Optimize IoT for Operating Wastewater Treatment Plant based on Visualizing User’s Thinking

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Abstract. Sewer system is the major facility of avoiding improper disposal of wastewater. As expanding wastewater treatment into rural areas, the supervision and the operation will be more difficult. The fast innovation of IoT in sensor, wireless communication and smart control is gaining more and more expectation of IoT to be the next-generation option of control system in wastewater treatment plant. At present IoT technology is moving rapidly and its market is very competitive. There are still many uncertainties while making the decision of upgrading control system to IoT. After all using IoT is an investment, the fault of choosing an unpopular product and then losing support before long should be avoided. This study shares the experiences how to identify the needs of IoT based on visualizing user's thinking and then propose an optimal design of IoT to operating a wastewater treatment plant.

1. Introduction

Right now we face a tough situation that water pollution induced by untreated wastewater is threatening the sustainable development in the downstream area of river. But so far the supervision about WWTPs is weak and most of them are far behind the art of AI technology. The improper disposal due to disorder management or chaotic operation still often happens. Although IoT is able to extend networks connectivity and computer capability to every device in our living [1], but I do not mean to suggest the manager of WWTPs immediately upgrading their system to IoT because of huge diversity from their technologies and prices yet. After all using IoT is an investment, the risk due to choosing an unpopular product and then losing support before long should be avoided.

By using IoT, Chen et al. [2] made a useful forecasting function of IoT by a neural network to minimize losses in an emergency. In Zaragoza, Spain, a smart water management model developed by Robles et al. [3] showed water management company a way to access a wider global market via adopting IoT in decision support, monitoring and water governance of a pumping system. Artificial intelligent in IoT will convert the monitoring records into valuable information, e.g. the timing and supply of critical device [4]. At present IoT technology is moving rapidly and the market is very competitive [5]. However people still have controversy over the anticipation that the management of WWTPs will enter the era of IoT. Is it necessary to promote the control system of WWTP to IoT? For seeking the truth we visited several wastewater treatment plants in the South Taiwan, interviewed managers and operators form 8 WWTPs and visualized their decision making.

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This study uses Evaluation Grid Method (EGM) to perform an in-depth interviews that is able to clearly visualize the user's cognition as an Evaluation Hierarchical Map [6-7]. Since Sanui modified Kelly's repertory grid technique to create this approach, EGM has been successfully employed in numerous product designs and service designs [8-10].

2. Methods

A schematic overview of the methodology employed was displayed in Figure 1. On April 8, 2017, we invited 42 experts composed of managers and operators coming from 10 WWTPs to join a meeting of discussing what kind of smart control they need. First we made a simply explain to these experts what this meeting is for, and then arrange all experts to take a field trip before sharing vision each other. This meeting derived a series of analysis at upgrading each device of WWTP to smart control and summarized their importance as Table 1.

The quality and quantity of information elicited from an interview relies on the personal ability of an interviewer. For this concern, we created a conceptual IoT for WWTP. In Taiwan almost every adult owns a smart phone with 4G or WiFi wireless communication. So smart phone become the first thing existing in the list of IoT we proposed. An App coding by Ruby-on-Rails (RoR) which connects with the monitoring database running at MySQL server, manipulates the state of visual relay in InduSoft© and power relay in distance to remote control the device, and supports user smart services such as device's knowledge, operating discipline, emergence response, etc. was created to be the interview material. We spent 3 months to cooperate with an interdisciplinary teams composed of 8 engineers with the expertise of wastewater, sensor, automatic control, and software. This App successfully promotes the interaction between interviewer and respondent during searching the attractiveness of IoT in the following in-depth interviews. Moreover some potential functions, e.g. artificial intelligent to detect the emerging disorder of machine, modelling the operation of engine by adding sensor of noise, vibration, and electric, were also included into the scope of conceptual IoT we proposed during interview.

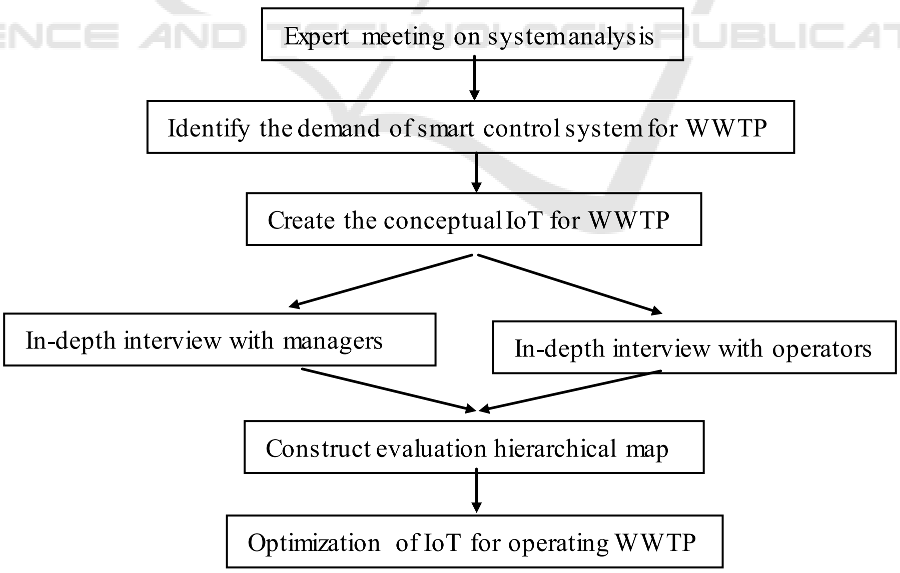

Figure 1. The schematic diagram of research methodology.

2.1. In-depth interview

Manager who has the power of dominating the budget of operating WWTP is of critical to offer valuable experiences to this study. We visited 8 wastewater treatment plants in the South Taiwan.

Each manager of these plants has been interviewed at least twice or more times. They were asked to determine their first impression, “satisfied/dissatisfied” or “most preferred/least preferred,” over the IoT we proposed. Then the discussion during interview will ladder up to identify the abstract reasons (e.g. value judgment) and ladder down to form concrete features (e.g. objective and concrete understanding). Such an in-depth interview could make the respondent much more time to confirm each evaluation item.

Operator will be in the closest relationship with IoT in WWTP. Basically IoT is a tool designed for assisting operator to serve their duty more efficient if the operator was willing to use it. This study invited more than 50 new operators to participate our in-depth interview. Discussions were focused on how they feel the help including machine knowledge, operating discipline, emergence response through APP we provided. Each operator was interviewed at least twice. After repeated in-depth interview, we extracted their original feelings while operating WWTP with the aid of IoT, and then extended to infer their abstract reasons and concrete features about the service supported by IoT. Eventually each personal evaluation hierarchical map was done as the structure of three-layer hierarchy

Table 1. The analysis at upgrading each device of WWTP to smart control.

Device	Demand to smart control	Unit	priority (1~5)
Water pump	Automatic control by water level	Most units	5
Grit chamber	Automatic control by sand thickness	Pumping station, primary clarifier	1
Clay washer	Operation linked with sand pump	Pumping station	3
Mechanical screen	Operation linked with flow rate	Inlet channel	2
Valve/gate	Automatic operation	Most units	3
Scraper	Automatic calibration, Automatic operation	Primary clarifier, final settling tank, sludge thickening tank	3
Deodorizer	Automatic control by odour concentration	Primary clarifier, aeration tank	4
Ventilating system	Staff security by operating with gas detector	Primary clarifier, aeration tank	5
Blower	Adjust air supply by detecting DO	Aeration tank, sand filter	5
De-foaming system	Operation by detecting the nozzle pressure	Aeration tank	2
Recycling Sludge system	Automatic waste sludge by F/M ratio	Aeration tank	2
Aeration system	Detect the oxygen profile	Aeration tank	5
Sludge pumping	Operating by grit/sludge thickness	final settling tank, sludge thickening tank	5
Scum pump	Automatic control by detecting scum	Final settling tank	4
Feeding pump	Automatic adjust the feeding rate	Sedimentation, filtration, chemical treatment	4
Screw pump	Detect bearing noise	Sludge thickening tank	2
Boiler	Monitoring the digestion state	Sludge digester	5
Dewatering machine	Detect the shift	Sludge dewatering	5
Conveyor	Detect system's noise	Sludge dewatering	2
Polymer preparation	Maintain the concentration of polymer	Aeration tank,	4

PS Priority at ranking 5 is the most importance

2.2. Evaluation grid method

In this study, we performed the following steps to extract the information from dialog with managers and operators. Then we adopted EGM to establish a map with three-layer hierarchical structure that comprises abstract reasons, original impressions, and concrete evaluations (Figure 2).

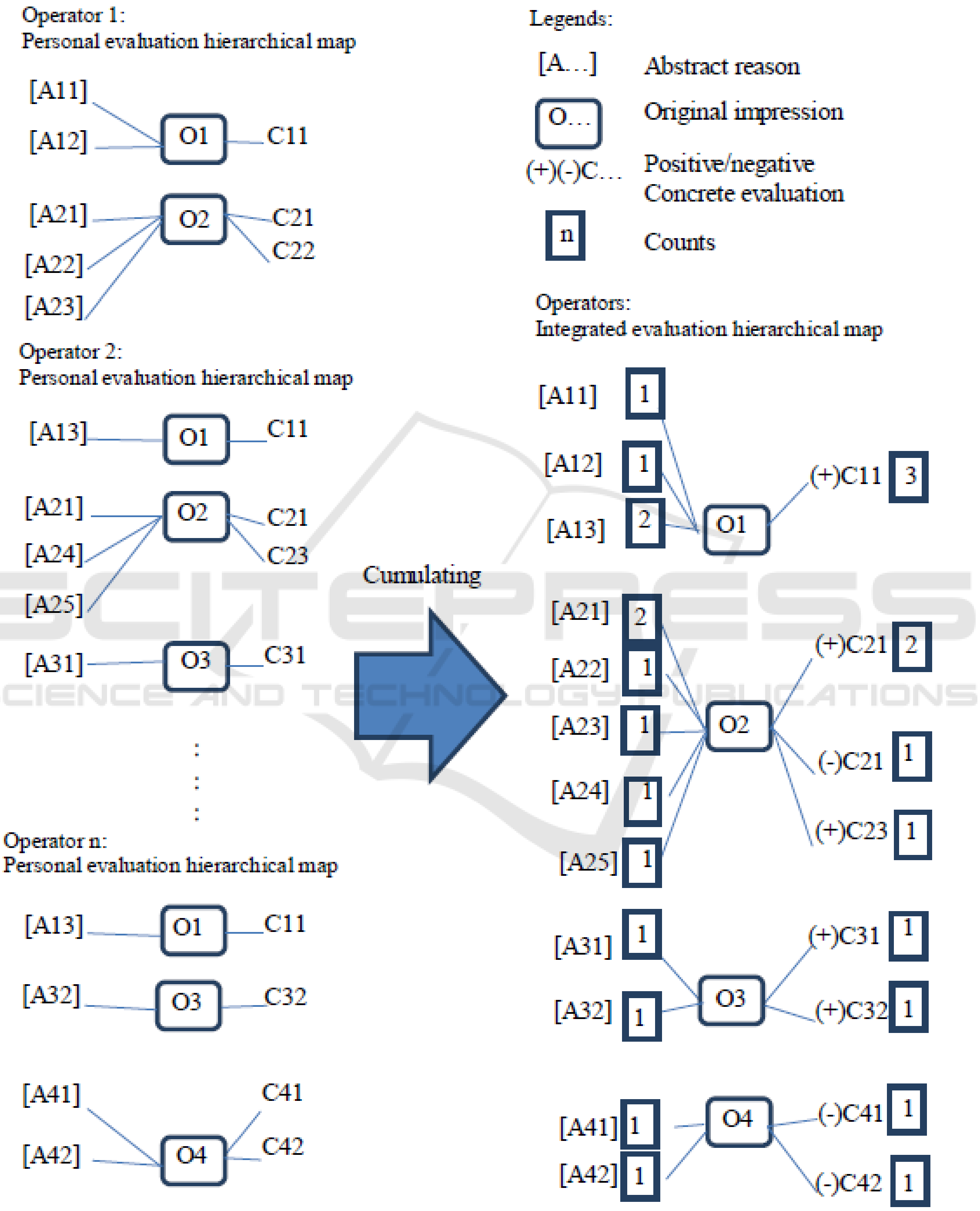

Figure 2. The process of forming evaluation hierarchical map.

2.3. Integrated evaluation hierarchical map

Overall EGM provides a method for analyzing product attractiveness factors and eliminates the potential influence of subjectivity from few decision makers. Then we compile the personal evaluation hierarchical maps of all the participants and calculate the number of overlapped evaluations to plot an integrated evaluation hierarchical map. Such a visualization of user's thinking does effectively systemize data obtained from in-depth interview and accurately interpret the needs during optimization of IoT designed for operating WWTP.

3. Results and discussion

Four original impressions including "Function", "Reliability", "Cost/Benefit", and "Design" are extracted from the dialogs with operators and managers (Figure 3 and 4). We found that operators give more concrete evaluations than managers with respect to its "Function". It implies that operators especially care how this future tool affects their daily works. From the view of product design, we should focus on the need of operators. But operator is not the buyer of IoT in this case. Manager or maybe more high rank position is the decision maker of promoting control system to IoT in practice. The factor of "Cost/Benefit" is what manager really concern. Interestingly operators also care about the factor of Cost/Benefit and they reflect many negative concrete evaluations, especially worrying about their salary been changed. Even though the IoT designed for operating WWTP is powerful, an expensive IoT would be not succeed in such a case which every manager doesn't want to see the resistance from operator. So the IoT suppliers have to seek a compromise between function and price.

When both managers and operators accept to use IoT they start to care its "Reliability" in choosing which service of IoT they can trust. The accuracy and security of data are the highest concerns during concrete evaluations of managers and operators. However hacker or terrorist might attack the control system to make a chaos in system operation as far as IoT extending networks connectivity to different device of WWTP. That is why I highlight IoT not a free or cheap service because its service needs a security of high cost.

The last original impression is "Design". The performance of manager in this item only concentrate on the abstract reasons, that is to say manager cares about what corporate image would be connected with using IoT. We suggest the supplier of IoT to taken into account of enterprise social responsibility in environmental protection during designing IoT for operating WWTP.

3.1. Technical demand of IoT in WWTP

We screen some critical demands out of Table 1. What kind of technical support does the IoT supplier have to provide for these demands? We makes an evaluation as Table 2. The architecture of IoT was generally divided into three layers: Perception Layer, Network Layer, and Application layer. Obviously the ability of perception is the most important service when these experts of WWTP take into account of IoT. Perception layer is in charge of converting the information to digital signals, which are more convenient for network transmission. This process of perception is based on several sensing technologies. However, some objects might not be perceived directly. Right now sensors of water level, dissolved oxygen, and sludge interface have been popularly used in WWTP. Air sensors with respect to odor and volatile organic compound are mature in technical development but not popular in use yet. But some sensors, like detecting the shift of dewatering machine and measuring polymer concentration, are still in developing.

Application Layer constitutes the front end of the whole IoT architecture through which user can obtain any kind of decision support. In this study, we provide cloud service including device's knowledge, operating discipline, emergence response and electric form of inspection to the operator on patrol through an App installed in mobile phone. Moreover, this layer provides the connection with actuating devices in distance. So expert system in cloud is able to automatically manipulate the distant device for avoiding the situation going into chaos. Usually pumping system is only operated by water level, but operation of pump in practice needs more expert's experience. Actually the inflow of WWTP is dynamic, the flowrate and the concentration of wastewater is variant and not the same as the condition of original design. Even a small rainfall, a significant raise at inlet flowrate could suddenly happen. Such a changing inflow will cause an unstable operation of WWTP, moreover severe situation during storm will induce combined sewage overflow. Thus operating rules extracted from historic records or expert's experiences from long career are of critical in the automatic control of pumping system, and are suggested to be developed as a technical service from IoT. Based on such a smart water management model, the IoT suppliers can access a wider global market via providing decision support, monitoring and water governance of a pumping system.

Activated sludge process is very popular used to degrade the nutrients, e.g. BOD, in wastewater. Most of sludge in this process is alive and aerobic, so a lot of air is continuously transported into this process via blower. A complex biodegradation is only executed by those activated sludge. So we have to waste the old sludge out and recycle the active back. This is not an easy job to operator, as we see, most of demands in Table 2 focuses on sludge. We suggest the supplier of IoT to make data mining from mega data of monitoring system in activated sludge process and then to provide operator a web-service with artificial intelligent about feeding sludge.

Next we evaluated the measurement of oxygen profile at aeration tank, the measurement of concentration at dosage, the alarm of health risk and the alarm of machine shift as the items which need technical support from network layer in IoT. So far the signal processing, the noise filter, the detecting way, the communication path for the measurements in these procedures are still immature. It is an opportunity for those IoT suppliers if they own critical patent at these new measurements.

3.2. Optimization of IoT in WWTP

After re-organizing the messages of evaluation hierarchical maps from Figure 3 and 4, we create three procedures as below to fulfil optimization of IoT we proposed in this study.

Principle I: Minimizing the negative concern from managers is the first step, so the IoT supplier have to meet data management in a high reliability.

Principle II: Then IoT supplier have to fast fix disorder, provide an efficient service at data management, effectively reduce the staff's accident to maximize the positive cognitions from managers, but any plan for principle II must be not against the first principle.

Principle III: "simple", "easily access data", "real-time control" would be essential functions in order to maximize the positive cognitions from operators. However designing these function must be not against principle I and II.

As you see in Figure 4 negative concerns connected with reliability are primarily focused on "security" and "noise at monitoring". Indeed there is a growing worry that control system of WWTP is too vulnerable to prevent cyber-attack. In addition to malicious intruder, adopting easy but vulnerable coding method, open to connect other networks, insecure remote connection are recognized to escalate the cyber risk of control system. In terms of security technologies and experiences, SCADA is more mature to securing control system than IoT at present. For meeting principle I, we suggest the decision maker of WWTP carefully extends the IoT tentacle on the basis of SCADA to operation.

To be contrary, the IoT supplier must make much more efforts on developing web services with predictive analysis to forecast system's risk and cloud knowledge base with prescriptive analysis to avoid staff stuck in the trouble of system's disorder. Any service created for principal II must be qualified by the standards of high information security. Here I suggest the control system and the web service adopt different communication networks and make a gap to avoid connecting each other networks for security. For example, the control system is connected with SCADA on the fiber network and the predictive analysis and the prescriptive analysis from IoT are transfer to smart phone on the wireless network.

Although manager controls the budget and owns the power of making decision to upgrade control system to IoT, operator will be in the closest relationship with IoT of all staffs in WWTP. Nature of IoT being a tool designed for assisting operators to serve their duty more efficient highlights an essential precondition that operators must be willing to use it. "simple", "easily access data", "real-time control" are the top 3 of features which be able to catch the eye of operators. But there is a tug of war between "simple" and "easily access data", also between "simple" and "real-time control" under the above principals. We suggest the IoT suppliers to make a fast copy of system monitoring data on different mirror server then to let operators easily access what they care about but can't let them touch the server of control system in practice. And we suggest a double-check procedure is necessary before putting a command of real-time control into action, that is to say, launching real-time control to cease system's disorder must be reconfirmed by more than two staffs.

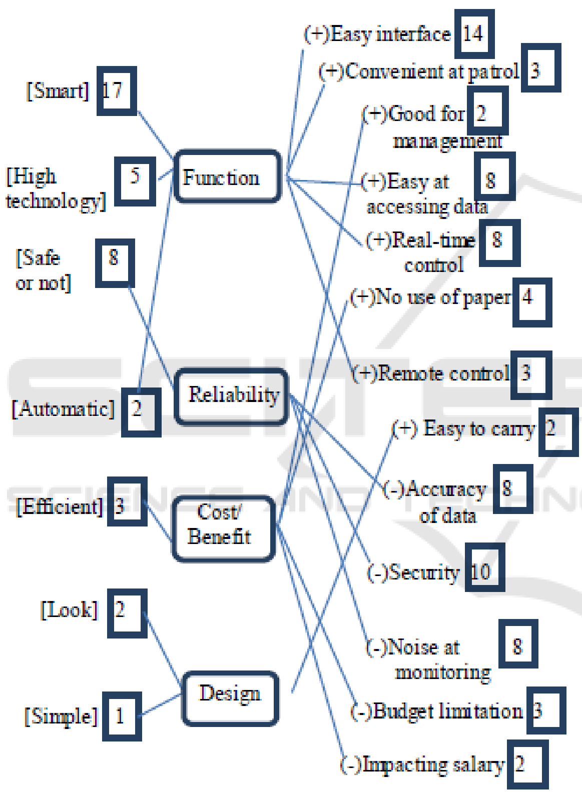

Figure 3. The integrated evaluation hierarchical map from operators.

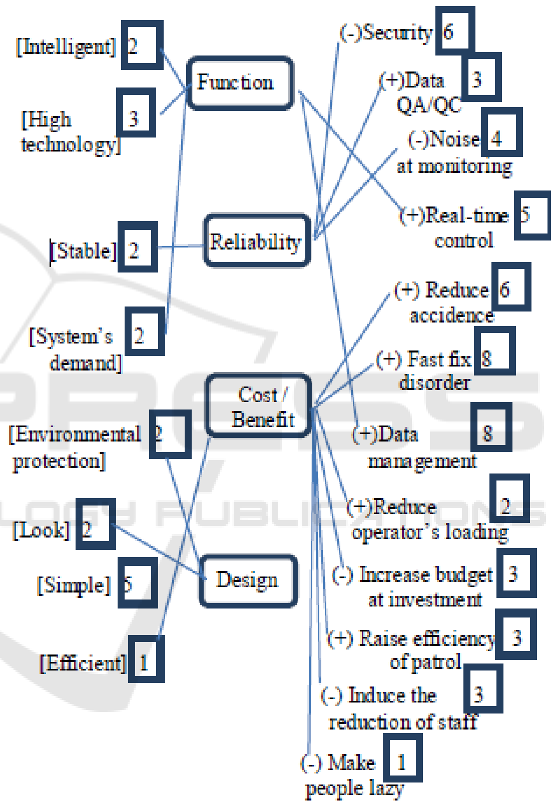

Figure 4. The integrated evaluation hierarchical map from managers.

Table 2. Evaluate the technical support of IoT to smart control of WWTP.

	The critical demand to smart control	Technical support of IoT		
		Perception	Network	Application
1	Automatic control of pumping system	○		○
2	Adjust air supply of blower	○		○
3	Sludge pumping	○		○
4	Detect the oxygen profile at aeration tank	○	○	
5	Automatic removal of scum	○		
6	Staff security	○	○	○
7	Automatic control of deodorizer	○		○
8	Preparation of chemical dosage	○	○	
9	Automatic dosage feeding	○		○
10	Operate & monitor sludge digestion	○		○
11	Detect the shift of dewatering machine	○	○	

PS "○" means that technical support of IoT is needed in this item.

4. Conclusions

As more and more wastewater treatment plants been built and in operation, IoT with novel sensors, wireless communication and smart control will become the part of control system in WWTP. At present IoT technology is moving rapidly and its market is very competitive. We suggest that "reliability" is the first criterion in priority during adopting IoT. The decision maker of WWTP had better add the IoT object into control system only being passed the qualification of information security. And we also suggest adding a gap to separate control system and web service running on different communication networks.

"simple", "easily access data", "real-time control" are the top 3 of IoT's features operators care. Is it necessary to promote the control system of WWTP to IoT? This study suggests WWTP step-by-step expand its IoT networks and only open its connection with different network after double-check security.

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