# Reliability model of organization management chain of South-to-North Water Diversion Project during construction period

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**Abstract:** In order to analyze the indispensability of the organization management chain of the South-to-North Water Diversion Project (SNWDP), two basic forms (series connection state and mixed state of both series connection and parallel connection) of the organization management chain can be abstracted. The indispensability of each form has been studied and is described in this paper. Through analysis of the reliability of the two basic forms, reliability models of the organization management chain in the series connection state and the mixed state of both series connection and parallel connection have been set up.

## 1 Introduction

The management chain of the SNWDP during the construction period facilitates the passage of management orders, business transactions, message transfers, etc. The reliability of the management chain directly affects the smoothness and effectiveness of these processes. For this reason, it is necessary to study the reliability of the management chain in regard to governmental management relationships, contract relationships, client relationships, supervisory and guaranty relationships, and relationships within the SNWDP organization. The SNWDP depends on the reliability of each relationship within the hierarchy of the management chain as well as the reliability of relationships among entities at equivalent management levels (both series connection and parallel connection).

In the present work, based on the two basic patterns of series connection and parallel connection of the management chain of the SNWDP, studies on the reliability of the organization management chain have been conducted and reliability models of the organization management chain in both the series connection state and the mixed state of series connection and parallel connection have been set up.

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## 2 Purposes of reliability study of organization management chain

The purposes of setting up the reliability index of the organization management chain and the optimum models are as follows:

(1) To contribute to improving the stability of the management chain network: The management chain of the SNWDP, influenced by several elements, is a complicated dynamic system and is very random. As a probability index, the reliability degree can effectively evaluate the systemic working stability of the management chain of the SNWDP.

(2) To provide technology for the plan of the management chain: The management chain network of the SNWDP should have the requisite smoothness and working capacity to guarantee that each relationship is regular and effective, thereby strengthening its flexibility and certainty. Moreover, the reliability of the organization management chain enhances emergency mechanisms for accidental incidents.

(3) To contribute to improving the efficiency of the management chain: In order to satisfy the minimum reliability of the management chain and ensure the fulfillment of essential tasks, the integrated structure is appraised and function strategies are compared.

## 3 Basic forms of organization management chain

The management chain of the SNWDP during the construction period consists of the organization management chain, the work breakdown structure (WBS) management chain, and the mix of the two. The relationships of the main body of the SNWDP include: the governmental management relationship and trade relationship between the government and the project legal personnel; the client relationships between the project legal personnel and the agent construction or management enterprises; and the contract relationship between the project legal personnel, consultation enterprises, work contract enterprises, supervision companies, and supply enterprises. According to each relationship of the main body, the organization of the SNWDP during the construction period has several forms of management chains, as shown in Figure 1.

According to various relationships in the organizational structure of the SNWDP, the management chain can be described in basic forms, while the main factors can be represented by dots, expressed as letters or numbers. Crunodes are connected to a string according to some method and order, thus forming a management chain (Chen et al. 2004; Wang et al. 2002; Wu 2003). The basic pattern of the management chain of the SNWDP has two forms. One is series connection, and the other is parallel connection.

The organization management chain of the SNWDP is complicated, and it is difficult to calculate its reliability, so it is necessary to abstract its basic forms (series connection state and mixed state of both series connection and parallel connection). By studying the reliability of the basic forms, an evaluation of the reliability of the organization management chain of the SNWDP can be conducted.
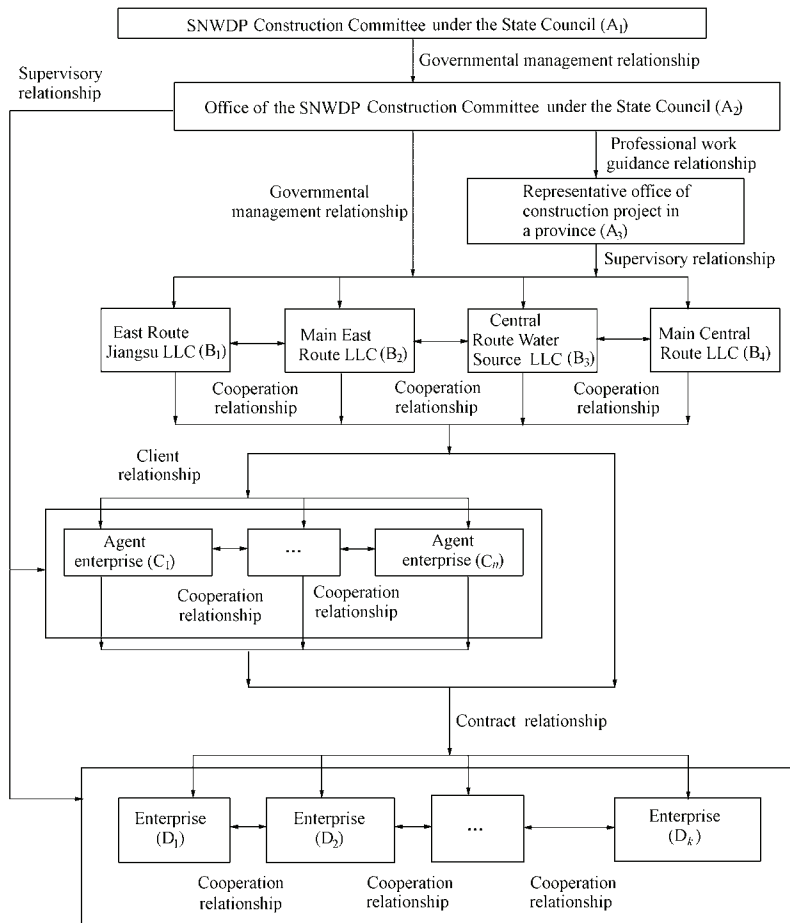
**Figure 1** Model of management chain of SNWDP during construction period

## 3.1 Basic form in series connection state

One of the basic forms of the organization management chain of the SNWDP is the series connection state, shown in Figure 2.
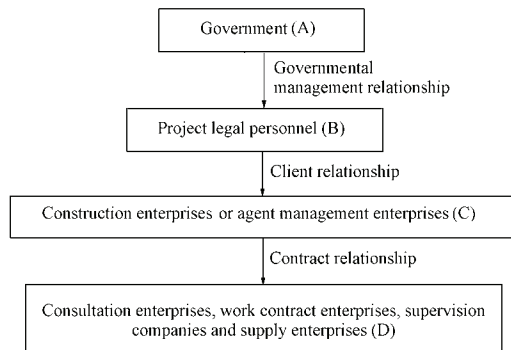


**Figure 2** Basic form of organization management chain of SNWDP in series connection state

## 3.2 Basic form in mixed state of both series connection and parallel connection

The other basic form of the organization management chain of the SNWDP is the mixed state of both series connection and parallel connection, shown in Figure 3.
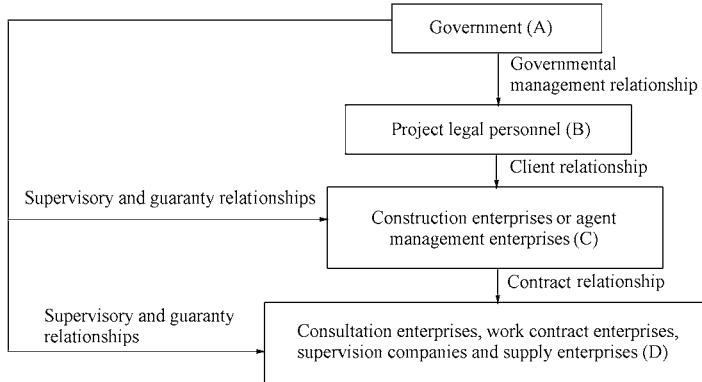


**Figure 3** Basic form of organization management chain of SNWDP in mixed state of both series connection and parallel connection

# 4 Constructed function of minimum reliability and invalidation probability of organization management chain

## 4.1 Basic unit reliability

The reliability of the organization management chain of the SNWDP depends on both node reliability and arc reliability. It is necessary to analyze and compute the reliability of each node and arc in the organization management chain. The computation load of the reliability of the management chain is directly proportional to the number of crunodes and arcs. Because some crunodes and arcs belong to the same project or the same main body, and their activities are correlated, it is difficult to distinguish them. It is also difficult to compute the reliability of crunodes and their following arcs, thus greatly increasing the computation load (Awakul and Ogunlana 2002; Lyneis et al. 2001).

In order to compute conveniently and reduce the computation load, node $i$ and its following $i$-$j$ arc are combined to construct a basic unit of the organization management chain, expressed by $(i, j)$. For those final crunodes without following arcs, it is assumed that a following arc exists. Moreover, both the number and the reliability are assumed to be 1.

In the basic unit of the organization management chain, the relationship between crunodes and arcs is connection in series. The reliability of $(i, j)$ is

$$R_{ij} = r_i r_{i\text{-}j} \tag{1}$$

where $R_{ij}$ is the reliability of the basic unit $(i, j)$, $r_i$ is the reliability of crunode $i$, and $r_{i\text{-}j}$ is the reliability of arc $i$-$j$.

## 4.2 Basic unit invalidation probability

According to the reliability of the basic unit of the organization management chain, the invalidation probability is

$$P_{ij} = 1 - R_{ij} = r_i(1 - r_{i-j}) + (1 - r_i)r_{i-j} + (1 - r_{i-j})(1 - r_i) \tag{2}$$

where $P_{ij}$ is the invalidation probability of a basic unit of the organization management chain, and other symbols are the same as in Eq. (1).

The basic units in the organization management chain are comparatively clear and independent, so, if it is difficult to compute the exact crunode reliability and arc reliability, the reliability of a basic unit can be computed directly with the approximate estimation method, thus making the computation of reliability of the management chain more convenient. At the same time, the number of basic units of the management chain is just half of the total number of crunodes and arcs, so the computation load can be greatly reduced.

## 4.3 Constructed function of minimum reliability

If variable $x_{ij}$ expresses the connectedness of the organization management ring, then

$$\begin{cases} x_{ij} = 1 & \text{if } (i, j) \text{ is a normal open path, and} \\ x_{ij} = 0 & \text{if } (i, j) \text{ is an abnormal open path} \end{cases} \tag{3}$$

Therefore, $P(x_{ij} = 1) = R_{ij}$ is the probability of the organization management chain in the normal state, and $P(x_{ij} = 0) = R_{ij}$ is the probability of the organization management chain in the abnormal state.

As the crunodes of the organization management chain are independent,

$$E(x_{ij}) = 1 \times P(x_{ij} = 1) + 0 \times P(x_{ij} = 0) = R_{ij} \tag{4}$$

where $E(x_{ij})$ is the expectation value of the BULL variable.

Therefore, the probability of the organization management chain in the normal state is equal to the expectation value.

Suppose that there are $S$ kinds of minimum path from $l$ to $m$, expressed as $T_1, T_2, \cdots, T_n, \cdots, T_S$, which are formed by rings in series. The formula is

$$T_n(x) = \prod_{(i,j) \in T_n} x_{ij} \tag{5}$$

where $T_n(x)$ is the constructed formula of the minimum path, and $x_{ij}$ is the connectedness of the management ring. From $l$ to $m$, the constructed formula of the entire organization management chain can be expressed as:

$$\pi(x) = \bigcup_{n=1}^{S} T_n(x) = 1 - \prod_{n=1}^{S} \left( 1 - \prod_{(i,j) \in T_n} x_{ij} \right) \tag{6}$$

On the basis of Eq. (6), the formula of the minimum reliability of the organization management chain can be constructed as follows:

$$R_{\min} = E\left[\pi(x)\right] = E\left[1 - \prod_{n=1}^{S}\left(1 - \prod_{(i,j)\in T_n} x_{ij}\right)\right] = 1 - \prod_{n=1}^{S}\left(1 - \prod_{(i,j)\in T_n} R_{ij}\right) \tag{7}$$

where $E\left[\pi(x)\right]$ is the expectation value of $\pi(x)$.

# 5 Reliability model of organization management chain

## 5.1 Reliability model for series connection state

In Figure 2, the model of the organization management chain in the series connection state reflects a unidirectional management relationship. This organization management chain includes seven basic units: A, B, C, D, AB, BC and CD. The minimum path set is $x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D$.

According to Eq. (7), the minimum reliability of the organization management chain in the state of series connection is shown by Eq. (8):

$$R_{\min} = E\left[1 - \prod_{n=1}^{S}\left(1 - \prod_{(i,j)\in T_n} x_{ij}\right)\right] =$$

$$E\left[1 - \prod_{n=1}^{S}\left(1 - x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D\right)\right] =$$

$$E\left(x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D\right) \tag{8}$$

## 5.2 Reliability model for mixed state of both series connection and parallel connection

In Figure 3, the basic pattern of the organization management chain includes both series connected relationships and parallel connected relationships. The basic pattern of this organization management chain has nine basic units: A, B, C, D, AB, BC, CD, AC and AD. The minimum path set is

$$\left(x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D,\ x_{AC}x_{CD}x_A x_C x_D,\ x_{AD}x_A x_D\right)$$

According to Eq. (7), the basic pattern reliability of the organization management chain in the parallel connection state can be obtained:

$$R_{\min} = E\left[1 - \prod_{n=1}^{S}\left(1 - \prod_{(i,j)\in T_n} x_{ij}\right)\right] =$$

$$E\left[1 - \left(1 - \prod_{(i,j)\in T_1} x_{ij}\right)\left(1 - \prod_{(i,j)\in T_2} x_{ij}\right)\left(1 - \prod_{(i,j)\in T_3} x_{ij}\right)\right] =$$

$$E\left[x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D + x_{AC}x_{CD}x_A x_C x_D + x_{AD}x_A x_D - \left(x_{AD}x_A x_D\right)\cdot\right.$$

$$\left(x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D\right) - \left(x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D\right)\left(x_{AC}x_{CD}x_A x_C x_D\right) -$$

$$\left(x_{AC}x_{CD}x_A x_C x_D\right)\left(x_{AD}x_A x_D\right) + \left(x_{AB}x_{BC}x_{CD}x_A x_B x_C x_D\right)\cdot$$

$$\left.\left(x_{AC}x_{CD}x_A x_C x_D\right)\left(x_{AD}x_A x_D\right)\right] \tag{9}$$

where $n = 1, 2, 3$, $T_1$ is the path of $x_{AB}x_{BC}x_{CD}x_Ax_Bx_Cx_D$, $T_2$ is the path of $x_{AC}x_{CD}x_Ax_Cx_D$, and $T_3$ is the path of $x_{AD}x_Ax_D$.

# 6 Conclusions

(1) The reliability of the organization management chain directly influences the key indexes of management order, business transactions, and information transfer of the main body of the SNWDP during the construction period. Therefore, it is necessary to study the reliability of the organization management chain regarding various relationships, such as those of governmental management, contracts, clientage, supervision, coordination and guaranty. It is also necessary to set up calculation models of reliability so as to conduct quantitative analysis of each relationship and interface and to overcome the disadvantages of qualitative analysis, thus making management of the SNWDP more scientific.

(2) The management chain of the SNWDP during the construction period consists of an organization management chain, a WBS management chain, and a management chain that is a mix of the two. This paper describes a study on the reliability of two basic forms of the organization management chain of the SNWDP. Its principle and results can be used as a reference for studies on the reliability of management chains.

(3) This study on the reliability of the series connection state and the mixed state of both series connection and parallel connection lays the foundation for setting up models of, analyzing and calculating the reliability of the organization management chain of the SNWDP.

# Acknowledgements

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