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OCC controller workload evaluation model and application

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Abstract

In order to evaluate and predict OCC controller's mental workload, we defined mental workload as time consumption of task during working time. Five subclasses of workload was found from task analysis in according with five kinds of work task - operation task, recording task, communication task, monitoring task and thinking task, and constructed the suggested workload model of this thesis which was expressed as the sum of consumption time of these five kinds task in a unit time. Then we built the basic task set encoding dictionary and the basic time consumption set to simplify the model, which was based on a larger number of observation behaviors data. At last, time pressure was considered to describe the time constraint effect on mental workload. In the application of validation examine, the subjective evaluation method, the physiological test and the suggested model were used to calculate the time occupancy rate, and results showed a high correlation between the actual and the prediction workload which also proved the validation of the suggested model.

Keywords: Mental workload; Task analysis; Time pressure

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1. Introduction

At present, methods used to research the mental workload of controllers mainly focused on the following three aspects[1]: the first is to work out the intensity of the staff's mental workload by physiological and behavioral measurement, including skin response to electric shock, heart rate, electrocardiogram, blood pressure, physiological analysis of body fluids and the numbers of keys, as well as the characteristic analysis of their actions and communications within unit time. The second is to identify the mental workload of staff by subjective evaluation

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based on observation and questionnaire forms, such as the ATW[2] technology of the Federal Aviation Administration of the United States; NASA TLX[3] of the United States; the SWAT[4] proposed by an institute of medicine located at an air force base of the United States; the CH[5] scale proposed by scholars Cooper and Harper; the DORATASK[6] based on experts' evaluation and proposed by the Planning and Analyzing Council of Britain; MBB[7] methods proposed by Germany's Messerschmitt, Korta, and Bloom; and the TAWL method [8] proposed by C.R. Bierbaum and L.A. Fulford, which is the task-centered method used to decompose task sources and so on. The third is to obtain the level of mental workload based on the complexity of the traffic guidance. In this part, W. Pawlak has defined the key factors of ATC complexity[9] and R. H. Mogford has pointed out that the main factor affecting the mental workload of ATC staff is the traffic characteristics [10] of the airspace.

Due to the instantaneous changes of operation condition, the subway dispatcher's workload is fluctuates up and down as a result of a variety of external and internal factors, therefore, to establish a kind of real-time, continuous and anti-interference assessment method of workload is particularly important. DORATASK method in this paper, as evaluation methods that applied in aviation area, could provide an assessment that divided the operation work into three parts as visible work, invisible work and the recovery time. And by analyzing of dispatcher behavior through objective nonintrusive record of the data in detail, the workload could be classified into monitor, cognitive workload, adjustment workload, record workload and modified model based on time pressure, and then the quantified evaluation model is established. Meanwhile, the subway dispatcher task coding dictionary and operation time table have been established by behavior observation, which could be used in task evaluation by means of time-weight table and assessment model as soon as the task coding sequence is determined, thus the complexity is considerably reduced as well as the and the predictability of the model is enhanced.

2. The workload analysis of subway dispatchers

2.1. The definition of subway dispatcher workload

There is no unified definition for mental workload in academic study. Generally, it considered as the demand that work tasks exert on people or the way people handle the allocation of limited resources when undertaking special tasks[11] [12]. However, Wickens puts forward a multiple resources model; he thinks that people possess a group of capacity-limited, property-similar, and functional attention resources[13]. The difference between resource capacity and resource requirement is said to be the remaining resources, which is the internal mechanism produced by mental workload. In short, mental workload is regarded as a notion of requirement of work, difficulty of task, pressure of time, ability of operation, level of effort, and personal feeling, which can be identified in different angles[14].

Operation of metro, passenger travelling and construction examination and fix of subway facility, OCC controller works under a high level of pressure. As a consequence, they need to work hard and consume time to relieve the pressure. In this way, we could treat the dispatcher workload as the time occupation in the given time. Briefly, we can use the time consumption for implement scheduling task in the given time to measure workload.

2.2. The classification of dispatcher workload

In order to build the universal model to evaluate the workload of dispatchers, one of the specifically useful tools is task analysis. Task analysis is the study of operational goals, the cognitive and physical actions taken to accomplish those goals by an operator or team of operators in a system, as well as the information needed to perform those tasks (Kirwan & Ainsworth, 1992). To do the analysis, we spend five months for observation of Shanghai subway dispatchers from, and go over the Work Book of Shanghai Subway Dispatcher. In considering whether scheduled behavior is good for easy observation, we divided the dispatcher task into observable operating tasks and unobservable cognitive tasks. The cognitive tasks can be further divided into AD, RE, and CO, and the five categories have 55 basic units. We then built an encoding dictionary. Table 1 describes the form and example of the encoding dictionary.

From the definition and job analysis results, we can find that workload of the traffic control is time consumption of the task sequence, about 55 basic task units. Therefore, the workload of dispatcher can be divided into operational load (load adjustment, record load, and communication load) and cognitive load (monitor load and thinking load). Each corresponds to time consumption of five kinds of tasks.

Table 1. An example of Dispatcher Activities and Sub-activities .

Classification	Identifying Code	Function	Sub
Physical Actions (40)	AD(20)	Line adjustment (AD1)	Route setting A1
			Route cancellingA2
			Establish terminal functionA3
			Setting reentry mode A4
		Signal adjustment(AD2)	Setting automatic signal A5
			Setting continuously pass signal A6
			Cancelling automatic signal A7
			Cancel continuously pass signal A8
		AD3、…、AD7	A9、…、A20
	RE(13)	RE1、…、RE7	R1、…、R13
	CO(7)	CO1、…、CO11	C1、…、C7
Cognitive Actions (15)	MO(9)	MO1、…、MO6	M1、…、M9
	TH(6)	TH1、…、TH2	T1、…、T6

3. Modeling of dispatcher workload

3.1. The workload estimation model

From the previous analysis, the dispatcher's workload per hour could be represented as:

$$W(t) = W_{AD}(t) + W_{RE}(t) + W_{CO}(t) + W_{MO}(t) + W_{TH}(t)$$
$$= \sum_{i=1}^{20} w_{A_i} + \sum_{i=1}^{13} w_{R_i} + \sum_{i=1}^{7} w_{C_i} + \sum_{i=1}^{9} w_{M_i} + \sum_{i=1}^{6} w_{T_i} \qquad (1)$$

$W(t)$ is the total workload of dispatcher at time t;$W_{AD}(t)$, $W_{RE}(t)$, $W_{CO}(t)$, $W_{MO}(t)$,$W_{TH}(t)$are adjustment workload, recording workload, communication workload, monitoring workload, and thinking workload, and W_{Ai}, W_{Ri}, W_{Ci}, W_{Mi}, W_{Ti} are the total time based on task unit costs.

In equation (1), operation workload- which included adjustment workload, recording workload, and communication workload- could be obtained by directly observing behavior, monitoring workload could be recorded by a visual tracker, while cognitive workload could be measured and calculated by cognitive task analysis[15] methodology, as described in table 2.

Table 2. The Cognitive Task Unit Average Workload Algorithm.

Cognitive task unit	algorithm	Parameter description
Simple reaction (T1)	$w_{T1} = T_p + T_c$	T_p is time constants of perception modules，ranges [50,200] ms，normally 100 ms；
Recognition and identify(T2)	$w_{T2} = T_p + 2T_c$	
Choice reaction(T3)	$w_{T3} = T_p + n \times T_c$	T_c is the cognitive time constant, ranges [25,170] ms，normally 70ms；
Calculated memories(T4)	$w_{T4} = T_c$	L_c is the reaction time constants ranges [50,157] normally 92ms ；
Decision making(T5)	$w_{T5} = T_p + T_c + I_c \log_2^{(2)}$	
Judgment(T6)	$w_{T6} = h[T_p + T_c + I_c \log_2^{(h+1)}]$	n is the amount which could be choose and h is the amount which are conidered.

As a consequence, the cognitive workload can be expressed as

$$W_{TH}(t) = \sum_{i=1}^{6} w_{T_i} = \sum_{i=1}^{6} \overline{w_{T_i}} \times N_{T_i} \tag{2}$$

3.2. Revision of workload model based on time weights

Time weights are the expectation value of operational time, and it is based on time research. Adopting an intensive sampling method, through continue observation to dispatcher directly and indirectly, analysis statistic of time consumption in every task unit in the process of operation, calculate measured time average of different basic task unit. This article chooses Shanghai positive dispatchers from years of operational experience, a good mentality, and standard operations for visual tracking, and it lasts for shifts which more than 120 hours.

Set up a basic task unit to observe the time in No. n respectively: X_1, X_2, X_3,… X_n, get the mean and standard deviation. For observation, deviation beyond $X \pm 3\sigma$ should be regarded as an outlier to be moved out[16]. We used the remaining qualified data to identify the time weights of 49 basic task units, respectively, except for the 6 basic task units of thought load, as table 3.

Table 3. Basic Task Unit Time Weights (parts) (unit: s).

Basic task unit	Time weights	Shortest time	Longest time	Standard deviation	Sample size
M1	4.004	0.735	16.694	4.23	3047
M2	5.307	0.833	24.386	6.36	3012
M3	3.143	1.177	6.013	0.96	1183
…	…	…	…	…	…
A11	1.496	0.718	2.284	0.28	646
A12	1.859	0.869	2.520	0.33	1314
A13	3.949	0.675	5.261	0.54	402
…	…	…	…	…	…

Therefore, we can revise the method of calculation about load adjustment, load record, load communication, and load supervision:

$$W_{AD}(t) = \sum_{i=1}^{20} \overline{w_{A_i}} \times N_{A_i} \tag{3}$$

$$W_{RE}(t) = \sum_{i=1}^{13} \overline{w_{R_i}} \times N_{R_i} \tag{4}$$

$$W_{CO}(t) = \sum_{i=1}^{7} \overline{w_{C_i}} \times N_{C_i} \tag{5}$$

$$W_{MO}(t) = \sum_{i=1}^{9} \overline{w_{M_i}} \times N_{M_i} \tag{6}$$

W_{Ai}, W_{Ri}, W_{Ci}, W_{Mi} are time weights of the basic task unit; N_{Ai}, N_{Ri}, N_{Ci}, N_{Mi} are the number of executation of task unit in one time unit. From equation (2), (3), and (6), we could get the revised the workload model as:

$$\overline{W(t)} = \sum_{i=1}^{20} \overline{w_{A_i}} \times N_{A_i} + \sum_{i=1}^{13} \overline{w_{R_i}} \times N_{R_i} + \sum_{i=1}^{7} \overline{w_{C_i}} \times N_{C_i} + \sum_{i=1}^{9} \overline{w_{M_i}} \times N_{M_i} + \sum_{i=1}^{6} \overline{w_{T_i}} \times N_{T_i} \quad (7)$$

3.3. Revision of workload model based on time pressure

The subway dispatchers have many time constraints in the process of executing tasks, especially in regard to time pressure during an emergency. Time pressure requires a dispatcher to finish corresponding tasks more quickly in a specific short time. Compared with enough operation time, information dealing ability increase a lot lead to heavy workload. According to the definition of workload in this article, time pressure can transfer to time consumption, we use the ratio of time needed to finish the work and time constrains in k time ranges to represent the time pressure coefficient:

$$TP_k = \frac{TD}{TA_k} \quad (8)$$

TP_K is the time pressure coefficient in the period of K. TD is the needed time to finish task in normal circumstances (time constraints) and TA_k is the time constrains in k time ranges. Based on the distribution of time domains in the scheduling of tasks, this article divides the whole working time into eleven time slots and one abnormal statue time slot. Through a questionnaire survey and the observation of statistic results can we get the pressure coefficient in different time slots in table 4.

Table 4. Time Pressure Coefficient (Shanghai Subway).

Time period	Start- End	Time pressure coefficient
Preoperative preparation	4:00-4:30	1.179
Train outbound train	4:30-7:00	1.264
Morning peak	7:00-9:30	1.469
Morning slack	9:30-12:00	1.242
Afternoon slack	12:00-17:30	1.147
Evening peak	17:30-19:30	1.404
Evening slack	19:30-23:00	1.192
Post-operation	23:00-24:00	1.134
Construction Registration	0:00-1:30	1.390
Construction Monitoring	1:30-3:00	1.177
Construction logout	3:00-4:00	1.339
Abnormal situation	/	1.473

Mapping the time pressure into the evaluated model and revised the workload as:

$$\overline{W(t)}_k = TP_k \times (\sum_{i=1}^{20} \overline{w_{A_i}} \times N_{A_i} + \sum_{i=1}^{13} \overline{w_{R_i}} \times N_{R_i} + \sum_{i=1}^{7} \overline{w_{C_i}} \times N_{C_i} + \sum_{i=1}^{9} \overline{w_{M_i}} \times N_{M_i} + \sum_{i=1}^{6} \overline{w_{T_i}} \times N_{T_i}) \quad (9)$$

We conducted a thorough video test and task analysis of Shanghai metro lines one and two to record the entire task in a finished continuous day and night shift. In one minute unit, we output all the responding statistic parameters of action, including four parts--cumulative duration of action, movement frequency, average execution time, and percentage of this action. These actions were then categorized according to the corresponding 55 items of the coding dictionary, and the output was 220 columns and 1440 row of data for those 24 hours to become the dispatching operation database. Statistical analysis of data obtained the expectation of execution time. In five minute units, 24 hours in a whole day can be divided into 228 successive time slots. Taking the created load model as an assessment to calculate the workload value and adding the workload in every time slot together results in a 24-hour assessment of the dispatchers, as shown in Fig. 1(a).

As Fig. 1(a) shows, traffic control showed a trend of fluctuation in some degree in the whole day, and clearly reveal three workload peak- construction registration, morning peak, and evening peak- and also three nadirs- construction supervision, afternoon off-peak, and evening off-peak.

The analysis result shows that traffic control has an 80% time occupancy, taking 8.3% of the whole working time. Due to heavy traffic in the morning peak, disordered operations, the centralized operation stage of night construction registration, high labor intensity, the dispatchers' workload is seriously overloaded and the operating strength is beyond its limit, which is bad for their mental and physical health. Because there is no recovery time to provide reserved energy, once an unexpected event happens, the dispatchers will not do their best to deal with an emergency, which is a hidden trouble for the safety of the metro. But the tasks of night construction monitoring and operation preparation are easy and repeated, and the numbers of main line trains reduce in afternoon off-peak and evening off-peak times. The operation order becomes normal, and the smaller system will adjust the travel delays automatically through intervention, which causes traffic-scheduling workload to be at a lower level.

4. Application and validation of model

4.1. Based on the subjective evaluation and confirmation of IWS scale

To confirm the availability of the model, this test compares the IWS scale from Research Center for Nottingham Railway and workload model of this article for analysis. The IWS scale is reformed from the Instantaneous Self-Assessment (ISA) scale of Nottingham University in Britain. Through talking with dispatchers about the abstract key workload dimension, which lists 47 description to describe controllers and through investigation and analysis, researchers put together the probability of all descriptions and divided them into 11 categories, then translated these into a 9 point scale, eventually forming a single dimension workload assessment consisting of a 9 measurement factors scale. The practical application shows that the IWS scale is suitable for application in a railway traffic environment and can effectively evaluate the work load of railway dispatching and reflect the changes in operator workload sensitively. Additionally, peak and valley values are prominent , which shows good discrimination[17].

Due to the continuity of the operation controller,,we developed an IWS workload assessment tool to eliminate the disturb to the operation process. The tool measures and records the workload in constant speed.

Since IWS subjective evaluation and the workload model are not have the uniform dimensions,we use the normal standard method to process the data, with the results shown in Fig. 1(b).

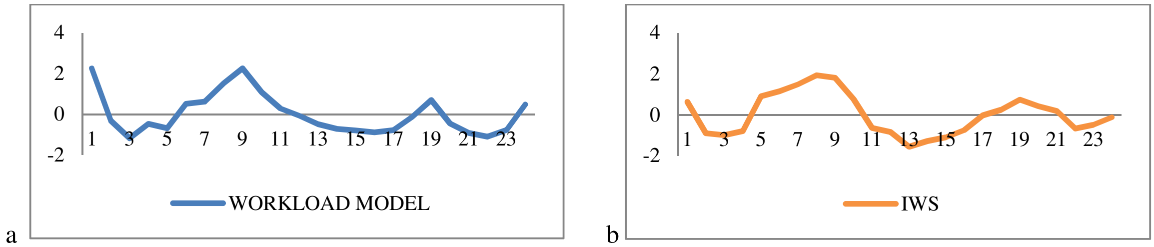

Fig. 1. (a) dispatcher workload evaluation results in 24 hours ; (b) IWS evaluation results in 24 hours.

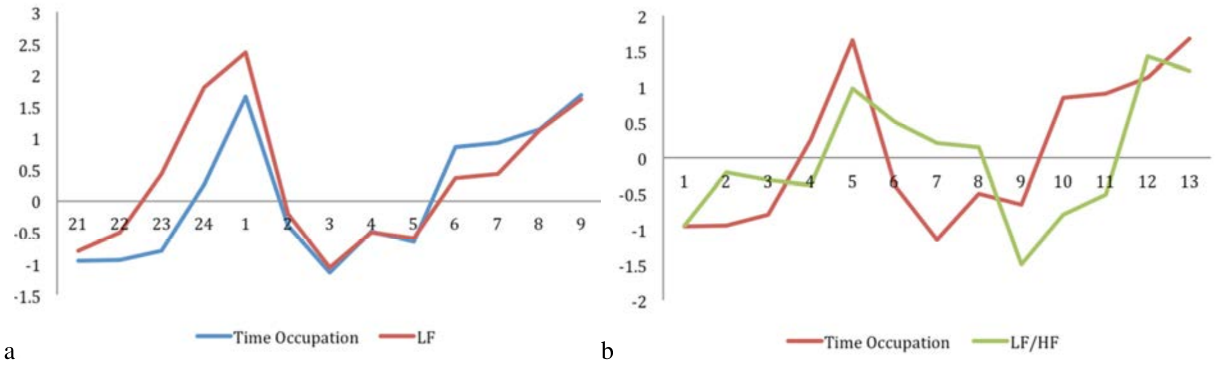

Fig. 2. (a) Comparison of results between time occupation and LF; (b) Comparison of results between time occupation and LF/HF.

The correlation coefficient of the IWS assessment value and the model evaluation value is 0.72, and they connect with each other significantly. From figure one we can see that the trend of two curves--IWS assessment value and evaluation assessment is almost the same. It means that the workload model has good availability.

4.2. Based on the subjective evaluation of physiological measurement

Physiological measurement reflects physiological change in the process of work, and HRV as sensitive index of workload has been certified and applied as a workload measurement. The HRV indicator mainly has sinus beat NN interval standard deviation (SDNN), root square of deviation between adjacent NN interval (rMSSD), low frequency power LF, high frequency power HF and low frequency power ratio LF/HF. Cui kai and other people utilize heart rate variability to measure the ratio of LF low-frequency power and low frequency power. LF/HF measure the physiology to dispatcher in order to assess workload value of work[18].

With 12-Lead Ambulatory Electrocardiogram, taking night shift dispatchers working from 9 pm. to 9 am for physiologic analysis. The results are shown in Fig. 2 (a)and (b). The correlation coefficients of LF index value and workload model value is 0.73 and the correlation coefficients of the LF/HF index value and workload model value is 0.62, which are regarded as a moderate collection. It illustrates that applying the evaluation model is feasible to evaluate traffic controlling.

5. Conclusion

In this thesis, we used the execution time and the time utilazation rate as the messurement standard to evaluate the workload of subway dispatchers. Then we established a workload evaluation model in terms of the five types of workloads we divided based on the task analysis. To simplify the evaluation process, we built an unit based coding dictionary and time weight by using a great amount of behavior observation data. In the practical application, the evaluation results from this model perfectly matched with the results from IWS value and the heart rate variablility physiological measurement.

Compared to the general subjective questionnaire, the physiological measurements and behaviour observation method, the workload evaluation model proposed in this study can objectively reflect the changes of the subway dispatcher workload in terms of the execution time. Therefore, this workload evaluation model can be used as a good forecaster in the future evaluation process, which can provide a reliable scientific basis for the subway dispatchers' workload evaluation, specifically the evaluation of the risks of the dispatching work and subway operations safety management.

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