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Integrated Evluation of the Safety Controller's Workload Based on Improved Extension Evaluation Model

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Abstract: The controller's performance directly affects the safety and the efficiency of ATC at any moment. It's a reasonable and feasible method to get the sorting results of the different planning schemes through the assessment of the sector controller workload. However, all planning schemes can not be implemented until it passed the practice test for the first-line controller. This study brings forward integrated evaluation of the controller's workload based on improved integrated evaluation model which combines the quantitative and the qualitative analysis. The condition set is constructed and the correlation value of the sample with practical data is calculated. The correlation function and the weight function are built. By the calculated value, the category is selected. The sample in the terminal control area of Shanghai confirms that the method is feasible.

Key words: Controller's workload, correlation, note field, improved extension evaluation model

INTRODUCTION

Airspace sectors, which is the minimum unit of control, its planning effect ultimately depends on the main body of the decision-making of the Air Traffic Controllers (ATC), the controller's performance (Casso *et al*., 2001) directly affects the safety and the efficiency of ATC at any moment. It's a reasonable and feasible method to get the sorting results of the different planning schemes through the assessment of the sector controller workload. All planning schemes can not be implemented until it passed the practice test for the first-line controller. The research of the controller's workload is the important part of ATC human performance and plays an essential role on ensuring aviation safety, checking the performance of the controller and optimizing the layout of control sector.

The time to the commencement of research on controller workload was from the late 1970's. Three distinct approaches have been employed for workload research. As the main of decision-making of Air Traffic Control (ATC), the controller's performance directly affects the safety and the efficiency of ATC at any moment.

The time to the commencement of research on controller workload was from the late 1970's.Three distinct approaches have been employed for workload research. The first technique attempts(Hankins and Wilson, 1998; Brookings *et al*., 1996) to measure the physiological state of the air traffic controller. Measurements of this type have included Galvanic Skin Response (GSR), heart rate, Electrocardiogram (ECG), blood pressure, biochemical analysis of body fluids and behavioral symptoms. As a related indicator of stress, this method has had limited success.

The second method attempts (Collet *et al*., 1998; Han, 2000; Mannings *et al*., 2001; Ylonen *et al*., 1997) to measure the controller workload in terms of the physical interactions with the human computer interface system. Measurements of this type include number of keystrokes, slew ball entries and communications per unit of time. The main difficulty of using these measurements as indicators of workload is that this method assumes that the task of air traffic control always manifests in an observable physical activity. This assumption does not completely capture the characteristics of the job of air traffic control which is primarily cognitive and information intensive, rather than physical and labor-intensive.

Due to the limitations of the physiological and physical activity measurements, the third method attempts (Athenes *et al*., 2002; Mogford *et al*., 1995; Pawlak *et al*., 1996; Smith,1980) to measure the psychological state of the air traffic controller. Workload is measured in terms of the cognitive demand of the task and the available mental capacity.

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The condition set is constructed and the correlation value of the sample with practical data is calculated. The correlation function and the weight function are built. By the calculated value, the category is selected. The sample confirms that the method is feasible.

MATERIALS AND METHODS

Improved extension safety control evaluation model: As we all know, Terminal airspace is a complex system (ICAO, 2010), if the multi-index comprehensive mathematical model is established on the basis of the above indicators, from the complexity of this model, the solving difficulty, as well as the actual fitting degree, this model is difficult to realize. The success of the planning program depends mainly on whether it facilitates the controller to control and use the airspace security. Therefore, the security assessment of the control in the terminal airspace is clearly the most important aspect. The extenics is the subject which studies the incompatible problem translating rules and methods. It illustrates the conflicts by establishing the model based on the matter-element analysis and resolves the conflicts by the translation of matter-element. The quantificational describing method of the extenics is establishing correlation function for the process of the quantitative and qualitative change. That is to say, we can quantificationally describe the quantitative and qualitative change by extenics field and critical element. The two conceptions of extenics set and matter-element provide likelihood for describing the matter’s property; translation and the matter’s invert process from not possessing some property to possessing some property. Extensive comprehensive evaluation model (Yang, 1998; Zhang and Han, 2008; Chen, 2007; Smith, 1980) adopts quantitative evaluation method; it is easy to realize by the computer, with the relatively objective evaluation results. These advantages can be entirely used to address the problem of the control of the security assessment. However, evaluation index data are often beyond the note field in this kind of extensive comprehensive evaluation model, for this reason, the model is not always applicable. Therefore, we conducted quantitative evaluation for these various planning programs:

- The basic extension evaluation model

Suppose that the orderly triple group R = (N, c, v), including N (the matter), c (the matter's property) and v (the property’s value), were defined as the basic cell, that is the matter-element of 1-dimension. So we can characterize N, c and v as the R's three elements, in which the binary group $M_j = (C_i, V_i)$ composed by c and v is called the property-element. Now suppose that the matter were characterized with n kinds of properties $(c_1, c_2, \ldots, c_n)$ and that the corresponding value of these properties were $v_1, v_2, \ldots, v_n$. Thus we can define the matter-element as:

$$R=\begin{bmatrix} N, & c_1, & v_1 \\ & c_2, & v_2 \\ & \vdots & \vdots \\ & c_n, & v_n \end{bmatrix}=\begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix}$$

- Confirm the classical field and node field of the controller’s workload

Confirm the classical field of the controller’s workload:

$$R_j=\left(N_j, c_i, v_{ji}\right)=\begin{bmatrix} N_j, & c_1, & v_{j1} \\ & c_2 & v_{j2} \\ & M & M \\ & c_n & v_{jn} \end{bmatrix}=\begin{bmatrix} N_j, & c_1, & \langle a_{j1}, b_{j1}\rangle \\ & c_2, & \langle a_{j2}, b_{j2}\rangle \\ & M & M \\ & c_n, & \langle a_{jn}, b_{jn}\rangle \end{bmatrix} \tag{1}$$

where, N_j is the workload grades, the grades number is j (j = 1, 2…, m), c_i is the property of N_j (i = 1, 2, …, n) and v_{ji} is the classical field of the controller’s workload, which represents the N_j 's range about c_i.

Confirm the node field of the controller’s workload:

$$R_P=\left(P, c_i, v_{pi}\right)=\begin{bmatrix} P, & c_1, & v_{p1} \\ & c_2, & v_{p2} \\ & M & M \\ & c_n, & v_{pn} \end{bmatrix}=\begin{bmatrix} P, & c_1, & \langle a_{p1}, b_{p1}\rangle \\ & c_2, & \langle a_{p2}, b_{p2}\rangle \\ & M & M \\ & c_n & \langle a_{pn}, b_{pn}\rangle \end{bmatrix} \tag{2}$$

where, P is the collection of all the controller's workload grades and v_{pi} is the P 's range about c_i:

- Confirm the correlation function of the controller’s workload grade

Now assume that P_0 were the controller's workload being estimated. The result of the estimation can be figured out with the matter-element:

$$R_0=\left(P_0, c_i, v_i\right)=\begin{bmatrix} P_0, & c_1 & v_1 \\ & c_2 & v_2 \\ & M & M \\ & c_n & v_n \end{bmatrix} \tag{3}$$

The relation between the i-th workload property field of P_0 and the j-th grade can be depicted by a correlation function:

$$K_j(v_i)=\begin{cases}\dfrac{\rho(v_i,v_{ji})}{\rho(v_i,v_{pi})-\rho(v_i,v_{ji})}, & v_i\notin v_{ji}\\ -\dfrac{\rho(v_i,v_{ji})}{|v_{ji}|}, & v_i\in v_{ji}\end{cases} \quad (4)$$

in which:

$$\rho(v_i,v_{ji})=\left|v_i-\frac{a_{ji}+b_{ji}}{2}\right|-\frac{1}{2}(b_{ji}-a_{ji}),$$
$$\rho(v_i,v_{pi})=\left|v_i-\frac{a_{pi}+b_{pi}}{2}\right|-\frac{1}{2}(b_{pi}-a_{pi}) \quad (5)$$

- Confirm the degree of association and the controller's workload estimating grade

Now confirm the weight coefficients of the controller's workload property (λ_{1j}, λ_{2j}, …, λ_{nj}), by which we can calculate the association degree of P_0 about the j-th grade. And the related formulation is:

$$K_j(P_0)=\sum_{i=1}^{n}\lambda_{ij}K_j(v_i) \quad (6)$$

Finally, consider the controller's workload estimating grade, which will be explained by:

$$K_j = \max K_j(P_0)\ (j = 1, 2, ..., m) \quad (7)$$

Limitations and improvements of the extension evaluation model: The Extension integrated model can be applied to the assessment of workload for controllers. But there still exists characteristic values of the matter element to be evaluated is beyond the range of the node field (such as in the special circumstances disposal state in air traffic control). There will appear that $\rho(v_i, v_{ji})$ equals to $\rho(v_i, v_{pi})$ in the calculation of integrated correlation degree. In this case, it's impossible to calculate the integrated correlation degree. Such as the data collected at a special circumstances state in shanghai terminal airspace. an indicator exceeds a normal workload standards, that is, communicating with the pilot is significantly higher than the standard of the normal load. If the above data was brought into the extensive comprehensive evaluation model, there will appear as follows:

The indicator c_6 of communication with the pilots, v_6 = 53 s min^{-1}, v_{46} = [36, 48], v_{P6} = [0, 48], then we can obtain:

$$\rho(v_6,v_{16})=5,\ \rho(v_6,v_{P6})=5, K_4(v_6)=\frac{\rho(v_6,v_{46})}{\rho(v_6,v_{p6})-\rho(v_6,v_{46})}=\frac{5}{5-5}$$

Therefore, we need to improve the current matter-element extension method so that we can get reasonable results when the characteristic value of matter-element to be evaluated exceeds the range of the node fields.

This study draws on the ideology of the Gray Relational Analysis (GRA) to set the distinguishing coefficient. For the case there exits some characteristic values of matter-element exceeds the range of the node fields, by adding a correction coefficient we can prevent the denominator of the correlation is equal to zero, in which case the equation can not be calculated correctly. We make some improvements of the basic extension evaluation model to solve existing problems, the details are as follows:

By adding the correction coefficient θ, the correlation can be expressed as:

$$K_j(v_i)=\begin{cases}\dfrac{\rho(v_i,v_{ji})}{\rho(v_i,v_{pi})-\rho(v_i,v_{ji})}, & v_i\notin v_{ji}, v_i\le v_{pi};\\ \dfrac{\rho(v_i,v_{ji})}{\rho(v_i,v_{pi})-\theta\cdot\rho(v_i,v_{ji})}, & v_i\notin v_{ji}, v_i> v_{pi};\\ -\dfrac{\rho(v_i,v_{ji})}{|v_{ji}|}, & v_i\in v_{ji}\end{cases} \quad (8)$$

the range of θ:

$$0<\theta<\frac{\rho(v_i,v_{pi})}{\rho(v_i,v_{ji})}, i=1, 2, ...n$$

RESULTS

Derived from the 02 sectors of the Shanghai terminal airspace ATC survey data obtained on May 17, 2013, we can confirm the classical field, node field and the grading standards of controller's workload. In this case, we use the general radar control simulator which used in training controllers currently. For a certain planning program, skilled controllers are employed to simulate command. The various indicators obtained via the data collection are normalized to obtain reliability data. The following is the normalized grading standards.

Table 1: Grading standards of the normalized indexes which affect the controller's workload

Index	First level	Second level	Third level	Forth level
Business Hours c_1	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Sensory system c_2	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Fatigue c_3	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Individual business capability c_4	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Attention c_5	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Communication with pilots c_6	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Team communication c_7	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Communication with manager c_8	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
The layout of the equipment c_9	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Operation sensitivity c_{10}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Communication quality c_{11}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Surveillance system function c_{12}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Safety regulations c_{13}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Disposal procedures c_{14}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Working procedures c_{15}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Indoor lighting c_{16}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Indoor humidity c_{17}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>
Indoor temperature c_{18}	<0.75,1>	<0.5,0.75>	<0.25,0.5>	<0,0.25>

In Table 1, the controller's workload has been graded according to its load. There are 4 classes in it. The first level indicates the maximum and the forth level, namely the last level, indicates the minimum.

In Table 1 the node field of the controller's workload is:

$$R_p = (P, c_i, v_{pi}) = \begin{bmatrix} \text{1st} - \text{4th}, & c_1, & \langle 0,1 \rangle \\ & c_2, & \langle 0,1 \rangle \\ & M & M \\ & c_{18} & \langle 0,1 \rangle \end{bmatrix}, i = 1, 2, ...18$$

And the four-level classical fields of the controller's workload respectively are:

$$R_1 = \begin{bmatrix} \text{1st}, & c_1, & \langle 0.75,1 \rangle \\ & c_2, & \langle 0.75,1 \rangle \\ & M & M \\ & c_{18}, & \langle 0.75,1 \rangle \end{bmatrix}, \quad R_2 = \begin{bmatrix} \text{2st}, & c_1, & \langle 0.5,0.75 \rangle \\ & c_2, & \langle 0.5,0.75 \rangle \\ & M & M \\ & c_{18}, & \langle 0.5,0.75 \rangle \end{bmatrix}$$

$$R_3 = \begin{bmatrix} \text{3rd}, & c_1, & \langle 0.25,1 \rangle \\ & c_2, & \langle 0.25,0.5 \rangle \\ & M & M \\ & c_{18}, & \langle 0.25,0.5 \rangle \end{bmatrix}, R_4 = \begin{bmatrix} \text{4th}, & c_1, & \langle 0,0.25 \rangle \\ & c_2, & \langle 0,0.25 \rangle \\ & M & M \\ & c_{18}, & \langle 0,0.25 \rangle \end{bmatrix}$$

Controller workload samples collected in section 2 of the state under special circumstances, after normalization, the indicators are as follows: $c_1 = 0.8$; $c_2 = 0.7$; $c_3 = 0.8$; $c_4 = 0.8$; $c_5 = 0.8$; $c_6 = 1.2$; $c_7 = 0.7$; $c_8 = 0.7$; $c_9 = 0.7$; $c_{10} = 0.6$; $c_{11} = 0.6$; $c_{12} = 0.8$; $c_{13} = 0.6$; $c_{14} = 0.7$; $c_{15} = 0.7$; $c_{16} = 0.4$; $c_{17} = 0.4$; $c_{18} = 0.7$. among them, c_6 beyond the range of the node field.

Table 2: Correlation between various indicators

Indicators	K_1 (v_i)	K_2 (v_i)	K_3 (v_i)	K_4 (v_i)
c_1	0.3333	-0.0625	-0.3750	-0.6875
c_2	-0.1714	0.2000	-0.2857	-0.6429
c_3	0.3333	-0.0625	-0.3750	-0.6875
c_4	0.3333	-0.0625	-0.3750	-0.6875
c_5	0.3333	-0.0625	-0.3750	-0.6875
c_6	5.0000	-2.8125	-1.9444	-1.6964
c_7	-0.1714	0.2000	-0.2857	-0.6429
c_8	-0.1714	0.2000	-0.2857	-0.6429
c_9	-0.1714	0.2000	-0.2857	-0.6429
c_{10}	0.2500	0.3330	-0.1667	-0.5833
c_{11}	0.2500	0.3330	-0.1667	-0.5833
c_{12}	0.3333	-0.0625	-0.3750	-0.6875
c_{13}	0.2500	0.3330	-0.1667	-0.5833
c_{14}	-0.1714	0.2000	-0.2857	-0.6429
c_{15}	-0.1714	0.2000	-0.2857	-0.6429
c_{16}	-0.8750	-0.2500	0.3333	-0.3750
c_{17}	-0.8750	-0.2500	0.3333	-0.3750
c_{18}	-0.1714	0.2000	-0.2857	-0.6429
K_j (P_0)	4.4668	-1.2250	-6.9861	-11.4466

Then we will draw correlation degree of the above 18 indexes based on the Eq. 8 and 6 and will finally figure out the controller's workload grades in this sample.

In Table 2, According to the Eq. 7, It is obvious that K_1 (P_0) is the maximum by maxizing K_j (P_0) (j = 1, ..., 4). Consequently, we can draw the conclusion that the workload is very heavy for the controllers. By investigating the control experts who executed simulated control of the second sector of the terminal airspace in shanghai, where we take a view of the data of the sample, it is easy to see that the controller's management task of the sector is heavier in the rush hour and the controller tends to suffering from fatigue. This practical application is consistent with the result of the evaluation and it has proved the validity of this model. Meanwhile we adopted the above method for processing several other data which extracted from the sample. In order to obtain the calculated data, the planning program of the other sectors in the terminal airspace was implemented. Then we evaluate this program based on the data collected with the extension integrated model, the results proved that the assessment was in line with the actual situation of the simulated control seat. The details are immune to discuss. From the aforementioned simulation example we can see that the correlations which beyond the range of the node fields is lager than the others after the extension correlation matrix has been revised. Consequently, there were significant difference between the four data of K_j (P_0) derived from Table 2, which is precisely owing to the value of θ in the calculations. So the coefficient θ processes amplification function of the distinguishing coefficient in the fuzzy evaluation. Both are different in approach but equally satisfactory in result. In the practical calculation, based on the Eq. 8, we adopted different values of θ in the computing trail to ensure the reliability and accuracy of the conclusions according to the actual situation beyond the node fields.

CONCLUSION

As the important research of air traffic control, the controller's workload is related to the aviation safety tightly. Affected by some subjective and objective factors, however, there is no recognized or effective measure for the workload evaluation. Therefore, this paper can draw the following conclusions:

- It's a tough work to establish a sound mathematical model to complete the assessment due to the complexity of the factors affecting the planning program evaluation of the airspace sectors. The optimal scheme could be obtained by the extension method to analyze correlation among the various program indicators based on the improved extension model we proposed
- This study provides the assessment methods of terminal airspace sectors, which can be completed through software programming and enhance the efficiency of the assessment when combined with simulation assessment of the airspace. It's a meritorious work and could be the focus of future research

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