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An Empirical Investigation on the Determinants of Smart Water Grid Adoption

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Abstract

Smart water management is emerging as a new paradigm. Smart water management combines existing water management techniques with cutting-edge IT to enable more sustainable water management. Developed countries have incorporated IT in a broad range of policies governing areas of Social Overhead Capital (SOC), ranging from water management to electricity, transportation, and the environment. As an IT powerhouse, Korea has an advantage in promoting smart water management, but the technologies in this particular field have not kept pace with those in more advanced countries. The Korean government has made a number of attempts to incorporate state-of-the-art IT and establish smart SOC, which is expected to greatly enhance infrastructure efficiency and functions. Water management has been included in SOC initiatives, and the deployment of a "Smart Water Grid" is underway. As a next-generation intelligent water management system, the Smart Water Grid has been well received around the world due to its potential to address dire water shortage problems. However, in Korea, studies on a Smart Water Grid are still at a nascent stage. This study aimed to lay the groundwork for the successful introduction of a new Smart Water Grid system by identifying factors that promote or restrict the adoption of innovative technology, analyze how various factors affect the intention to adopt a Smart Water Grid, and attempt to find a causal relationship between the identified factors and the intention to adopt the new IT system.

Keywords: Information Technology (IT), Isomorphism, Resistance, Smart Water Grid (SWG), Social Overhead Capital (SOC)

1. Introduction

Water management has become an extremely important issue in the global community in recent years against a background of explosive population growth, massive migration to cities, and climate changes, which have brought about dramatic changes in water circulation. The population growth and rapid urban sprawl add pressure on the demand side, whereas flood and draught add pressure on the supply side. These environmental changes pose risks to water management. However, at the same time, they open up new opportunities for water-related industries.

Under these circumstances, "smart water management" is emerging as a new paradigm. Smart water management combines existing water management techniques with cutting-edge IT to enable more sustainable water management. Developed countries have incorporated IT in a broad range of policies governing areas of Social Overhead Capital (SOC), ranging from water management to electricity, transportation, and the environment. As an IT powerhouse, Korea has an advantage in promoting smart water management, but the technologies in this particular field have not kept pace with those in more advanced countries.

The Korean government has made a number of attempts to incorporate state-of-the-art IT and establish smart SOC, which is expected to greatly enhance infrastructure efficiency and functions. Water management has been included in SOC initiatives, and the deployment of a "Smart Water Grid" is underway. As a next-generation intelligent water management system, the Smart Water Grid has been well received around the world due to its potential to address dire water shortage

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problems. However, in Korea, studies on a Smart Water Grid are still at a nascent stage[17].

This study aimed to lay the groundwork for the successful introduction of a new Smart Water Grid system by identifying factors that promote or restrict the adoption of innovative technology, analyze how various factors affect the intention to adopt a Smart Water Grid, and attempt to find a causal relationship between the identified factors and the intention to adopt the new IT system.

Specifically, the objectives of the study were to define a Smart Water Grid and examine its current status, both at home and abroad, review previous studies of the adoption of innovative new technologies and the resistance to such technologies to identify factors that might affect the acceptance or rejection of a Smart Water Grid, conduct an empirical analysis of the identified factors and the intention to adopt the system to demonstrate a causal relationship, and propose how to introduce and deploy a Smart Water Grid, focusing on the factors identified in the empirical analysis.

2. Literature Review

The literature on IT adoption by enterprises has identified a variety of factors as the influence factors of successful IT adoption. In order to gain a comprehensive view on what factors may impact the adoption of a Smart Water Grid, we adopted the Technology-Organization-Environment (TOE) framework in conjunction with innovation diffusion theory and institutional theory in identifying important determinants of the adoption.

2.1 Technology-Organization-Environment (TOR) Framework

The Technology Acceptance Model (TAM) proposed by Davis[9] examined the acceptance of IT and its outcomes at an individual level of organizational members and consumers. The Technology-Organization-Environment (TOE) framework examined IT acceptance at an organizational level. The framework demonstrated that technological, organizational, and environmental contexts were exogenous variables that affected an organization's acceptance of innovative technology, with each variable affecting an organization's intention to adopt the technology and the outcome of the technological innovation. A number of studies make use of a Technology–Organization–Environment (TOE) framework as a research model for investigating the adoption of innovative technology at an organization level.

First, technology can contribute to increases in the productivity of an organization. In this case, the term technology does not only refer to internal technologies within an organization but also includes technologies available outside an organization. Second, the structure and processes of an organization play a role in enabling or restricting the adoption of innovative technology. An organization is defined by factors like company size, centralization, formalization, quality of human resources, complication of business administration, and internally available resources, which include internal communication and decision making. Third, the environment refers to a setting that is relevant to the business being performed by the organization, including the skills of the labor force, macroeconomic environment, competitiveness of the organization, relationship with customers and suppliers, industrial structure that the organization belongs to, and legal and institutional environment, such as government regulations.

Based on the TOE framework, Zhu et al.[48] conducted an empirical study of technology diffusion among electronic businesses.

2.2. Institutional Theory

DiMaggio and Powell[10] claimed that efforts to transform an organization led to homogenization among different organizations, indicating such a motive as 'isomorphism'. DiMaggio and Powell[10] described the following three mechanisms of isomorphism:

- Coercive isomorphism: pressure from organizations or bodies (e.g., in the form of mandates by governments or public institutions) on which a company is dependent upon
- Mimetic isomorphism: imitation of exemplary organizations due to uncertainty in the environment. Typically, an organization imitates other model organizations and decides whether to accept an innovation based on the other organizations' experiences of success/failure.
- Normative isomorphism: a process of homogenization brought about by norms, with isomorphism taking place among professionals in different fields. A social consensus on the norm leads to homogenization among organizations. This bind looks loose on the outside but is, in fact, the most powerful motive for isomorphism.

Recently, a number of studies have analyzed the adoption factors surrounding Information Technology (IT) by combining the previously mentioned TOE framework with three isomorphisms. Gibbs and Kraemer[12], Li[22], and Soares-Aguiar and Palma-dos-Reis[39] are examples of researchers who have produced analyses of organizations' adoption and dissemination of IT where coercive isomorphism, mimetic isomorphism, and normative isomorphism, which are founded in institutionalism theory, are used as environmental factors in the TOE framework.

2.3. Innovation Resistance Model

Sheth[38], Ram[32] conducted some of the leading research on the resistance to technological innovation. According to Ram[32], previous studies on the diffusion of innovation overemphasized successful aspects of the innovation. Ram[32] further claimed that resistance to innovation is not the opposite of acceptance but a variable in the process leading up to acceptance. He identified three factors that affect resistance to innovation: innovation characteristics, consumer characteristics, and propagation mechanisms.

In previous water management systems, the real-time management of water demand was not possible. This caused an imbalance between supply and demand as well as decreased the efficiency of facility operations. Loss of water from leaks as well as excessive energy use for water production and delivery were identified as the main problems of the previous system. A Smart Water Grid is expected to cause diverse effects such as enhancing the efficiency of water production and treatment. This will enable the systematic management of the facility with fewer costs and address regional imbalances in water resources. A Smart Water Grid is one of the newer technological innovations available in water management.

The introduction of a Smart Water Grid, which is a combination of the latest IT and water management technology, is a new technological innovation that delivers innovative change by moving away from the water management systems of the past. This study attempts to build a research model by combining the institutionalism theory of DiMaggio and Powell[10] with the innovation resistance theory of Ram[32]; this combined model has features that are complementary to the previously mentioned TOE framework by Tornatzky et al[42,50-52].

3. Research Model

A preliminary study of the feasibility of a Smart Water Grid showed that a comprehensive, multifaceted approach needs to be adopted to understand the many factors that influence the acceptance of such a grid. Accordingly, a comprehensive analytical research model of the acceptance of new technology at an organizational level was designed based on the TOE framework developed by Tornatzky et al[42].

To analyze the environmental factors that affect the acceptance of a Smart Water Grid, this study applied the three mechanisms of isomorphism identified by Di Maggio and Powell[10], as noted earlier. The institutional model was chosen because political factors are likely to affect national projects, such as a Smart Water Grid. Interviews with water experts revealed that plans to introduce a Smart Water Grid in some countries were abandoned due to public resistance to associated risks. Thus, the 'resistance to innovation' was included as a variable in the model of innovation resistance developed by Ram[32].

Based on the discussion above, we formulated a research model and hypothesis including factors which may greatly affect the Smart Water Grid adoption decision by Korean public utilities (Figure 1).

The factors that influence the acceptance of a Smart Water Grid were categorized into technological, organizational, and environmental elements. The dependent variables were divided into resistance to innovation and acceptance of innovation. The technological factors included "perceived benefits", "perceived costs", and "perceived risks". The organizational factors included "support from a decision maker", "centralization of decision making", and "organizational resources". The environmental factors included "coercive isomorphism", "mimetic isomorphism", and "normative isomorphism". The influence of these factors on the dependent variables of resistance to innovation and acceptance of innovation was then analyzed.

4. Research Method

4.1 Demographic of Survey Subjects

In this study, the initial sample size collected for the

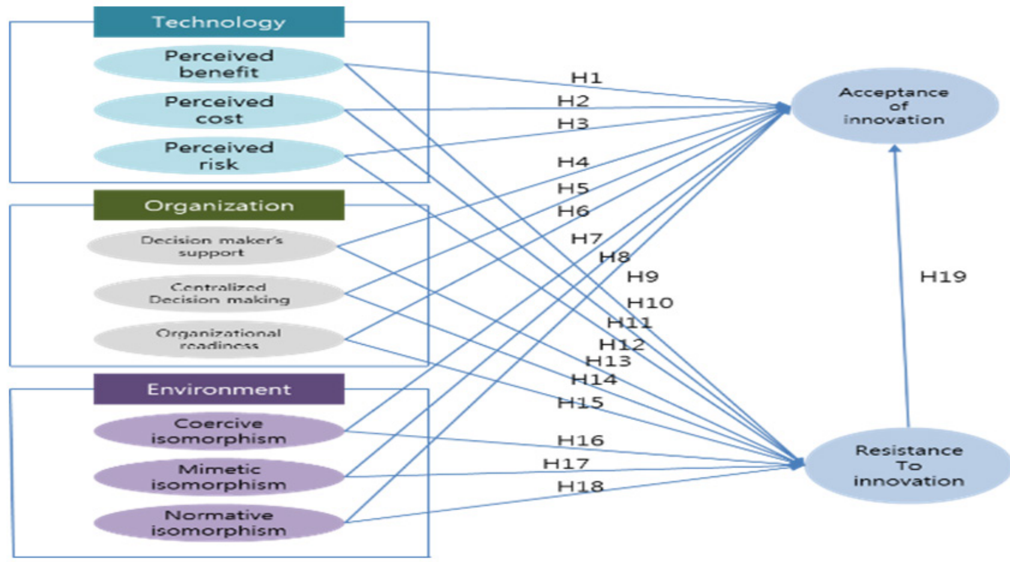

Figure 1. Research Model for Smart Water Grid Adoption.

survey was 232, among which 20 samples had untruthful responses and were excluded; the final sample size for the analysis was 212. Frequency analysis was conducted to understand the demographic situation of the 212 samples.

The following results were obtained. Of the 212 total respondents, 185 (87.3%) were male and 27 (12.7%) were female. Concerning work experience, 55 (25.9%) had less than five years of experience, 65 (30.7%) had 5–10 years of experience, 43 (20.3%) had 10–15 years of experience, 27 (12.7%) had 15–20 years of experience, and 22 (10.4%) had more than 20 years of experience. Concerning participants' ages, 20 (9.4%) were in their twenties, 111 (52.4%) were in their thirties, 67 (31.6%) were in their forties, and 14 (6.6%) were in their fifties.

4.2 Exploratory Factor and Analysis and Reliability Analysis

4.2.1 Technical Attributes

Concerning the thirteen questions about technical attributes, an exploratory factor analysis and a reliability analysis were performed to confirm the construct validity and reliability of perceived benefit, perceived cost, and perceived risk. The results of the analysis are described below.

The model was acceptable with KMO=0.748 and Bartlett's p=0.000. According to the results, after four rotations it was composed of three components whose characteristic values were 3.599, 2.815, and 2.211, which are all larger than 1. The overall variance was 66.347%. The questions from t1–t6 involved perceived benefit, t7–t10 involved perceived cost, and t11–t13 involved perceived risk. According to the reliability of the results based on the value of Cronbach's α, reliability was high for perceived benefit at 0.861, perceived cost at 0.847, and perceived risk at 0.806.

4.2.2 Organizational Attributes

Concerning the nine questions regarding organizational attributes, an exploratory factor analysis and reliability analysis were performed to confirm the construct validity and reliability of supports from champions, the centralization of decision making, and organizations' resources. The results of the analysis are described below.

This model was acceptable with KMO=0.755 and Bartlett's p=0.000. According to the results, after five rotations it was composed of three components whose characteristic values were 1.747, 1.621, and 1.592, which are all larger than one. The overall variance was 82.674%. The questions from o2–o3 involved supports from champions, o5–o6 involved the centralization of decision making, and o8–o9 involved organizations' resources. According to the reliability of the results based on the value of Cronbach's α, reliability was high for the centralization of decision making at 0.726, organizations' resources at 0.777, and supports from champions at 0.831.

4.2.3 Environmental Attributes

Concerning the nine questions regarding environmental attributes, an exploratory factor analysis and reliability analysis were performed to confirm the construct validity and reliability of coercive isomorphism, mimetic isomorphism, and normative isomorphism. According to the first reliability results of the analysis, the reliability of mimetic isomorphism was too low at 0.548. This can be attributed to the current situation in domestic water markets where the introduction of a Smart Water Grid is still in its fledgling stages. It is therefore difficult to find cases regarding mimetic isomorphism. Hence, exploratory factor analysis and reliability were examined for coercive isomorphism and normative isomorphism after discarding mimetic isomorphism that could not obtain consistent responses.

The model was acceptable with KMO=0.559 and Bartlett's p=0.000. According to the results, after three rotations it was composed of two components whose characteristic values were 1.779 and 1.525, both of which are larger than one. The overall variance was 82.596%, and the questions from p1–p2 involved coercive isomorphism, while p8–p9 involved normative isomorphism. According to the reliability of the results based on the value of Cronbach's α, reliability was high for coercive isomorphism at 0.870 and normative isomorphism at 0.685.

4.2.4 Acceptance and Resistance

Concerning the eight questions regarding acceptance and resistance, an exploratory factor analysis and reliability analysis were performed to confirm the construct validity and reliability of adoption and resistance. The results of the analysis are described below.

The model was acceptable with KMO=0.892 and Bartlett's p=0.000. According to the results, after three rotations it was composed of two components whose characteristic values were 2.907 and 2.830, which are larger than one. The overall variance was 70.461%, and the questions from s1–s4 involved adoption, while s5–s8 involved resistance. According to the reliability results based on the value of Cronbach's α, reliability was high with 0.873 for adoption and 0.835 for resistance.

4.3 Confirmatory Factor Analysis

A confirmatory factor analysis indicated the following goodness of fit results. After evaluating the goodness of fit, the first analysis did not show desirable results in indices other than RMR=0.040 and RMSEA=0.072. However, after modifying the model, RMR=0.043, RMSEA=0.059, and IFI=0.917. Additionally, CFI=0.915 showed desirable results in the final model, indicating a decent goodness of fit in the final model.

Using the analysis results, the estimated parameter value of CR and the AVE were obtained and are described below. As for the estimates for the parameter value between factor and measurement, all the βs were statistically significantly with values larger than 0.4 and $p<0.05$. The CR value was larger than 0.7, and the AVE value was larger than 0.5, satisfying the condition for convergent validity.

To verify discriminant validity, a correlation analysis was conducted among the measured variables using SPSS. These values were compared with the square root of AVE. If the square root of AVE is larger than the correlation coefficient r, discriminant validity can be confirmed. The results of the analysis are described below.

After analyzing the correlation among the measured variables, all the r values showed a statistically significant and positive relationship with $p<0.05$. Comparing the relevant r value and square root of AVE, $r<\sqrt{AVE}$ was confirmed in every index, implying that every index has discriminant validity.

4.4 Results of the Analysis

The estimated parameter values are described below. According to the parameter estimates, significant parameter values for innovation resistance were as follows: resistance ← benefit (β=-0.473***) and resistance ← organization resources (β=-0.327*). Significant parameter values for the innovation adoption consisted of adoption ← risk (β=0.150*), adoption ← coercive isomorphism (β=0.165*), adoption ← supports from champions (β=0.168*), and adoption ← resistance (β=-0.499***). The figure below describes the overall analysis results of the structural model.

The results of the analysis showed that the "perceived benefit" and "organizational readiness" were a meaningful "resistance to innovation" parameter. In contrast, the "perceived risk", "coercive isomorphism", "support from a decision maker" and "resistance to innovation" were important "acceptance of innovation" parameters. Specifically, with regard to the resistance to innovation,

Table 1. Estimated parameter value of CR and the AVE

			B	S.E.		P	β	C.R	AVE
t1	←	Perceived benefit	1				0.567	0.898	0.604
t2	←	Perceived benefit	0.873	0.085	10.228	***	0.514		
t3	←	Perceived benefit	1.264	0.168	7.517	***	0.634		
t4	←	Perceived benefit	1.346	0.176	7.64	***	0.7		
t5	←	Perceived benefit	1.527	0.171	8.916	***	0.831		
t6	←	Perceived benefit	1.739	0.19	9.167	***	0.934		
t7	←	Perceived cost	1				0.87	0.948	0.823
t8	←	Perceived cost	0.883	0.074	11.959	***	0.81		
t9	←	Perceived cost	0.98	0.091	10.722	***	0.855		
t10	←	Perceived cost	0.757	0.081	9.292	***	0.633		
o2	←	Decision maker's support	1				0.923	0.894	0.810
o3	←	Decision maker's support	0.894	0.095	9.424	***	0.773		
o5	←	Centralized decision making	1				0.725	0.814	0.687
o6	←	Centralized decision making	1.066	0.123	8.639	***	0.786		
s1	←	Acceptance of innovation	1				0.721	0.924	0.753
s2	←	Acceptance of innovation	1.324	0.116	11.451	***	0.829		
s3	←	Acceptance of innovation	1.238	0.105	11.814	***	0.858		
s4	←	Acceptance of innovation	1.24	0.114	10.865	***	0.785		
s5	←	Resistance to innovation	1				0.655	0.890	0.674
s6	←	Resistance to innovation	1.339	0.138	9.73	***	0.795		
s7	←	Resistance to innovation	1.161	0.136	8.532	***	0.675		
s8	←	Resistance to innovation	1.493	0.143	10.43	***	0.887		
t11	←	Perceived risk	1				0.816	0.837	0.633
t12	←	Perceived risk	1.002	0.101	9.918	***	0.803		
t13	←	Perceived risk	0.76	0.084	9.029	***	0.67		
p1	←	Coercive isomorphism	1				0.944	0.949	0.903
p2	←	Coercive isomorphism	0.932	0.1	9.316	***	0.817		
p8	←	Normative isomorphism	1				0.813	0.838	0.724
p9	←	Normative isomorphism	0.74	0.121	6.092	***	0.642		
o8	←	Organizational readiness	1				0.778	0.852	0.743
o9	←	Organizational readiness	1.103	0.109	10.142	***	0.818		

Table 2. Correlation matrix

	1	2	3	4	5	6	7	8	9	10
Perceived benefit	0.777									
Perceived cost	0.071**	0.907								
Perceived risk	0.046	0.233**	0.796							
Decision maker's support	0.393**	-0.018	0.093	0.950						
Centralized decisionmaking	0.397**	0.140**	0.128**	0.420**	0.851					
Organizational readiness	0.472**	0.117*	0.088	0.449**	0.527**	0.900				
Coercive isomorphism	0.110*	-0.301**	-0.042	0.168**	0.060	0.140**	0.829			
Normative isomorphism	0.277**	-0.145**	-0.049	0.173**	0.274**	0.131**	0.303**	0.862		
Acceptance of innovation	0.562**	0.032	0.232**	0.413**	0.400**	0.462**	0.265**	0.223**	0.868	
Resistance to innovation	-0.587**	-0.137**	-0.169**	-0.339**	-0.347**	-0.482**	-0.133**	-0.118*	-0.615**	0.821
Average	3.351	1.833	2.714	03.524	03.059	3.309	4.160	3.526	3.557	2.886
Standard Deviation	0.636	0.506	0.779	0.717	0.692	0.710	0.570	0.587	0.653	0.669

*p<.05 **p<.01.

Table 3. Summary of hypothesis tests

			B	S.E.	C.R.	P	β	Result
Resistance to innovation	←	Perceived benefit	-0.522	0.114	-4.562	***	-0.473	Supported
	←	Perceived cost	-0.021	0.063	-0.324	0.746	-0.022	Not supported
	←	Perceived risk	-0.069	0.044	-1.566	0.117	-0.107	Not supported
	←	Coercive isomorphism	-0.135	0.069	-1.945	0.052	-0.15	Not supported
	←	Normative isomorphism	0.127	0.091	1.394	0.163	0.145	Not supported
	←	Decision maker's support	0.015	0.066	0.232	0.816	0.019	Not supported
	←	Centralized decision making	-0.01	0.124	-0.078	0.938	-0.011	Not supported
	←	Organizational readiness	-0.271	0.116	-2.331	0.02*	-0.327	Supported
Acceptance of innovation	←	Perceived benefit	0.082	0.097	0.848	0.397	0.072	Not supported
	←	Perceived cost	-0.013	0.058	-0.217	0.828	-0.013	Not supported
	←	Perceived risk	0.1	0.041	2.415	0.016*	0.15	Supported
	←	Coercive isomorphism	0.153	0.065	2.351	0.019*	0.165	Supported
	←	Normative isomorphism	0.052	0.082	0.638	0.524	0.058	Not supported
	←	Decision maker's support	0.139	0.062	2.237	0.025*	0.168	Supported
	←	Centralized decision making	0.066	0.113	0.587	0.557	0.074	Not supported
	←	Organizational readiness	0.026	0.107	0.248	0.804	0.031	Not supported
	←	Resistance to innovation	-0.515	0.103	-4.992	***	-0.499	Supported

*p<.05 **p<.01 ***p<.001

the higher the perceived benefit of the technology, the lower the resistance.

The path coefficient for perceived benefits having a negative impact on resistance to innovation was 0.473, indicating that this factor was influential. The path coefficient for organizational resources having a negative impact on resistance to innovation was 0.327, indicating that this factor was influential.

The path coefficient for perceived risks having a negative impact on acceptance of innovation was 0.15, indicating that this factor was influential. The path coefficient for coercive isomorphism having a positive impact on acceptance of innovation was 0.165, indicating that this factor was influential. The path coefficient for support from a decision maker having a positive impact on acceptance of innovation was 0.168, also indicating that this factor was influential. The path coefficient for resistance to innovation having a negative impact on acceptance of innovation was 0.499, indicating that this factor was influential.

In terms of the acceptance of innovation, the higher the perceived benefit of the technology, the higher the acceptance of innovation, and the lower the perceived risks, the higher the acceptance of innovation (Technological Context). The stronger the coercive isomorphism, the higher the acceptance of innovation (Environmental Context), and the stronger the decision-maker's support, the higher the acceptance of innovation (Organizational Context).

5. Discussion

In terms of the acceptance of innovation, the higher the perceived benefit of the technology, the higher the acceptance of innovation, and the lower the perceived risks, the higher the acceptance of innovation. The stronger the coercive isomorphism, the higher the acceptance of innovation, and the stronger the decision-maker's support, the higher the acceptance of innovation. With regard to the relationship between resistance to and acceptance of innovation, the findings suggest that resistance should be mitigated to stimulate acceptance, as the two parameters have an inverse relationship. To lower the resistance to innovation, perceived benefits should be increased.

These findings can be used to develop strategies to promote the adoption of Smart Water Grid by Korean public utilities. This study is also helpful to developing validated predictor of enterprises' Smart Water Grid adoption in developing countries and understanding the global diffusion of Smart Water Grid.

These findings suggest that when attempting to implement a Smart Water Grid, priority needs to be given to reducing the perceived risks of innovative technology and that strong support from decision makers and institutional pressure from the government and public institutions could have a positive impact on the acceptance of new technology.

From the perspective of resistance to innovation, the current study showed that the perceived benefits of the technology and the organization's resources had a significant impact on resistance to innovation. To reduce employees' resistance to innovation, greater efforts should be made to promote the benefits of a Smart Water Grid to employees in advance of its implementation and mobilize sufficient resources to introduce the new system.

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