On Human Factors in the Design of Locomotive Cab: An Investigation on Driver’s Cognitive and Behavioral Characteristics

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ABSTRACT
In this paper an investigation on locomotive drivers’ cognitive and behavioral characteristics is conducted and advice for the redesign of locomotive cab considering human factors is proposed. The results of the investigation show that most behaviors of locomotive driving are skill- and rule-based, and previous behavior template plays an important role in locomotive driving, with an obvious process of information feed-forward. Though the operation comfort degree of all the mentioned joysticks is rated low, no significant correlation between controller’s operability and driver’s age, driving experience, handedness or educational level is found. Significant correlation and no variance are found between the speedometer and speed graphic curves on the monitor, indicating both ways for displaying running speed information should coexist to provide necessary information redundancy. According to driver’s characteristics, advice on locomotive cab redesign is proposed with focuses on ergonomic performance, consistency and readability, explicitness and simplicity, and error prevention.

INTRODUCTION
Locomotive cab is a particular place, where locomotive drivers obtain the real-time running information, and the design of the cab has a special significance on driving safety. Previous studies mainly focused on ergonomic performance of the in-cab equipment and driver’s occupational health. After the 2000s, human factors including driver’s cognitive characteristics, driving task analysis and its application in cab design began to appear in worldwide literatures. T. Luke et al. researched trainman’s visual strategies using eye-tracking system and found that signal aspect, preceding signal aspects, signal type and signal complexity affected driver’s visual behavior [1].

With the rapid development of China’s high-speed train manufacturing, the design of locomotive cab attracted more and more attention in China in recent years. For instance, Luo Z Q, Fang W N and Zhang J H studied on the optimized position of the devices and display units in locomotive cab based on the important degrees of the
devices, using the fuzzy operator [2]. However, current design of locomotive cab is still based on machine-centered design idea, which takes the efficiency of machine system as prime target and needs the operators to adapt to the demands of the machines.

On the contrary, industrial design emphasizes on the idea of user-centered design, which insists that user research should be carried out firstly, and that is also the direction of the development in the field of human-machine interface design. The purpose of this thesis is to study on the driver’s cognitive and behavioral characteristics, and its relevant requirements for cab redesign, in order to improve the design of the locomotive cab accordingly.

The focuses of cab design usually include the dimension of the main equipment, such as the height of operation board or seat, the layout of the instruments and monitors, the symbols and icons, and so on. Generally, the anthropometric data is the foundation of the design of equipment, and the driver’s cognitive and behavioral characteristics could guide the design of the driving interface. As to driver’s cognitive and behavioral characteristics, it is much more complex than an interdisciplinary subject. Jens Rasmussen demonstrated human performance in routine task environment and in unfamiliar task conditions, and he presented different types of models to represent performances at the skill-, rule-, and knowledge-based levels, together with different levels in terms of signals, signs, and symbols. That study indicated that human factors and human-machine interface could be studied and designed from the perspective of psychology [3]. Norman D A built a user task model which is now widely used in the field of user research [4]. Based on that, Li L S studied on industrial design psychology and developed a new method, called non-rational user model (including metal model and task model), to describe human factors [5]. However, he didn’t propose a general structure of the user model, and his work mainly focused on the description of user’s task and mental properties, which were very similar to what the author called behavioral and cognitive characteristics in this paper.

Usually there are two ways to study on human’s cognitive characteristics: testing and survey. Eye-tracking, biopac and physiological analyser systems are the common equipment for testing, and several parameters that can indirectly reflect the user’s cognitive characteristics could be recorded with those equipment. In the meantime, questionnaire survey is a conventional method to study on user’s cognitive characteristics too. Li L S suggested describing user model from the perspectives of perception, cognition, task, error and learning as well, and he developed a sophisticated technology to research user needs via questionnaire survey which was called design investigation [6].

In this paper, a design investigation is implemented to study on the driver’s cognitive and behavioral characteristics. The aim of this study is to describe the driver’s cognitive and behavioral characteristics in details and provide some guidance for the redesign of locomotive cab.

METHODS

The design investigation consisted of two stages: interview and questionnaire survey (Figure1). At the first stage, interviews were conducted with experts and ordinary drivers to establish a frame of investigation factors. At the second stage, a questionnaire was designed and answered by drivers.
From prior survey, the interview outlines were summarized, and the formal interview with experts and ordinary drivers was implemented at stage 1. After the formal interviews, a framework of questionnaire factors was established. Then the primary factors were disintegrated, along with the secondary and tertiary factors, and some interpretations of the factors were obtained. At stage 2, each interpretation was transformed into one or two questions for the questionnaire, and a questionnaire manuscript was generated. Then a pilot study was carried out to examine the effect of the questionnaire, and the questionnaire manuscript could be revised. Finally the formal questionnaire was established and the formal investigation was implemented.

Stage 1: interview

Participants

Interviews usually should be implemented with experts, general users and freshmen separately in order to ensure the sufficiency of information [5]. However, in this interview the author abandoned the freshmen because of the driver’s occupational particularity that an assistant driver has to pass various tests over years to become a formal driver. So three experts and five ordinary drivers were interviewed. Among the experts, two have worked in a railcar manufacturing enterprise for over 15 years, knowing very well about the history and the design properties of locomotive cab. The third one is an old driver with over 20 years’ driving experience. The five ordinary drivers all worked in Chengdu locomotive depot at that time.

Procedure

In prior survey (Figure 2), an ordinary driver was invited to introduce the main activities when driving a locomotive, and he also demonstrated how he operated the in-cab controllers. Therefore, the author could get a whole picture of locomotive driving and find out what the driver cares about when driving a locomotive. After the prior survey, the interview outlines were listed.

For the formal interview, one of the experts introduced the design of the locomotive cab freely, and he was never interrupted so that the interviewer could get as much information as possible. While the second expert was interviewed, more questions and detailed information were proposed. After the two experts’ interviews, an outline for the interview was formed. With the outline, the third expert’s interview was conducted to check and revise the questions and information. When the interview outline was finalized, the five ordinary drivers were interviewed in a locomotive cab (SS4 model). The drivers answered the questions in detail while operating and introducing the usual situation of driving tasks, and they also illustrated the expectation for the cab.
Through the interviews, the author found that current cab designers began to notice the ergonomic performance of equipment, and great progress was achieved in the new locomotive, e.g. HXD1C (Figure 3), which was highly praised by the drivers. However, there were great differences in cabs of different types, which brought the problem of inadaptation.

Norman D A suggested studying user activities from four stages including goal, selection, operation and assessment [4]. Li L S further pointed out that the framework of the user research questionnaire should be constructed separately from the goals, planning, operation, evaluation, error and abnormal situation according to different tasks [7, 8]. However, as to locomotive driving, there are too many tasks of driving locomotive, and the operations are mainly similar and repeated. Taking feasibility and convenience into account, the author chose behavior, cognition, evaluation and abnormal situation as the primary factors to build the questionnaire frame, integrating goals and planning into cognition and error into abnormal situation (Table 1). For each of the primary factors, the lower levels of the secondary factors and tertiary factors were analyzed, and each tertiary factor was expounded in detail, each of which was corresponding to one or several survey questions that finally formed a questionnaire.

<table>
<thead>
<tr>
<th>Primary factors</th>
<th>Secondary factors</th>
<th>Tertiary factors</th>
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<tbody>
<tr>
<td>Behavior</td>
<td>Operation of the joysticks</td>
<td>Operating pattern</td>
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<td></td>
<td>Layout of the joysticks</td>
<td>Operating performance</td>
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<tr>
<td>Cognition</td>
<td>task analysis</td>
<td>Characteristics of information processing</td>
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<td>Information acquisition</td>
<td>Information Position</td>
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<td>Characteristics of information processing</td>
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<td>Evaluation</td>
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<td>Abnormal situation</td>
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<td>Characteristics of information processing</td>
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<td>Emergency</td>
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Table 1. The frame of questionnaire factors.

Stage 2: questionnaire survey

Participants

In theory, the respondents of this study should be all the drivers who work in different locomotive depots all over China. In fact, locomotive depots play the roles of natural clusters very well, making it pretty suitable for cluster sampling. Furthermore, because of the identity of locomotive depots, the variance between the clusters is small, and one depot is good enough to be representative. Therefore the author chose Chengdu locomotive depot as the primary sampling unit, and 150 drivers were recruited randomly. The participants ranged from 23 to 48 years old (average = 37 years), and 50% of them are younger than 37 years old. Of all the participants, more than 90% were right-handed, only 14% received college education, and their duration of being locomotive crew ranged from 1 to 10 years (average = 8 years).

Procedure

According to the frame of questionnaire factors (Table 1), a preliminary manuscript was designed and used for a pilot study in Mar. 2011. The participants in pilot study were 25 locomotive drivers from Chengdu locomotive depot, who attended a short-term training class held in Southwest Jiaotong University at that time.
Through the pilot study, the initial questionnaire was modified and the formal questionnaire was established as shown in Appendix 1. For the respondents, the most familiar types of locomotive were SS4 and SS7, which were mainly employed in passenger railroads, while locomotive HXD1C was mainly employed in freight railroads. The instruments and controllers installed on the operation desk could be classified into three groups: traction unit, braking unit and monitoring unit. However, as shown in Figure 2 and 3, the layout of the operation desk, the controller the display and communication units were quite different. Therefore the questionnaire wasn’t designed according to a certain locomotive, and most of the meters and controllers adopted in different types of locomotive cabs were included in the formal questionnaire, in order to acquire sufficient information. Besides, in order to avoid being misleading since the questions were grouped in the same way, all the terms in the questionnaire were intentionally scrambled based on the order as shown in Table 1.

In May 2011, the formal investigation was carried out. A total of 150 questionnaires were dispatched at Chengdu locomotive depot, and 127 were returned after one week, with a response rate of 84.7%. Due to incomplete information or obvious contradiction, 22 questionnaires were invalid and eliminated, and the other 105 were valid and analyzed.

Data analysis

Each question was a description of a certain operation or cognition, measured with Likert scale ranging from 1 to 5, representing different attitudes to the statement: 1=totally disagree and 5=totally agree, and the respondents were asked to assess the statement according to their own experiences.

All the data were coded and analyzed via the SPSS software for Windows. Above all, reliability analysis was utilized to examine the internal consistency of the measurement. Then the descriptive statistics were conducted using frequency analysis. For several key questions, the bivariate correlation analysis was employed to identify the relationship between the questions and the basic information of the drivers such as age, educational background and duration of driving, and then partial correlation analysis was adopted to examine the relationship between the questions when the other questions were controlled. Furthermore, the analysis of variance (One-Way ANOVA) was used to examine the significant differences between handedness and driving behavior, and paired-samples T test was utilized to identify the differences between the two different ways for displaying the speed information. When the means were compared, the statistical significance was set at a probability level of 0.05.

RESULTS

For all the valid 105 questionnaires, Cronbach’s Alpha was 0.920 which indicated a high internal consistency. For each question, the mean, mode and variance of each term were calculated. It’s shown that the operation of all the joysticks involved in the questionnaire was rated low, with means below 3 and modes of 1 or 2, indicating a low comfort degree of the operation. Some of the controllers, e.g. the hand wheel controller and joystick, were designed to meet the needs of high reliability, for lack of consideration on the unhealthy influence of constant muscle tension over prolonged periods of handling the controllers. However, it’s also demonstrated that most locomotive drivers could operate all the controllers sophisticatedly after being trained.

On the contrary, the cognition of the icons, graphs and the different colors of the graphs was rather good. In prior survey, a locomotive driver was invited to introduce
the operation and the cognition of the icons and graphs. It showed that semantics played an important role in recognition. If the icon was designed according to working status of the equipment, it would be beneficial for recognizing. For example, the icons ( and ) directly reflected different status of the pantograph, and most of the drivers could appropriately understand them. Additionally, the classification of the joysticks and meters should be more reasonable and it should be displayed with different colors to distinguish whether the faults have been dealt with or not.

Moreover, we learnt that most drivers asked for standardization and unification of the design in different cabs, and operation pattern should adapt to the driver’s daily habit. It’s also shown that locomotive driving was a labor of both physical and metal, which demanded quick response, and the cognitive process was too short to be detected. The readability of both cross-pointer speedometer and windowing meter was pretty high, and environmental lighting usually affected the readability. Prompt text box emerging, ceaseless flashing and alarm were all effective ways for warning, with an ascending trend in the effect.

The results demonstrated that the correlation among the recognizing efficiency of windowing meter, age and driving duration of the drivers was significant at the 0.05 level (2-tailed), indicating a positive correlation between the readability of windowing meter and the driver’s age and experience, i.e., the more training and experience, the more efficient on reading windowing meter. The results of bivariate correlation analysis showed the predication of each operation, the habit of observing signals, the recognizing efficiency of windowing meter were pairwise significantly correlated at the 0.05 level (2-tailed). Correlation was illustrated between the prediction of operation and the expectation of signals, because both of them were derived from feed-forward information. Moreover, the two ways (cross-pointer speedometer and graphic curves on the monitor) to show running speed information were highly correlated with each other too, indicating both were significant for the drivers to get speed information.

The result of One-Way ANOVA demonstrated that, there was no significant difference between left-handed operations and right-handed operations mentioned in whether the operation of joysticks and knobs should be adapted to the habit of daily life, whether the operation of joysticks can be handled skillfully, and the operating comfort degree of different joysticks ( ). Paired-samples T test was utilized with the two ways for drivers to get running speed information, and no significant difference was proved ( ). While at the same time, the correlation coefficient was 0.551 and the concomitant probability was 0.001, which indicated a high paired effect. Again, it indicated the two ways to show speed information (speedometer and graphic curves) should exist simultaneously in the cab, as necessary information redundancy.

DISCUSSION

In prior survey, some typical driving tasks were observed and recorded, which could be beneficial to understand the results of the investigation. Taking a typical solution of abnormal situation for example, in which pedestrian suddenly appears in the railroads. As usual, the driver holds the traction draw bar for speed regulation, glancing over the speed graphic curves on the monitor rapidly and briefly to keep appropriate traction level, while he keeps observing the railroads and signal lights. Suddenly the driver finds someone walking along the locomotive lines, and immediately releases the traction draw bar and presses the air horn. If the pedestrian leaves, the driver holds the traction bar again; and if the abnormal situation remains, he presses the air horn again and active the EBV (Electric Brake Valve) unit; if the pedestrian still remains in railroads, the
driver will take emergency brake at once. The procedure was shown in Figure 4, which
could be considered as a typical behavior template.

![Figure 4. A typical behavior template.](image)

In Figure 4, the rhombuses were the conditions to trigger a certain behavior, the
rectangles were behaviors with a short cognition process, and the ellipses were
behaviors without obvious cognition process, i.e., behavior and cognition were
simultaneous in the ellipses. Scilicet, the behaviors in the rectangles were rule-based,
and the behaviors in the ellipses were skill-based with obvious feed-forward
intentionality. While the driver was paying attention to speed regulation, the
“perception-operation chain” [5] was formed and the main behavior of driving was to
monitor the railroads and lights. During the long time lookout, glancing on meters and
monitor was rapid and brief, therefore locomotive drivers were used to observe at a
particular direction. According to the driver’s cognitive and behavioral characteristics
mentioned above, some advice for locomotive cab design could be developed as
follows.

**Ergonomic performance**

Most drivers rate the operational comfort degree of all mentioned joysticks low, and
a more humanized and comfortable cab is expected. As the results show, the
assessment score of the EBV controller involved is relatively higher than the other
controllers’, indicating the T-shaped joystick could have better ergonomic performance.
The operation desk shown in Figure 3 is highly praised for its cambered desk, which
makes the controllers, e.g. the acknowledgement button, can be installed within the
range that the driver could reach comfortably. In a word, more should be done on the
design of the in-cab equipment to improve their ergonomic performance.

**Consistency and readability**

As behavior template plays an important role in locomotive driving, consistency
should be paid more attention in redesign of the locomotive cab. Excessive and rapid
equipment replacement and update might make previous experience or operation rules
invalid, so unified equipment should be adopted in cabs of different types, and the
operational procedure of different joysticks should be consistent. The layout of the
meters and monitors should adapt to daily life, adopting familiar arrangement strategy
and avoiding big adjustment in new cabs. In addition, in order to improve readability,
meters and monitors should be placed in the optimal visual field, and the messages on
the page should be white or yellow-on-black, which is also the requirement of
ergonomic performance. Besides, the painting and lights in the cab should be
moderated because strong lighting may reduce the readability.

**Explicitness and simplicity**

As locomotive driving is both a mental and physical labor, and the cognition
procedure is rather short in driving, explicitness and simplicity should also be
significant in cab design. Explicitness means the accuracy of semantic depiction, and
simplicity indicates clear and distinct signals or icons without meaningful senses. The
shape and operational logic of joysticks and their relationship with instruments should be specific and obvious. For example, the major monitor should skip to the page of the main interface automatically when the driver starts the locomotive, which is convenient to observe the network voltage value, and the switch of the main circuit breaker may cancel the “0” tap position, and only “closed” and “off” positions are set, which can meet the requirement of simplicity. Besides, the monitor interface should be simple, clear and explicit. Because the cognitive procedure of driving belongs to elementary level, the design of icons, menu and graphic curves of the display interface should adapt to daily life, and the symbols with meaningful senses should be eliminated.

Error prevention

Error prevention is the requirement of expert system. Most drivers expect that fault diagnosis information should be displayed alone on a monitor. Besides the traction unit, braking unit and monitoring unit mentioned above, a diagnosis unit can be designed on the operation desk, where the necessary prompts and helps should be provided in an individual monitor. Because locomotive driving is mainly rule-based, available operational rules should be fully considered in the design of locomotive cabs. When fault appears, help messages should emerge precisely on the monitor accordingly, and the causes, types and grades of the fault should be showed directly. The events untreated should be displayed differently, and help information should be conspicuous.

CONCLUSIONS

According to the investigation conducted in this paper, the cognitive and behavioral features of the driver are summarized, and some suggestions for locomotive cab redesign are provided, which are helpful to improve the performance of locomotive design.

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REFERENCES