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An Interpretive Structural Analysis for Challenges of Application of 5G Technology

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Short Research Paper

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Abstract: This paper aims at identifying challenges in the application of 5G technology and analyze the challenges based on experts' opinions. We recognize the barriers and challenges of application of 5G technology by reviewing literature and interviewing experts. We analyze the identified challenges using the interpretive structural modeling (ISM) and cross-impact matrix multiplication applied to classification analysis (MICMAC), determining the relationship between the challenges, finding out how they interact with each other, and finally uncovering the root causes that trigger other challenges. Suggestions are given to promote the application of 5G technology, including 1) study deeply into related technologies of 5G communication network, 2) devoted to the development of 5G technology-related talents in various industries and enhance enterprises' understanding of 5G technology, 3) refine the laws, supporting standards and regulations for the application and 4) arrange more base stations. Practitioners can infer what challenges should be firstly taken into consideration and then decide on what measures should be taken to reduce the negative impact in the process of promoting 5G application.

Keywords: 5G challenges, 5G application, interpretive structural modeling(ISM), matrix multiplication applied to classification analysis (MICMAC)

1. INTRODUCTION

5G is the 5th Generation Mobile Communication Technology, which is a general term for a new generation of global mobile communication technologies. It has the characteristics of high speed, low latency and large bandwidth. The application of 5G technology enables new developments in various industries. For example, the 5G Internet of vehicles helps to achieve efficient logistics in industrial parks [1]. 5G networks provide reliable technical support for high-quality online education [2]. 5G networks are great guarantee in real-time telemedicine and remote emergency care [3].

However, there are still many obstacles to the promotion and application of 5G technology. The applications of 5G technology are mostly enterprise-level at present, and there are fewer applications for individual users. Even in enterprise-level applications, due to the high cost of introducing 5G technology [4], Small and medium enterprise (SMEs) cannot apply 5G technology on a large scale. Moreover, the industry ecology of 5G technology application is still in its infancy. It is difficult to carry out cooperation and supervision between different industries [6][7][10] currently. Other factors, such as the infrastructure of 5G technology, enterprises' awareness of 5G and users' attitudes towards 5G, can also affect the promotion of 5G applications.

This paper aims to identify the main challenges of 5G technology promotion and application, and analyze the relationship between these challenges. The research includes three steps. Firstly, we identify and list the main challenges of the application of 5G technology by reviewing literature. Secondly, we invite 3 experts from China Telecom who are familiar with the application of 5G technology and 2 experts who are engaged in 5G business in other industries to discuss these challenges using the Delphi method, and then the experts score after discussing and correcting the identified challenges. Thirdly, we analyze the scoring results with interpretive structural modeling (ISM) and matrix multiplication applied to classification analysis (MICMAC).

The structure of this paper is as follows. Section 1 is introduction, showing the research idea of this paper. Section 2 is methodology. We analyze the relationship between 5G technology application challenges with ISM and MICMAC. Section 3 is conclusion. We give the problems that should be paid attention to in the process of solving the challenges of 5G technology application and put forward solutions.

2. METHODOLOGY

2.1 Identification of challenges

First of all, we search in CNKI and web of science databases with search terms such as "5G challenges", "5G application", "5G barriers" and "5G difficulties", select literatures related to the application of 5G technology in various industries and list the main challenges, combined with related articles that are released by Ministry of Industry and Information Technology of the People's Republic China. Subsequently, We invite experts to discuss on the predefined challenges, evaluating and correcting the listed challenges. Finally, the corrected application challenges of 5G technology and their coding are as followed:

S_1: High cost of 5G application. Due to the high cost of base station construction and maintenance, enterprises need to bear higher costs when introducing 5G technology [4].

S_2: Limited 5G infrastructure makes it difficult to fully promote 5G services. Service capabilities of existing base stations cannot meet the needs of all scenarios and envisaged services cannot be fully developed [5].

S_3: It is difficult to supervise the industry ecosystem of 5G application. There is a lack of targeted laws, regulations and clear specifications for the use of technology. The boundaries of power between different industries are not clear [6][7].

S_4: 5G technology lacks integration with other IT technologies, causing imperfected industry ecosystem of 5G application [7].

S_5: Enterprises have little understanding of 5G technology. Lack of talents with 5G literacy makes it difficult to deeply apply 5G technology [8].

S_6: 5G applications lack effective business models so large-scale applications have not yet been formed [9].

S_7: Application standards related to 5G technology are not perfect, resulting in difficult cross-industry cooperation. Standards of 5G application and data format in various industries are not uniform, causing narrow application scope of 5G [10].

S_8: Low capabilities of information security assurance on application side affects public's confidence in 5G technology [11].

S_9: Users' low trust in 5G applications. Users suspect that personal information are more likely to be stolen with wider connectivity, so they are reluctant to share data with companies and unwilling to be perceived [12].

S_{10}: The cost-effectiveness of 5G terminals needs to be improved. 5G applications are mainly enterprise-level, and there are fewer individual applications. As a result, individuals who are willing to consume for 5G networks are relatively fewer [9][13].

2.2 Interpretive structural modeling

ISM requires people's practical experience and knowledge to transform ambiguous thoughts and opinions into intuitive models with good structural relationships. It is suitable for system analysis with many variables, complex relationships and unclear structures.The ISM methodology includes the following steps.

1) Listing the variables to be evaluated.

2) Defining the relationship between variables through experts' evaluation with Delphi methodology. The evaluation of the relationship between variables focuses on whether solving one challenge helps to solve another challenge, or whether they have a bidirectional relationship.

3) Generating structural self-interaction matrix (SSIM) according to the relationship of each pair of

variables. The relationship is defined as follows.

V: Solving obstacle i also solves obstacle j.

A: Solving obstacle j also solves obstacle i.

X: Obstacles i and j influence each other.

O: There is no relationship between obstacles i and j.

Table 1. Structural Self-Interaction Matrix (SSIM)

Challenges	S10	S9	S8	S7	S6	S5	S4	S3	S2
S1	V	O	O	O	O	O	O	V	V
S2	O	O	O	O	O	O	O	O	-
S3	O	O	V	V	X	A	A	-	-
S4	O	V	V	O	V	O	-	-	-
S5	O	O	O	O	V	-	-	-	-
S6	V	O	O	V	-	-	-	-	-
S7	O	O	O	-	-	-	-	-	-
S8	O	V	-	-	-	-	-	-	-
S9	O	-	-	-	-	-	-	-	-
S10	-	-	-	-	-	-	-	-	-

4) Drawing the initial directed graph according to SSIM generated in step 3). Initial directed graph is shown in Figure 1.

5) Generating reachability matrix according to the SSIM and the initial directed graph and checking the transitivity of reachability matrix. The reachability matrix should be transitive. Generation of reachability matrix obeys the following substitution rules.

V: (i, j) entrance becomes 1, and (j, i) entrance becomes 0.

A: (i, j) entrance becomes 0, and (j, i) entrance becomes 1.

X: (i, j) entrance becomes 1, and (j, i) entrance becomes 1.

O: (i, j) entrance becomes 0, and (j, i) entrance becomes 0.

The generated reachability matrix is shown in Table 3.

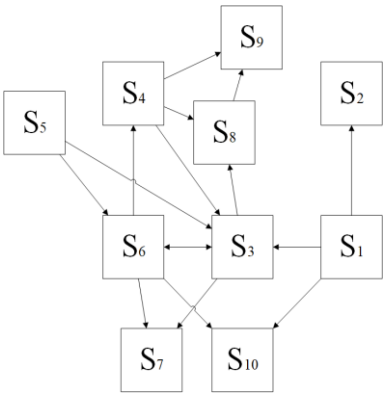

Figure 1. Initial directed graph

Table 2. Adjacency matrix

Challenges	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
S1	1	1	1	0	0	0	0	0	0	1
S2	0	1	0	0	0	0	0	0	0	0
S3	0	0	1	0	0	1	1	1	0	0
S4	0	0	1	1	0	0	0	1	1	0
S5	0	0	1	0	1	1	0	0	0	0
S6	0	0	1	1	0	1	1	0	0	1
S7	0	0	0	0	0	0	1	0	0	0
S8	0	0	0	0	0	0	0	1	1	0
S9	0	0	0	0	0	0	0	0	1	0
S10	0	0	0	0	0	0	0	0	0	1

Table 3. Reachability matrix

Challenges	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	Driving Power
S1	-	1	1	1	0	1	1	1	1	1	8
S2	0	-	0	0	0	0	0	0	0	0	0
S3	0	0	-	1	0	1	1	1	1	1	6
S4	0	0	1	-	0	1	1	1	1	1	6
S5	0	0	1	1	-	1	1	1	1	1	7
S6	0	0	1	1	0	-	1	1	1	1	6
S7	0	0	0	0	0	0	-	0	0	0	0
S8	0	0	0	0	0	0	0	-	1	0	1
S9	0	0	0	0	0	0	0	0	-	0	0
S10	0	0	0	0	0	0	0	0	0	-	0
Dependence Power	0	1	4	4	0	4	5	5	6	5	34

6) Partitioning the reachability matrix. The reachable set includes the challenge itself and the challenges it points to, and the antecedent set includes the challenge itself and the challenges that point to it. The partition results are shown in Table 4.

Table 4. Partitions of reachability matrix

Challenges	Reachability Set	Processor Set	Intersection
S_1	1,2,3,4,6,7,8,9,10	1	1
S_2	2	1,2	2
S_3	3,4,6,7,8,9,10	1,3,4,5,6	3,4,6
S_4	3,4,6,7,8,9,10	1,3,4,5,6	3,4,6
S_5	3,4,5,6,7,8,9,10	5	5
S_6	3,4,6,7,8,9,10	1,3,4,5,6	3,4,6
S_7	7	1,3,4,5,6,7	7
S_8	8,9	1,3,4,5,6,8	8
S_9	9	1,3,4,5,6,8,9	9
S_{10}	10	1,3,4,5,6,10	10

7) Finding out the intersection of reachable set and processor set corresponding to each factor. The challenges whose reachable set is the same with intersection are placed in the first layer of interpretive structural model (I). Delete the row and column where the elements of the first layer are located to form a new reachability matrix, and repeat the above steps.

8) Substituting encoding with concrete sentences and converting initial directed graphs into interpretive structural model.

9) Revising interpretive structural model.

According to reachability matrix, the hierarchical division result of challenges and the initial directed graph, interpretive structural model of challenges of 5G technology application is obtained, which is shown in Figure 2.

The challenge factors at the bottom are S_1 and S_5. These factors are the most fundamental reasons for difficulties in 5G technology application, and directly or indirectly affect other factors. The middle layer is the second and third layers. S_8 stays at the second layer and the third layer includes S_3, S_4 and S_6. These challenges are both influenced by the challenges at next layer and have an impact on challenges at the previous layer.

Moreover, the three challenge factors in the third layer are also interconnected and influence each other. At the top are S_2, S_7, S_9, and S_{10}. These 4 factors are directly or indirectly affected by all the factors below, but their changes will hardly affect other factors.

We will give an example to interpret this model. In order to improve users' trust in 5G technology (S_9), it is necessary to improve data security on the application side of 5G (S_8), making users believe that their privacy will not be leaked. Limited 5G infrastructure (S_2), non-uniform data formats on application side (S_7) and low cost-effectiveness of 5G terminals(S_{10}) are not priorities because they don' t directly point to S_9. When optimizing 5G application-side data security issues, it is necessary to combine with IT technology with stronger confidentiality to improved 5G industry ecology and jointly defend against security risks (S_3), explore effective business models to attract other industries to join and integrate (S_6), and cooperate with perfect application-side laws and regulations for supervision (S_4). The formation of industry ecology, business models, and supporting laws and regulations is closely related to the expenses that enterprises need to bear (S_1) and enterprises' understanding of 5G (S_5). When exploring 5G applications, if enterprises who are willing to develop new applications cannot afford the cost of introducing 5G technology, they may not have a try. If enterprises do not understand 5G technology, applications of 5G will only stay at a shallow level, making it difficult to form an industry ecology, create a business model with strong profitability and discover the hidden dangers may exist in the process of exploring 5G application and form targeted supervision plans.

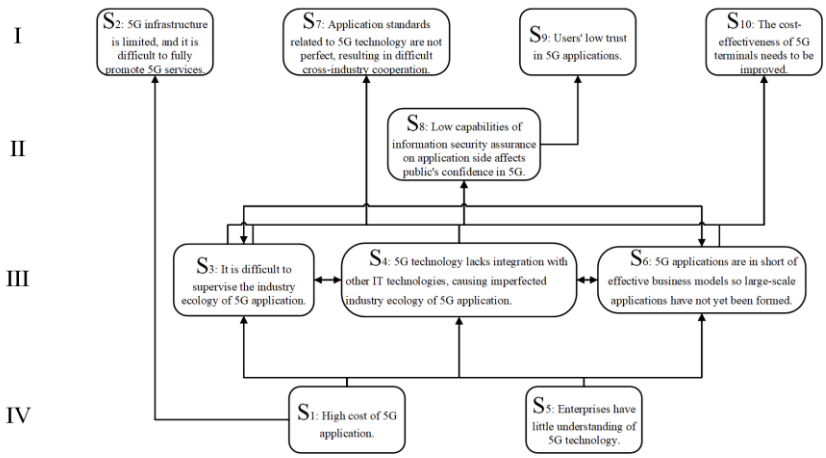

Figure 2. Final interpretive structural model

2.3 MICMAC analysis

MICMAC methodology is used to identify high driving force variables and high dependence variables in the system. The driving force and dependence power of each factor in the reachability matrix are calculated and shown in Table 2. The average value of driving force and dependence is 3.4, and the 10 factors are divided into 4 categories based on this average value, namely independent variables, linking variables, autonomous variables and dependent variables. The classification of challenges is shown in Figure 3.

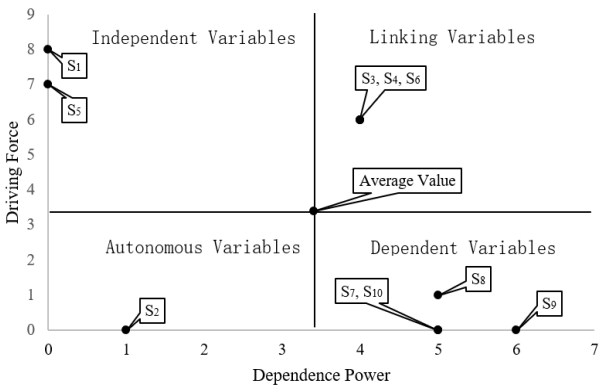

Figure 3. Classification of challenges

Independent variables include S_1 and S_5. Such challenges affect other challenges a lot and are less affected by others. They are generally the source of a specific problem. Autonomous variable includes S_2. It has little influence or dependence on other challenges. Linking variables include S_3, S_4 and S_6, which have high driving force and dependence power and can establish links between other challenges. Dependent variables include S_7, S_8, S_9 and S_{10}. Such challenges are mainly caused by other factors and have little effect on other factors.

3. CONCLUSIONS

This paper identified the challenges that affect the promotion and application of 5G technology through literature review and expert interviews. We applied ISM and MICMAC to sort out the hierarchical relationship between challenges and analyze the driving force and dependence power of each challenge, revealing the inner connection between challenges and find out the key issues for the promotion and application of 5G technology. We found that the factors at the bottom of interpretive structural model are often the independent variables under MICMAC analysis, while the factors at the top of interpretive structural model are often the dependent variables. The two models may corroborate each other, identifying the easiest and most fundamental factors in problem solving.

It is necessary to focus on two independent variables at the bottom of ISM to explore and promote the application of 5G technology, that is, to focus on solving the problems that enterprises need to bear the high cost of introducing 5G technology and enterprises have insufficient understanding of 5G technology. Suggestions are as followed:

1) Study deeply into related technologies of 5G communication network to reduce the cost of 5G technology application in all aspects. From numerical analysis and network layout to algorithm optimization, we should develop new technologies to obtain better performance in terms of data processing speed, data capacity, transmission equipment stability, data transmission accuracy, data transmission efficiency, power distribution network, etc. and improve the efficiency of data transmission in all aspects, so that we can reduce the energy cost and operating cost of base stations. As a consequence, we can lower the cost of introducing 5G technology to develop new applications, encouraging more enterprises to join in and explore 5G applications.

2) Devoted to the development of 5G technology-related talents in various industries and enhance enterprises' understanding of 5G technology. Employees' understanding of 5G could be improved in specific working with the promotion and education of their enterprises. Schools are responsible for training students' ability of applying 5G technology to complete their professional courses. For example, setting up practical courses related to 5G technology and building virtual platforms for students to practice could be helpful. Schools and enterprises can cooperate jointly to train talents, building a talent training database to continuously track participants' learning and improve the teaching process. Schools can provide systematic theoretical knowledge and enterprises offer great work to utilize the theoretical knowledge, which implies that with the cooperation of schools and enterprises, 5G technologies are like to be truly and fully applied to concrete practical processes such as product development and production management.

3) Refine the laws, supporting standards and regulations for the application. Supporting standards here include common standards between different industries and regulatory measures for 5G applications. Organizing seminars and lectures to discuss industry standards on 5G application contributes to unify data forms in various industries, promoting industry integration and the building of 5G industry ecosystem. Improving the supervision of 5G application in a policy-oriented manner could be effective when it comes to protecting users' personality, privacy and property security.

4) Arrange more base stations in proper positions and optimize long-distance transmission technology to support different tentative plans of 5G application. 5G technologies could contribute a lot in terms of resource allocation. Exploiting 5G technologies to promote the sharing of social resources such as educational resources and medical resources helps to drive the development of backward areas. This is the contribution that 5G technology can bring to social justice, which is worthy of further exploration in the application of 5G technology.

Furthermore, our study deserves further exploration. Some possible future studies are listed below.

Firstly, the resolution of each challenges can be broken down into several problems that can be studied

further. For example, S_{10} can be decomposed into: high power consumption of 5G terminals, high tariffs of 5G terminals, and few 5G-related applications. In the future, scholars can choose one or several of the 10 challenges summarized in this paper to conduct in-depth disassembly and propose a complete set of solutions.

In addition, this paper conducts a qualitative analysis of 10 challenges. In the future, scholars can introduce weights to qualitatively analyze these challenges and build new interpretive structural models. For example, formulate a series of scoring criteria, invite experts to evaluate the weight of challenges, construct a new interpretive structure model and quantitatively analyze the importance of these challenges to solve the problem of hindering the application of 5G technology.

Finally, barriers to the adoption of 5G technology in a specific industry are also worth studying. This article focuses on barriers and challenges that are prevalent across multiple industries. The obstacles and challenges each specific industry encounters in adopting 5G technology may differ from those presented in this paper. For example, in manufacturing, the operational skills of workers and existing backward equipment that is difficult to access 5G networks may affect the efficiency of 5G applications.

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