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Development of a method for finding a better display and control layout through random search and incremental improvement

– 무작위 탐색과 점진적 개선을 통한 표시 제어 장치의 배치 설계 방법 개발–

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ABSTRACT

A display and control layout design should be ergonomically sound, and, at the same time, be able to satisfy user preference. This study developed a display and control layout design method based on ergonomics design principles and user preference. The proposed layout design method adopts a multi-criteria heuristic algorithm to find the layout design that maximizes ergonomic conformance and user preference. The method consists of two phases, the generation phase and the evaluation phase. In the generation phase, two types of generation methods are performed independently: 1) a random search for finding ergonomically sound arrangements, and 2) incremental improvement performed by improving existing layout designs to identify similar yet ergonomically improved layout designs. The incremental improvement is based on the assumption that layout designs similar to the existing layouts are likely to be preferred by the operators due to their similarity. In the evaluation phase, the layout design alternatives obtained in the search phase are evaluated in terms of both ergonomic excellence and user preference. Afterwards, the Pareto optimal solutions are obtained. Finally, a single optimal solution is determined among all Pareto optimal solutions through a consensus process between stakeholders. A case study is presented to demonstrate the method, using the example problem of designing the train driver's display-control interface inside a railway cab. The results show that the generated layout design is indeed in accordance with the ergonomics design principles and satisfies user preference.

Keywords: display and control layout design, ergonomic design principle, user preference, computer based search algorithm

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1. Introduction

1.1. Background

Trains, airplanes, or nuclear power plants require the control of complicated systems. Poorly designed display and control interfaces may induce human error, leading to accidents and safety problems (Norman, 1988; Rasmussen and Vicente, 1989; Reason, 1990; Senders and Moray, 1991; Maxion and Reeder, 2005). For example, train drivers use complicated display and control interfaces on a daily basis. In such an environment human error was one of the key factors in rail accidents (Reinach and Viale, 2006; Baysari et al, 2008). Additionally, it is known that a faulty display and control interface decreases the work efficiency of the driver, and increases work stress (Sanders and McCormick, 1987; Xu et al, 2010).

There are many methods being used to design a display and control interface of a complicated machine system in the current industry. One widely used method requires an ergonomic expert or a design expert with ergonomic knowledge to lead the design of the interface based on previous experience and knowledge (Xu et al, 2010). For example, Alstom, a French rail company, conducted a project in which experts in ergonomics and design jointly collaborated to design the display and control interface of the rail cab of the TGV-NG (Train à Grande Vitesse-Nouvelle Génération) (Sagot et al, 2003).

Additionally in Korea, professionals design the arrangement of the interface of a rail cab employing the UIC 651 standards, which are based on ergonomic design principles (Jeon et al, 2013).

The expert-led design method mentioned above requires previous ergonomic design knowledge along with user data. For example, Sagot et al. (2003), Ruiz-Rodriguez et al. (2012), Han et al. (2015) are examples of projects that collected user opinions in order to either improve the original interface or design a new interface. This process also included a strong base of ergonomic design principles. It is critical to consider both user opinions as well as ergonomic design principles. This is because the ergonomic perfection of a design means nothing if user preference is low. Ergonomic conformance and user preference are related in some way, but do not completely correspond with each other. For example, users may prefer the original interface due to repeated use, and in this case will not be open to a different interface (Alppay and Bayazit et al., 2015). Also the QWERTY Keyboard is another example of the disagreement of the two factors. Therefore, the goal should be to find an interface alternative that satisfies ergonomic principles and increases user preference.

The aforementioned expert-led design approach will result in a design that satisfies ergonomic principles and user preference if the following are possible: the approach uses the ergonomic background knowledge of the expert and incorporates design information collected from the user, the expert has experience and knowledge in the field, and the complexity of the problem can be handled (Ruiz-Rodriguez et al., 2012; Han et al., 2015). However, in the case of a complicated system with various controls and displays, there are an immense number of possible arrangements. In such a case, it is difficult and inefficient for the designer to consider the various alternatives to select the final arrangement (Xu et al., 2010). Additionally, the designer's subjective opinion may affect the creation and selection of the final arrangement, making it difficult to create an optimal interface.

Because the large number of alternatives makes it difficult for designers to search and evaluate each alternative, some research suggests the use of search algorithms to solve this problem (Li et al., 2015; Bonney and Williams, 1977; Wang et al., 1991; Jung et al., 1995; Holman et al., 2003; Xu et al., 2010; Lin and Wu, 2010; Grobelny and Michalski et al., 2015; Deng et al., 2016). One of the methods used is the use of ergonomic design principles as a constraint to optimize a function. Some recent methods used recently include meta heuristic methods such as the genetic algorithm or simulated annealing to solve the arrangement problem.

Although the use of computers comes with the advantage of a quicker, more efficient way to compare and evaluate many different alternatives, there are a few disadvantages in the current search algorithm method. One of the main disadvantages is that user preference is not reflected in the objective function or constraints, meaning that the final solutions may not be accepted or preferred by users. For example, Holman et al. (2003) used linear programming to design an arrangement with minimized movement distance, but it is not certain if this arrangement will be preferred by users. If the new arrangement differs greatly from the existing arrangement, users may prefer the existing one over the new ones. It is thought that researchers have not been able to formulate user preference as an objective function or constraint, because it is difficult to translate the effects that design variables have on the user preference.

1.2. Goals of the research

Considering the advantages and disadvantages of the existing design methods and research, it is necessary to consider both ergonomic conformance and user preference in both processes of searching for and comparing alternatives. To this date, there is almost no research that considers both factors to design a display and control arrangement. Jung et al. (1995) has suggested a method that used the CSP method to design and improve a console arrangement with the knowledge of an ergonomics expert. However, this method is limited in that it reflects the opinions of only a few users or experts.

Therefore, the goal of this research is developing a display and control arrangement design method that considers both ergonomic conformance and user preference. The proposed method is related to solving an optimization problem with two objective functions, which are ergonomic conformance and user preference. In order to solve this optimization problem, it should be possible to evaluate the objective function values for all possible solutions. However, it is practically impossible to do so for user preference, as user preference values need to be collected empirically from users. In order to solve this problem, this method suggests a new heuristic method. This process for this heuristic method is as follows. Layouts are first generated, and those with high ergonomic conformance are selected to be candidates for the final solution. Next, user preference is evaluated for each of these layouts. Lastly, the best layout among the candidates is selected by considering both ergonomic conformance and user preference.

The new design method is composed of two solution generation steps:

1) Generation of ergonomically excellent design alternatives by random exploration

2) Generation of ergonomically improved design alternatives based on manually improving the existing arrangement

Generation method 1 aims to produce various layout alternatives that are ergonomically excellent. Generation method 2 is based on the theory that alternative layouts similar to the existing layout will be higher in user preference due to the likeness of the interfaces. The goal of Generation method 2 is to reflect a user preference factor to the design process, as it had been neglected in Generation method 1.

Through these two generation methods, this study considers various new layouts that are completely different from the existing layout, along with those that are ergonomically improved, but similar versions of the existing layout. This allows for a search within a larger variety of layouts than possible with the existing design method. Additionally, it is possible to identify layouts that are superior to the existing layout in terms of ergonomic conformance and user preference. With the use of this method, it is possible to create designs that decrease the workload while using the interface, as the layout will be ergonomically improved. This may be able to contribute to the reduction or prevention of human errors. Additionally, the layout will be improved in terms of user preference. Despite being a new layout, will be easily accepted by users, as user preference will also be considered.

1.3. Contents

This master's thesis consists of 6 chapters with the following contents. Chapter 1 discusses the research backgrounds and needs, and, the research objectives. Chapter 2 provides a summary of existing research about methods to design display and control interface arrangements, and Chapter 3 discusses the solution to this design problem that is suggested in this research. And chapter 4 suggests a design method for finding a better display and control layout. Chapter 5 introduces a case study of the aforementioned design method suggested in this research, in which the method was applied to a rail cab driver display and control interface. Lastly, Chapter 6 summarizes the method suggested in this research, and discusses the applications and limitations of the current study, and some future research directions.

2. Literature review

There are two main methods in designing display and control interfaces. Alternatives can be created either by manual design improvement by an ergonomics expert or designer, or using a computer-based search algorithm.

2.1. Design by an ergonomics expert or designer

This method requires an ergonomics expert or designer to use ergonomic design principles to generate and evaluate display and control interface alternatives in order to select the most optimal arrangement. Stevenson et al. (2000) observed users to understand the factors that induce musculoskeletal diseases or physical discomfort related to poor design, and collected user opinions about design improvements. Sagot et al. (2003) also incorporated the knowledge of ergonomics experts and designers to apply ergonomics knowledge in designing the rail cab interface. This study evaluated and ergonomically improved the existing design. Ruiz-Rodriguez et al. (2012) suggested considering the ergonomics aspect of the problem by having the ergonomics expert design and improve the rail cab interface based on the results of a user evaluation. In this study, the existing design was improved by reflecting user opinions. This type of method was also suggested for use in many other fields other than the rail cab interface. Han et al. (2015) created a method for ergonomics experts to design a console arrangement. Han developed a new design through the results of user interviews and surveys, and improved the design through feedback by the ergonomics expert. In the study of Alppay and Bayazit (2015), ergonomics experts designed a helicopter interface. Helicopter pilots were interviewed for collecting design-informing data, and a new helicopter interface was designed based on this data. Jenkins et al. (2016) conducted a user evaluation of the existing arrangement, and the users designed their own arrangement that they thought to be optimal. This process was repeated for multiple users, and one design was finally selected through an agreement by the users.

2.2. Computer based search algorithms

This method uses a computer based search algorithm to locate an optimal display and control arrangement. There is no current application of the computer based search algorithm in the train industry, but various heuristic algorithms have been suggested in other fields. Bonney and Williams (1977) invented a computer program named CAPABLE, to solve the arrangement problem. This program divided the arrangement problem into three subdivisions and used a different heuristic method for each subdivision to find one optimal arrangement. Wang et al. (1991) suggested the use of the spiral placement algorithm to optimize the display and control arrangements. The factors taken into account were the displays' and controls' importance, frequency of use, and order of use, and placed the comparatively important controls in the center. Jung et al. (1995) used the CSP (Constraint Satisfaction Problem) to create a console arrangement design method. This method searches for solutions that satisfy ergonomic design principles such as importance, frequency of use, similarity of function, and order of use. Sargent et al. (1997) developed an optimization method that arranged the controls and displays based on importance, visibility, and reachability. Xu et al. (2010) optimized the console arrangement by using the particle swarm algorithm. In this study, the frequency and order of use was considered to ensure the safety and increase the efficiency of the interface. Lin and Wu (2010) applied the link analysis method to design the user interface arrangement. The user's control distance was minimized employing an existing link analysis method modified to fit the current situation, and using the brand-and-bound algorithm. Chen et al. (2014) used multiple optimization methods (CSP, particle swarm optimization algorithm, fuzzy mathematics) to design the most efficient arrangement of the displays and controls of the rail cab interface, and compared the results of each method. Grobelny and Michalski (2015) used the simulated annealing algorithm to optimize the arrangement of the control panel, and proved its excellence by comparing the results to two other algorithms (CRAFT, Pairs). Deng et al. (2016) attempted to take cognitive psychological factors into account by using the GA-ACA (Genetic Algorithm and Ant Colony Algorithm) during design. By doing this, they succeeded in designing a human-machine interface arrangement that maximized the satisfaction of human-machine interface design principles.

3. Display and control arrangement problem

3.1. Problem description

A display and control arrangement problem is concerned with positioning a given number of units within a space available. The space may be 2- or 3-dimensional. In this study, the space will be assumed to be two dimensional, and is represented as a finite number of small square blocks. These square blocks are candidate locations for where the displays and controls may be placed, and the arrangement space is the set of all the square blocks (Pulat and Ayoub, 1985; Jung et al., 1995). The arrangement space includes areas that can or cannot be seen well by the user. The set of areas that can be seen well by the user is called the *PV* (primary visual area). Additionally, the arrangement space includes areas that can and cannot be reached easily by the user. The set of areas that can be reached easily is called the *CR* (comfortable reach area) (Jung et al., 1995).

3.2. Constraints

When arranging the display and control devices, the following constraints must be satisfied. First, all units should be specified as a rectangular-shaped set of square units in the arrangement space. Second, all display and control devices must be located in the arrangement space. Therefore, all the square units occupied by a device must all be located within the arrangement space. Additionally, the devices should be arranged in a way that does not cause them to overlap with each other. In other words, multiple devices cannot occupy one square unit. Lastly, there should be extra space available for each device, to allow for comfort while controlling the devices. Each device will be expressed larger than original size horizontally and vertically to secure this extra space (Jung et al., 2012). The optimal layout should satisfy these constraints while maximizing the two objective functions mentioned in the next section.

3.3. Objective functions

The goal of the display and control arrangement problem is to find the positions of the devices that maximize the following two objective functions. The information given to solve this problem includes the size and shape of the arrangement space; size and shape of the devices; and functional grouping, sequence of use, importance of use, and frequency of use of each device.

Objective Function 1: The Ergonomic conformance of the arrangement

Objective Function 2: The user preference of the arrangement

3.3.1. Objective function 1: The ergonomic conformance of the arrangement

Ergonomic conformance scores a layout arrangement based on ergonomic design principles. These principles are considered in the objective function, and are stated in Table 1, listed below (Sanders and McCormick, 1993). Existing research has designed arrangements using a part or all of the ergonomic design principles listed in Table 1 (Jung et al, 1995; Lin and Wu, 2010; Jung et al., 2012; Alppay and Bayazit, 2015; Bo et al, 2015; Grobelny and Michalski, 2015; Han et al., 2015; Deng et al, 2016). In this research, importance and frequency of use of a device was considered as one index. Additionally, functional grouping and sequence of use were each considered as an index.

Table 1. Ergonomic design principles and variables

Ergonomic design principles	Details	Variable
Importance and frequency of use	Devices with high importance or frequency of use must be located within the PV or CR	$IF(P_i)$
Functional grouping	Devices with similar functionality must be located near each other	$GS(G_j)$
Sequence of use	Devices must be located in accord to sequence of use	$SS(T_k)$

There is information necessary to apply the ergonomic design principles to a certain display and control interface. First, the researcher must understand which device has high importance and frequency of use in order to apply the first principle, and this set is represented as set *I*. Next, to apply the principle of functional grouping, devices with similar functions are grouped and represented as set G_j. The number of G_j is expressed as N_G. Lastly to apply the principle of sequence of use, the researcher must collect information about the sequence of use of all the devices. These sets are represented as T_k, and the number of T_k is represented as N_T.

Ergonomic conformance is determined based on previously collected information, and results in a score representing the degree to which an arrangement satisfied the ergonomic design principles. The criteria for satisfying the ergonomic design principles is as follows.

First is the principles of importance and frequency of use, and its representative evaluation variable $IF(P_i)$. With respect to the devices that belong to set *I*, $IF(P_i)=1$ if the center of the device lays within the *PV* or *CR*, and equals 0 if the center of the devices lays outside the *PV* and *CR*. The equation for $IF(P_i)$ is shown in (1).

$$IF(P_i) = \begin{cases} 1, & \text{if } P_i \in PV \text{ or } P_i \in CR \\ 0, & \text{otherwise} \end{cases} \qquad (1)$$

Where $i \in I$, P_i = the central point of the device i

Next, the principle of functional grouping is represented by the variable $GS(G_j)$. Devices are stated to be grouped correctly if the following is satisfied. A circle with a central point in the middle of the devices is drawn. The distance of the radius is that of the central point to the farthest device within G_j. If the devices within this circle are only those of G_j, a value of 1 is given to $GS(G_j)$. If this is not true, a value of 0 is given. This formula is shown in (2).

$$GS(G_j) = \begin{cases} 1, \text{ if } \left\| P_i - C_j \right\|_2 > \max_{l \in G_j} \{ \left\| P_l - C_j \right\|_2 \} \text{ for } \forall i \in G_j^c \\ 0, \text{ otherwise} \end{cases} \tag{2}$$

Where C_j = the central point in the middle of devices in G_j

Lastly, the principle of sequence of use is represented by the variable $SS(T_k)$. This index is comprised of indexes for the x and y axes, each represented by $SS_x(T_k)$ and $SS_y(T_k)$. This index is given a value of 1 if the devices in T_k are arranged in a uniform direction for each axis. If the direction of the arrangement is not uniform, the index is given a value of 0. Each score is then multiplied by 0.5 and added to calculate $SS(T_k)$. The formula for this index is stated in (3).

$$SS(T_k) = 0.5SS_x(T_k) + 0.5SS_y(T_k) \tag{3}$$

$$SS_x(T_k) = 1, \text{ if } (x_n^k - x_{n+1}^k)(x_m^k - x_{m+1}^k) \geq 0 \text{ for } \forall n,m \in N_k = \{1,2,\ldots,n_k\}$$

0, otherwise

$SS_y(T_k) = 1$, *if* $(y_n^k - y_{n+1}^k)(y_m^k - y_{m+1}^k) \geq 0$ *for* $\forall n,m \in N_k = \{1,2,\ldots,n_k\}$

0, otherwise

Where (x_n^k, y_n^k) = *the device which is used in* n_{th} *order of* T_k,

n_k = *the number of elements of* T_k

The formula for ergonomic conformance can be represented by utilizing the ergonomic design principle indexes stated above. This formula is shown in (4). The weight for each term, w_i, is decided based on the situation of the problem or the designer.

$$f_1(P) = w_1 \sum_{i \in Im} IF(P_i) + w_2 \sum_{j=1}^{N_G} GS(G_j) + w_3 \sum_{k=1}^{N_T} SS(T_k) \quad (4)$$

3.3.2. Objective functions 2: The user preference of the arrangement

The user preference is represented by the average user evaluation score for each arrangement. This can be represented as function (5). The elements of set *M* should be made up of an experienced users or potential users.

$$f_2(D) = \frac{\sum_{i=1}^{M} pref_i(D)}{M} \qquad (5)$$

Where $pref_i(D)$ *= the user i′s preference score for arrangement D,*

M *= the number of users*

3.4. Establishing the optimization problem

The solution to the display and control arrangement problem must satisfy the constraints described in Section 3.2 while maximizing functions (4) and (5). The importance levels of the two objective functions may not be comparable. Therefore, the solution is derived by finding a set of optimal solutions with the use of the Pareto optimality. This can be represented as an optimization model as shown in (6).

Maximize $(f_1(P)), f_2(P))$ (6)

s.t. $P_i \in S$ *for* $i = 1, 2, \ldots, N$

$$\operatorname{sgn}\left(|x_i - x_j| - \left(0.5wt(i) + 0.5wt(j)\right)\right) + \operatorname{sgn}\left(|y_i - y_j| - \left(0.5ht(i) + 0.5ht(j)\right)\right) > -2$$

for $i, j = 1, 2, \ldots, N$

Where P_i = *the central point of the device i*

S = coordinate space for where the devices may be placed

$wt(i) = 1.1\mathrm{HL}_i$

$ht(i) = 1.1\mathrm{VL}_i$

HL_i = *the width of the device*

VL_i= *the height of the device*

4. Problem solving method

The objective function values for all arrangements must be known in order to solve the optimization problem defined in Chapter 3. This is difficult as Objective function 2 requires data collection from users. Because it is not possible to find the optimal solution to the original problem, a heuristic method is needed to solve the problem. Therefore, this study has developed a method to discover layouts that are superior to the existing layout. The method consists of three steps: user interview and observation, development of layout alternatives, and user evaluation of the alternative layouts.

In the first stage of user interview and observation, user interface information is collected. This data is needed to design the interface based on the four ergonomic design principles stated by Sanders and McCormick (1993). In order to apply these ergonomic design principles, information about the characteristics and features of the specific interface must be known (e.g., importance or frequency of use for each device).

Second, the alternative layouts are generated with the use of two methods: design by an ergonomics expert and layout generation through a random search. The first method consists of one or more ergonomic experts improving the existing layout according to previous experience and knowledge. Through this method, it may be possible to design a layout similar, but superior, to the existing layout. The second method, random search, first generates random arrangements of the devices in the predefined arrangement space. Afterwards, the alternatives that satisfy a large number of the ergonomic layout design principles are selected. Because the generation occurs randomly, it is possible to generate many different alternatives that are ergonomically excellent. After the alternatives are generated through these two methods, a user evaluation is conducted in the last step. The experienced users or potential users will evaluate the user evaluation of the generated alternatives in the second step.

Lastly, the layout that is both high in ergonomics conformance score and user preference is selected. The process of the search method of display and control arrangements is shown below, and will be explained in more detail in the next section.

4.1. Alternative generation and evaluation by an ergonomics expert

An ergonomic expert improves the existing layout with knowledge on ergonomic design principles. The alternatives designed in this step are to an improvement over the existing layout in terms of ergonomic conformance. First, the ergonomic conformance of the existing layout is measured, and the arrangements that violated the ergonomic design principles are pinpointed. Next, the ergonomics expert improves the existing layout in order to increase the ergonomics conformance. The layout alternative designed in this step is listed as an alternative candidate. Though this method generates an alternative that is rather similar to the existing layout, this alternative may be ergonomically improved and perhaps easy to learn, and thus must be listed as an alternative candidate. Because of the limited number of designs, there is the problem of the difficulty in comparing the results with alternatives of different shapes. This problem will be solved through the alternative generation and evaluation by random search, described in the next section.

4.2. Alternative generation and evaluation through random search

This step explores various possible layouts of the display and control interface, generates a sufficient amount of alternatives, and selects the ergonomically excellent designs. In order to perform this step, a random search algorithm was developed. The steps of the algorithm are as follows. First, it collects data about the devices that need to be arranged, and the arrangement space. Second, the algorithm collects data about devices that have fixed locations or spatial relationships, and sets them as constraints accordingly, in order to decrease unneeded random searches. Third, the algorithm uses a random number generator to place each device in a certain location. Fourth, the algorithm then checks if the device meets all the constraints, and if the constraints are not met, another location is selected through random number generation. Steps three and four are repeated until all devices are located in one arrangement space, generating one layout alternative. Lastly, the ergonomics conformance of the generated layouts is calculated by using equation (4). The algorithm then selects the layout alternatives that have an ergonomics conformance score higher than a value decided by ergonomics experts or decision makers. These layouts, along with the layouts generated in the previous method, are selected to be the candidates for the final solution.

4.3. User preference evaluation

Due to limitations of time and cost, it is not possible to collect the information for the second objective function, user preference, for all available arrangement alternatives. Therefore, user preference is evaluated for the selected alternatives. These alternatives have a high ergonomics conformance score. In this step, a user preference evaluation is conducted for the alternative candidates selected in the previous steps. For each alternative layout, the preference scores are averaged, and the average serves as the value of the second objective function.

4.4. Obtainment of Pareto optimal alternatives

This step is concerned with determining a good design given the two objective functions - ergonomic conformance and user preference. This problem is essentially a multi-objective optimization problem, and, a trade-off relationship between the two objective functions must be considered.

Various methods are available for solving multi-objective optimization problems, including the weighted sum and Pareto optimal solution methods. The weighted sum method takes into account the differences between the objective functions in relative importance, but is not useful when there is not much information about the relative importance of the objective functions. Since the information about the relative importance of the two objective functions is generally not available, this study proposes employing the Pareto optimal solution method. The Pareto optimal solution method can result in one or more solutions that cannot be improved with any objective functions, regardless of the comparative importance between the objective functions. For example, alternatives A and B do not have any other alternatives that dominate each said alternative, thus becoming the Pareto optimal solutions. The Pareto optimal solution method is applied in this step to identify the Pareto optimal solutions for the two objective functions.

4.5. Selection of an optimal layout

In this step, a single layout design within the set of Pareto optimal solutions is selected as the final solution. The Pareto optimal solutions have trade-offs in terms of ergonomic conformance and user preference. This study proposes a team approach for the final solution selection where an evaluation team consisting of user representatives, ergonomics experts, designers and other stakeholders reviews the Pareto optimal solutions and make the final decision together. Differences in opinion are resolved through discussion to reach a consensus.

5. Case study

5.1. Korean Train Express (KTX)'s displays and controls interface problem

The layout of the existing displays and controls interface of KTX is provided in Figure 6. The arrangement space for the displays and controls interface consists of 9 subdivisions, 6 displays, and 36 control devices. All arrangement spaces are comprised of small squares of size 2.5 × 2.5(cm).

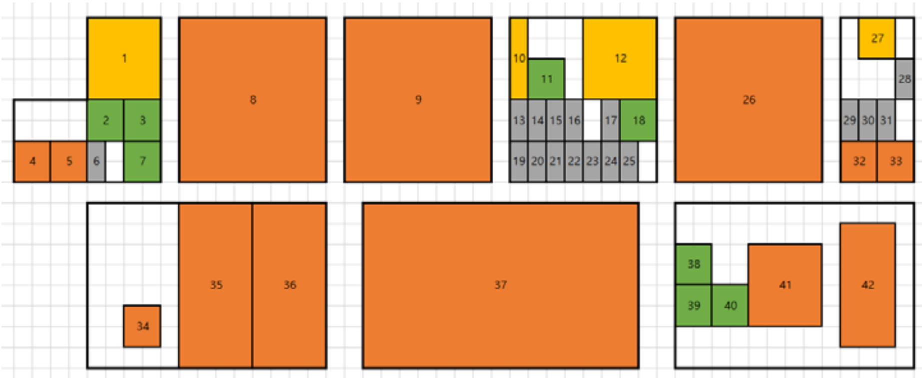


Figure 1. The existing displays and controls interface

5.2. Preliminary data collection

30 KTX drivers were surveyed, interviewed, and instructed to complete a test drive in order to collect information necessary for developing the scheme for evaluating layout designs for the KTX displays and controls interface in ergonomic conformance. Collected data includes the importance and frequency of use for each device, groups of devices with similar functions, the devices' sequence of use by task, and factors to consider while designing the alternatives. The methods of data collection and results are organized in sections 5.2.2 to 5.2.4.

5.2.1. Participants

30 KTX drivers participated in this case study. The drivers' average train driving experience is 23.8 years (SD: 8.46), and they drive the train an average of 5.45 hours per day (SD: 1.75).

5.2.2. Frequency of use and importance

30 train drivers were surveyed about the frequency of use and importance of the display and control devices. A 7-point semantic differential scale was used, and the form used in the survey is included in Appendix A. The frequency and importance score for each device is listed in Table 2. A device with high frequency of use or importance was one that had an average score of 6 or above in either category. The devices with high frequency of use or importance were: MMI monitor, TDCS monitor-1, TDCS monitor-2, Catenaries volt meter, MCB on-off indicator, Air pressure gauge, Brake lever, Traction/braking lever, PB switch for MCB control, Vigilance sensor, PB switch for MCB close, Signal MMI Ack. switch, Driver's key, PB switch 1 for external lighting, Left-side door open button, Door close button, Forward/reverse select lever, Driving mode select lever, Emergency panto down push button switch, Right-side door open switch, Horn lever, Left-side door release button, Holding brake button, PB switch for PSTK 1 ARMING, PB switch for PSTK 2 ARMING, PB switch for service retention, and Right-side door release switch.

Table 2. The frequency of use and importance score for each device

Device	Frequency of use score	Importance score
Air Pressure Gauge	5.93	6.71
Lamp for Parking Brake	3.61	4.65

Holding Brake Switch	5.42	6.06
Left-side Door Open Switch	6.00	6.48
Left-side Door Release Switch	5.87	6.13
Service Retention Cancelation Switch	4.90	5.23
Brake Release Button	3.42	5.71
ZBGIS Select Switch	2.52	3.90
PB Switch for PSTK 1 ARMING	3.84	6.06
PB Switch for PSTK 2 ARMING	3.84	6.06
PB Switch for PSTK Disarming	3.29	6.00
Right-side Door Release Switch	5.74	6.00
Right-side Door Open Switch	5.87	6.32
Signal MMI Ack. Switch	6.37	6.45
Catenaries Volt Meter	6.19	6.42
MCB On-Off Indicator	6.13	6.32
Set speed Speedometer	3.87	4.58
PB Switch for MCB Control	6.71	6.87
PB Switch for MCB Close	6.61	6.87
PB Switch for Reset	3.73	5.70
PB Switch for Demister	3.00	3.94
PB Switch for Service Retention	5.52	6.06

Driver's Key	6.13	6.74
PB Switch for ATS Reset	3.90	5.77
PB Switch Phone Transfer	2.87	3.32
PB Switch 1 for Desk Lighting	4.58	4.52
PB Switch 1 for External Lighting	5.42	5.55
PB Switch for Vigilance Cancel	3.65	4.77
PB Switch for Vigilance Alarm Test	4.39	5.00
PB Switch for Isolation	2.97	4.97
Start Buzzer	5.26	5.19
Lamp for HVAC Back-up Indicator	3.29	3.65
Door Close Button	6.00	6.45
External Alarm Push Button	4.26	5.84
ATS Acknowledgement Lamp	4.68	5.48
Horn Lever	4.90	6.23
Emergency Panto Down Push Button Switch	5.55	6.48
Driving Mode Select Lever	5.90	6.61
Forward/Reverse Select Lever	5.87	6.65
Traction/Braking Lever	6.87	6.97
Vigilance Sensor	6.65	6.39

Time Table Lamp Switch	5.74	4.84
Headlight High Beam Switch	6.13	5.81
Brake Lever	6.90	6.97
Aux. Brake Lever	3.19	5.19
Vigilance Push Button	4.16	4.65
TDCS Monitor-1	6.74	6.68
MMI Monitor	6.90	6.87
TDCS Monitor-2	6.68	6.68
Passenger Ack. Switch	3.65	5.35
Lamp for Switch Checking	4.26	5.29
Lamp for Relay Test	4.03	5.10
Emergency Brake Button	3.55	5.65

5.2.3. Grouping devices with similar functions

One train driver and four ergonomics experts utilized the KJ method in order to group devices with similar functions. The results of the grouping are shown in Table 3.

Table 3. The results of the functional grouping

Group	Function	Device
1	Brake switch	Brake lever, Aux. brake lever
2	Brake acknowledgement	Brake release button, holding brake switch, Air pressure gauge
3	Service	Service retention cancelation switch, PB switch for service retention, Driver's key
4	MCB	PB switch for MCB control, PB switch for MCB close, MCB on-off indicator, Catenaries volt meter
5	Failure identification	Lamp for relay test, Lamp for switch checking
6	Driving	Traction/braking lever, Forward/reverse select lever, Driving mode select lever
7	Action for failure	PB switch for reset, PB switch for isolation, ZBGIS select switch
8	MMI	MMI monitor, Signal MMI ack.

		switch
9	PSTK	PB switch for PSTK 1 ARMING, PB switch for PSTK 2 ARMING, PB switch for PSTK disarming
10	ATS	PB switch for ATS reset, ATS acknowledgement push button
11	Alarm	Horn lever, External alarm push button
12	Left-side door	Left-side door open button, Left-side door release button
13	Right-side door	Right-side door open button, Right-side door release button
14	External light	Headlight high beam switch, PB switch for external lighting
15	Internal light	Time table lamp switch, PB switch for desk lighting

5.2.4. Sequence of use

One train driver was instructed to complete a test drive on the train simulator. In order to observe the movements of the hands and eyes during the test drive, a camera and an eye tracker (Figure 2) were used. With the data collected from the camera and the eye-tracker, the primary tasks during the test drive and the order of use of devices for each task were identified. The results of this analysis is provided in Table 4 - the primary tasks and the order of device use for each task are presented.

Figure 2. Eye tracker (Dikablis)

Table 4. Primary tasks and device sequence of use for each task

Primary task	Devices used in task by sequence of usage
Pantograph elevation	Driver’s key
	Panto select switch
	Catenaries volt meter
MCB close	PB switch for MCB control
	PB switch for MCB close
	TDCS monitor-1
	TDCS monitor-2
Start preparation	Forward/reverse select lever
	Driving mode select lever
	Traction/braking lever
Service retention (1)	Panto select switch
	Service retention cancelation switch
	PB switch for MCB control
Service retention (2)	Panto select switch
	Driver’s key
	Brake lever

5.2.5. Miscellaneous constraints on the interface layout design

The data collected on the display and controls' importance and frequency of use, similarity in function, and order of use are important considerations for developing interface layouts; however, they do not represent the entirety of the information guiding the design and evaluation of interface layouts. There are important design knowledge not included in the dataset.

A survey was conducted with 30 train drivers in order to collect such design knowledge. In the survey, various information was collected, some of which includes the locations or arrangements of devices that may cause driver mistakes and those that need to be improved. Also collected was information about the devices that should not be moved from the current locations, be placed together or far apart, and reasons for these opinions. Based on the results of the survey, the mentioned devices, reason, and frequency of responses were analyzed in order to generate constraints for the interface layout design. These conditions specify a group of devices that should be in the current location, a group of devices that should be on the CR, and a group of devices that should be located together. The devices that should stay in the current location are MMI monitor, TDCS monitor-1, TDCS monitor-1, Forward/reverse select lever, Driving mode select lever, Traction/braking lever, Brake lever, Door open/release button, and Panto select switch. The devices that should be within the CR are Signal MMI ack. Switch, Driver’s key, and External alarm push button. The devices that should be located together are PB switch for ATS reset and ATS acknowledgement push button, PB switch for MCB control and PB switch for MCB close, and PB switch for PSTK 1 ARMING, PB switch for PSTK 2 ARMING and PB switch for PSTK Disarming. An interface layout must satisfy the constraints to qualify as a feasible solution.

5.3. Generation of the alternative candidates

Two methods were used to generate these layouts.

5.3.1. Alternative layout generation through random search

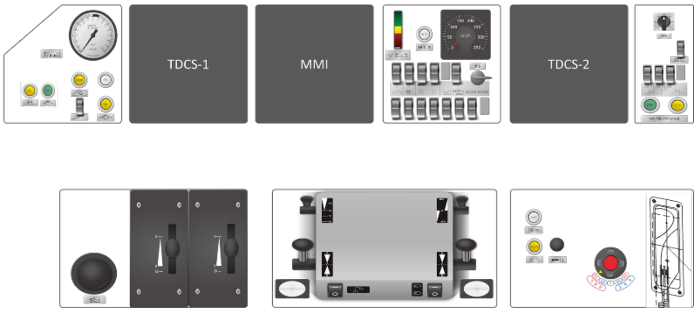
1.5 million alternative layouts were explored with the use of the random search algorithm. The critical value determined in this case study was 46 points, and the alternative layouts that had a score of the critical value or above were selected to be in the alternative candidates. Within the 1.5 million alternative layouts, there were 14 layouts with an ergonomic conformance score of 46, and one layout with a score of 47. These layouts were selected to be in the alternative candidates. The images of each of the alternative candidates is included in Appendix B.

5.3.2. Generation of alternative layouts by ergonomics experts

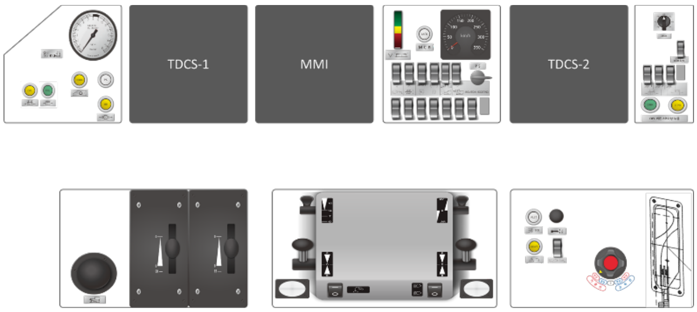
The existing arrangement was found to have an ergonomic conformance score of 26. Two ergonomic experts analyzed the existing arrangement in order to find the ergonomic design principles in violation. Afterwards, they designed two new layouts by improving the existing interface. The ergonomic conformance of each layout is stated in Table 5. The existing layout and the two improved layouts were selected to be in the alternative candidates. The alternative layouts are shown in Figure 3.

Table 5. The ergonomic conformance scores for alternative candidates

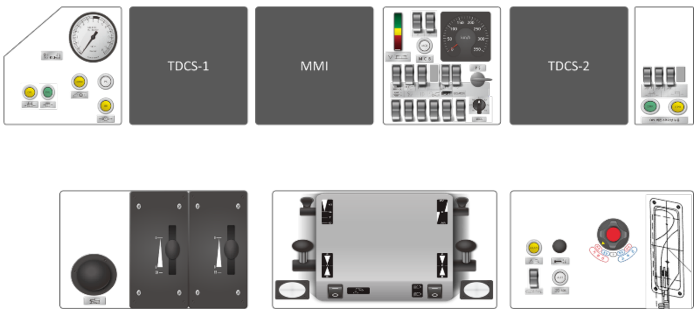
Layout candidates	Ergonomic conformance scores
The existing layout	26
Alternative layout 16	31
Alternative layout 17	34



(a) The existing layout



(b) Alternative layout 16



(c) Alternative layout 17

Figure 3. The existing layout and alternative candidates designed by ergonomic expert

5.4. User preference evaluation

5.4.1. Participants

Four KTX drivers participated in the user preference evaluation. The drivers' average train driving experience is 23.75 years (SD: 3.30), and they drive the train an average of 5.75 hours per day (SD: 1.71).

5.4.2. Results of the evaluation

The user preference evaluation and ergonomic conformance for each of the 18 layout alternatives is organized in Table 6.

Table 6. The user preference score and ergonomic conformance for alternative layouts

Layout candidates	User preference score	Ergonomic conformance
Alternative layout 1	3.00	46
Alternative layout 2	3.00	46
Alternative layout 3	2.90	46
Alternative layout 4	2.75	46
Alternative layout 5	3.45	46
Alternative layout 6	3.79	46
Alternative layout 7	3.15	46
Alternative layout 8	3.53	46
Alternative layout 9	3.60	46
Alternative layout 10	3.11	46

Alternative layout 11	2.60	46
Alternative layout 12	3.05	46
Alternative layout 13	1.95	46
Alternative layout 14	3.85	46
Alternative layout 15	3.89	47
The existing layout	5.25	26
Alternative layout 16	5.75	31
Alternative layout 17	3.75	34

5.5. Selection of an optimal layout

The alternative candidates are displayed on a 2D plane with the ergonomic conformance and user preference scores as *x* and *y* axis. Afterwards, the set of alternatives on the Pareto frontier are selected to be the Pareto Optimal set. Alternatives in the Pareto Optimal set are alternative layout 15, 16, 17. Finally, 5 ergonomics experts selected the final solution among the layouts in the Pareto optimal set. The selected design solution is shown in Figure 3. Though the optimal layout did not have the highest ergonomics conformance score of all the layouts, it was higher than the existing layout. Additionally, it had the highest user preference score. Other layouts with high ergonomic conformance scores were found to be very low in user preference. This is thought to be because they were very different from the existing layout, causing resistance from the users. No matter how high the ergonomics conformance score of a layout is, it is difficult to choose the layout as the final solution if users refuse to accept the layout. Therefore, a layout that shows an improvement over the existing one in the ergonomic conformance score and also is preferred by the users was selected as the final solution.

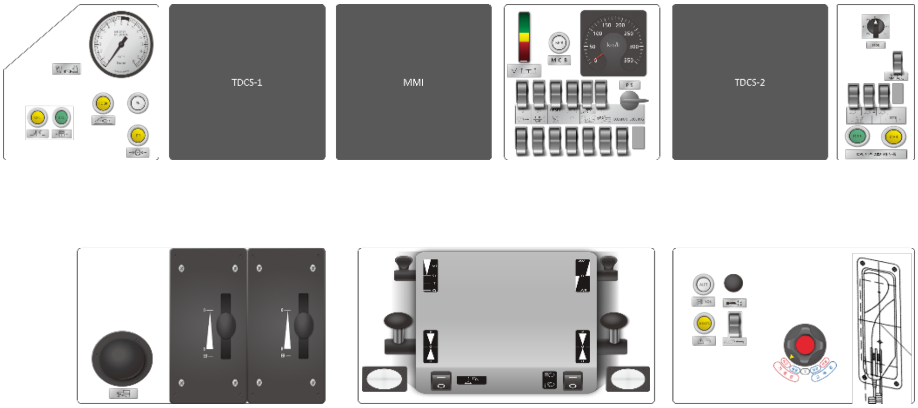


Figure 4. The final optimal layout

6. Discussion

This thesis presented a new method for designing the display and control interface for operating a complex system. The display and control interface layout design problem was formulated as a multi-objective optimization problem that has ergonomic conformance and user preference as the objective functions. An ergonomic conformance measure was developed, which quantitatively express the degree to which a layout design satisfies ergonomic design principles for displays and controls layout design - the more ergonomic design principles a layout design satisfies, the higher the ergonomic conformance of the design is. Additionally, a heuristic method to find the solution to this problem has been proposed.

The objective of the heuristic method is to find a good layout design that satisfies ergonomic design principles and improves user preference. To generate alternative layouts, the method first thoroughly searches possible arrangements through random exploration. Then, the layouts that maximally satisfy the ergonomic design principles are selected. Additionally, ergonomics experts improve the existing layout based on ergonomic design principles, and generate an improved layout alternative. Lastly, the generated layout alternatives are evaluated in terms of user preference. The best layout that is in accordance with ergonomic design principles and user preference is then selected.

The method was applied to an existing Korean Express Train control interface. The results of the user preference evaluation in the case study showed a relationship between the ergonomic conformance and user preference. In Table 6, ergonomic layout alternatives have low user preference evaluation scores, whereas the layouts with low ergonomic conformance scores had high user preference. From these results, it can be seen that a layout with high ergonomics conformance is not always preferred by the user. Layouts with a high ergonomic conformance score had arrangements very different from the existing layout. It may be that the users were not familiar with the layouts and thus resisted them. On the other hand, the alternative layout with a high user preference was what resulted from slightly modifying the existing layout to improve ergonomic conformance. This allows for the maintaining the similarity between the alternative and the existing layout. Though the ergonomic conformance score is not comparatively high for a certain layout, the user preference may be high due to familiarity and easier understanding of the arrangement. This may explain the higher user preference scores for the layouts resulting from incrementally improving the existing layout.

In order to determine the final design solution considering both the ergonomic conformance and user preference, this method finds multiple solutions. Ergonomics experts reached an agreement through discussion so as to choose one among the multiple solutions that were found. The final design solution showed an improvement over the existing design in both ergonomic conformance and user preference. The case study result demonstrated that the proposed design method could accomplish improving the existing interface design.

6.1. Implications

This research has proposed a method for display and control interface design based on ergonomic design principles and user preference, and showed its utility through a case study. This design method considers objective functions focusing on ergonomic conformance and user preference. These factors are basic characteristics required for any interface type. Therefore, this method may be applied to numerous design problems in various fields. It will be applicable to the problems in the fields that have traditionally emphasized ergonomics, such as automobiles and aviation. Additionally, it may be applied to newly rising fields such as web and mobile applications, Virtual Reality, or robotics. Also, other researchers will be able to refer to the case study conducted in this research in order to apply the method to their own field.

Furthermore, this research developed a quantitative measure of ergonomic conformance, one of the objective functions within the design problem. The ergonomic conformance measure is an index that quantitatively represents whether or not the ergonomic principles are satisfied. The ergonomic principles include the display and control devices' importance, similar functionality, and order of use. This quantitative measure can be used when designing the arrangement of devices, and also when evaluating whether an interface satisfies ergonomic design principles. The ergonomic conformance measure is very practical, as non-ergonomic experts with little background in ergonomics can use this index.

6.2. Limitations and future works

The limitations of this work and some future research directions are as follows.

First, there is the limitation of the improvement method of the existing layout. The layout generation method suggested in this study consists of an ergonomics expert manually improving the existing layout. This may result in a highly subjective design decision, influenced by the ergonomic expert's personal experience. Also, it is difficult to thoroughly search various arrangements that are more ergonomically sound than the existing layout. Therefore, more iterative improvement efforts seem needed in order to overcome this and identify layouts with higher ergonomic conformance scores. Through multiple independent processes of iterative improvement, it may be possible to identify an alternative layout that cannot be improved further.

Second, there is the limitation of the random exploration method. This method randomly searches for possible alternative layouts, and identifies the optimal layout. Because the search is done randomly, there is the advantage of being able to consider many various arrangements. However, the random search can cover only a small part of the vast number of possible alternative layouts. Thus, it is difficult to conclude that layouts with high user preference can be discovered. Also, the fact that the search is random results in ineffective search that takes a long time. It is necessary to improve the algorithm to effectively search the possible alternatives in a certain goal or direction.

Future works may include verification of the final layout solution resulting from the method proposed in this study. This may be done by empirically comparing the results of the method of this research with the results of another research. It may be possible to conduct the verification through multiple experiments employing various quantitative measures. These measures may include performance efficiency, number of errors and subjective user evaluation.

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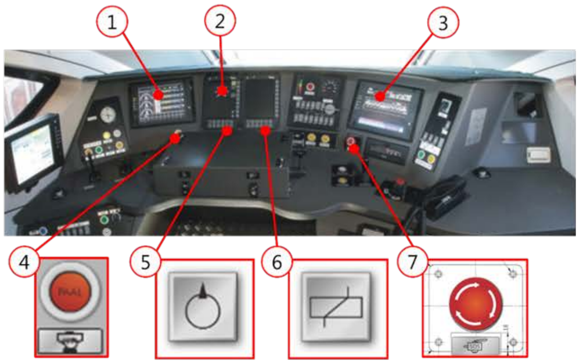
APPENDIX A: Questionnaire on frequency and importance of use

Questionnaire on frequency and importance of use about 53 devices of displays and controls on KTX desk is as follows.

1. KTX 운전실의 제어대를 구성하는 53가지 표시·제어장치들이 나열되어 있습니다. 각 장치의 명칭과 그림을 보고, 그림 오른쪽이나 아래쪽에 위치한 사용빈도 평가란에 사용빈도 점수를 "V"표 해주시기 바랍니다. (1점 - 전혀 사용하지 않음, 4점 – 보통, 7점 – 매우 자주 사용함)

(예시) TDCS 모니터-1(DU1)이 매우 자주 사용된다고 생각할 경우: 7 점에 "V"표

8) 기타 위치



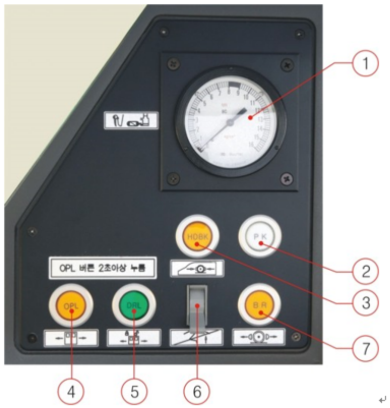
1 2 3 4 5 6 7

(전혀 사용하지 않음) (보통) (매우 자주 사용함)

이제 **<u>설문 문항 1</u>**가 시작됩니다. 각 표시·제어장치의 명칭과 그림을 보고, 사용빈도 점수를 "V"표 해주시기 바랍니다.

(1점 - 전혀 사용하지 않음, 4점 – 보통, 7점 – 매우 자주 사용함)

1) 운전실 데스크 전면 좌측



① [BC & MR 압력계]

1 2 3 4 5 6 7

② [주차제동 표시 램프]

1 2 3 4 5 6 7

③ [홀딩 제동 스위치]

1 2 3 4 5 6 7

④ [좌측 승강문 열림 스위치]

1 2 3 4 5 6 7

⑤ [좌측 승강문 해제 스위치]

1 2 3 4 5 6 7

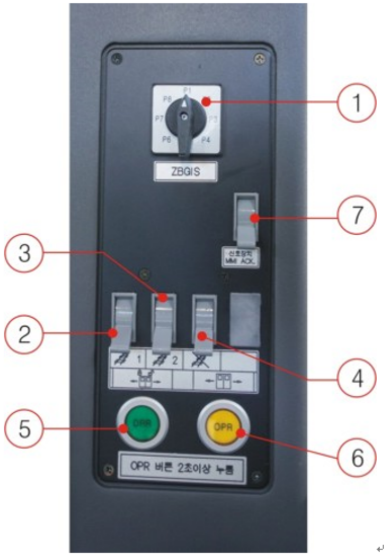
⑥ [서비스 유지 취소 스위치]

1 2 3 4 5 6 7

⑦ [제동 완해 버튼]

1 2 3 4 5 6 7

2) 운전실 데스크 전면 우측



① [ZBGIS 선택 스위치]

1 2 3 4 5 6 7

② [하선군 PSTK 동작 버튼]

1 2 3 4 5 6 7

③ [상선군 PSTK 동작 버튼]

1 2 3 4 5 6 7

④ [PSTK 동작 종료 버튼]

1 2 3 4 5 6 7

⑤ [우측 승강문 해제 스위치]

1 2 3 4 5 6 7

⑥ [우측 승강문 열림 스위치]

1 2 3 4 5 6 7

⑦ [MMI 확인버튼]

1 2 3 4 5 6 7

3) 운전실 데스크 전면 중앙

① [가선 전압계]

1 2 3 4 5 6 7

② [MCB 투입표시등]

1 2 3 4 5 6 7

③ [설정 속도계]

1 2 3 4 5 6 7

④ [MCB 스위치]

1 2 3 4 5 6 7

⑤ [MCB 투입 스위치]

1 2 3 4 5 6 7

⑥ [리셋 스위치]

1 2 3 4 5 6 7

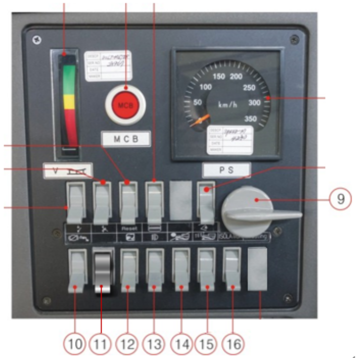
⑦ [제상기 스위치]

1 2 3 4 5 6 7

⑧ [서비스 유지 스위치]

1 2 3 4 5 6 7

3) 운전실 데스크 전면 중앙 (계속)



⑨ [운전실 선택 스위치]

1 2 3 4 5 6 7

⑩ [ATS 리셋 스위치]

1 2 3 4 5 6 7

⑪ [무전기 절환 스위치]

1 2 3 4 5 6 7

⑫ [운전대 조명 스위치]

1 2 3 4 5 6 7

⑬ [전조등 스위치]

1 2 3 4 5 6 7

⑭ [운전자 경계 알람 취소 스위치]

1 2 3 4 5 6 7

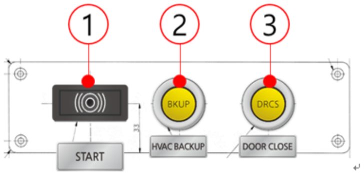
⑮ [운전자 경계 알람 테스트 스위치]

1 2 3 4 5 6 7

⑯ [차단 스위치]

1 2 3 4 5 6 7

4) 운전실 데스크 전면 중앙 (하부)



① [출발부저]

1 2 3 4 5 6 7

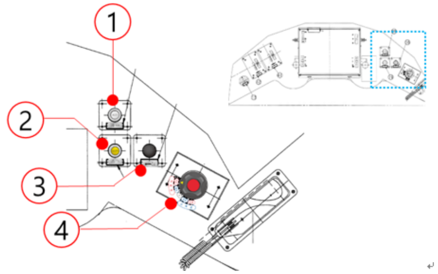
② [에어컨 백업 표시 램프]

1 2 3 4 5 6 7

③ [승강문 닫힘 스위치]

1 2 3 4 5 6 7

5) 운전실 데스크 우측



① [기적 버튼 / SOS 버튼]

1 2 3 4 5 6 7

② [ATS 확인 버튼]

1 2 3 4 5 6 7

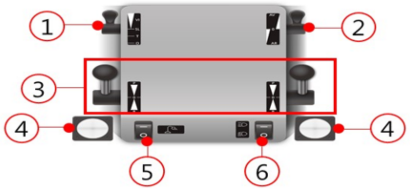
③ [기적]

1 2 3 4 5 6 7

④ [비상팬터다운 / 팬터 선택 스위치]

1 2 3 4 5 6 7

6) 운전실 데스크 중앙



① [운전모드 선택기]

1 2 3 4 5 6 7

② [역전간]

1 2 3 4 5 6 7

③ [주제어간]

1 2 3 4 5 6 7

④ [운전자 경계장치 센서]

1 2 3 4 5 6 7

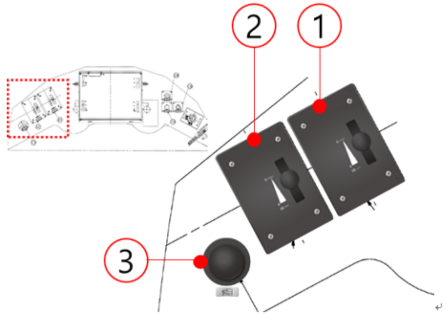
⑤ [제어대 램프 스위치]

1 2 3 4 5 6 7

⑥ [전조등 램프 선택(상향/하향)]

1 2 3 4 5 6 7

7) 운전실 데스크 좌측



① [제동간]

1 2 3 4 5 6 7

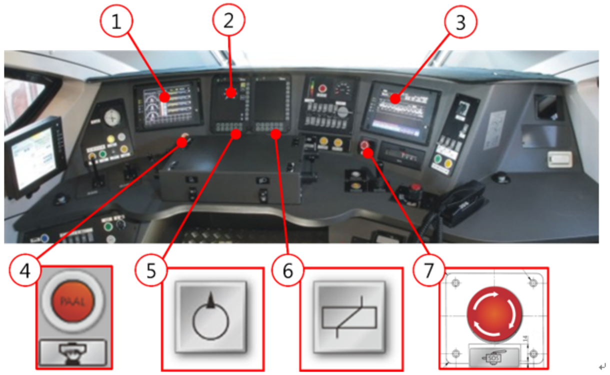
② [보조제동간]

1 2 3 4 5 6 7

③ [운전자 경계장치 왼쪽 버튼]

1 2 3 4 5 6 7

8) 기타 위치



① **[TDCS 모니터-1(DU1)]**

1 2 3 4 5 6 7

② **[MMI 모니터]**

1 2 3 4 5 6 7

③ **[TDCS 모니터-2(DU2)]**

1 2 3 4 5 6 7

④ **[승객 비상 경보 확인 버튼]**

1 2 3 4 5 6 7

⑤ **[스위치 체크 램프]**

1 2 3 4 5 6 7

⑥ **[릴레이 테스트 램프]**

1 2 3 4 5 6 7

⑦ **[비상 제동 스위치]**

1 2 3 4 5 6 7

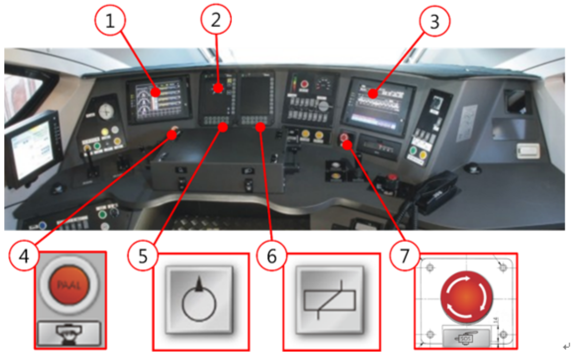
이로써 **설문 문항 1**가 끝났습니다.

다음 문항으로 넘어가 주시기 바랍니다.

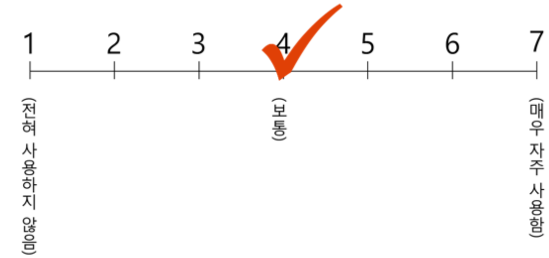
2. KTX 운전실의 제어대를 구성하는 53가지 표시·제어장치들이 나열되어 있습니다. 각 장치의 명칭과 그림을 보고, 그림 오른쪽이나 아래쪽에 위치한 중요도 평가란에 중요도 점수를 "V"표 해주시기 바랍니다. (1점 - 전혀 중요하지 않음, 4점 – 보통, 7점 – 매우 중요함)

(예시) TDCS 모니터-1(DU1)의 중요도가 보통이라고 생각할 경우: 4 점에 "V"표

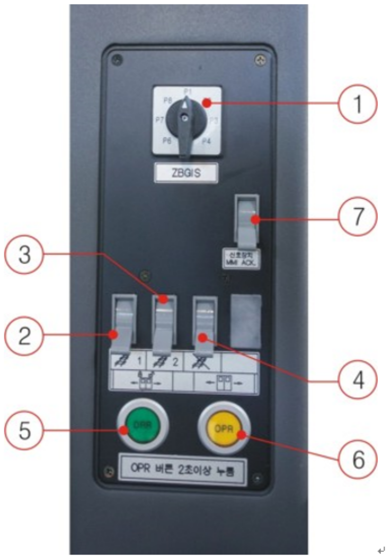
8) 기타 위치



① [TDCS 모니터-1(DU1)]



2) 운전실 데스크 전면 우측



① [ZBGIS 선택 스위치]

1 2 3 4 5 6 7

② [하선군 PSTK 동작 버튼]

1 2 3 4 5 6 7

③ [상선군 PSTK 동작 버튼]

1 2 3 4 5 6 7

④ [PSTK 동작 종료 버튼]

1 2 3 4 5 6 7

⑤ [우측 승강문 해제 스위치]

1 2 3 4 5 6 7

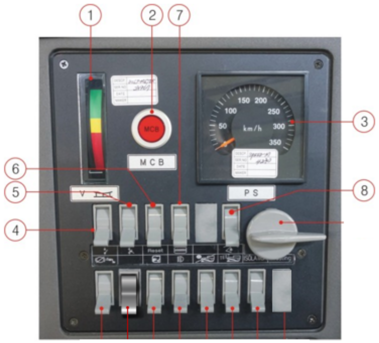
⑥ [우측 승강문 열림 스위치]

1 2 3 4 5 6 7

⑦ [MMI 확인버튼]

1 2 3 4 5 6 7

3) 운전실 데스크 전면 중앙



① **[가선 전압계]**

1 2 3 4 5 6 7

② **[MCB 투입표시등]**

1 2 3 4 5 6 7

③ **[설정 속도계]**

1 2 3 4 5 6 7

④ **[MCB 스위치]**

1 2 3 4 5 6 7

⑤ **[MCB 투입 스위치]**

1 2 3 4 5 6 7

⑥ **[리셋 스위치]**

1 2 3 4 5 6 7

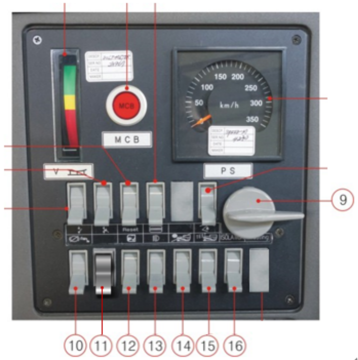
⑦ **[제상기 스위치]**

1 2 3 4 5 6 7

⑧ **[서비스 유지 스위치]**

1 2 3 4 5 6 7

3) 운전실 데스크 전면 중앙 (계속)



⑨ [운전실 선택 스위치]

1 2 3 4 5 6 7

⑩ [ATS 리셋 스위치]

1 2 3 4 5 6 7

⑪ [무전기 절환 스위치]

1 2 3 4 5 6 7

⑫ [운전대 조명 스위치]

1 2 3 4 5 6 7

⑬ [전조등 스위치]

1 2 3 4 5 6 7

⑭ [운전자 경계 알람 취소 스위치]

1 2 3 4 5 6 7

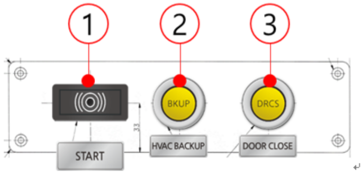
⑮ [운전자 경계 알람 테스트 스위치]

1 2 3 4 5 6 7

⑯ [차단 스위치]

1 2 3 4 5 6 7

4) 운전실 데스크 전면 중앙 (하부)



① [출발부저]

1 2 3 4 5 6 7

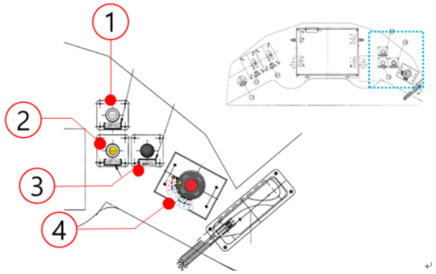
② [에어컨 백업 표시 램프]

1 2 3 4 5 6 7

③ [승강문 닫힘 스위치]

1 2 3 4 5 6 7

5) 운전실 데스크 우측



① [기적 버튼 / SOS 버튼]

1 2 3 4 5 6 7

② [ATS 확인 버튼]

1 2 3 4 5 6 7

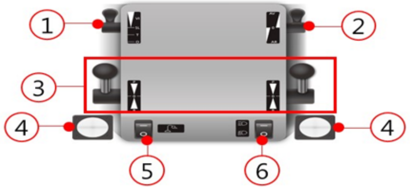
③ [기적]

1 2 3 4 5 6 7

④ [비상팬터다운 / 팬터 선택 스위치]

1 2 3 4 5 6 7

6) 운전실 데스크 중앙



① [운전모드 선택기]

1 2 3 4 5 6 7

② [역전간]

1 2 3 4 5 6 7

③ [주제어간]

1 2 3 4 5 6 7

④ [운전자 경계장치 센서]

1 2 3 4 5 6 7

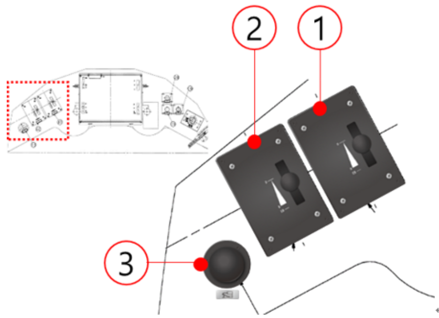
⑤ [제어대 램프 스위치]

1 2 3 4 5 6 7

⑥ [전조등 램프 선택(상향/하향)]

1 2 3 4 5 6 7

7) 운전실 데스크 좌측



① [제동간]

1 2 3 4 5 6 7

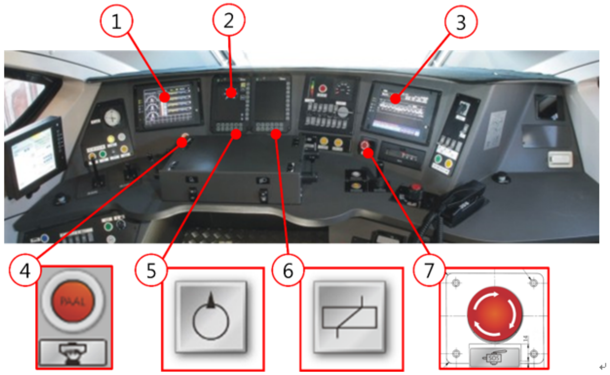
② [보조제동간]

1 2 3 4 5 6 7

③ [운전자 경계장치 왼쪽 버튼]

1 2 3 4 5 6 7

8) 기타 위치



① [TDCS 모니터-1(DU1)]

1 2 3 4 5 6 7

② [MMI 모니터]

1 2 3 4 5 6 7

③ [TDCS 모니터-2(DU2)]

1 2 3 4 5 6 7

④ [승객 비상 경보 확인 버튼]

1 2 3 4 5 6 7

⑤ [스위치 체크 램프]

1 2 3 4 5 6 7

⑥ [릴레이 테스트 램프]

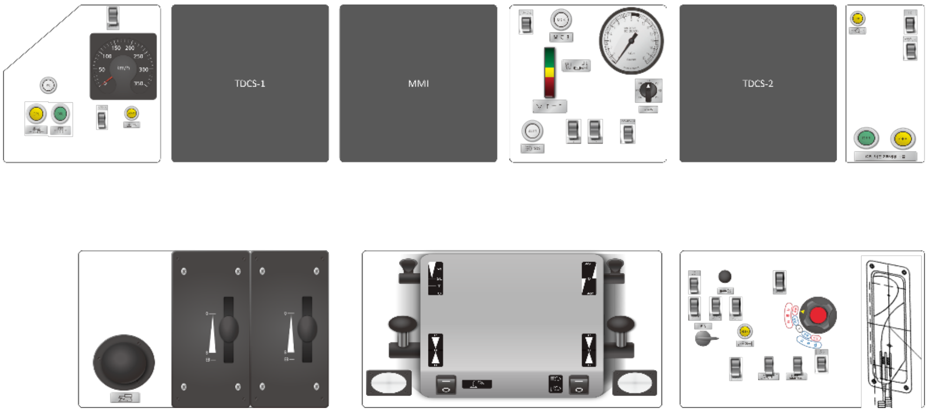
1 2 3 4 5 6 7

⑦ [비상 제동 스위치]

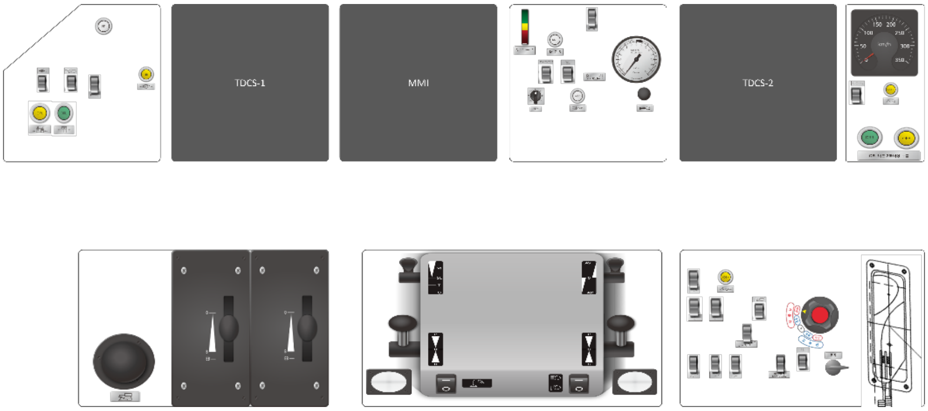
1 2 3 4 5 6 7

APPENDIX B: Alternative layout generation through random search

Layouts generated through random search with high ergonomic conformance are selected to be candidates for the alternative layout. Candidates are as follows.



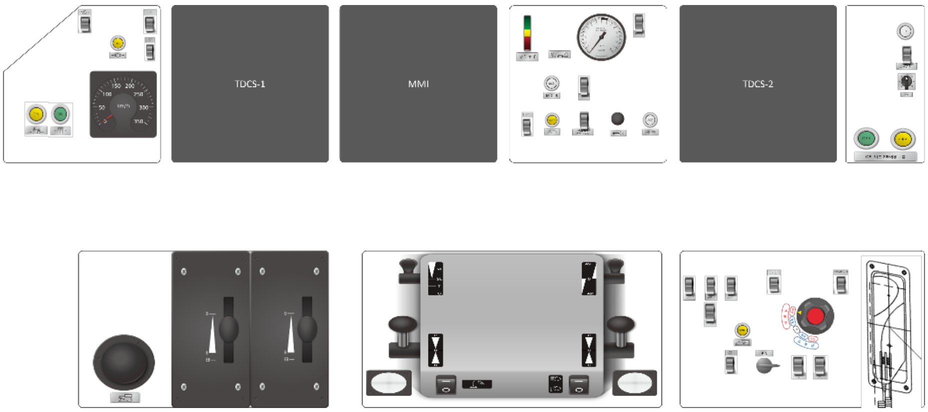
Alternative layout 1 (ergonomic conformance: 46)



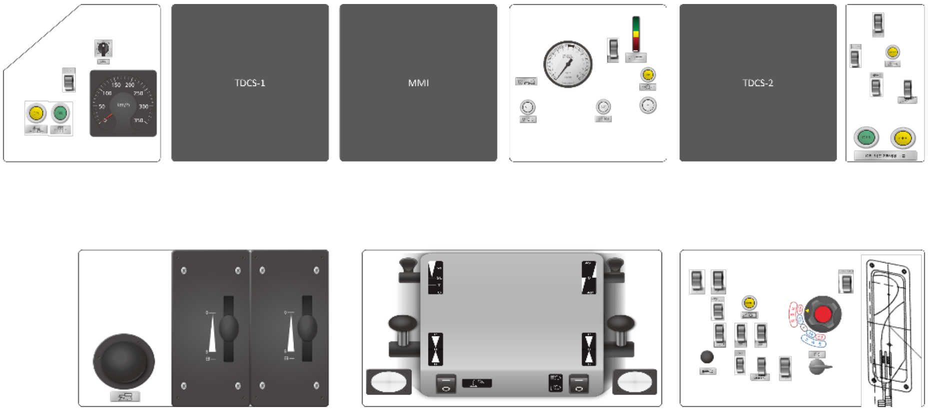
Alternative layout 2 (ergonomic conformance: 46)

Alternative layout 3 (ergonomic conformance: 46)

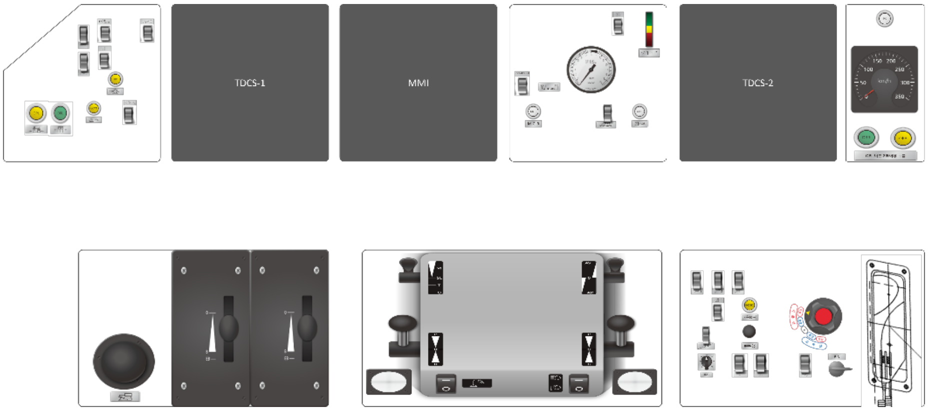
Alternative layout 4 (ergonomic conformance: 46)



Alternative layout 5 (ergonomic conformance: 46)

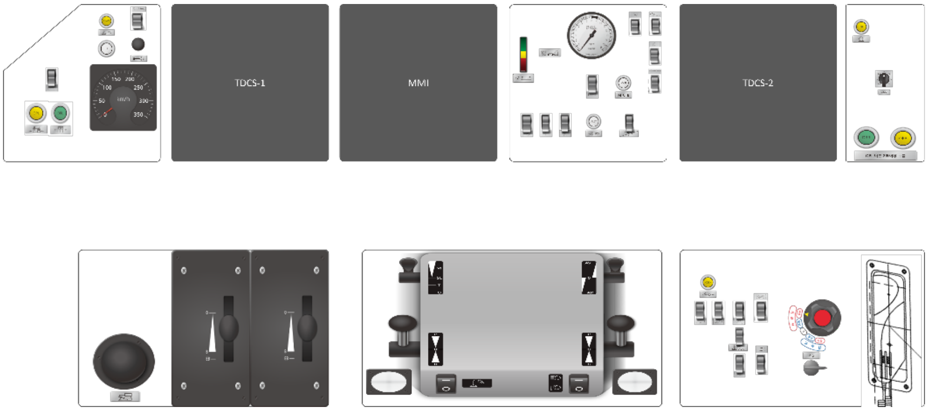


Alternative layout 6 (ergonomic conformance: 46)

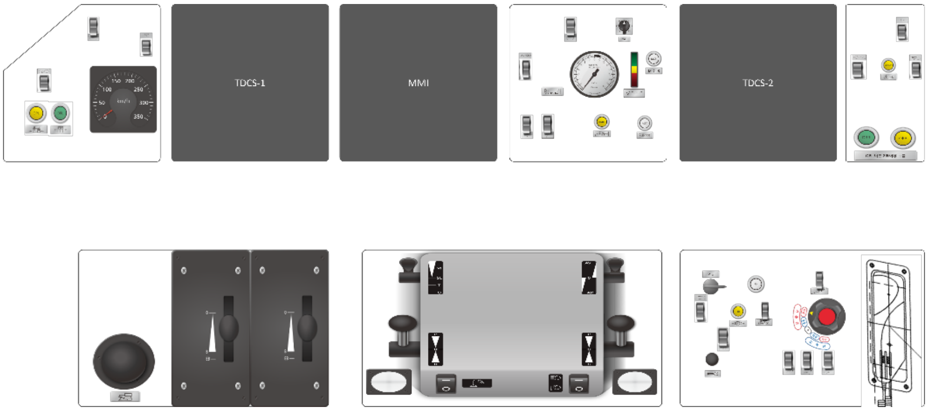


Alternative layout 7 (ergonomic conformance: 46)

Alternative layout 8 (ergonomic conformance: 46)

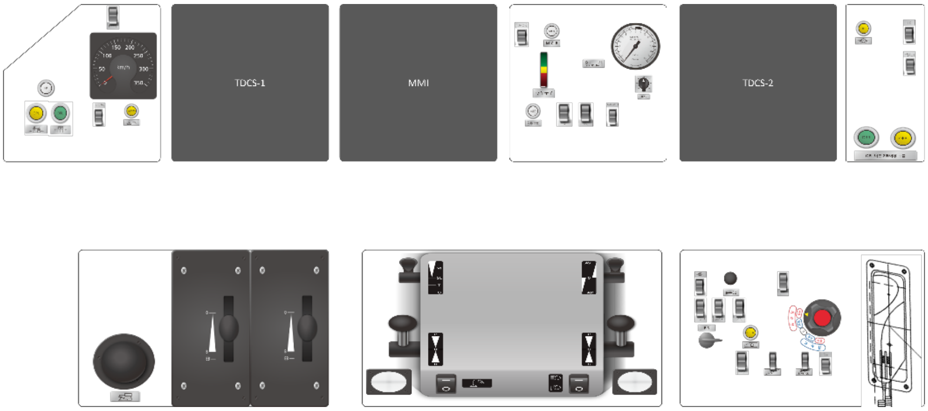


Alternative layout 9 (ergonomic conformance: 46)



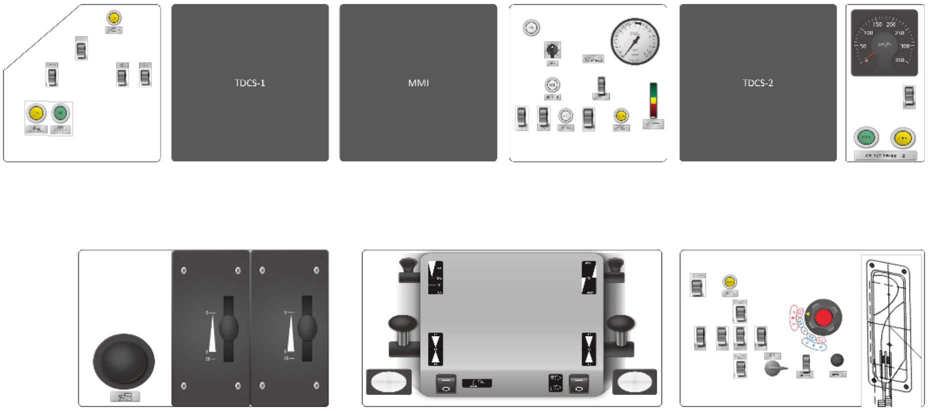
Alternative layout 10 (ergonomic conformance: 46)

Alternative layout 11 (ergonomic conformance: 46)

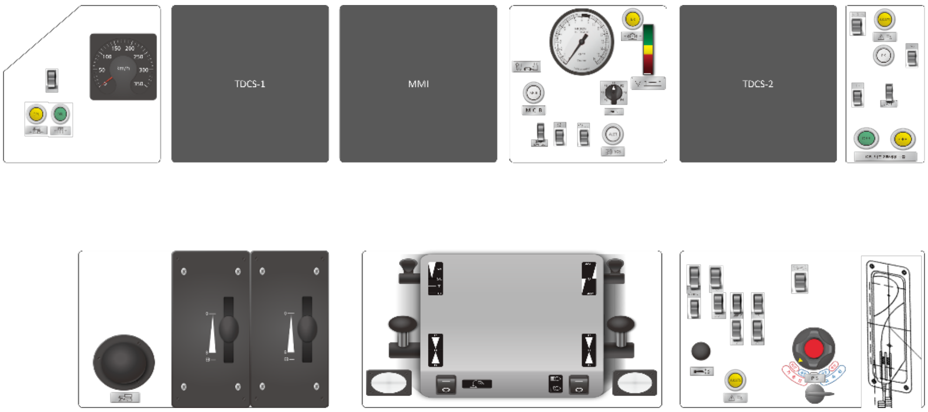


Alternative layout 12 (ergonomic conformance: 46)

Alternative layout 13 (ergonomic conformance: 46)



Alternative layout 14 (ergonomic conformance: 46)



Alternative layout 15 (ergonomic conformance: 47)

ABSTRACT

Development of a method for finding a better display and control layout through random search and incremental improvement

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Ergonomics, Industrial Engineering
The Graduate School
Seoul National University

A display and control layout design should be ergonomically sound, and, at the same time, be able to satisfy user preference. This study developed a display and control layout design method based on ergonomics design principles and user preference. The proposed layout design method adopts a multi-criteria heuristic algorithm to find the layout design that maximizes ergonomic conformance and user preference. The method consists of two phases, the generation phase and the evaluation phase. In the generation phase, two types of generation methods are performed independently: 1) a random search for finding ergonomically sound arrangements, and 2) incremental improvement performed by improving existing layout designs to identify similar yet ergonomically improved layout designs. The incremental improvement is based on the assumption that layout designs similar to the existing layouts are likely to be preferred by the operators due to their similarity. In the evaluation phase, the layout design alternatives obtained in the search phase are evaluated in terms of both ergonomic excellence and user preference. Afterwards, the Pareto optimal solutions are obtained. Finally, a single optimal solution is determined among all Pareto optimal solutions through a consensus process between stakeholders. A case study is presented to demonstrate the method, using the example problem of designing the train driver's display-control interface inside a railway cab. The results show that the generated layout design is indeed in accordance with the ergonomics design principles and satisfies user preference.

Keywords: display and control layout design, ergonomic design principle, user preference, computer based search algorithm

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