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How to realize digital transformation in satellite communication industry? -- Configuration analysis based on the technology-organization-environment framework

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Introduction: Digital transformation is the key link of the prosperity and development of digital economy, and the successful digital transformation is the result of the synergy of multi-level factors.

Methods: Based on the theoretical framework of technology-organization-environment, this paper takes 27 satellite communication enterprises as samples and uses fuzzy set qualitative comparative analysis method to explore the configuration effect of six antecedent conditions at the level of technology, organization and environment on digital transformation of satellite communication enterprises.

Results: The results show that a single antecedent condition does not constitute a necessary condition for digital transformation. There are four configuration paths for digital transformation of satellite communication industry, which are technology-organization-oriented, technology-organization-environment collaboration-oriented, technology-organization-oriented environment collaboration, and organization-environment-oriented. Under certain conditions, there is substitution effect between antecedents.

Discussion: The complex causes of the digital transformation of Chinese satellite communication enterprises, and can provide beneficial enlightenment for the digital transformation of satellite communication enterprises.

KEYWORDS

digital economy, technology-organization-environment framework (TOE), satellite communication industry, fuzzy-set qualitative comparative analysis (fsQCA), digital transformation

1 Introduction

With the emergence of a new round of scientific and technological revolution and industrial transformation, the Internet, big data, cloud computing, artificial intelligence and other digital technologies are changing with each new day. The digital economy, with data resources as an important factor of production and total factor digital transformation as an important driving force, has developed vigorously (Pan et al., 2022). Under the new wave of scientific and technological revolution and industrial transformation, the Chinese government attaches great importance to the digital economy. In the 14th Five-Year Plan and the outline of 2035 vision goal, China has clearly proposed to promote the building of a space power and digital China (Zhang et al., 2018). Under the background of digital economy, satellite communication industry, as the main battlefield of China's development of digital economy, is the main direction and key breakthrough to promote the integration of digital economy and real economy (Ding et al., 2022). Especially in the international situation where the United States and other developed countries are vigorously implementing the "Star-link" strategy to further widen the gap with developing countries, the development of China's space industry will be under increasing pressure (Lee et al., 2021). How to realize the digital transformation of satellite communication industry with digital technology is an important topic for realizing smart spaceflight (Pagani, 2013), improving the development mode of China aerospace + China Service, and implementing the national strategy of "One Belt and One Road" spatial information corridor (Liu and Suk, 2022). Therefore, the digital transformation of satellite communication industry is not only an important way to promote the high-quality development of China's satellite communication industry (Wen et al., 2022), but also an important support to drive the development and growth of China's digital economy. At the same time, exploring the law of digital transformation of satellite communication industry has also become a theoretical issue of academic focus (Amankwah-Amoah et al., 2021).

Satellite communication industry is a kind of industry that uses radio communication technology, sophisticated materials and other production factors and uses artificial Earth satellites as relay stations to forward radio waves, so as to realize communication between two or more Earth stations (Faheem et al., 2018). China's 14th Five-year Plan calls for economic development to focus on the real economy, accelerating the development of China's space power and satellite communications industry (Suk-Ching Tang and Lee, 2003), and promoting the deep integration of the Internet, big data, artificial intelligence and the real economy (Allam and Dhunny, 2019). Against the backdrop of weakening momentum of the global economic cycle, promoting high-quality development of the satellite communication industry is the basic support for the formation of a new development pattern and an urgent need to meet the demand of China's huge domestic market. Under the tide of digital economy, China's satellite communication industry has a strong desire for digital transformation (Zaki, 2019). However, due to the widespread problems of resource rigidity, path dependence and innovation burnout in enterprises, artificial intelligence, industrial Internet, block chain and other digital technologies are difficult to organically integrate into the satellite communication industry in a short period of time, and ultimately, the role of digital technology in leading the high-quality transformation and upgrading of the satellite communication industry is not obvious (Wenzel, 2015). Moreover, there are huge differences in production capacity, technical level and number of employees among enterprises, and the countermeasures obtained through single path research cannot well guide China's satellite communication enterprises to realize digital transformation (Vergne and Durand, 2010). Therefore, this paper regards the digital transformation of satellite communication enterprises as a process of the organic integration of satellite communication industry and digital technology, in which the satellite communication industry applies digital technology to promote its own high-quality development (Birner et al., 2021). Based on this, this paper combines the technology-organization-environment (TOE) theoretical framework, which is suitable for the study of emerging technology transfer. This paper takes 27 Chinese satellite communication enterprises as cases, and uses the qualitative Comparative analysis (QCA) method. This paper discusses the configuration paths of digital transformation of satellite communication enterprises promoted by the pre-factors such as digital technology transition and management mode transformation, further explores the similarities and differences between the configuration paths of digital transformation of different satellite communication enterprises, and tries to open the "black box" of digital transformation of satellite communication enterprises. Combined with the results of empirical analysis, this paper puts forward management enlightenment to promote the digital transformation of satellite communication enterprises, and promote the "key minority" of China's space industry -- satellite communication industry under the background of digital economy. On the premise of maintaining high-quality development, we should take the lead in realizing digital transformation, give full play to the "head goose effect", stimulate the vitality of geese, provide guidance for other aerospace enterprises in digital transformation, and ensure the completion of high-quality transformation and upgrading of China's aerospace industry. In short, this study aims to accomplish two main objectives:

- Explain whether a single factor is a necessary condition for the digital transformation of satellite communication enterprises.
- To study the configuration effect of the T-O-E framework on the digital transformation of satellite communication enterprises.

2 Literature review and research model

2.1 Literature review

In recent years, scholars have found that the process of enterprise digital transformation is affected by many factors, such as the awareness of digital transformation (Hanelt et al., 2021); Technological transition (Rohracher, 2001); Infrastructure construction (Chang and Kendall, 2011); Management change (Jilte et al., 2021); Internal factors of enterprises (Chi et al., 2022); Policy promotion (Vu and Hartley, 2022); Enterprise cooperation (Zhang et al., 2022); Influence of external factors

such as government guidance (Llopis-Albert et al., 2021); Environmental factors (Feroz et al., 2021; Chen and Tian, 2022). In the context of China, the digital transformation of satellite communication enterprises needs to be considered comprehensively by combining their own characteristics and integrating various factors (Giua et al., 2022). Previous scholars have done a lot of research on the factors influencing the digital transformation of space enterprises from the technical, organizational and environmental levels, and relevant fruitful research results have important reference significance and inspiration for further discussion on the path of digital transformation of satellite communication enterprises (Lin and Yi, 2022). However, from the single level of technology, organization, only considering the single factors promote the net effect of the digital transformation, aerospace industry is difficult to reflect different dimensions of factors on the combined influence of the digital transformation, aerospace industry cannot explain system digital transformation of enterprises of different space complex multi-factor joint mechanism (Yaacoub et al., 2022). Are the driving factors for digital transformation of satellite communication enterprises necessary conditions? What is the difference in linkage matching effect between single factor and various factors? And what are the similarities and differences in driving paths? The relationship and difference between the factors influencing the digital transformation of satellite communication enterprises and whether different factors have a combination role in promoting the digital transformation of satellite communication enterprises still need to be further discussed.

2.2 Research model

This paper integrates the TOE theoretical framework and existing studies with the specific context of digital transformation of satellite communication enterprises in China, and identifies the condition variables driving digital transformation of satellite communication enterprises in terms of technology, organization, and environment, taking into account various factors such as research samples, research methods, and research feasibility.

The influencing factors of technological dimension are mainly reflected in digital technology transition and digital facilities construction, which are the important forces to promote the digital transformation of satellite communication enterprises (Zhao et al., 2018; Gangi et al., 2022; Gao and Yuan, 2022). In this paper, digital technology transition refers to that satellite communication enterprises rely on digital technology to meet users' expectations or change market standards by transforming technology orbit and providing new functional attributes (Ometov et al., 2021). Digital facility construction refers to the improvement of digital hardware level of satellite communication enterprises through digital infrastructure construction and industrial Internet supporting facilities construction in order to realize the organic integration of digital technology and itself (Yu and He, 2022). Digital technologies represented by artificial intelligence and industrial Internet have disruptive potential, which can help satellite communication enterprises meet users' expectations or change market standards by transforming technological track and providing new functional attributes (Alaimo, 2022), so as to realize technological transition and enhance technological innovation capability of enterprises (Ryu et al., 2021). Therefore, digital technology transition is an important guarantee for the digital transformation of satellite communication enterprises as a prerequisite for enhancing technological innovation capability of enterprises (AlNuaimi et al., 2022). In addition, existing studies have proved that the construction of digital facilities will significantly promote industrial digitization and promote the upgrading of aerospace industrial structure (Borowski, 2021). Therefore, digital technology transition and digital facilities construction are important prerequisites for the digital transformation of satellite communication enterprises.

The influencing factors of organizational dimension are mainly reflected in the reform of management mode and improvement of production process, which are important space for the digital transformation of satellite communication enterprises (Eito-Brun and Amescua-Seco, 2018; Chen et al., 2021; Li et al., 2022). Within the research scope of this paper, management mode reform refers to that satellite communication enterprises rely on intelligent execution systems such as ERP and MES to promote the realization of intelligent aerospace technology by eliminating "digital islands" and improving the quality of employees (Guo et al., 2021). Production process improvement refers to that satellite communication enterprises rely on intelligent processing equipment, intelligent execution system and other advanced production factors to achieve workshop production data transparency and improve their own production process with digital information feedback. The digital management information system with ERP as the typical representative is considered as one of the important foundations for the internal digital transformation of enterprises (Pizzi et al., 2021). Digital technology will also promote satellite communication enterprises to improve the production process with products and processes as the entry point and promote the digital transformation of manufacturing industry (Mushi et al., 2022; Wen et al., 2022). Therefore, management mode reform and production process improvement can effectively promote the formation of internal advantages of digital transformation of satellite communication enterprises.

The influencing factors of the environmental dimension are mainly reflected in the two aspects of industry development level and enterprise competitive pressure, which are important opportunities for satellite communication enterprises to speed up their digital transformation. In the scope of this paper, industry development level refers to the operation level, development level and industry cluster construction level of the industry in which satellite communication enterprises are located; enterprise competitive pressure refers to the pressure brought by regional performance assessment, enterprise efficiency evaluation, and inter-enterprise market scramble and other behaviors on satellite communication enterprises. The level of development of the aerospace industry is the basis and an important carrier for the digital transformation of satellite communication enterprises, and regions with good development bases in the aerospace industry can rely on industrial advantages to carry the rapid development of industry digitalization in the region (Pathak and Dhakate, 2022). In

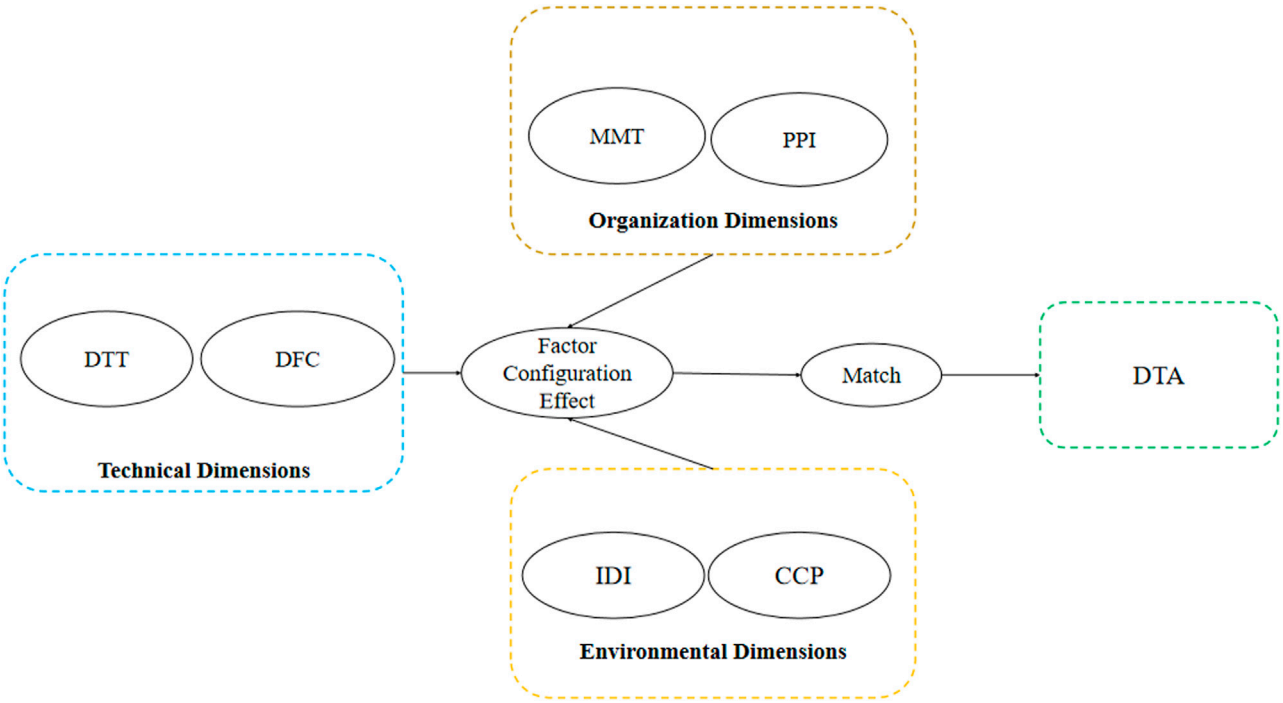

FIGURE 1
Research model.

the face of performance assessment each regional government must respond, so the competition between geographically close peer governments will inevitably affect the attention and behavior of local governments (Zhang et al., 2021). The digital transformation of the aerospace industry is the main pillar to promote the high-quality development of the digital economy, thus, when regional governments face competitive pressure from the digital high-quality development of the aerospace industry in neighboring regions, they will stimulate local governments to promote the digital development of the industry by means of digital transformation of satellite communication enterprises (Ganichev and Koshovets, 2019). The competitive pressure between regions is transmitted to satellite communication enterprises in each region through the government, which affects the digital transformation process of satellite communication enterprises. Therefore, the level of industry development and the competitive pressure of enterprises have an important impact on the advantages of digital transformation of satellite communication enterprises.

In summary, the digital transformation driver model of satellite communication enterprises constructed in this paper is shown in Figure 1.

3 Methodology

3.1 Sample

The reasons why satellite communication enterprises are selected as digital transformation research samples in this paper are as follows: One is satellite communications enterprises as digital technology and aerospace industry play in depth fusion, there was a significant difference between traditional price competition in digital economy as the main line of business model—satellite communications enterprises for the realization of the intelligent space, will actively seek digital core technology, intelligent management system and create a business model of rapid iteration. Therefore, satellite communication enterprises are the ideal objects to study the digital transformation of space industry. Second, compared with traditional aerospace enterprises, satellite communication enterprises integrate more high-tech achievements and apply more modern management experience, laying a good foundation for the realization of digital transformation of enterprises. It creates the possibility of value co-creation based on digital technologies such as industrial Internet and artificial intelligence, and provides a good soil for enterprises to connect with digital economy technologies such as artificial intelligence, industrial Internet and blockchain.

According to relevant studies on QCA model specifications, when the antecedent conditions of the model are six and the sample number is greater than 25, random data and real data can be distinguished to ensure the internal validity of configuration results (Fiss, 2011). On the basis of data collection principles such as typicality, richness and accessibility, combined with industry planning and think tank research reports such as “2021 China Unicorn Enterprise Research Report” and “2021 Space Industry Cluster White Paper”, this study finally selected 27 satellite communication enterprises for analysis.

TABLE 1 Assignment criteria for digital transformation outcome variables for satellite communication enterprises.

Construct	Items	Score
Digital transformation advantage of satellite communication enterprises (DTA)	The company has complete digital transformation equipment and technical conditions, and is realizing the organic integration of digital technology and management mode and production process, with strong market influence	1
	The company has good digital transformation equipment and technology conditions, and is in the process of organic integration of digital technology and management mode, production process, and good market performance	0.67
	The company has sufficient digital transformation equipment, technical conditions, digital technology to promote the change of management mode, production processes, and faster growth in market share	0.33
	The company fail to has sufficient digital transformation equipment, technical conditions, digital technology has not yet driven the management model, production process changes, the market performance is general	0

TABLE 2 Assignment criteria for digital transformation condition variables of satellite communication enterprises.

Construct	Variable	Items	Assignment criteria	References
Technical Dimensions	Digital Technology Transition (DTT)	Nine criteria are measured in terms of digital technology sources, digital technology performance and digital technology development potential	In line with 7 or more criteria are met, the value is 1; In line with 4–6, the value is 0.67; In line with 2-3, the value is 0.33; If 1 or below is met, the value is 0	Teixeira et al. (2022)
	Digital Facility Construction (DFC)	Nine criteria are measured in terms of infrastructure construction, industrial Internet and network security facilities construction		Borowski (2021)
Organization Dimensions	Management Mode Transformation (MMT)	Nine criteria are measured in terms of digital information fluency and utilization capability, intelligent personnel quality trainingetc.	In line with 7 or more criteria are met, the value is 1; In line with 4–6, the value is 0.67; In line with 2-3, the value is 0.33; If 1 or below is met, the value is 0	Zhao et al. (2017)
	Production Process Improvement (PPI)	Nine criteria are measured in terms of the degree of process intelligence and the degree of intelligent integration of logistics and supply chain		Pizzi et al. (2021)
Environmental Dimensions	Industry Development Level (IDI)	Eleven criteria are measured in terms of industry operation overview, carrier construction situation and industry development status	In line with 9 or more criteria are met, the value is 1; In line with 6–8, the value is 0.67; In line with 3–5, the value is 0.33; If 2 or below is met, the value is 0	Li et al. (2022)
	Corporate Competitive Pressure (CCP)	Eleven criteria are measured in terms of corporate partnerships, product market recognition, and government support		Gangi et al. (2022)

3.2 Data analysis technique

Based on set theory and Boolean operation, fsQCA deeply mines the interaction between antecedent conditions and their joint effect on results through configuration analysis (Chen and Tian, 2022). The reasons for applying fsQCA method in this paper are as follows: 1) fsQCA method integrates the advantages of quantitative and qualitative analysis, and can solve the problems of complex causality and common path in management research (Afonso et al., 2018). 2) fsQCA method is suitable for digital transformation research with "combination" characteristics (Mikalef and Pateli, 2017), which can explore how the collaborative interaction between variables successfully drives digital transformation from the perspective of configuration. 3) fsQCA method can be used to study small and medium-sized samples. Since there are only a few listed satellite communication enterprises at present, there are only 27 sample cases in this paper, which does not meet the requirements of multiple regression on sample size; 4) fsQCA method does not require special treatment of cross-level antecedent conditions, which is suitable for the multi-level analysis framework of this paper (Ragin, 2014).

3.3 Variable measurement and calibration

This study carried out the investigation according to the process of designing the scale, conducting small-scale investigation, improving the scale and issuing questionnaires, and then collected relevant data. In order to ensure that the scale has good reliability and validity, this study tries to draw lessons from previous research assumptions and research results, and tries to design the scale by adopting the items in the mature scale of existing literature. At the initial stage of designing the scale, we discussed several times

TABLE 3 Test the necessity and sufficiency of conditional variables.

Condition	Consistency	Coverage
DTT	0.810	0.979
~ DTT	0.032	1.000
DFC	0.788	0.979
~ DFC	0.287	0.988
MMT	0.713	0.988
~ MMT	0.371	1.000
PPI	0.730	0.988
~ PPI	0.354	0.993
IDI	0.784	0.989
~ IDI	0.300	1.000
CCP	0.814	1.000
~ CCP	0.278	1.000

with doctors who conducted relevant industry researches and middle and senior management personnel of enterprises to get the initial scale. In the middle stage, a small scale survey was carried out combined with the initial scale. In the later stage, the questionnaire items were repeatedly improved based on the survey feedback data, and the final scale was obtained.

For scholars from the production process, enterprise network characteristics, design a variety of external environment such as dimension index to depict the multidimensional characteristics of satellite communication enterprises digital transformation, give the inspirations of this study are as follows: one is the digital technology although plays an important role in the process of enterprise digital transformation, but rely on digital technology is not well realize satellite communication enterprises digital transformation. Enterprises need to apply digital technology science to all production links and make intelligent decisions based on data in combination with corresponding digital technology, so as to better accumulate the advantages of digital transformation of satellite communication enterprises. Second, if satellite communication enterprises do not pay attention to the importance of digital transformation, they will gradually lose their original advantages in resources, technology and management, increasing the difficulty for enterprises to break through the development bottleneck. Therefore, satellite communication enterprises also need to actively transition to digital transformation, give full play to their own advantages, combined with digital technology to promote their own better industrial upgrading.

In this paper, the digital transformation advantage of satellite communication enterprises (DTA) is taken as the result variable of the configuration model of digital transformation of satellite communication enterprises. Considering that the research data came from 27 case materials of satellite communication enterprises, the anchor points of the result variables were set as 0, 0.33, 0.67 and 1, among which "1" and "0" stand for complete membership and non-membership, and "0.67" and "0.33" are intersection points, that is, partial membership and partial non-membership (Fiss, 2007). The assignment criteria are shown in Table 1. Since the digital transformation of satellite communication enterprises is a fuzzy construct, this study, on the basis of integrating previous studies, takes the influencing factors at different levels such as digital technology level, management and production mode and external environment adaptability as conditional variables. The influence of its combined configuration on the digital transformation of satellite communication enterprises is discussed. The questionnaire measurement and evaluation criteria are shown in Table 2.

TABLE 4 Configuration for high DTA.

Configuration	Solution			
	1	2	3	4
DTT	●	●	●	⊗
DFC	●	●		●
MMT	●		●	●
PPI	⊗	●	●	●
IDI		●	●	●
CCP	●	●	●	⊗
Consistency	1.000	0.980	0.990	0.970
Raw Coverage	0.310	0.490	0.430	0.170
Unique Coverage	0.120	0.100	0.040	0.040
Overall solution consistency	0.990			
Overall solution coverage	0.700			

Note: ● Core causal condition (presence). ● Peripheral causal condition (presence). ⊗Core causal condition (absence). ⊗Peripheral causal condition (absence). The blank cells represent do not care conditions.

4 Result

4.1 Necessity conditions analysis

Firstly, the necessity analysis of all the preconditions and their anti-conditions is carried out to judge the necessity of each condition in the realization of the result variable. The analysis results are shown in Table 3. If there is a single factor consistency rate higher than 0.9, it should be considered as a necessary condition. In this study, no single factor consistency rate is higher than 0.9, indicating that a single precondition is weak in explaining the digital transformation of satellite communication enterprises and should not be discussed as a necessary condition. Configuration matching is required to affect the digital transformation of satellite communication enterprises (The symbol "~" in the text represents the lack of antecedent elements or the opposite state).

4.2 Sufficient solutions

We used fsQCA3.0 software to analyze the standardized data. In line with established research, we conducted a sufficiency analysis by using a minimum case frequency benchmark ≥1. We also applied PRI (proportional reduction in inconsistency) to further filter the truth table rows that are reliably linked to the outcome. As the configurations with a PRI score below 0.5 may show inconsistency (Greckhamer et al., 2018), we adjusted four rows of data to 0 based on comprehensive analysis of case details and data distribution. Using these comprehensive standards, we obtained the truth table rows that meet the requirements and obtained the configurational paths by running the data. The results are given in Table 4. We identified four pathways that can lead to high levels of digital maturity. The overall solution consistency is 0.99, which explains the significance level of all configurations as a whole. The results show that the five configurations captured 70% of high-level digital maturity.

Configuration path 1: technology-organization-oriented (DTECT × DFC × MSC × ~PPI × CCP). This path shows that satellite communication enterprises with high degree of digital technology transition and management mode transformation, better digital facilities construction, less competitive pressure of enterprises and less investment in production process improvement can realize digital transformation faster. Digital technology transition (technology) and management mode transformation (organization) are the core conditions, while digital facility construction (technology), production process improvement (organization) and enterprise competitive pressure (environment) are the marginal conditions. This configuration path can explain about 31% of high-quality digital transformation cases in satellite communication enterprises, and 12% of them can be explained by this path alone.

Configuration path 2: technology-organization-environment collaboration-oriented (DTECT × DFC × PPI × IDI × CCP). This path shows that satellite communication enterprises with high digital technology transition degree, production process improvement degree and industry development level, better digital facilities construction and less competitive pressure can realize digital transformation faster. Among them, digital technology transition (technology), production process improvement (organization), industry development level (environment) are the core conditions, digital facility construction (technology), enterprise competitive pressure (environment) are the edge conditions. This configuration path can explain about 49% of high-quality digital transformation cases in satellite communication enterprises, and 10% of them are explained by this path alone.

Configuration path 3: technology-organization-oriented environment collaboration (DTECT × MSC × PPI × IDI × CCP). This path shows that satellite communication enterprises with high degree of digital technology transition and management mode transformation, better improvement of production process, less competitive pressure of enterprises and higher level of industry development can realize digital transformation faster. Among them, digital technology transition (technology) and management mode change (organization) are the core conditions, while production process improvement (organization), industry development level (environment) and enterprise competitive pressure (environment) are the marginal conditions. This configuration path can explain about 43% of high-quality digital transformation cases in satellite communication enterprises, and 4% of them can be explained by this path alone.

Configuration path 4: organization-environment-oriented (~DTECT × DFC × MSC × PPI × IDI × ~ CCP). This path shows that the satellite communication enterprises with high level of development and high degree of management mode transformation, good situation of digital facilities construction and production process improvement, and the satellite communication enterprises with no excessive investment in technological transition and high competitive pressure can realize digital transformation faster. The core conditions are management mode change (organization) and industry development level (environment), while the edge conditions are digital technology transition (technology), digital facility construction (technology), production process improvement (organization) and enterprise competitive pressure (environment). This configuration path can explain about 17% of high-quality digital transformation cases in satellite communication enterprises, and 4% of them are explained by this path alone.

4.3 Analysis of overlapping paths and potential alternatives

This study finds that there may be overlapping paths and potential substitutions among the preconditions of configuration paths for digital transformation of satellite communication enterprises. In order to intuitively reflect the connection between each path, this study made a Venn diagram (see Figure 2) combining configuration analysis data to show the block and coverage of each path in the fuzzy set.

This study focuses on the overlapping paths among paths 1, 2 and 3 and the potential substitution of factors. As the original coverage of path 4 is much lower than the other three paths, it is not included in the research scope. According to the visualization results of the original coverage and unique coverage of the three paths on the Venn diagram of configuration path connection, it can be seen

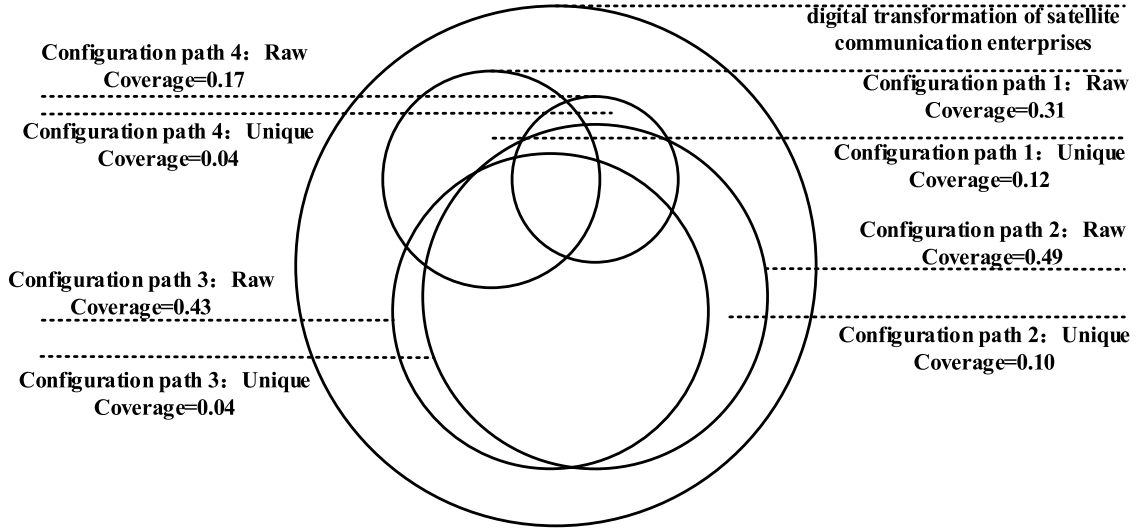

FIGURE 2
Configuration path connection status.

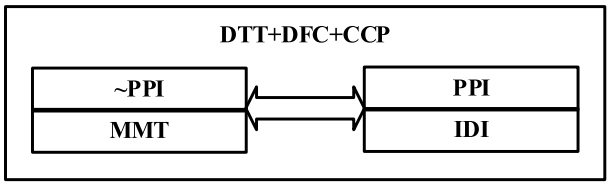

FIGURE 3
Overlapping paths and substitution relationships between path 1 and path 2.

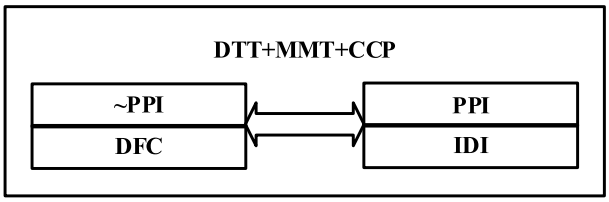

FIGURE 5
Overlapping paths and substitution relationships between path 1 and path 3.

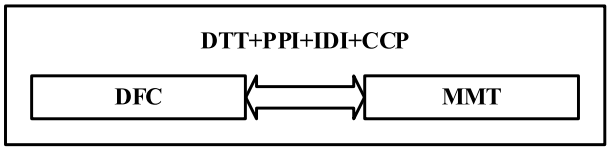

FIGURE 4
Overlapping paths and substitution relationships between path 2 and path 3.

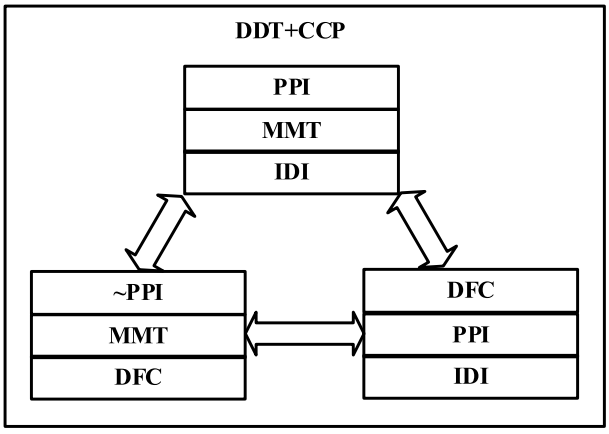

FIGURE 6
Overlapping paths and substitution relationships among path 1, path 2, and path 3.

that the three paths are not completely isolated, and there is a strong connection between paths. Therefore, on the premise that the three paths overlap, this study attempts to explore the possible substitution relationship among the three configuration paths of the digital transformation of satellite communication enterprises.

Firstly, there are overlapping paths between path 1 and Path 2, which are composed of digital technology transition, digital infrastructure construction and enterprise competitive pressure. Under this premise, there is a substitution relationship between ~ production process improvement, management mode change, industry development level and production process improvement, as shown in Figure 3. Secondly, there are overlapping paths between path 2 and path 3, which consist of digital technology transition,

production process improvement, industry development level and enterprise competitive pressure. Under this premise, there is a substitution relationship between digital facility construction and management mode reform, as shown in Figure 4. Thirdly, there are overlapping paths between path 1 and path 3, which consist of digital technology transition, management mode transformation and enterprise competitive pressure. On this basis, there is a substitution relationship between ~ production process improvement, digital facility construction, production process improvement and industry development level, as shown in Figure 5. Finally, the three paths are further analyzed. There are overlapping paths composed of digital technology transition and enterprise competitive pressure between paths 1, 2 and 3. On this basis, there is a substitution relationship between ~ production process improvement, digital facility construction, management mode change and production process improvement, digital facility construction, industry development level and management mode change, production process improvement and industry development level, as shown in Figure 6.

5 Conclusion

Based on the sample data of 27 satellite communication enterprises, this study combined TOE theoretical framework and fsQCA method to explore the configuration path of digital transformation of satellite communication enterprises, and explored the overlapping paths among the configuration paths and the potential substitution relationship of pre-factors. The research conclusion of this paper mainly includes the following two points: First, any single antecedent condition in the dimensions of technology, environment and organization cannot constitute the necessary condition for digital transformation of satellite communication enterprises, and antecedent condition needs configuration matching to promote digital transformation of satellite communication enterprises. There are four driving paths for digital transformation of satellite communication enterprises, which are technology-organization-oriented (path 1), technology-organization-environment collaboration-oriented (path 2), technology-organization-oriented environment collaboration (path 3) and organization-environment-oriented (path 4). Second, there are overlapping paths and potential substitution relationships between path 1 and path 2, path 2 and path 3, and path 1 and path 3. Further research finds that there are also overlapping paths and potential substitution relationships between path 1, path 2 and path 3.

6 Discussion and implication

6.1 Implication

From the perspective of configuration path, enterprise managers should realize the superiority of configuration path development strategy in digital transformation strategy and attach importance to the application of configuration coordination thinking. The results show that although digital technology transition and management mode transformation are the core conditions in the configuration path of digital transformation of satellite communication enterprises, a single precondition cannot guide them to realize digital transformation. In terms of the results of guiding the digital transformation of satellite communication enterprises, the multi-factor combination driven strategy is obviously better than the single factor driven strategy (Zhao et al., 2018; Gangi et al., 2022). Therefore, satellite communication enterprise managers should pay attention to the combined utility of technology, organization, environment and other factors, attach great importance to the coordination of various conditions on the premise of clarifying the technical conditions, management ability and environmental advantages of the enterprise, and formulate the configuration path of digital transformation in line with the current enterprise situation (van Grootel et al., 2020; Li et al., 2022).

From the perspective of overlapping paths and alternative factors, enterprise managers should clarify the relationship between overlapping paths and alternative factors and make the optimal decision of digital transformation of satellite communication enterprises in a short time (Eito-Brun and Amescua-Seco, 2018; Pathak and Dhakate, 2022). The results show that the combination of "digital technology transition + enterprise competitive pressure" is the most universal; On the premise that the enterprise improves the combination of such factors, managers can make optimal development decisions at each key node of digital transformation by combining the characteristics of the enterprise and the substitution relationship of factors. When an enterprise wants to realize its digital transformation through the technology-organization oriented path, the optimal strategy at the key nodes is to prioritize the construction of digital facilities or reform management mode on the premise of improving the combination of "technological transition + enterprise competitive pressure" elements. The development path can be adjusted at any time according to the status of enterprise digital transformation while realizing digital transformation according to technology-organization oriented path. Therefore, managers should give full consideration to overlapping paths and alternative factors when making short-term decisions at key nodes of digital transformation, so as to improve the fault tolerance rate of decisions while ensuring correct decisions.

From the perspective of influencing factors, enterprise managers should pay attention to the characteristics of the preconditions and formulate the corresponding long-term cultivation strategy of factors combined with the enterprise's own conditions. The results show that digital technology transition and management mode transformation are the core conditions in the configuration path of digital transformation of satellite communication enterprises. Production process improvement, industry development level of core conditions and edge conditions; Digital facility construction and enterprise competitive pressure are mostly marginal conditions. First of all, enterprise managers should attach great importance to the positive effect of digital technology transition and management mode reform on the digital transformation of satellite communication enterprises; Secondly, enterprise managers need to realize that production process improvement and industry development level are also important factors in the process of digital transformation. Finally, enterprise managers need to understand that the construction of digital facilities and the competitive pressure of enterprises are the keys to promote the digital transformation of satellite communication enterprises. Therefore, enterprise managers need to combine the characteristics of the pre-conditions and the characteristics of the enterprise itself to develop the corresponding factor training program, to complement the shortcomings of the pre-factors of the enterprise and relieve the dependence on single advantage, and drive the high-quality transformation and upgrading of the enterprise.

6.2 Limitations and future research

Since there are few maturity scales in the field of digital transformation of satellite communication enterprises and data collection principles such as typicality, richness and accessibility are taken into account, the questionnaire is designed in the form of scoring scale in this study, and likert scale can be used to design the questionnaire later. In addition, in the empirical analysis of this study, different characteristics are found in digital transformation paths of satellite communication enterprises in different fields. Subsequent attempts can be made to analyze the connection and difference between configuration paths of digital transformation of satellite communication enterprises in different fields.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for this study as per local and institutional guidelines.

Author contributions

Methodology and software, LW and LJ.; formal analysis, LW and JH; resources and data curation, HZ, LJ and QW; investigation, LW; writing-original draft preparation, LW; writing-review and editing, LS and KD; supervision and project administration, PL and JH; All authors have read and agreed to the published version of the manuscript.

Conflict of interest

LW, KD, PL, and JH were employed by Xi'an Aerors Data Technology Co., Ltd.; HZ, LJ, QW, and LS were employed by Space Star Technology Co., Ltd.

The remaining author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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