5th International/11th Construction Specialty Conference
5e International/11e Conférence spécialisée sur la construction

Vancouver, British Columbia
June 8 to June 10, 2015 / *8 juin au 10 juin 2015*

A SYSTEMATIC PROGRESS MODEL FOR CONSTRUCTION METHOD INNOVATION

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Abstract: The rapid development of Construction Method has posed a challenge for construction industry. This paper utilizes current Technological Innovation Method to accelerate the development of Construction Method. The Rapid Innovation Model is established based on the traditional technology innovation. This model contains four parts which can be divided into nine steps: definition of problem, fundamental reason analysis, selection of target technique, functional model analysis, scheme evaluation, experiment method, effect evaluation, summary and further application. Moreover, this paper introduces the process of SPIP Method which contains three phases: interpreting the problem according to basic reasons, seeking the answer by patent analysis and construction model and getting the solution by TRIZ and invention principle. In summary, the rapid innovation model meets both the speed and the quality requirements of Construction model development, pointing out a new way of developing construction model.

1 INTRODUCTION

The efficient and sustained, steady and rapid development of construction depends on the support of construction innovation technology. The current construction enterprise faces more challenging changes from market environment. Capability of rapid innovation in construction methods has become an important factor in determining the speed of enterprise development. Unlike other industries, the construction enterprise and its technology innovation has a strong characteristic. Construction business innovations can be classified by their functions, including engineering methods, customer service, design, construction, information technology, management, materials, occupational health and safety and ecological design and construction. Nam and Tatum(1989), based on the survey of the construction product innovation, pointed out that there were four key factors playing important roles in construction process: the owner's needs, problems, design of technical reserves, and the contractor's technology level. Dulaimi, Ling and Bajracharya(2004) discussed the possibility of construction projects to adopt innovative motivation and innovation activities interaction between participants in the organization based on two organizational theories regarding motivation and organizational relationship. Foreign scholars who specialized on the method of related studies have focused on the technical level of the specific construction methods, while the research of management mode of the method is limited. There is only a minimal amount of literature within the nation that comes from the perspective of qualitative description in connotation of methods, characteristics and significance and etc. Such literature stays in the summary of universal knowledge, and there is no further discussion of construction management in the method development process and the principle and constructive problem in the development of innovative

models. Overall, the existing research results are unable to provide guidance and examples to further support or strengthen the construction management innovation.

In the field of construction, the technology innovation is slower than other industries mainly due to the lack of innovative tools and systematic approaches. At the same time, along with the uncertainty of construction environment increasing, the innovation of construction method itself and the methods for construction method developed is needed; some new ideas are in great demand in the study of problem related to the development of engineering methods. How to develop a complex method as soon as possible has become a hot topic both in theories and practices, since the modern construction technology is no longer a traditional simple technique, but rather a complex integrated system. Based on the current situation, this paper developed a model of complex systematic engineering methods in order to rapidly develop innovative process (SPIP) for technology application. Combining with existing innovative approaches, this paper proposed a SPIP system model for rapid development of construction method.

2 CONSTRUCTION METHOD INNOVATIVE SYSTEM PROCESS MODELS

As the owners' expectation and demands for the safety, quality and time cost of the project raised, advanced construction methods are required due to the needs of higher construction speed and quality. In this scenario, the speed of technique innovation has become as important as other business factors such as cost and quality strategy.

2.1 Traditional Construction Process Engineering Methods Developed

Method development should not only focus on building products, but also on resolving all sorts of building problems in the process of overall consideration. Therefore, the method development is a complex and innovative process, a mature product from construction enterprises accelerating their scientific and technological achievements. It is also a planned and organized activity of study, improvement and promotion of construction methods. Method management of construction enterprises includes new understanding of the power of innovation and opportunities, generation of innovative atmosphere and development of the necessary skills, providing the construction enterprises new construction technologies after testing, refinement and implementation.

Today, the implementation of the method system in China is still a novel thing. Generally, enterprise develops construction method from summaries after action, of which the main work includes: the development of construction method and establishment of management system, technical data collection, decision of development theme, novel finding in construction method theme, redacting construction method materials according to the writing code of construction technique, construction method declaration, construction method validation, engineering methods application, and summarization and improvement. The traditional development method of construction methods is a management-driven and consolidation-based development model. It recreates and formulates new construction methods through studying and refining the experiences accumulated in the past.

With the progress of technology and social development, the great uncertainty of the external and internal environment of projects lead to enormous challenges in traditional construction method development model. Construction method belongs to the category of construction enterprise standards. It is an important component of enterprise standard, which is a standardizing description of the stable and deterministic content in the project. Therefore, the precondition of the method development is the certainty and repeatability of the construction content itself. However, the fluidity of the construction process, the one-piece quality and type-diversity of the construction product and the complexity of the construction production process have determined that the construction method in construction production process is uncertain. Traditional hindsight paradigm has become insufficient to meet the increasing personalized needs of the construction, unable to bring sustainable competitive advantage for construction companies.

2.2 The Process Model of Construction Method Innovative System

The rapid-develop approaches of complex construction method include comprehensive transplantation type, development-oriented type, unearthing type, local modification type and reverse development of type. Comprehensive transplantation type means to transplant the existing soft and hard technology to create a new technology or to improve existing technology function significantly; development-oriented type is the result of the use of new technologies, new materials, new processes and new equipment; unearthing type refers to study, refine and demonstrate the experience accumulated in the past or the approaches for new situations encountered in the field, and then create a new construction methods; local modification type refers to a partial improvement of existing engineering methods in the promotion of the application shortcomings; reverse development type refers to the introduction of engineering methods to decipher analysis, combining with corporate and project circumstances absorption and transformation. Based on the common feature of all the types mentioned above, this paper extracts the process model of complex construction method innovative system (Figure 1). Complex method process model of innovation system includes four parts which can be divided into. The four parts are subject inspection method, evaluation, design, methods and diffusion method. The nine steps include the definition of method design problem, root cause analysis, target technology selection, function model analysis and correction, scheme evaluation, test, evaluation, summarize the method and application.

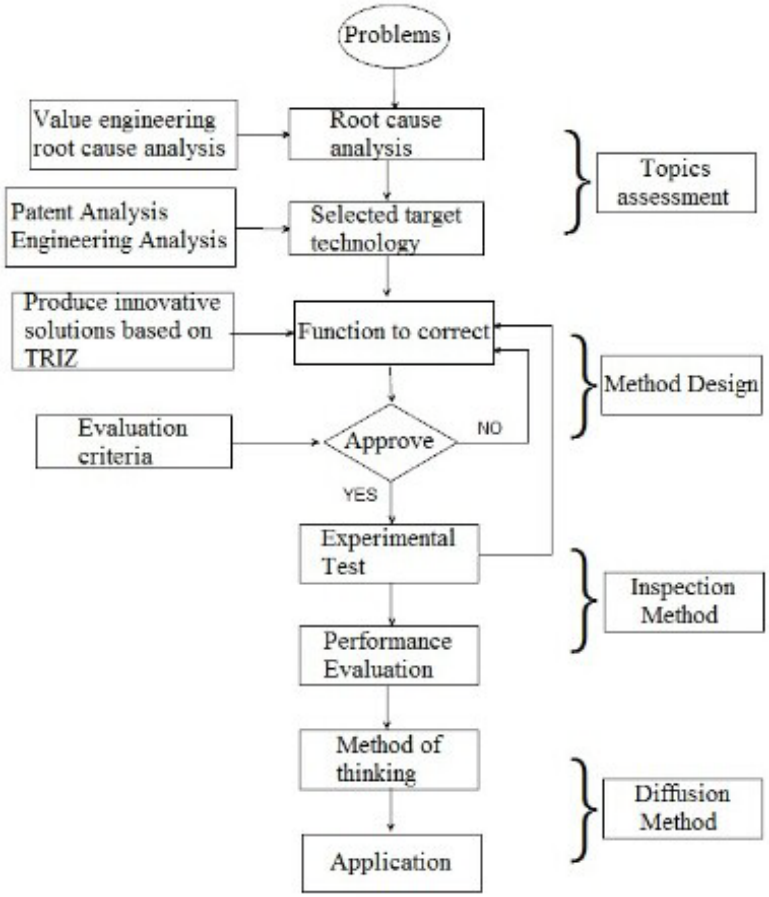

Figure 1: The Systematic Process Model of Complex Construction Method Innovation

3 DETERMINATION AND ASSESSMENT OF METHOD INNOVATION TOPIC SELECTION

The topic scope and differences of the construction method directly affect the development and popularization of method. Construction method topic is not only the fist step for developers to think about and prepare for the method, but also an important factor affecting the quality of construction method. Topic selection is the foundation of technique innovation. The pertinence of the topic to a certain extent

determines the success or failure of technique innovation. In the method management, it is clear that topic selection should be combined with technical research, scientific and technological achievements, promoting the transformation of scientific and technological achievements. In the actual development process, the method choice should emphasize not only advancement but also practicability. Therefore it is an important link during which decisions are difficult to make.

3.1 Methods Determination of Topic Selection

The purpose of construction method development is to accelerate the application of scientific and technological achievements to realistic productivity and advanced construction experience, to transform conventional technology with advanced technology, to replace the retiring method with advanced experience and to replace empirical evidence with scientific process. Therefore, we cannot use the construction method for the sake of using it; instead, we should be able to summarize and extract from the construction methods, improve construction skills and management system. Principles for theme selection of construction method include opportunity evaluation, importance evaluation and controllability evaluation. The opportunity evaluation refers to the company's business activity levels and company personnel that determine the corporate vision to explore construction methods. The importance evaluation includes innovation and practicality. According to the construction method, it must be proven by practice of the mature technology, and controllability evaluation includes two aspects: research and development strength and construction project performance.

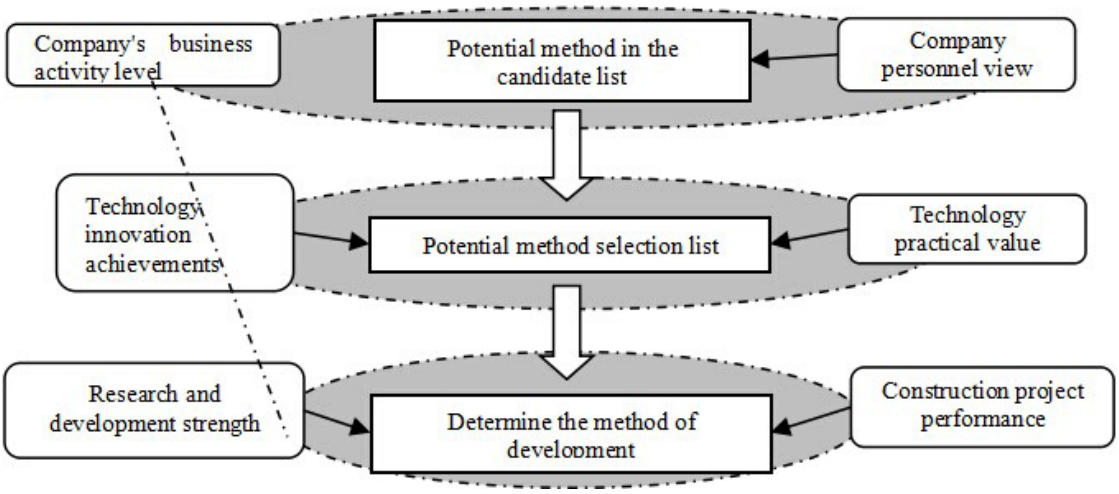

Figure 2: The Funnel Model of Selecting Construction Method Theme

General construction method development process is divided into technical data collection, development theme determination, theme method research, construction methods writing, the examination and approval of application of method, method declaration, method application and summarization and improvement. The method filter funnel is formulated by the possibility of phase optimization in the construction method theme as the phases proceed (Figure 2). Funnel model refers to the fact that during the development process, the construction technique (also called latent construction method) is gradually transformed into the actual working model law. The model vividly describes the process and the mechanism of making choice.

In addition, for complex method, it also needs to apply value-engineering methods to determine the development of specific targets. Because it is difficult to accurately select the object of innovation in scheme design, we can use the coefficient of function evaluation as basis and select value as evaluation yardstick to develop construction method target. By means of quantitative evaluation on each constitutional element in the system, there are many levels to choose developing object of construction methods for developers, pointing out the direction for further improvement.

3.2 The Root Cause Analysis of Topic Selection Evaluation Method

For the development of construction methods, the first step is to figure out what construction question is and what is the cause of the problem. Method emphasizes the application as the guidance and chose the problem in the construction process as a starting point. There are many reasons that have caused the problems, but the root cause is the key. The problem can be solved fundamentally merely through identifying and troubleshooting the root cause.

Most difficult problems in the construction have more than one single coping method. These different solutions pose different resource requirements for the construction enterprises. Root cause analysis of the problems (Root Cause Analysis, abbreviated as RCA) is a structured problem solving approach that gradually identifies the root cause of the problem and resolves it, which includes analysis to determine the cause of the problem, solutions to problems and preventative measures to the problems.

Generally there are various causes of problems, such as physical conditions, human factors and system behavior or process factors. But the root cause, as the most fundamental cause of the problem, should be mostly concerned. RCA includes: problem identification (what), root cause analysis (why), corrective and preventive actions (any way to prevent problems from happening again).

For example, the pipeline leakage in multiple high-rise buildings will induce secondary damage to building structure and interior decoration. There are many reasons of leakage, and the establishment of RCA model is shown in Figure 3. Through it we can find out the key causes of pipeline leakage. Figure 3 shows that the root cause of pipeline leakage is "concrete crack" or "rupture". The reasons for these two fundamental factors include earthquakes, corrosion and temperature. RCA model also shows that if these two fundamental reasons are resolved, pipeline leakage can be repaired. Therefore, according to the RCA model, the possible rehabilitation program can be "concrete block gap" and "fix broken pipes."

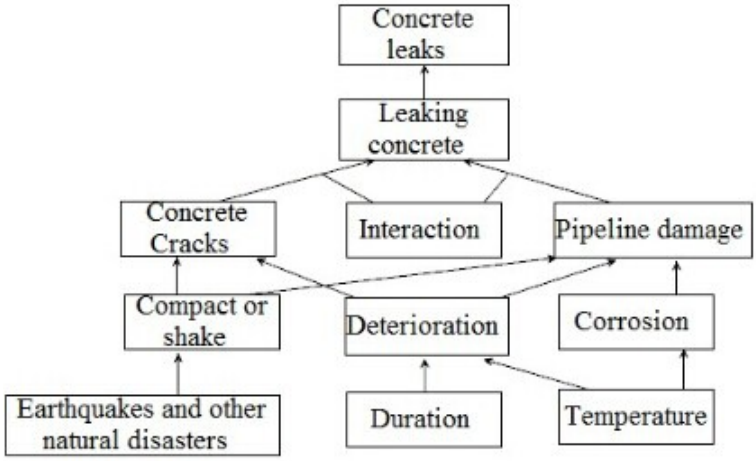

Figure 3: The RCA Model of Pipeline Leakage

3.3 The Project Technology of the Selected Topic Selection Evaluation Method

Since the construction method has become a new method that construction techniques, new materials and new equipment are combined with, innovative ingredients in the construction method are also increasing. Patents and construction methods that were once separated are now combined, and the combination has become tighter and tighter. As a result, there has been construction method patents and patent method that are of mutual transformation trend. Therefore, analysis and patent analysis should be strengthened in the topic selection evaluation method in order to enhance innovative method.

3.3.1 Engineering Method Analysis

Construction method of science and technology novelty search has become the precondition of the construction enterprise technology development and the first step. Compared to other professional science and technology novelty search, construction method of science and technology novelty has some common characteristics as well as its unique features. Novelty searching work is based on the literature, and the method of novelty search is the same. It is retrieved from the method directory, which has been released by the nation or the province, and find out whether the same method exists. Even if the construction project is the same, as long as there is a new operation method or the construction technology, new method development can be achieved. The pioneering research of shield construction methods of Sany Group, for example, set up a professional team on the shield construction methods that include wide sets of shield construction methods and cases both at home and abroad, summarizing previous construction experience and forming a huge shield method database that contains thousands of shield construction method, construction cases, failure model and solving scheme, and etc.

During the process of construction method of science and technology novelty search, based mainly on statistical analysis of construction method, the current status, level and the future of Chinese construction method are understood. This paper, summarizing the method published by the national and provincial in decades, has extracted and refined the keywords as shown in Table 1, Table 2 and Table 3 below. From keyword density (frequency), the hotspot of construction method development comes out.

Method keyword analysis can be used in the long term. As new data added each year, it will be able to observe the changes along with time and its trends of development. Method keywords play a connecting role in information analysis work and it is the base for the analysis of construction method information. Through the construction method of comparative analysis and keyword research, we can make predictions and judgments and extract valuable information about development level, status and trend, providing a reference for the development of construction method decisions.

Table 1: The First Level Analysis: the Distribution of Construction Method Keywords

Category name	The first keyword	Category name	The first keyword
Construction Engineering	Surveying Engineering	Civil Engineering	HVAC
	Earthwork and foundation engineering		Water supply and drainage engineering
	Main structural works		Road engineering
	Steel structure engineering		Bridge Engineering
	Strengthening and Retrofitting Project		Water Resources and Hydro-power Engineering
	Roofing construction		Municipal Engineering
	Waterproof engineering		Tunnel engineering
	Energy-saving insulation engineering		Geotechnical slope support engineering
	Curtain wall project		Port and Waterway Engineering
	Decoration Engineering		
Industrial installation engineering		other	

Table 2: The second level analysis: the construction method keywords of earth-rock work and foundation engineering

The second key word	Provincial method number in 2007-14year				2007-14year National	Total
	Guangzhou	Zhejiang	Jiangsu	Hunan		
Excavation	3	8	0	0	4	15
Pile	18	25	18	16	13	90
Basement	10	7	5	5	0	27
Underground continuous wall	5	2	2	1	3	13
Underground concrete	2	1	0	1	0	4
Dig holes	4	1	0	1	0	6
Foundation	0	4	5	3	4	16
Foundation drainage	11	3	13	4	8	39
Fill Construction	2	0	0	0	0	2
Foundation treatment	0	1	6	1	1	9
Foundation pit supporting	6	4	6	2	5	23
Blasting	2	3	0	0	4	9
Grouting	0	0	2	0	1	3
Grouting repair	0	1	0	0	0	1
The foundation bearing floor	0	0	0	1	0	1
Earthwork Computer Aided	1	0	0	0	0	1
Total	64	60	57	35	43	259

Tab.3 The third level analysis: the construction method keywords of foundation excavation

Third Keywords	Provincial method number in2007-14year				2007-14year National	Total	Proportion
	Guangdong	Zhejiang	Jiangsu	Hunan			
Lattice	1	0	0	0	0	1	6.7%
Earthwork excavation layered disc	1	0	0	0	0	1	6.7%
Reversed	0	3	0	0	2	5	33.3%
Along the edge in the inverse	0	0	0	0	1	1	6.7%
Structure center island	0	0	0	0	1	1	6.7%
Relief hole	0	1	0	0	0	1	6.7%
Large-diameter pipeline protection	0	1	0	0	0	1	6.7%
Anti-leakage	0	2	0	0	0	2	13.3%
Consolidation muck	0	1	0	0	0	1	6.7%
Large transfer beam	1	0	0	0	0	1	6.7%
Total	3	8	0	0	4	15	

3.3.2 Patent Analysis

With the emergence of complex construction systems, the construction method that includes patents emerges in large numbers. For example, in Wuhan's China Petroleum Building project, China Metallurgical used a "major axis diameter of 56 meters, 48 meters in diameter in the minor axis of the ellipse combination of structural support, within two oval combination of vertical structural support" construction method for the world's first, remarkably shorting the construction period. The construction method has also resolved the deformation control, strength increase, water seepage reduction and other technical problems. A complete set of methods includes four patent technologies of China Metallurgical. If

a construction method can meet the novelty, inventive and practical features, it can be declared for patent protection. Therefore, when assessing topics in construction methods, patent analysis strengthen is needed. Since the patent has the characteristics of creativity, novelty and practicability, patent information becomes an important source for scientific research of new product and research results on the social and enterprise level. Patent analysis refers to searching the relevant patent literature, statistics, analysis and screening, and turning the patent into available information for construction method.

For example, leakage repairing of pipeline embedded in the reinforced concrete, the alternative repair plan can be "block concrete crack" and "fix a broken pipe". From existing evidence in the United States patent search, the related patents are shown in table 4.

Table 4: Some patents of United States patent and trademark office

Patent number	Proprietary name	Publication Date
US20070249779 A1	Composition and method for sealing concrete cracks	2007
US6948716B2	Sealing leaks and damp improve sealing function	2005
US6478561B2	Partially foamed polyurethane prepolymer fill cracks kit	2002
US20010054474 A1	Crack filling system and foamed polyurethane prepolymer method to fill cracks	2001
US6309493B1	Methods foamed polyurethane prepolymer filling a gap in concrete structures	2001
US5226279	Sealed with Portland cement concrete methods	1993
US4758295	Stop leaking concrete structure methods	1988
US4744193	Methods to seal leaks in concrete structures	1988
US4360994	Concrete Crack Sealing Systems	1982

After studying the patent directory, Yu, Wu and Lien (2008) found that US4758295 (method to stop leakage phenomenon in concrete structures) used in foaming agent as the repair material can be an innovative option.

4 TRIZ ANALYSIS IN THE DESIGN OF CONSTRUCTION METHODS

Theory of inventive problem solving, also known as TRIZ theory, is a theory developed by the former Soviet Union inventor Altshuller GS. It is a theoretical system that builds an integrated multi-disciplinary field of methods and studies solutions of various technical issues and the methods and algorithms to achieve innovation development.

The core of construction method is the key technology in construction process, and the entire process is working around key technologies. The key technology in construction method may be advanced technology, intermediate technology, or even a junior one. The choice of construction methods topics is made from integrating a large number of existing materials, technology and techniques and extracting the key principles. The idea is established from the key technology or the expansion, divergence and construction process of key technologies structures. The basic idea of TRIZ to solve the problem of innovation is studying the basic condition deeply, combined with system evolution model to confirm the problem of ideal solution and the contradictions of system, and then find the resources available to eliminate contradictions so as to solve the problem.

4.1 Problem Description

To analyze a given problem, the first thing is transforming the practical problems into TRIZ. TRIZ theory believes that the core of the invention is to solve the problem of contradiction. In the repairing of pipe embedded in reinforced concrete structure, the problem can be defined as a technology contradiction, the parameter intending to improve is "moving object area" and the degraded parameter is "structural stability". The parameters intend to improve and degrade consist of the contradiction in the technical system. In other words, construction parameter (EP) 5 (Area of Moving Object) needs to be changed under the condition of degraded EP 21. The contradiction matrix for reference is shown in table 5.

Table 5: The contradiction matrix for reference

The problem	Contradiction		Conceptual schemes
How to achieve high permeability liquid sealant	Improvement: EP 05 "moving object area"	IP19	:"Periodic Operati
		IP10	:"Preliminary"
	Deterioration: EP 21 "structural stability"	IP32	:"Vib
		IP18	:"Mechanical Vi

To Help users to optimize and accelerate the process of technological innovation, a funerary wares company has developed a unique tool that effectively combines innovation process called the Goldfire Innovator ™. Goldfire Innovator supports product and process innovation, and can be used to determine the need to analyze systematically the question, confirm the innovation concept and examine the innovation concept by its methods and some application examples. The conceptual solutions developed through Goldfire Innovator ™'s proposed Innovative solution generator (ISG) tools include the principles of the invention (IPs): (1)IP19: "regular operation"; (2)IP10: "initial actions"; (3)IP32: "vibration characteristics change"; (4) IP18: "mechanical vibration."

4.2 The Solution

Solving the problem of the invention is the core of product innovation design. Goldfire Innovator ™ offers two built-in databases (scientific impact and patent database) to generate solutions. After entering the following requirements: 1. How to stop / repair leaking water permeating into concrete; 2. How to improve liquid / fluid flow / permeability, science influence database gives four solutions: (1) increase the pressure difference between the molecular energy to improve mobile liquid;(2) derive droplets from the mixture of soda capillary water;(3) use sound to increase the diameter of bubble in water;(4) bubbles dissolve the air in the water. According to the four solutions, the model in Figure 4 obtained to modify the proposed pipeline leak method from US4758295 shown in Table 4.

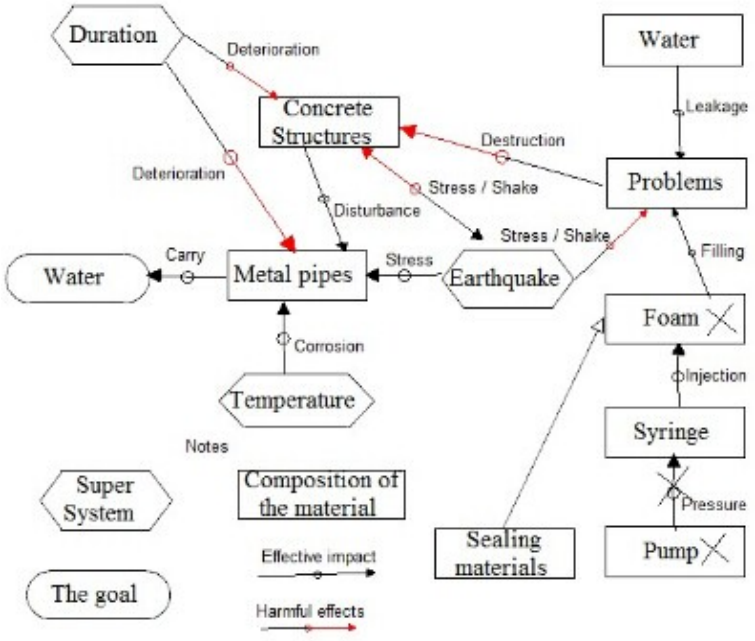

Figure 4: The revised model

4.3 The key technical scheme design

Nominal design is the way to solve conventional problem, and innovative design is the way to solve invention problem. Innovative technology is based on the conceptual solution development. Compared with traditional construction technology, engineering construction key technology should achieve

technology innovation, technology maturation, project quality assurance, construction efficiency improvement, engineering cost reduction, remarkable achievements in energy conservation and environmental protection, and etc. The final innovation of the technology solution to fix the pipeline embedded in reinforced concrete structures is as follows: put the liquid sealing material into an open mixer; open the air compressor to provide compressed air for mixing vessel; open the ultrasonic generator vibration for mixer; under the action of air pressure and vibration, the liquid sealing material gradually flow into the crack in concrete and repair the broken pipe.

5 CONCLUSION

The current focus of competition in construction enterprises usually is not the ability to manufacture engineering products, but being capable in developing a new method meeting the project requirements, using competitive new construction method in a faster speed, lower costs and higher quality to complete the construction process. In view of the method in the demand of the rapid development for the current construction enterprise and the organic combination of the innovation of the existing methods, this paper presents a system model for rapid development of the complex construction methods. The model includes: problem definition, root cause analysis, target technology selection, functional model analysis and modification, program evaluation, laboratory testing, impact assessment, construction method application and summary. Root cause analysis (RCA) model is used to describe the problem. The solution to the problem is obtained through patent analysis and method analysis. TRIZ theory and principles of the invention are also used to generate innovative solutions. System process model can satisfy both the speed and quality requirement of the new method development, and it also points out a new way to develop method.

Since the construction method is combined with advanced technology and scientific management, the process and pattern of construction method development is different from the general technological innovation. Due to limited time and data, this paper was not thorough enough in practical studies of construction method. Further research can be implemented by choosing some representative enterprises, tracking their construction method development process to obtain appropriate data and analyze the development process of construction methods. The understanding of meaning and significance of the rapid development of construction method will be more clearly.

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