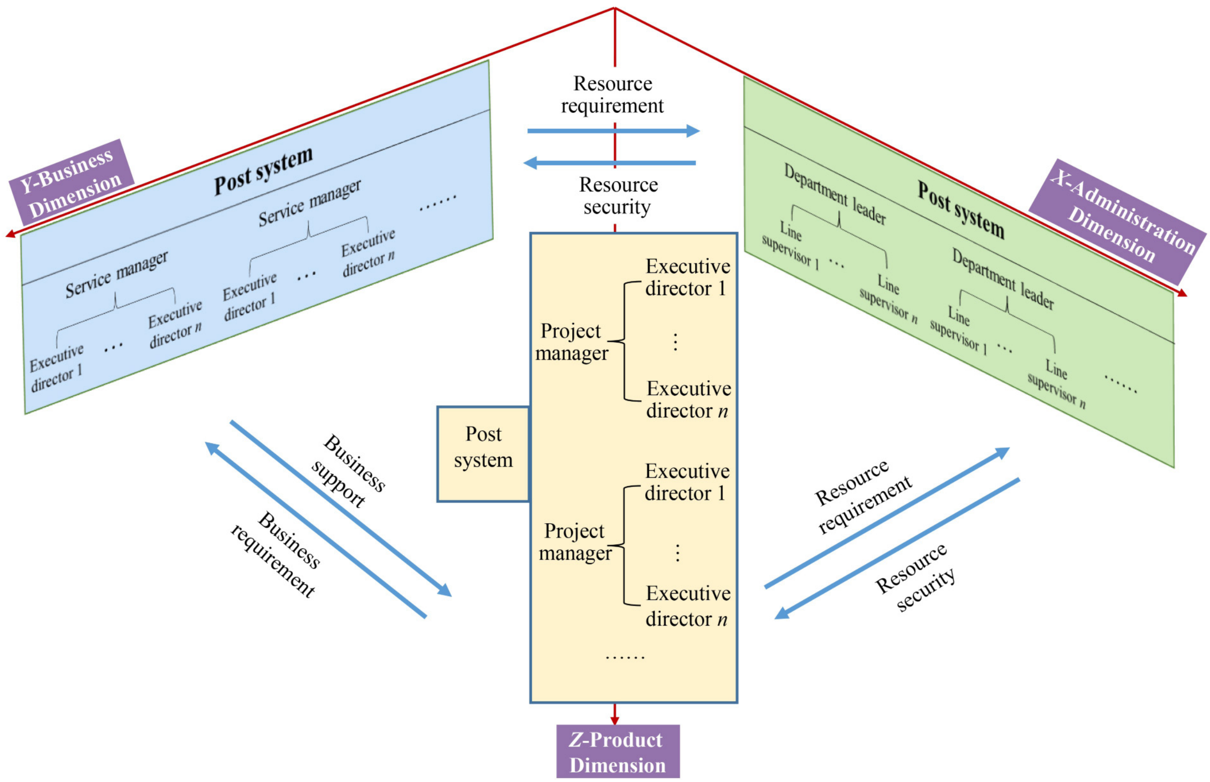

Fig. 8 System operation model of 3D magic-cube organization structure.

has improved. Figure 9 shows the 3D geometric model implemented.

4.1.1 Product dimension design

According to the division of each product dimension, the firm’s batch products, research products, and expanded industry projects were sorted based on the differences in product characteristics and relative independence of objectives. There were three major categories and 16 product items of different types or categories, as shown in Fig. 10.

4.1.2 Business dimension design

Based on the principle that the division of each business dimension is relatively independent, “business” was stripped from “administration” to establish a de-administrative and cross-functional business system. The business and functional departments jointly participate in and support business processes, which breaks through the relatively fixed division of labor of traditional organizations and enhances the overall business support and coordination capabilities of the organization. Driven by products, 15 types of supporting businesses were established as shown in Fig. 11: Strategic performance, production management, research management, technical management, equipment and facilities, material security, party building and human resources, quality and safety, service security, informatization and knowledge management, finance, audit, administration, discipline inspection, and supervision.

4.1.3 Administration dimension design

Finally, traditional resource aggregation with the administrative units at the organizational level was developed. Administrative management was decentralized to grassroot administrative units, such as relevant functional departments, branch plants, and production workshops. In this way, the organization was equipped with relatively independent and flexible decision-making capabilities, the internal proceedings of the organization were simplified, and the responsiveness and synergy of each participating unit were enhanced. Thus, the resources and capabilities of the administration dimension can better serve the product and business realization. Based on the principle of relatively integrated resources and relatively independent power setting of each administrative unit, the administrative departments of each unit were sorted and reorganized to enhance the management efficiency of the administrative framework, as shown in Fig. 12.

4.2 Reconstruction of post system

Through the management standard system, post qualification capabilities and work standards, all product-related responsibilities, such as quality, schedule, cost, and safety,

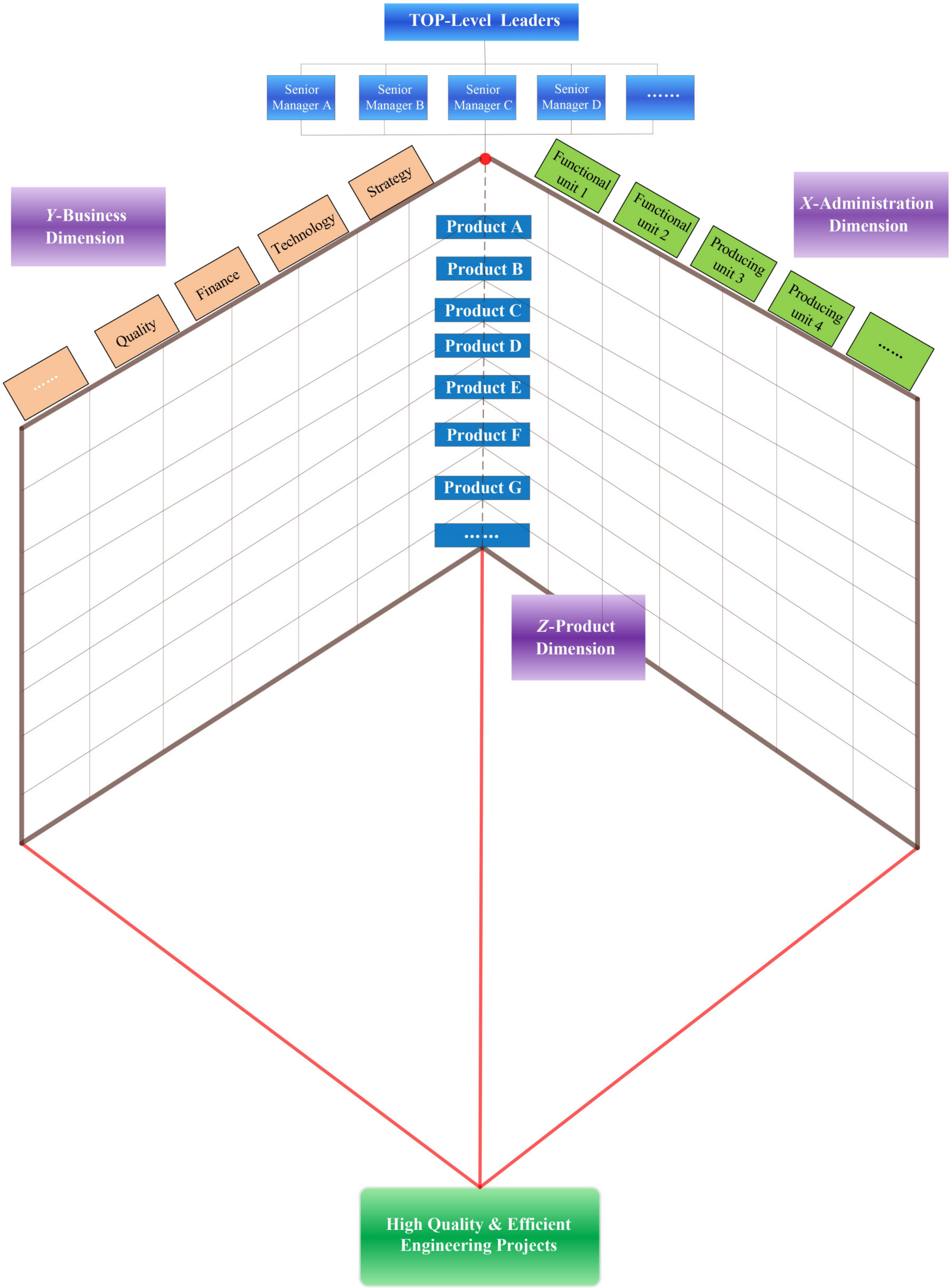

Fig. 9 Implemented model of 3D magic-cube organization structure for the pilot firm.

were fully integrated into the job qualification capabilities and work standards of all levels and types of personnel. The assessment standards of responsibility indicators were clarified, and the product responsibilities were effectively transferred to each post and employee. All personnel of different categories in the region were brought into a unified broadband ladder post system to integrate the management of all personnel and posts.

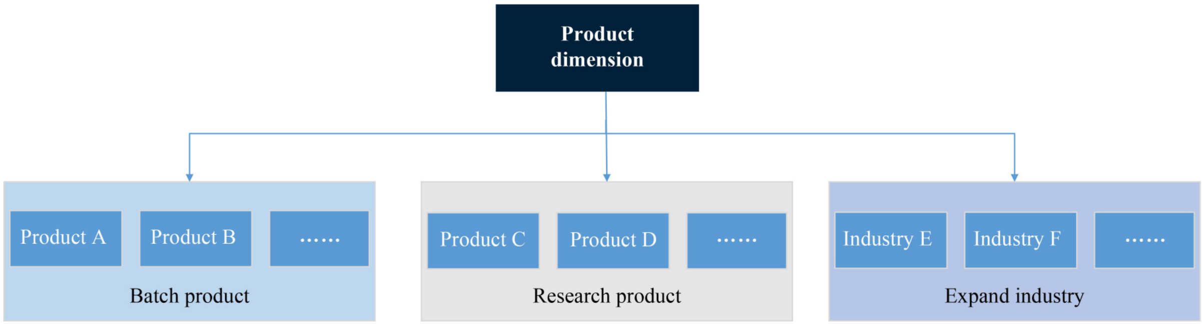

Fig. 10 Product dimension.

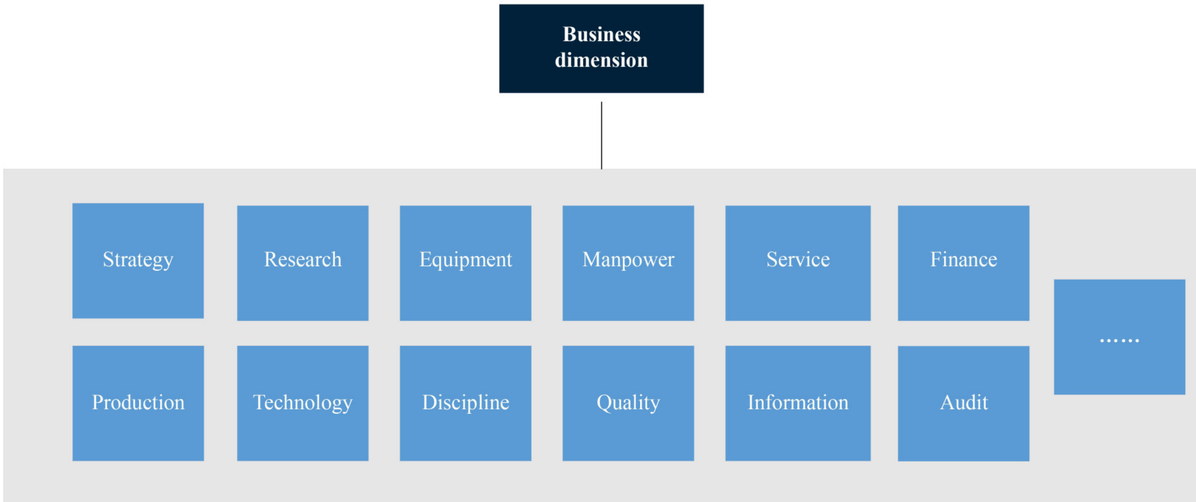

Fig. 11 Business dimension.

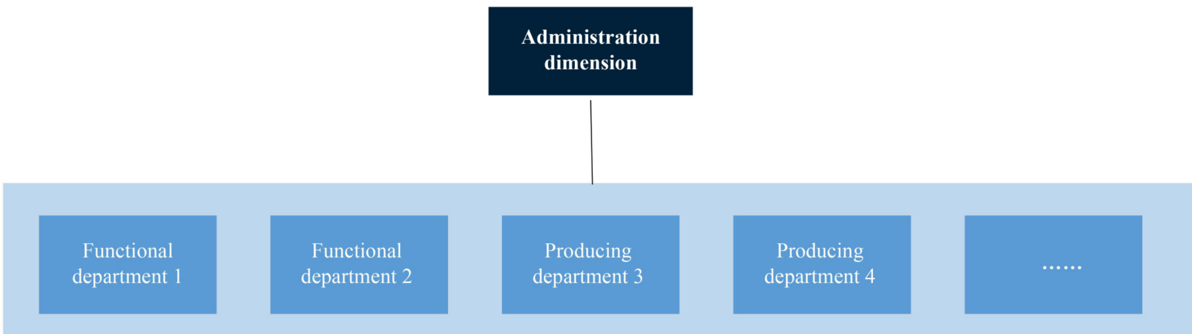

Fig. 12 Administration dimension.

4.2.1 Post system of the product dimension

For all products under repair and research, a post system was established with "top manager in charge of product – product/project manager – product/project leader" as the main body, as shown in Fig. 13; it is responsible for the whole process management of the product. To focus on product development, a cross-functional product project team was established to stimulate business system support and administrative resource guarantee, promote production, and highlight the traction role of the product dimension.

4.2.2 Post system of the business dimension

The post system with "top manager in charge of business – business manager – business leader" as the main body was established, as shown in Fig. 14. It is responsible for the construction, daily operation, inspection, and evaluation of the business system and the building of a

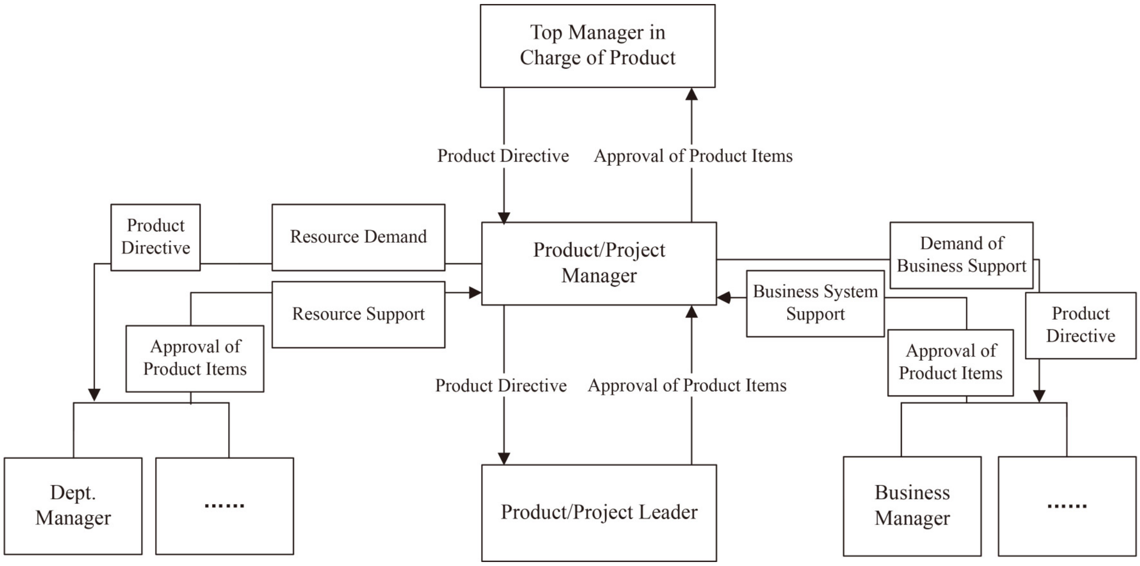

Fig. 13 Post system of the product dimension.

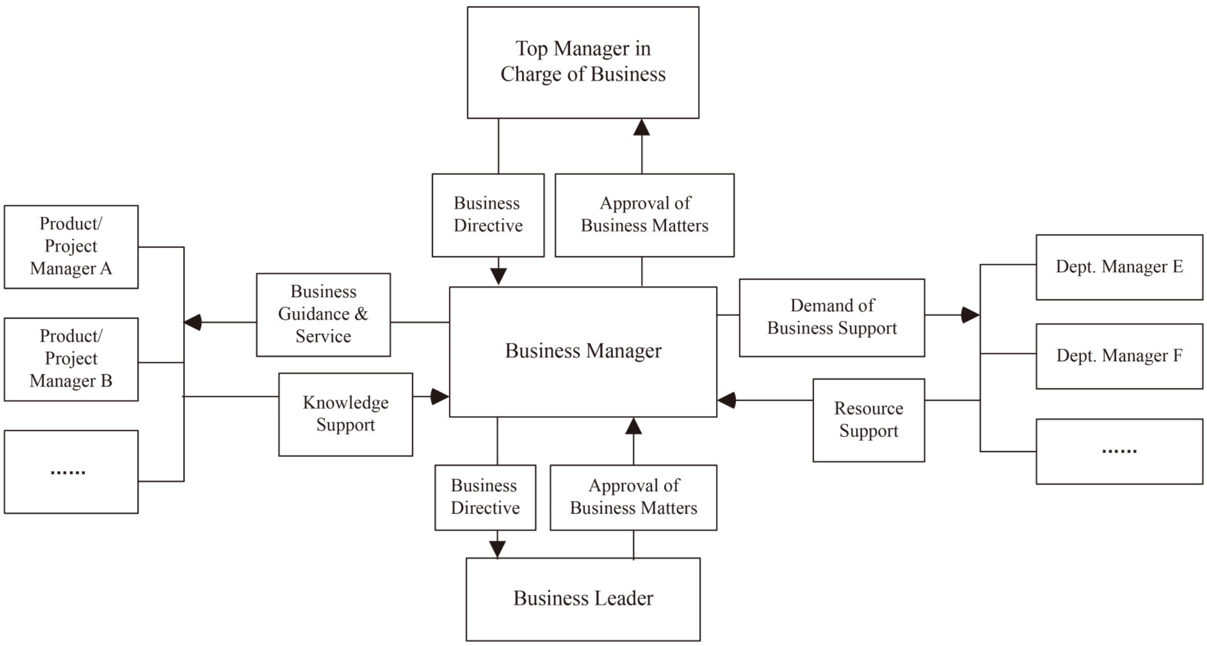

Fig. 14 Post system of the business dimension.

professional business team. It can promote the guarantee of administrative resources with the business system and support product realization. In this way, the post system can maximize the supporting role of business resources in the process of product realization.

4.2.3 Post system of the administration dimension

A post system with "top manager in charge of administration – department manager – team leaders" as the main body was established, as shown in Fig. 15. It responds to the resource demands of the product team and business team, takes charge of administrative resources, and provides personnel and other administrative resources for production and business support.

4.3 Establishment of project-driven coordination mechanisms

The 3D magic-cube organization required a matched driving and cooperation mechanism to promote the effective operation of the 3D magic-cube organizational structure. From a project management perspective, the firm established a collaborative mechanism with project

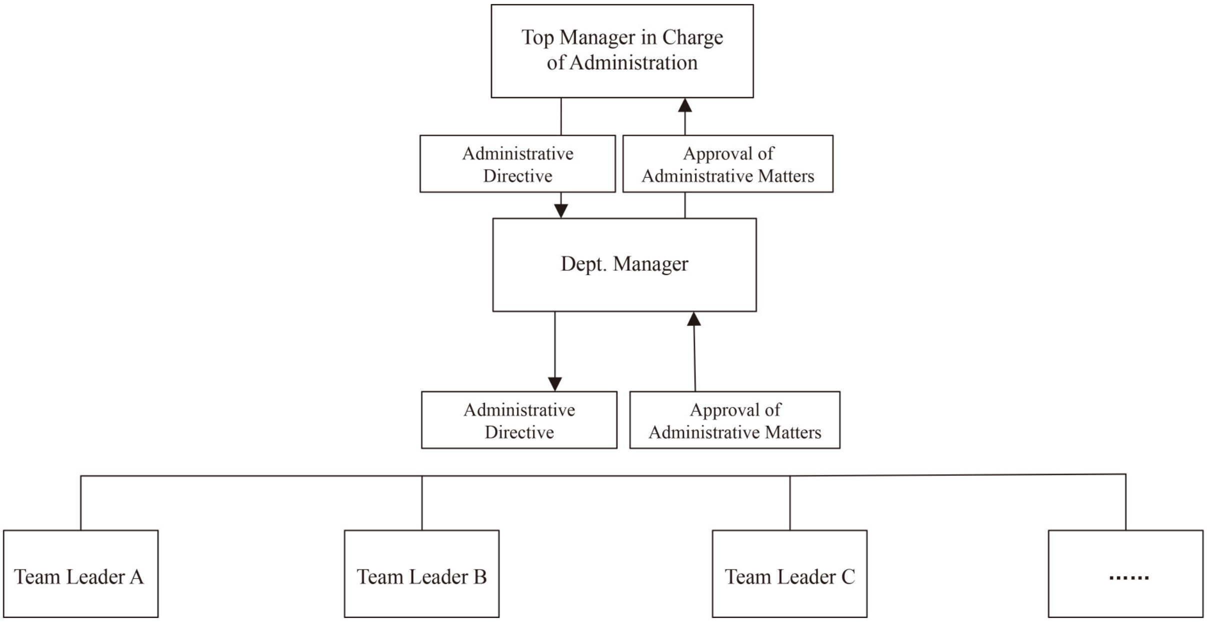

Fig. 15 Post system of the administration dimension.

management as the carrier and product realization as main processes running through business and administration; the mechanism focused on production. The problems of "what to do and how to do" were resolved through the planning, organization, command, coordination, and control of specific projects. According to the internal situation and external environment, the 3D magic-cube organization needs to clarify the process of work objectives and make goal orientations associated with production; thus, specific projects should be formed to coordinate various resources and activities.

The transformation of responsibility performance from "function-driven" to "process-driven" was promoted, and the guarantee of project resources was emphasized. The seamless connection and collaborative operation of management responsibilities, steps, and requirements were enhanced. "Operation procedure" system documents were established, and "centralized management" was implemented. Product mainstream and business support processes were standardized and made explicit. The strong supporting role of "business dimension" on products was highlighted, and the responsibility of business for the system construction, daily operation, inspection, evaluation, guidance, and improvement of the firm was strengthened. The "de-administration" of business departments was realized; they shifted their focus from functional and administrative departments to the whole firm and extended business work from system construction to implementation. Deviations and their causes can be identified on time, and measures can be taken accordingly for adjustment. In this way, the goals and plans can be achieved.

4.4 Development of performance evaluation system for project-based management

After rationalizing the main product realization, business support, and administrative management processes, the firm established the system of project management and performance evaluation with "product performance", "business performance", and "administration performance" for each department. The organization set up three types of pay for performance methods and drafted specific rules of departmental performance evaluation. The performance implementation effect of each department was evaluated every month, and the compensation of each department was determined to strengthen the internal sharing mechanism of market profits.

4.4.1 Product performance

The firm specified hierarchical compensation of each unit by different product types and accounted for the floating coefficient of compensation in accordance with the quantity, quality, schedule, and cost of delivered products. Each business department set the target values of quality, schedule, and cost according to product classes and types, evaluated the achievement of a single-unit(class) delivery target, and gave the reward and penalty coefficients respectively. The equation for float compensation is as follows:

$$P = C * K, \quad K = 1 + k_1 + k_2 + \ldots + k_n, \tag{1}$$

where P is the single-unit(class) floating compensation, C is the single-unit(class) rated compensation, K is the floating compensation coefficient, and k_1, k_2, ..., k_n are the reward coefficients for the achievement of product quality, schedule, cost, and other targets, respectively.

4.4.2 Business performance

For business-oriented departments, the business performance was associated with the product types and was adjusted according to "product traction". That is, to strengthen the supporting role of business departments, the performance of business dimension was highly linked to the product and project objectives, so the business performance was evaluated every month and based on the completion of projects. Senior leaders, product/project managers, and key project leaders can also propose opinions to performance evaluation. Finally, the department responsible for performance will comprehensively determine the evaluation coefficient.

For example, for research business, R&D project management was implemented. The firm defined the target of research projects and technical support for batch products. According to the actual completion of the project objectives, the performance evaluation department shall pay the R&D compensation according to the proportion of the project commission.

4.4.3 Administration performance

The compensation of administration dimension was linked to the extent of resource support to the product and business dimensions. The senior leadership, product/project managers and key project leaders, and all functional departments can jointly participate in the quantitative evaluations.

4.4.4 Compensation budget extraction matrix

Based on the organizational performance evaluation system of "product performance", "business performance", and "administration performance", the compensation extraction matrix of the product and functional departments was formed.

For the product departments, product compensation (followed by business compensation) was the primary part. For the business departments, business compensation was the primary part, whereas the other parts of compensation were associated with the delivery time, quality, and cost of products. The total compensation can be calculated using:

$$R = \sum P_i + \sum B_j + \sum A_k, \tag{2}$$

where R is the total compensation, and P, B, and A represent the product, business, and administration compensations, respectively.

4.5 Statistical analysis of implementation effects

After the implementation of the 3D magic-cube organizational structure, the pilot manufacturing firm has established a network organizational structure with product traction, business support, and administrative guarantee mechanisms. It promoted flexible sharing and project-based utilization of resources and the control of the whole production process. The point organization has formed the "responsibility for products, process management, resource interdependence" and "pay for performance" mechanism. The production cycle was scientifically compressed, the production cost was reasonably decreased, and the product quality was effectively improved. As shown in Fig. 16, since 2014, the gross industrial output value increased by 74.79%, with an average annual growth rate of 8.30%. The total profit increased by 1691.95%, with an average annual growth rate of 51.02%. The total size of employees increased only by 3%, while the total labor productivity of employees increased by 32.89%, with an average annual growth rate of 4.15%. The total annual income per capita increased by 88.06%, with an average annual growth rate of 9.44%. In sum, there is relatively significant change effect of the pilot firm (since 2014) after conducting the 3D magic-cube organizational structure.

5 General discussion

The 3D magic-cube organizational structure integrates the theories of economics, organizational structure, industrial engineering technology, information technology, and engineering management. Focusing on the realization of organizational goals and taking the 3D magic-cube organizational structure of product, business, and administration as the core, the resource utilization and allocation mechanism of "product traction, business (system) support, and administrative (resource) guarantee" is established, enhancing the flexible sharing and project-based utilization of resources. The study conducted literature review and field research to demonstrate the effectiveness of the 3D magic-cube organization, enriching the existing organizational structure theory.

5.1 Theoretical contributions

First, this study may contribute to the traditional organizational structure theory. The 3D magic-cube organization has similar characteristics to that of matrix, network, MTS, and platform organizations, such as network strategy, multi-unit coordination, and co-value creation. By conducting a field study, this research found that the 3D magic-cube organization is decentralized, flat, and specialized and benefits the intra-organizational coordination. These findings are consistent with prior studies on

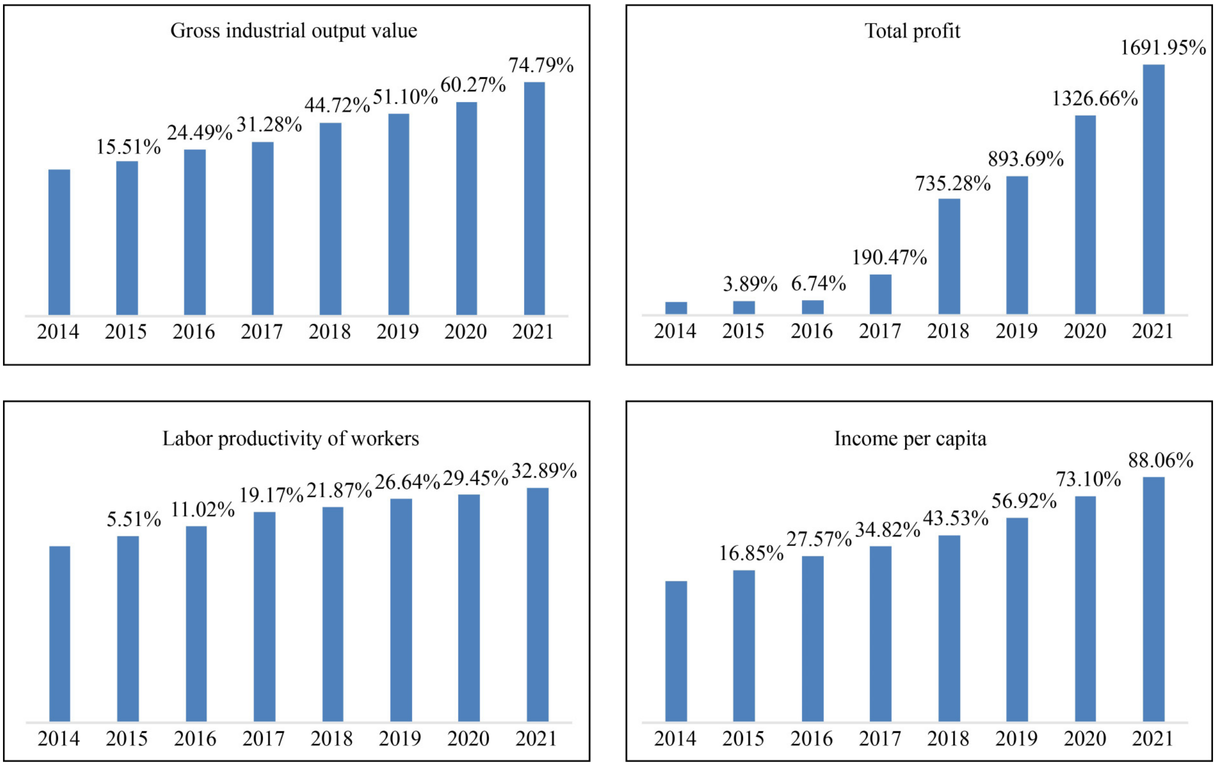

Fig. 16 Change effect of the implementation of 3D magic-cube organization structure (Note: The annotated data is the growth rate compared with the data in year 2014).

organizational structure (Daugherty et al., 2011; Iranmanesh et al., 2021).

Second, this study may contribute to the organizational coordination theory. There are two factors that influence the mechanism of organizational coordination. One is the degree of interdependence between organizational activities and the other is the form of organization (Victor and Blackburn, 1987). The 3D organization establishes the collaborative and supportive relationships among the product, business, and administration dimensions, enabling the organization to set up a cross-functional and boundary spanning mechanism.

Third, by redesigning the post system, projects mechanism, and performance compensation evaluation system of the pilot firm, specific measures and motivations to alleviate coordination barriers among functional units were demonstrated. Moreover, the effectiveness of the 3D magic-cube organization was tested successfully, demonstrated by the increase in the firm's financial profit, output value, labor productivity, and income per capita. This empirically contributes to the theory on organizational structure and coordination activities (Annosi and Brunetta, 2017; Shahani, 2020).

5.2 Practical contributions

The empirical test of the 3D magic-cube organization shows its effectiveness on the firm's financial profit, gross output value, labor productivity, and per capita income. It demonstrates the positive effects of the 3D model on the firm's intra-organizational coordination and productivity. The 3D model can be adopted by large- or medium-sized organizations, particularly for firms with demands of multi-species production and development. As the organization's size grows, managers become typically concerned with coordination and boundary-spanning barriers (Ghislanzoni et al., 2008), and multi-species production can easily cause resource scarcity and conflicts between functional units (Samimi and Sydow, 2021). Despite the practicality of the 3D model, the pilot firm's post system was also rebuilt based on three dimensions. Moreover, the pay system to pay for performance was redesigned, providing practical implications for innovative manufacturing firms.

5.3 Limitations and future research directions

The present research has several limitations. First, although the effectiveness of the proposed 3D model was successfully tested in a large-sized aeroengine manufacturing firm, it may not be applicable to some other manufacturing firms with different business, locations, or organizational sizes. Future research can empirically test the 3D magic-cube model and the new organization forms reviewed above (i.e., network organization, MTS, platform organization) in different fields of manufacturing (e.g., civil and export manufacturing) and show various findings for the relationship between organizational structure and product innovation. In addition, the proposed 3D magic-cube model focuses on intra-organizational coordination among functional units. Owing to the globalization, international expansion, and collaboration demand for manufacturing firms, future research should test the inter-organizational coordination mechanism among organizations (e.g., suppliers and partner companies) for further findings. Finally, although organizational structure is highly associated with coordination and innovation activities in organizations (Daugherty et al., 2011; Annosi and Brunetta, 2017), there are many other influences, such as leadership, the use of technology, and task allocation (Thoben et al., 2017; Sandhu and Kulik, 2019). Future research can demonstrate the influences of organizational coordination from various perspectives and make contributions to the theory of organizational coordination.

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