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# Contrastive Analysis on Network Performance of Information System

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## *Abstract*

*In order to explore how to design an information system with ideal network property under the background of information era, contrastive analysis is conducted in this paper on the performances of "tree" network and fully connected network. The mathematical models of "tree" information system and fully connected network are established, of which the network performance indicators are calculated by complex network theory and analyzed by comparison. As only partial indicators of both networks are favorable, the plan is proposed that information system is established through optimization based on both of the two network structures. The new algorithm to build information system network model proposed in this paper and the plan that information system is established are of significant reference value for relevant fields.*

**Keywords:** *"tree" information system; complex network theory; fully connected network*

## 1. Introduction

Traditional information systems grow out of the large industrial era, so information exchange relationship between the components shows a hierarchical communication of command from top to bottom, and a hierarchical report of information from bottom to top. If the system components are abstracted into network nodes, and the interactions of existing information between the components are abstracted into network links, the established network model of information system has a "tree" structure. This is a hierarchical network; the higher the level, the fewer the nodes, the greater the amount of information possessed by nodes and the more authoritative the command issued; lower level means more nodes, less information possessed by nodes and more nodes that execute commands.

The current society is in transition of historical stage from large industrial era to the information age, so how to design and achieve an ideal information system to meet the requirements of the information age is worth thinking and researching. According to the existing research results [1-5], it is feasible to establish the network model of the existing system and apply complex network theory for investigation.

The algorithm for building network model for information system is proposed, the mathematical models of "tree" information system and fully connected network are established, of which the network performance indicators are studied by complex network theory. The advantages and disadvantages of these two types of networks in performance are summarized by contrastive analysis of the "tree" network and fully connected network,

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and a technical design plan of information system to meet the requirements of the information era is proposed finally.

## 2. Modeling Study on Mathematical Models of “tree” Network and Fully Connected Network

### 2.1. Premises and Assumptions of Modeling

(1) Network node types are divided into command-issue node and command-response node.

(2) The command-issue nodes of each level can exchange information between upper and lower levels.

(3) The command-response nodes of each level can only exchange information with corresponding command-issue nodes.

### 2.2. Mathematical Model of “tree” Network

Adjacency matrix is a mathematical model to describe complex network. The order of the matrix represents the number of network nodes, and the element of matrix is used to describe the interactions between the nodes. If the network G has vertex set $V(\mathrm{G})=\{\mathrm{v}_1,\mathrm{v}_2,...,\mathrm{v}_n\}$ and edge set $\mathrm{E(G)}=\{\mathrm{e}_1,\mathrm{e}_2,...,\mathrm{e}_n\}$, the $n\times n$ adjacency matrix can be defined as $A=[\mathrm{a}_{ij}]$ to describe it, in which

$$a_{ij}=\begin{cases}1, & v_iv_j\in E(\mathrm{G})\\ 0, & other\quad conditions\end{cases} \tag{1}$$

The algorithm for building the mathematical model of this network is as follows.

Step 1. Four adjacency matrices that constitute “tree” information system network model are initialized. Firstly, the initialization is applied to the adjacency matrix that describes the interaction of information between the various components within the “tree” information system, called as “tree” network adjacency matrix; secondly, the initialization is applied to the adjacency matrix that describes the interaction between the various nodes within the basic sub-network; then the initialization is applied to the adjacency matrix that describes the exchange of various information within the basic sub-network, called as the adjacency matrix module. Finally, the initialization is applied to the adjacency matrix that describes the interaction of information between command-issuing nodes, called as transition matrix.

Step 2. Basic sub-network adjacency matrix is established.

Step 3. Adjacency matrix module is established.

Step 4. Transition matrix is established, and the module type numbers corresponding to the interaction between the various sub-networks are stored in the transition matrix.

Step 5. The value of each element in the corresponding type of module matrix is stored in the corresponding location in adjacency matrix of the “tree” network.

The flowchart of algorithm is shown in Figure. 1, in which n is the order of the transition matrix.

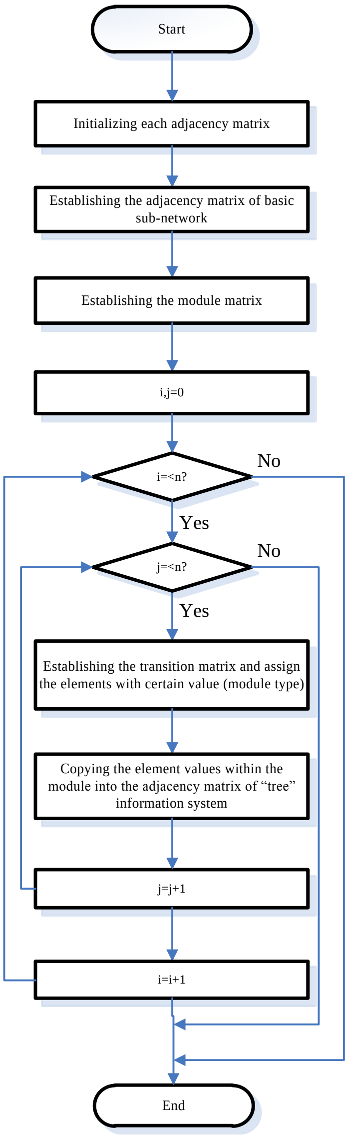

Figure 1. The Flowchart of the Algorithm

Assuming the network model of a "tree" information system includes a total of 300 nodes—50 command-issue nodes (denoted by C) and 250 command-response nodes (denoted by A). As shown in Figure 2, each command-issue node and five command-response nodes compose a basic sub-network, and all the sub-networks form a top-down network in accordance with the levels of command-issue nodes. Figure. 3 shows a sub-network of command transfer composed by command-issue nodes in the network model.

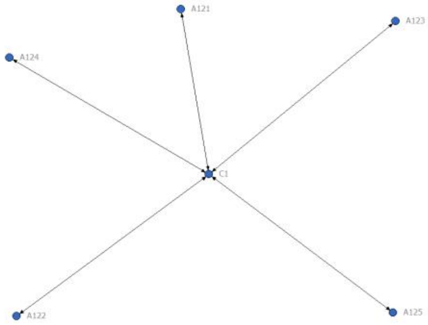

Figure 2. Basic Sub-Network

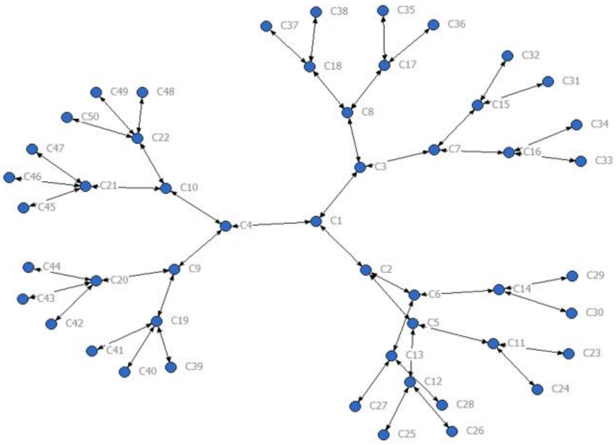

Figure 3. Sub-Network of Command Transfer

The process of constructing mathematical model is as follows.

Step 1: four kinds of adjacent matrix that constitute “tree” information system network model are initialized, and the elements in the matrix are assigned with the value of 0.

Step 2: there is only one kind of sub-network model in the network mathematical model, of which the adjacent matrix is shown in Figure. 4.

$$\begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 4. Adjacent Matrix of Basic Sub-Network

Step 3: make sure there are three kinds of adjacent matrix for describing the interactions of sub-network models, as shown in Figure 5, Figure 6 and Figure 7.

$$\begin{pmatrix} 0 & 1 & 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 5. Adjacent Matrix of Module One

$$\begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 6. Adjacent Matrix of Module Two

$$\begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

Figure 7. Adjacent Matrix of Module Three

Step 4: the transition matrix is established and each element is assigned with value, and according to the interaction between the sub-network models, 1, 2 and 0 are used to represent the corresponding module respectively as shown in Figure 8.

$$\begin{bmatrix} 12220 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 0 \\ 2100220 \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots 0 \\ 201000220 \cdots\cdots\cdots\cdots\cdots\cdots\cdots 0 \\ 20010000220 \cdots\cdots\cdots\cdots\cdots\cdots 0 \\ 0200100000220 \cdots\cdots\cdots\cdots\cdots 0 \\ \vdots \\ 0 \cdots\cdots\cdots\cdots 020 \cdots\cdots\cdots 010000 \\ 0 \cdots\cdots\cdots\cdots 020 \cdots\cdots\cdots 01000 \\ 0 \cdots\cdots\cdots\cdots 020 \cdots\cdots\cdots 0100 \\ 0 \cdots\cdots\cdots\cdots 020 \cdots\cdots\cdots 010 \\ 0 \cdots\cdots\cdots\cdots 020 \cdots\cdots\cdots 01 \end{bmatrix}$$

Figure 8. Transition Matrix

Step 4: From the elements in first row and first column of the transition matrix, the module type is judged according to element values, and the adjacency matrix values of the module are copied to the adjacency matrix describing the network mathematical model.

So far the adjacency matrix of the entire network has been obtained, which is visualized to get 2D and 3D views of network model, as shown in Figure. 9, Figure. 10 and Figure 11.

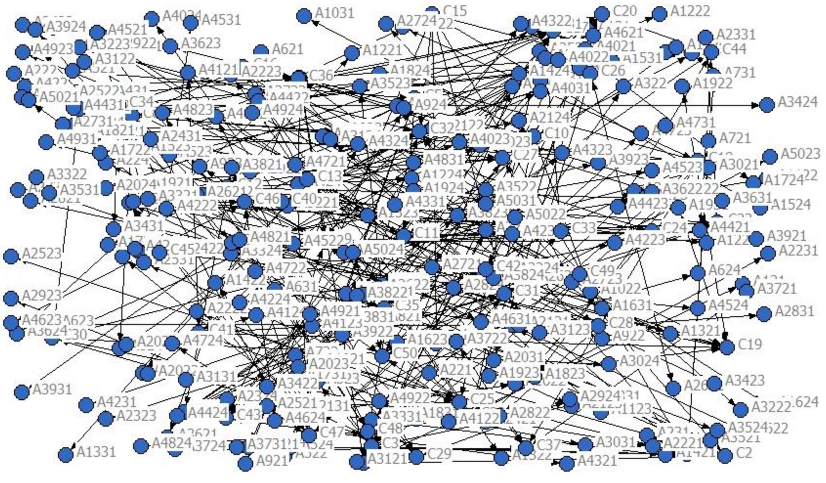

Figure 9. 2D View of “tree” Network Model

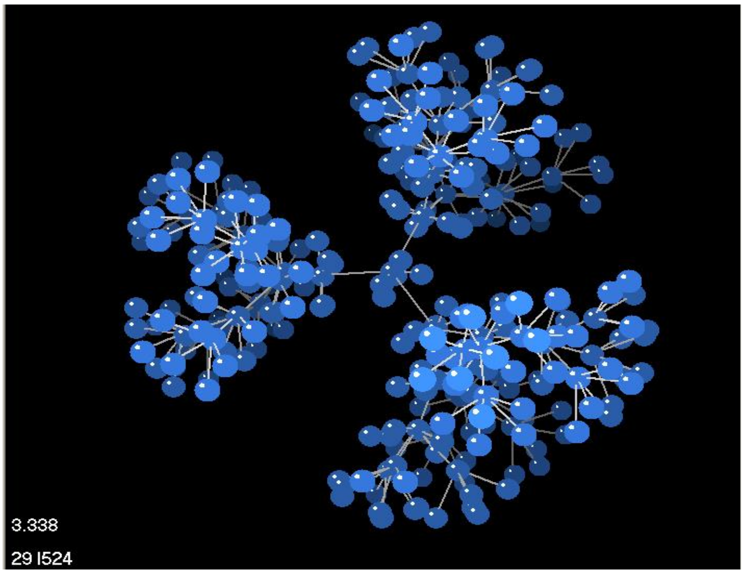

Figure 10. 3D View of “tree” Network Model

Figure 11. 3D Model of the Interactions Among “tree” Network Nodes

### 2.3. Mathematical Model of Fully Connected Network

Fully connected network model is an idealized information system network model, in which each node in the network is directly connected with each other. The advantages of his network include the largest redundancy, the best robustness, the maximum clustering coefficient and the shortest average path length. However, because the cost of constructing such a network is the highest among all the networks of the same scale, so that cannot be applied to any actual network system. As an idealized network model, fully connected network model is an effective reference for the study on how to build high-performance information system. Figure 12 shows a fully connected network with 6 network nodes, of which the corresponding mathematical model is shown in Figure 13.

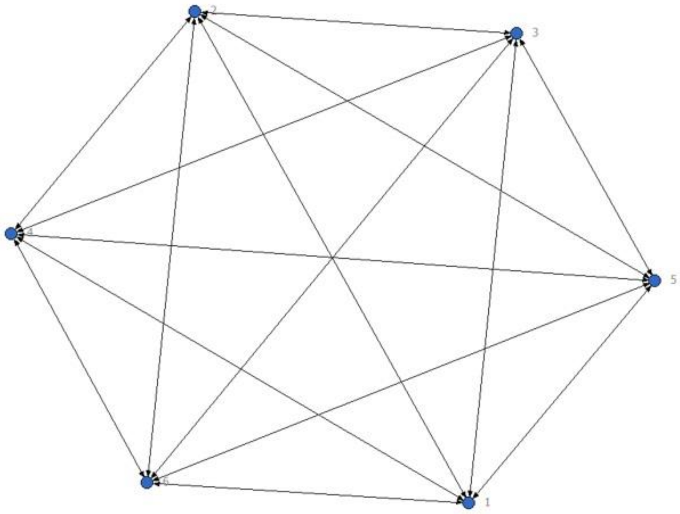

Figure 12. 2D View of Fully Connected Network with 6 Nodes

$$\begin{bmatrix} 1 & 1 & 11 & 1 & 1 \\ 1 & 1 & 11 & 1 & 1 \\ 1 & 1 & 11 & 1 & 1 \\ 1 & 1 & 11 & 1 & 1 \\ 1 & 1 & 11 & 1 & 1 \\ 1 & 1 & 11 & 1 & 1 \end{bmatrix}$$

Figure 13. Adjacent Matrix of Fully Connected Network with 6 Nodes

Eventually a fully connected network model of 300 nodes is established according to the requirement of the research in this paper, of which the three-dimensional view is shown in Figure 14.

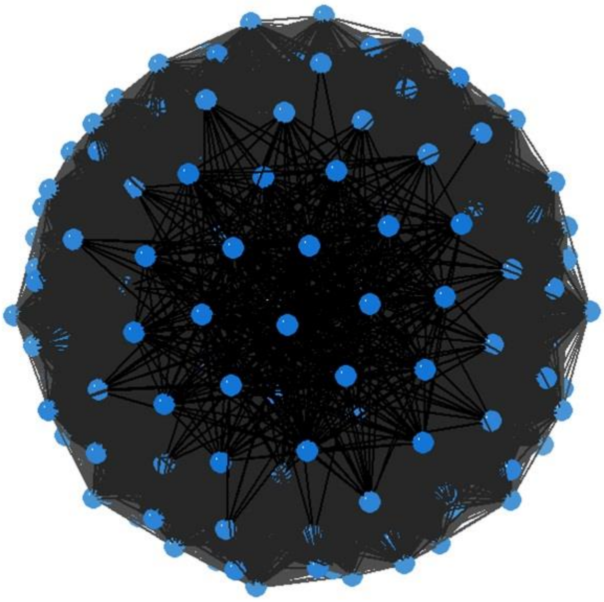

Figure 14. 3D View of Fully Connected Network

# 3. Contrastive Analysis of the "tree" Network and Fully Connected Network

## 3.1. Classification and Measurement of Network Performance

(1)Network construction cost. The cost for constructing network can be divided into absolute cost, relative cost and average cost, of which the corresponding indicators are the number of links, the network density and the link-node ratio respectively. The number of links is the sum of the interactions between the nodes in the network. The larger number of links means more complex information relationship between nodes, and the higher cost for building the network. Network density [1] is the proportion of actual existing links in the total amount of the network links that may exist. The measure range is [0, 1]. The larger network density suggests the higher cost for the network construction. If the network is undirected one, the network density is:

$$D=\frac{2m}{n(\mathrm{n}-1)} \tag{2}$$

where m is the number of actual links of network and n is the number of network nodes; if the network is directed one, the network density is: Link-node ratio is the ratio of the number of links and the number of network nodes. Link-node ratio shows the sharing average cost of a node in the network. Link-node ratio can be used to compare the construction cost of networks of different sizes.

(2) Transfer efficiency of information. The indicator for measuring the transfer efficiency of network information is the average length of paths. The average length of paths L is the mean value of the distance between any two nodes in the network [2], namely

$$L=\frac{1}{\frac{1}{2}N(N+1)}\sum_{i\geq j} d_{ij} \tag{3}$$

where $\mathrm{N}$ is the number of network nodes, $\mathrm{d_{ij}}$ is the distance between any two nodes in the network, namely the number of sides in the shortest path of two nodes.

(3) Network efficiency. Network efficiency is used to measure the degree of existing redundant links in network, of which the corresponding indicator is network efficiency coefficient. Network efficiency is used to measure the degree of existing redundant links under the premise of normal interaction of all the nodes. The larger the number of redundant links, the lower the network efficiency. The calculation formula is as follows.

$$GE=1-\frac{V}{\max(V)} \tag{4}$$

$V$ is the number of redundant links.

(4) Information monitoring ability. Information monitoring ability is used to measure whether the node capable of monitoring information exists in network, of which the corresponding indicator is cluster coefficient [3]. Assuming $V_i$ is a node of complex network $G(V,E)$ and there are $k_i$ sides in node $V_i$ connected with other nodes, it can be known that $k_i(k_i-1)/2$ sides at most exist among $k_i$ nodes. If there are actually $E_i$ sides among $k_i$ nodes, the cluster coefficient of node $V_i$ can be expressed as:

$$C_i=\frac{2E_i}{\left(k_i\left(k_i-1\right)\right)} \tag{5}$$

The cluster coefficient of the complex network $G(V,E)$ can be expressed as:

$$C = \frac{\sum_{i=1}^{|V|} C_i}{|V|} \tag{6}$$

### 3.2. Contrastive Analysis of Network Performance

The performance indicators of “tree” network and fully connected network that are both with 300 nodes are shown in the Table. below. Contrastive analysis of network performance is conducted combined with indicators.

**Table. 1. Performance Comparison of “tree” Network and Fully Connected Network**

| Indicator | “Tree” network | Fully connected network |
|---|---|---|
| Network scale | 300 | 300 |
| Link | 598 | 89700 |
| Link-node ratio | 1.993 | 299 |
| Network density | 0.0067 | 1 |
| Cluster coefficient | 0 | 1 |
| Average length of paths | 7.139 | 1 |
| Network efficiency | 1 | 0 |

**3.2.1 Network Construction Cost:** Network construction cost is inevitable. for the information exchange between the components of information system. The information system that meets the requirements of information era should have the characteristics of low cost and high-level performance. The number of links in “tree” network is 598 according to the above Table, so the absolute cost is 598, while the fully connected network with the same nodes has 89700 links. Therefore, it can be seen that the absolute cost for building a fully connected network is 150 times of that for “tree” network in the same condition. Network density is to measure the relative cost of building the network, of which the value is positively correlated with the informatization degree of networks. Larger network density means higher relative cost, and the higher degree of informatization. The above Table shows that the network density of “tree” network is 0.0067, while the network density of a fully connected network is 1. Therefore, the relative cost of “tree” network is very low, but the extent of the information network is very low, so the relative cost of building a fully connected network is higher as it is also with the highest degree of informatization. Link-node ratio is a measure of the average cost of building the network, namely the average cost of each node added into the network. The above Table shows that the link-node ratio of “tree” network is 1.993, indicating that on average about two links per node interact with the other nodes. The link-node ratio of fully connected network is 299, indicating the average cost in building fully connected network is higher than that of “tree” network in the same conditions; on the other hand, it can be seen through the link-node ratio, any two nodes in fully connected network have direct interaction in information.

**3.2.2 Transfer Efficiency of Information:** The above Table shows that the average path length of “tree” network is 7.139. While the average path length for a fully connected network is 1. It can be seen the transfer efficiency of the “tree” network is low. The average path length for a fully connected network is 1, indicating the information transfer efficiency of fully connected network is maximal, which also means the information can be passed to other nodes via a link by any node in the network.

**3.2.3 Network Efficiency:** The above Table shows that the network efficiency coefficient of “tree” network is 1, which indicates no redundant links in “tree” network, and the network efficiency reaches maximum. But since no redundant links exist, there is no redundant link as a backup to maintain the normal operation of the network when subject to network attacks or partial failure, which means the robustness of the “tree” network, is poor. Efficiency coefficient of fully connected network is 0, mainly because any node of the fully connected network has direct interaction with other nodes, with the largest redundancy, thus the lowest network efficiency, however, the robustness of is the best.

**3.2.4 Information Monitoring Ability:** The above Table shows that the information monitoring ability of “tree” network is 0, as each node in the “tree” network cannot obtain the information of other nodes through direct information exchange. Clustering coefficient value of a fully connected network is 1, which shows that the node that has the ability to monitor the information existing in fully connected network.

## 4. Conclusions

The main advantages of “tree” network include low cost, high network efficiency while the main disadvantages are low efficiency of information transfer, poor network robustness, and poor information monitoring ability; the main advantages of fully connected network are high efficiency of information transfer, strong information monitoring ability and high network robustness while the main disadvantages are low network efficiency and high cost. Neither “tree” information system nor the “fully connected network” information system is the ideal one that can meet the need of information age information systems due to the shortcomings. But as both of the two systems have some advantages of the ideal information system, they can be studied, providing reference for designing ideal system to meet the requirements of the information era.

Finally, two kinds of information technology solutions for the design and implementation of ideal information system to meet the requirements of the age are proposed. First, it is optimized on the basis of the “tree” information system and the system is attached with the advantages of “fully connected network” information system through certain payment with the retention of original advantages. The second one is to optimize the “fully connected network” information system, minimizing the cost in the condition of the advantages of “tree” information system retained.

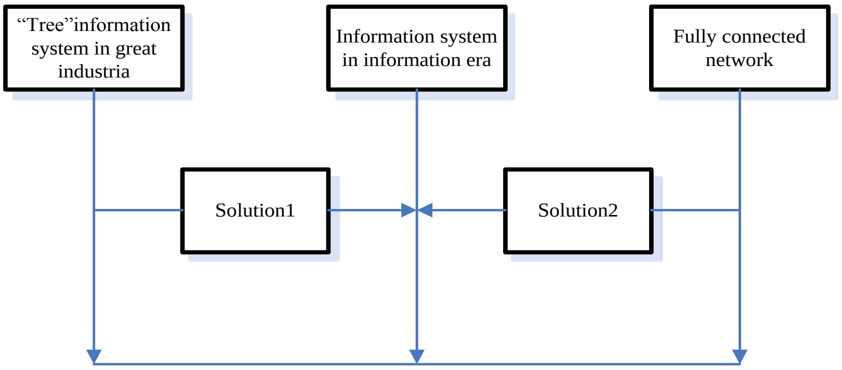

Figure 15. Implementation Comparison between Solution One and Solution Two

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