

## Research on System Integration Alliance of Urban Rail Transit Safety Monitoring

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### **Abstract**

*Fulfilling system integrated requirement of unitive resource management is the key issue of urban rail transit safety monitoring system. To solve this problem, firstly, this paper analyses the value chain of information flow. Then, it proposes alliance structure model and assesses method of compositive safety system. A model is also established for choosing system alliance with the aid of DEA and AHP. This approach provides an effective decision-making means in promoting compositive system service efficiency.*

**Keywords:** *Urban rail transit, System integration alliance, DEA, AHP*

### **1. Introduction**

Along with the rapid development of urban rail transit in China, the equipment and technology constitution of urban rail transit is becoming more and more complex, how to improve safety guarantee ability level to ensure urban rail transit rapid and sustainable development is becoming the most important and urgent strategic task. Urban rail transit operation safety guarantee is fully optimize all fixed, mobile, space, time and human resources in rail transit under the conditions which infrastructure is certain configured. It's key problem to realize high efficiency and quality service and key objective of urban rail modernization. At present, there are many kinds of safety guarantee system with different functions and structures but hard to realize interconnection. In the corresponding safety science theories, methods and integrated technological system, on the basis of recognizing the nature of urban rail transit safety system it is urgent to develop deeper research to constitute a complete urban rail transit safety guarantee theoretical system and solve multi-system integration technologies, Narrowing the gap with the developed areas to adapt to the rapid development of urban rail transit.

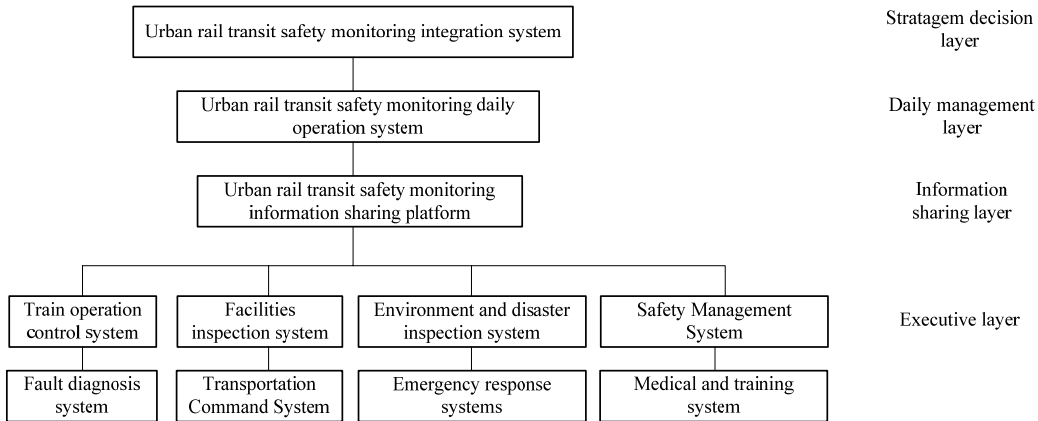
From the essential characteristic of urban rail transit, safety is taken for a class of complex dynamic system. Complex system theory is applied in safety to realize in-depth analysis of basic problems, a variety of complex systems methods and techniques are applied in system modeling, analysis and control of safety issues. Eventually forming an effective application theory in safety monitoring, evaluation and guarantee is international emerging domestic research focus [2]. Paper [3] adopted artificial neural network method to solve safety prediction problems during mass transit system operation, and obtained system safety prediction information by changing the neural network. In paper [4], an interacting multiple-model algorithm is adopted for mass transit vehicle fault detection method, which achieved vehicles systematic safety assessment by detecting structure and parameters changes in a variety of models. On the basis of integrated safety monitoring system, paper [5] proposed quantitative assessment based on the decision tree and given safety evaluation rules to guide the system risk assessment, and the actual application meets the reliability test vehicle speed security assessment requirements.

This paper firstly discusses the key problems in urban rail transit security system integration, then puts forward the structure models and evaluation methods of safety system integration alliance and analyzes the information flow value chain of interconnected systems. Result of the research builds the foundation of improving responsivity, security and reliability of urban rail transit comprehensive integration platform system.

## 2. System integration alliance of Urban Rail Transit

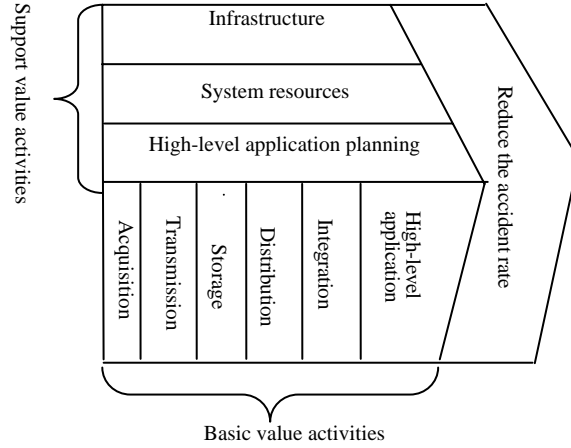
With fully automatic, fully digital and high intelligence development of urban rail transit, transportation safety and emergency support system is facing severe challenges. The major targets referred to urban rail transit comprehensive security system involves safety elements and dynamic mechanisms of man-made disasters, equipment and facilities and natural disasters, these key elements and their relationship determines the internal and external demands and technology structure of safety systems. According to the overall demand including service structure, logical structure, physical structure, multiple safety subsystems form a comprehensive safety systems. At the time safety systems integration to meet the needs of the overall purpose, these subsystem form a definite alliance which named as system integration alliance. There are internal and external information exchange, sharing and system interconnection among these subsystems and the basic of the relationship is information flow services among systems. Through information flow services among systems, the alliance constitutes a hierarchical information acquisition, transmission, integration and mining processes.

Systems integration alliance information flow supports safety status acquisition, integration and processing related to infrastructure, transport vehicle and transport organization process, explains the human - machine - environment interaction mechanism and process, embodies in the process of carrying on the security the, monitoring and early warning methods and techniques of equipment safety, transportation safety, public safety and their evolution, and eventually form a comprehensive integrated security-oriented organizations, early warning and emergency response operations, maintenance, support and disaster relief resources planning services. Urban rail safety monitoring integration system structure is shown in Figure 1.



**Figure 1.** Urban rail safety monitoring integration system structure

The essence of establishing systems integration alliances is to meet the actual needs of comprehensive integrated system, establish system service relationship based on information flow, carry out system logical service, and form flow value chain on the basis of information flow. Value chain refers to information acquisition, transmission, storage, distribution and high-level application services among systems. The value of the value chain consists of two activities which are basic and support value activities. Basic value activities are the activities directly related to information transfer and services, such as transmission (including centralized transmission and distribution transmission), storage, distribution and high-level applications, etc. Support value activities are to provide infrastructure information, system resources and high-level application planning and designing support. The basic structure shown in Figure 2.



**Figure 2.** Value chain of system integration alliances

In the value activities in information flow-based safety systems integration alliance, due to its own resources and capacity constraints any one safety subsystem can not have all the links advantages in the value chain. By selecting appropriate alliance system such as rail transit geographic information system which rich in resources and high efficiency processing as the core partners [1], to make up for its negative factors such as lack of resources, technology and service capabilities disadvantage negative factors to improve response degree, safety and reliability of the overall system, and form an application customization service system in short time.

### 3. Choice of subsystem of system integration alliance

Urban rail transit safety monitoring system integration alliance is a dynamic complex system which is participated by large number of heterogeneous systems. Therefore, how to evaluate the systems being selected and select the composition of systems integration alliance is very important. This study uses data envelopment analysis to evaluate subsystems to be selected.

Data envelopment analysis is an effective method to solve multi-objective decision problems, its characteristics is evaluated the decision-making unit by variation weight based on the observed input and output data [6-9].

Define the rail transit safety unit being selected to be decision-making unit, there are  $n$  safety systems, which denoted as  $DMU_j$  ( $j=1,2,\dots,n$ ). There are  $m$  kinds input indicator and  $s$  kinds output indicator to each safety system, its input indicator set is  $x_{ij}$  ( $i=1,2,\dots,m$ ), output indicator set is  $y_{rj}$  ( $r=1,2,\dots,s$ ). The input and output indicator data to these  $n$  evaluation unit is described as follows:

Evaluation unit :  $DMU_1, DMU_2, \dots, DMU_n$

Input indicator :  $x_{ij}$  ( $i=1,2,\dots,m$ )

Output indicator :  $y_{rj}$  ( $r=1,2,\dots,s$ )

$x_{ij}, y_{rj}$  is input and output indicator data of Evaluation unit  $DMU_j$ .

Definition:

$$h_j = \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \quad (j=1,2,\dots,n)$$

is efficiency Indicator of safety system  $j$ ,  $u_r$  and  $v_i$  are chosen weight indicator so that  $h_j \leq 1$  ( $j=1,2,\dots,n$ ).

To evaluate the efficiency of safety system  $j$ , take weight indicator  $v_i$  and  $u_r$  to be variables, take efficiency indicator of safety system  $j$  as the target and efficiency indicator of all safety system as constraint, establish the fractional model as:

$$H_j = \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \quad (1)$$

$$\text{S.T.} \quad \frac{\sum_{r=1}^s u_r y_{rj}}{\sum_{i=1}^m v_i x_{ij}} \leq 1 \quad (j = 1, 2, \dots, n)$$

This model can be changed into :

$$E_j = \max_{u_r, v_i} \sum_{r=1}^s u_r y_{rj} \quad (2)$$

$$\text{S.T.} \quad \sum_{r=1}^s u_r y_{rj} \leq 1; \quad \sum_{j=1}^m v_i x_{ij} = 1$$

$$\sum_{r=1}^s u_r y_{rj} - \sum_{j=1}^m v_i x_{ij} \leq 0 \quad (j = 1, 2, \dots, n)$$

Here  $v = (v_1, v_2, \dots, v_m)^T, v_i \geq 0$ ,

$u = (u_1, u_2, \dots, u_s)^T, u_r \geq 0$

If the optimal solution of model (2)  $u^*$  and  $v^*$  meet  $E_j = 1$ , the safety system to be selected is effective, which means safety system  $j$  and urban rail transit safety integration system can achieve the best status with technical and scale effectiveness. Therefore, it is suitable to establish system integration alliance with safety system  $j$ .

If  $E_j < 1$ , the safety system to be selected is invalid which means safety system  $j$  and urban rail transit safety integration system cannot achieve the best status with technical and scale effectiveness. Therefore, it is not suitable to establish system integration alliance with safety system  $j$ .

If safety system to be selected is evaluated relatively ineffective means the safety system  $j$  is at a disadvantage in all indicators.

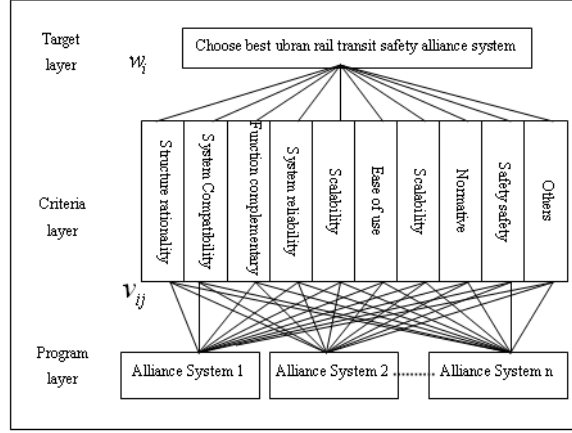
On the basis of evaluation of safety monitoring subsystem to be selected, standard subsystem integration sequence and integration alliance are formed to be elected.

#### 4. System integration alliance selection model

After the formation of subsystem sequence meets the demand of urban rail transit system integration standard, due to the complexity of integration and the importance of alliances in the system design will create a variety of integration solutions. How to choose the best system integration and adaptive evaluate the integration system selected becomes a new focus of research. In this study, an improved AHP is selected to evaluate the variety of integration options.

AHP stress human thinking judge's role in the decision-making process, it is suit for multi-criteria, multi-objective decision-making analysis of complex issues and combination of qualitative and quantitative factors, especially for the decision-making problems with qualitative factors. AHP denotes relative importance of different factors with weight vector. The problem firstly being divided into different levels according to the nature and of system integration, then constitutes a multi-level analysis model. Due to the characteristics of urban rail transit safety system integration alliance, improved AHP evaluation process will be divided into the following four stages:

(1) The evaluation of the integration solutions should be analyzed includes system architecture and software system compatibility, function complementary, system reliability, scalability, ease of use, scalability, standardization, and other aspects of system safety analysis. So define the evaluation criteria as  $R_i (i = 1, 2, \dots, n)$ , corresponding to the above characteristics to determine the hierarchical structure model is shown in Figure 3.



**Figure 3.** Hierarchical structure model

(2) According to the selection criteria elements of rail safety system integration alliance in the hierarchy model above, compare and quantify the corresponding comparison matrix form. Apply characteristic vector method to determine the rail safety system integration alliance selection criterion of the matrix  $A$  ( $A = [a_{ij}]$ ,  $a_{ij} = 1/a_{ji}$ ) (indicator weight assignment by 10/10 to 18/2 scaling), the symmetric matrix of  $A$  is  $B = \lg A$  ( $b_{ij} = \lg a_{ij}, \forall i, j$ ).

$$A = \begin{pmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{1n} & \dots & 1 \end{pmatrix}$$

(3) Solving the corresponding optimal transfer matrix  $B$  is  $C$  ( $c_{ij} = \frac{1}{n} \sum_{k=1}^n (b_{ik} - b_{jk})$ , meets  $\sum_{i=1}^n \sum_{j=1}^n (c_{ij} - b_{ij})^2$  is minimum value). A Quasi-optimal for solving the same matrix  $V$ ,  $v_{ij}^* = 10^{c_{ij}}$ , meets  $\sum_{i=1}^n \sum_{j=1}^n (\lg v_{ij}^* - \lg a_{ij})^2$  is minimum value.

(4) Solve the feature vector  $V$ , the weight of each factor value under initial matrix are given, and the system with larger weights is safety integration system to be selected by safety alliance system.

## 5. System efficiency evaluation of integration alliance

After the system integration solutions being selected, it is required to evaluate the efficiency under standard  $R_i$  of overall integration system and each subsystem to evaluate the effect of selection.

(1) Construction the evaluation indicator set  $R_i$  ( $i = 1, 2, \dots, n$ ), corresponding to the above characteristics.

(2) According to the evaluation indicator set  $R_i$  statistics experience and expert evaluation, compare the comparison matrix, determine the selection criteria weights  $\omega_i$  ( $i = 1, 2, \dots, k$ ) of rail transit systems integration alliance.

(3) Calculating each criteria weight  $v_{ij}$  ( $i = 1, 2, \dots, n$ ;  $j = 1, 2, \dots, k$ ) of rail transit system integration alliance.

Calculate the evaluation value of each safety system  $i$  aiming at each criterion. To qualitative indicators regulate the measured data, and constitute the matrix to each criterion of safety system  $i$ .

(4) Assessed by experts to determine the system integration alliance on the evaluation of value index set  $R_i$ , which is  $s_i$  (  $i=1, 2, \dots, n$  ) .

(5) Calculate union weights of the integrated sub -systems integrated  $U_{ij} = \sum_{j=1}^k \omega_j v_{ij}$  and evaluation value of the overall system  $E = \sum_{i=0}^n s_i \omega_i$  as a basis for the selection of system is safety alliance.

## 6. Conclusion

Building Urban Rail Transit operating and safety comprehensive monitoring integration system, fully integrated system dynamic safety information and daily transport information of train, vehicles, power, signal, facilities and environment to achieve whole process comprehensive monitoring, warning and safety management is the core of urban rail safety issues. In this paper, according to the large number, complex relationships, spatial range characteristics of safety guarantee system, puts forward a system integration alliance system selection method to establish comprehensive integrated monitoring system with high safe and reliability. In this method, the integration of sharing and service is next focus to study.

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