Cognitive Awareness Prototype Development on User Interface Design

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ABSTRACT
Human error is a crucial problem in manufacturing industries. Due to the misinterpretation of information on interface system design, accidents or death may occur at workplace. Lack of human cognition criteria in interface system design is also one of the contributions to the failure in using the system effectively. Therefore, this paper describes stages of evaluation process on powder handling system prototype. In the study, the prototype was evaluated based on cognitive awareness criteria for interface system design: perception, comprehension, and projection. Five experts with more than five years of experience from engineering and information technology fields were involved in the evaluation process. Results in this study are essential to the researcher in order to improve powder handling system prototype. It is hoped that mapping up the cognitive awareness criteria in interface system design will help users to make better decisions while handling the system at the workplace.

INTRODUCTION
Accidents could happen at workplace without warning. This is due to human limitations in handling certain tasks that are beyond their control and expectations. In addition, lack of information while using the system is one of the results in human error. There are two types of accident implications: permanent disabilities and death. Thus, accidents cause a great lost of expertise, time, and money especially for the family, organisation, and community as whole. After the World War II, demands for research on complex technical system have increased rapidly. Researchers and engineers have started to develop an automated system and focus more on system functions without knowing that too many automatic functions embedded on the system cause difficulties for human to control the system (Hollnagel and Woods, 2005).

Then, the research continues on investigating tasks that can be done automatically by a system and tasks that can be controlled by human. In relation to this, technology system becomes more complex in order to accommodate the role of human as the main user of the system. The ease of use of a system is needed in order to support learnability process among users. Ability to understand the system will help users to minimise human error. In fact, in line with cognitive research, there is still limited number of researches that focus on interface system design as a mediator in system interaction. Therefore, the role of interface system design is crucial in providing input for users to make correct judgments in handling the system.

Hence, this study was conducted with the goal to improve system prototype that included human cognitive criteria into interface system design. The prototype was developed in stages and the prototype was improved as the evaluation got along. Five experts were involved in the participatory design process starting from the prototype sketching until the final powder handling failure configuration functions. In addition, five evaluators were sufficient for the discovery of about 75% of the overall system evaluation problems and it was possible to achieve substantially better performance by aggregating problems from several evaluators (Preece et. al, 1994). Results from this study were crucial in order to improve the powder handling simulation system in accordance to increased human awareness in handling the system effectively.

Cognitive Model
Classic human cognitive model is also known as Human Information Processing System. The model explains how human receives the information from sensory input and transfers it to the brain. The brain will then make an interpretation and human will perform an action upon it.

To make an interpretation, firstly the information from sensory inputs such as visual and auditory information will be sent to human working memory. At this stage, if the information is activated by the user regularly, the information will be sent to human long term memory. Information stored in long term memory will decay if the information remains passive (Friedemberg and Silverman, 2015). To help users to retain their knowledge on a particular system, system designers should consider ways to help the users to make use of their knowledge stored in the long term memory.

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Interface system design plays an important role to trigger human long term memory because via interface design, user will be able to recognise the information that they used before (Thimbleby, 1998). For that reason, one of the solutions is to incorporate the cognitive model into the interface system design. This solution will help users to use the system in an effective way.

Interface design, as an intermediary between users and system plays, an important role for a system. Users will perceive information from the interface and interpret the information into meaningful information. Users then will act towards related information that is stored in their memory. Sequentially, it is important to include cognitive criteria on interface system design because any wrong information conveyed to users via interface system design may lead to hazardous condition. Thus, in this study, our aim was to enhance human decision making by integrating the cognitive criteria in interface system design.

Situational Awareness (SA) is commonly defined as perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 1995). In order to make a wise decision in handling a system, the role of SA in interface system design is to provide useable cognitive information for users. In other words, users need to understand available information around them because if any unexpected incident happens, users are ready to give immediate response.

Furthermore, recognition-primed decision making research explains that pattern recognition is important in decision making (Klein, 1989). Human will select the best alternatives from pattern recognition process rather than comparing other alternatives in order to select ultimate solution (Figure 1). For that reason, system designers need to consider complementing users' cognitive requirements in interface system design. Additionally, there is interconnected relationship between SA and decision making; if SA is activated, then decision making is also activated, and vice versa (Adams, Tenney and Pew, 1995).

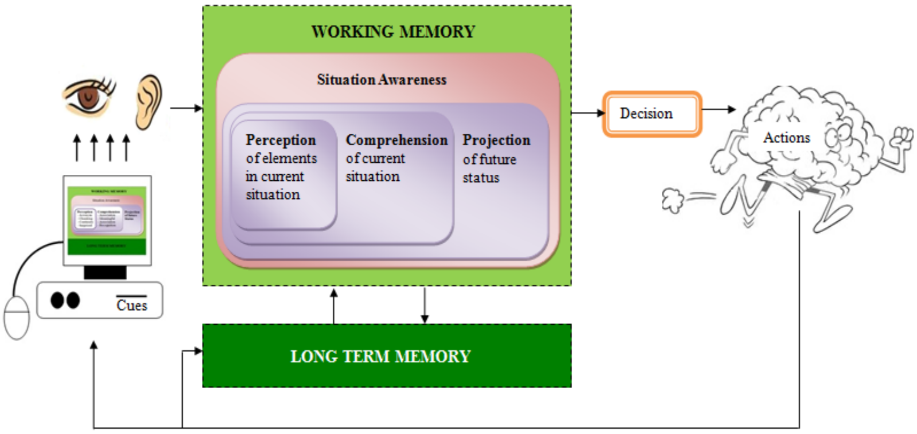

Figure. 1. Cognitive Awareness Model for interface system design.

Theory Mapping

Enhancing the prototype interface system design is crucial in mapping up cognitive awareness theory into the system design process. In this study, cognitive criteria that will be incorporated in this powder handling system were identified through several analyses that we had done earlier (Rosli, 2010; 2011; 2012). Then, the cognitive criteria were categorised based on the three levels of SA: perception, comprehension, and projection. Next, as shown in Figure 2, the cognitive criteria were mapped up in the powder handling simulation system prototype.

Perception

Users perceive useful information from cues in the environment. Stored knowledge in users' long term memory helps them to classify perceived information into meaningful representations. This information is structured in accordance with situated time and space. The information is also known as attention-based selection on task requirements (Endsley, 1995). Perceived information that matches with the stored information is ready to be retrieved by users as a basis for user awareness.

Affordance is the design aspect of an object that suggests how the object should be used (McGrenere and Ho, 2000). In other words, affordance provides strong clues to the operation of things. For example, buttons with two

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layer images (Figure 2) usually give hints to user that the buttons are active and the user can click on the buttons. Additionally, by integrating affordances into the interface system design, the user knows what to do by just looking at the design, thus instructions, label or pictures are not required (McGrenere and Ho, 2000).

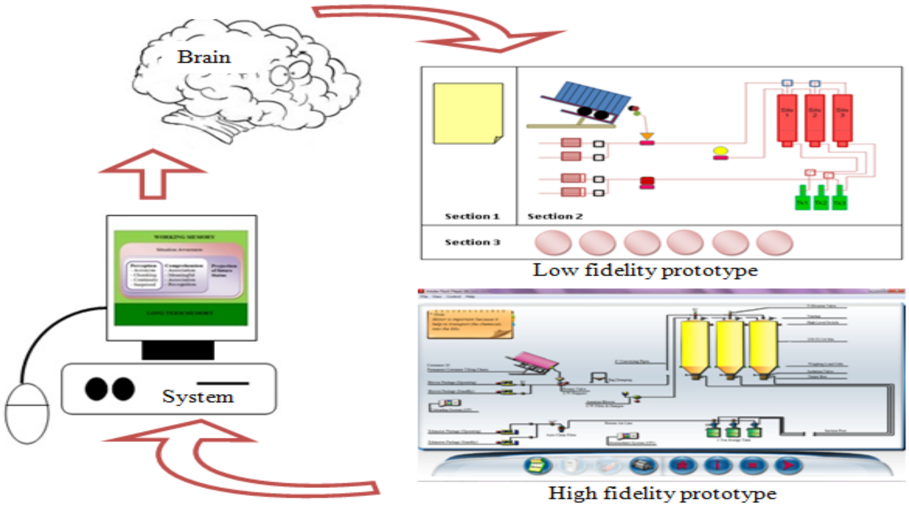

Figure. 2. Cognitive awareness model mapped with interface system design prototype.

Furthermore, chunking was also used as a technique to combine many units of information into a limited number of units or chunks. According to Miller's magic number, human can process information in 7±2 items or chunks at one time (Banbury and Tremblay, 2004). Thus, short and simple instructions incorporated in the interface system design are easy to process and comprehend by users. Chunking information will help users to increase their recall performance because structured information is easy to retrieve from their long-term memory. Additionally, chunking is used when people are required to recall and retain information. In contrast, chunking is not applicable for applications that require searching and scanning information functions.

Moreover, Gestalt design principles were also used to group buttons with similar functions. For example, the navigation buttons are grouped together at the bottom right of the screen, and buttons that represent system failure are failed are on the bottom left (Figure 2). Similarities state that things sharing visual characteristics such as shape, size, and colour will be perceived as a part of the same form. The eye will easily spot on sections for similar functions in order to avoid confusion (Wickens et. al, 2004).

In addition, to support human mental model in perceiving information in the environment, familiarity, visibility, and consistent images and icons will improve the recognition of information that is useful, and help users to understand the system. For instance, images that represent an action of an object or concept are meaningful to users and require less time to learn. Moreover, this will reduce users' mental workload and due to that, users will be able to focus on more critical tasks (Shneiderman and Plaisant, 2010).

Comprehension

At the comprehension level, users will organize and understand the significance of perceived information on a particular situation. Moreover, with meaningful interpretation, users will be able to have a mental model about the situation stored in their long term memory. At this level, SA is defined as a situational model depicting the current state of the mental model (Endsley, 1995).

In this study, to help users to comprehend information from a system, association cognitive criteria were incorporated in the prototype design. For instance, classical conditioning technique was used to associate a stimulus with an unconscious physical response (Sobel, 2001). In other words, this technique was to influence the appeal of a design with a trigger stimulus, which would evoke an unconscious response. For example, in the prototype system design, a blinking red and yellow animated image with high pitch alarm would attract users' attention. In addition, salient cues used in prototype design made the signal visible and noticeable by users (Dix et. al, 2004).

Moreover, to aid users with better understanding in handling the system, information displayed on the interface system design needs to be semantically associated together. For example, in the prototype system simulation in this study, if the user clicked the "play" button, the powder will be transferred from the container to Silo tanks.

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An indicator will move up from its original position to show that the powder was filled up into the Silo tank. Once the Silo tank was full, the tank will change colour to inform users that the tank had been loaded with powder chemical. The same general concept applies when we fill up a bottle with water. By including general and informative information in the design, it is hoped that users will be able to enhance their learnability process in using the system.

Projection

At the final stage of SA, projection is achieved via knowledge of the status and the dynamics of the elements and comprehension of the situation (Endsley, 1995). The mental model helps users to understand the situation and allows them to generate probable solutions to deal with future states of the system.

Feedback projection criteria included in system design is important to guide people in using the system. Feedback is crucial as the system will send back information about the next actions that users they need to take. For example, in system design, feedback can be observed visually or auditorily. Furthermore, to include feedback cognitive criteria in interface system design, feedback should provide direct and simple feedback that users can understand.

Additionally, pop out messages and signal display incorporated in the system will help users to make a wise prediction on actions that they need to take. Therefore, it is important to design a system that is meaningful so that users will understand the overall concept of the system that they use in their daily working tasks. For that reason, in this study, we included three common problems in system maintenance, which are motor, cable position, and driver failure problems. In relation to this, short messages on system failure configuration solutions will be displayed upon request by users. Therefore, it is hoped that by mapping up the cognitive criteria in the interface system design will help users to understand and perform well while interacting with the system..

Prototype Development

Prototype evaluation process is essential to seek comments or ideas in improving the final outcome of a system. The activity done in developing a prototype encourages reflection in design (Schon, 1983). In fact, the activity is an important feature in design process. The aim of having a prototype evaluation is to move through diverse design ideas until the idea that meets user requirements has finally been identified.

In this study, the prototype evaluation ran in stages. The four basic steps were designing, developing, testing, and analysing. For each stage of the prototype evaluation process, participants were asked to explore the prototype. No specific time was allocated for them to explore the prototype. Once they were satisfied with the prototype, they were then to answer the prototype checklist given to them. Then, feedback from the participants were collected and analysed in order to retrieve ideas to improve the system design. Next, the suggestions were incorporated into the next stage of prototype development process. This process was complete when all of the system requirements were fulfilled.

The evaluation began from low fidelity prototype to high fidelity prototype. For instance, in this study, the low fidelity prototype included prototype storyboards of the interface system design. In fact, the low fidelity prototype storyboards consisted of a graphical representation of the real system design without any actual system functioning (Dix et. al, 2004). Since the low fidelity prototype highlighted only the layout of the system, the prototype checklist given to them only covered the cognitive awareness perception criteria (Table 1). In contrast with high fidelity prototype, the prototype included interactive screens with the final interface system design. At this stage, the prototype checklist given to the participants consisted of cognitive criteria literally related to perception, comprehension, and projection.

Table 1: Stages of prototype evaluation process.

Prototype	Cognitive Awareness Criteria
Low fidelity prototype 1	Perception
Low fidelity prototype 2	Perception
High fidelity prototype 3	Perception, Projection, Comprehension
High fidelity prototype 4	Perception, Projection, Comprehension
High fidelity prototype 5	Perception, Projection, Comprehension

Participatory Design Evaluation Process

Participatory design is an evaluation design that covers overall prototype development process. Participants whom are usually experts in the work context are encouraged to be actively involved in the design process in order to improve the system design. In this study, participatory design was employed for a few reasons. First, the

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participatory design allowed the participants to contribute directly in the system development stages. Second, the participatory design was able to enhance the interaction between the system and working environment. Third, the participatory design was used to evaluate and refine the system design at each prototype development stage.

In this study, five experts from Engineering and Information Technology (IT) background were involved in improving the prototype interface system design. At this stage, two engineering experts who had experience in system maintenance contributed in improving the interface and functions of the system and the other three experts were from the Technical Education and IT field who concentrated on the interface and interaction of the prototype. To gather ideas and comments from the participants, a prototype checklist was given to each of them. There was no restriction of time for them to complete the prototype checklist, but they were given at least 2 weeks to evaluate the prototype. Then, the checklist was collected from the participants for further analysis.

Table 2: Participants' background

Participant	Designation	Years of service	Expert's role
P1	Instrumentation Engineer	>10 years	Interface and system functions
P2	Maintenance Engineer	>5 years	Interface and system functions
P3	Technical Education Instructor	>5 years	Interface and interaction
P5	IT Instructor	>10 years	Interface and interaction
P6	IT Instructor	>10 years	Interface and interaction

The prototype checklist used in this prototype evaluation process consisted of a checklist and open-ended questions. During the evaluation process, participants were encouraged to give comments and ideas related to the prototype interface system design. Participants were also free to ask questions to the researcher should they required further explanation about the system or any other problems that they encountered during the evaluation process.

The prototype checklist used in this study consisted of three levels of interface design cognitive awareness criteria, which were analysed from researcher's related studies. Most of the criteria were analysed from cognitive theories, interface design principles, interaction design, cognitive method studies, and ISO system design principles (Rosli, 2012).

FINDINGS AND DISCUSSION

Comments and ideas from the participants were essential at this stage to improve the final prototype interface system design. One of the challenges in participatory design in prototype evaluation process was time constraint. Generally, it took more than six months for the researcher to develop the prototype, to seek feedback from experts, and to improve the prototype until the experts were satisfied with the prototype. Findings from each level of the prototype were organised in a table form Feedbacks from the participants are discussed in the following sections.

Findings on Perception

At each stage of the prototype evaluation process, the prototype was improved based on inputs from the participants. In relation to visibility criteria, almost all the participants understood the information displayed on the system at all stages of the prototypes (Figure 3). For example, three basic saturated colours were used in the prototype design due to the fact that saturated colours were able to attract user attention. Even to date red and yellow colours are used for alarm signal because they resemble alarm signal in normal daily life. The red-coloured signal represents danger while yellow-coloured signal alerts people to always get ready for any circumstances that could occur. Moreover, red is commonly used to show danger signal because the colour has the longest wavelength and therefore it can be seen from afar (Forsyth and Ponce, 2011).

Next, similar to visibility cognitive criteria, almost all of the participants were familiar with the functions of powder handling system. For instance, they knew that the system begins with first stage of low fidelity prototype and ends with final stage of high fidelity prototype. However, three participants claimed that the system design should help them to recall any knowledge about system technology that has been stored in their long term memory. Two participants highlighted that, indication signal showing the Silo tank was filled with powder was rather small. In order to improve the design, the size of the indicator should be bigger. Besides, the participants also suggested for the Silo tank to be changed to other colour to indicate that the Silo tank was full with the chemical. As a matter of fact, visible information is vital in interface system design as it helps users to recall information that they have experienced before (Chance, 2008).

Moreover, for chunking, consistency, and affordance criteria, almost all the participants reported that the cognitive criteria were properly integrated in the system starting from prototype stage four. Therefore, focus should be given to these three criteria in order to design a system that could help to enhance human performance. Instructions and solutions should be designed in short and simple words so that designer can chunk the words, highlight important words, and bold or colour the text. If the sentences are too long, designer can use bulleted form or break the sentences into shorter sentences. On top of that, less time will be used by users to find useful information while interacting with the system.

As for affordance criteria, system designer can design the button with big to small or bright to dim button style if their concern is it to attract user attention in using the system. In the study, the participants also claimed that the prototype was yet to be consistent after stage three because only one or two buttons were linked to the correct page. It is important that to retain users' interest to the system, thus the system should be free from broken linkages. Other than that, the participants also stated that it was not necessary to arrange the buttons according to frequency of use, i.e., most frequently used button is at the bottom right corner while the least used button is on the left.

Next, in terms of system prototype layout, the participants were satisfied with the system layout as the simulation area was designed in the middle of the system's screen and the buttons were arranged at the bottom. In point of fact, users will be more focused on the simulation if it is in line with human focal point (Wickens et. al, 2004).

Prototype	I					II					III					IV					V				
Characteristic	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
Affordances	-	0	-	-	-	0	0	-	-	-	0	0	0	-	-	1	1	1	1	1	1	1	1	1	1
Chunking	0	-	0	-	-	1	-	0	-	-	1	-	1	-	1	1	-	1	1	1	1	-	1	1	1
Consistency	0	1	-	-	-	0	-	-	-	-	0	1	-	0	-	1	1	1	1	1	1	1	1	1	1
Familiarity	-	0	1	1	0	1	1	1	1	0	1	1	1	-	0	1	1	1	1	1	1	1	1	1	1
Recognizability	-	-	-	0	-	-	0	0	1	0	1	-	1	-	1	1	-	1	1	1	1	-	1	1	1
Visibility	-	-	1	1	0	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1
*Note	"-" No feedback								"0" Disagree										"1" Agree							

Figure. 3. Perception design criteria.

Findings on Comprehension

Comprehension and projection criteria were only evaluated by the participants starting from high fidelity prototype type because stage I and stage II of the prototype only concentrated on ways users perceived the system. Therefore, as shown in Figure 4, almost all the participants agreed that generalisation characteristic in comprehension criteria should be improved continuously until the final stage of prototype.

Prototype	I					II					III					IV					V				
Characteristic	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
Association	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	1	-	1	-	1	1	-	1	1	1
Generalisation	-	-	-	-	-	-	-	-	-	-	1	-	1	1	1	1	-	1	1	1	1	-	1	1	1
Learnability	-	-	-	-	-	-	-	-	-	-	0	1	0	-	-	1	1	1	1	1	1	1	1	1	1
Informative	-	-	-	-	-	-	-	-	-	-	0	-	-	-	0	1	-	1	-	-	1	-	1	1	1
*Note	"-" No feedback								"0" Disagree										"1" Agree							

Figure. 4. Comprehension design criteria.

A system that is easy to use should provide functions that are general so that the system is applicable for users of all levels such as the novice, intermediate, and expert users. For instance, options to display or hide labelling for the prototype system design is included in the prototype design. The system labelling is useful for the novice users. On the other hand, expert users will only retrieve the information if they find that the system labelling is needed. Moreover, it is important to design a system that fulfils user requirements, so that users will be able to

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comprehend information conveyed to them via the interface system design.

The participants also agreed on the signals that used daily life routine in association with system design concept (Thimbleby, 1998). In conjunction with learnability and informative criteria, the participants seemed to understand the short notes provided at the top left corner of the systems. The short notes explained the impact if one of the system components broke down. The short notes also helped the participants to recall possible consequences that could happen to lead them think of the solutions to overcome any arising problems (Preece, Rogers and Sharp, 2006). To optimise safety at workplace, users will always be ready to face any hazardous situations as long as cues or information is visible and able to capture their attention. Thus, users can at least immediately think of the solutions to safe one's life.

Findings on Projection

It is a challenge to integrate projection design criteria in the prototype interface system design. This is because system designer needs to develop a system that can guide users to give positive response while using the system. In this study, the participants showed that an improvement was still needed even at the final stage of the prototype system evaluation to make sure that users can deal with the information conveyed to them accordingly (Figure 5).

Prototype	I					II					III					IV					V				
Characteristic	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5	P1	P2	P3	P4	P5
Concept	-	-	-	-	-	-	-	-	-	-	1	1	1	1	1	1	-	1	1	1	1	1	1	1	1
Feedback	-	-	-	-	-	-	-	-	-	-	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1
Meaningful	-	-	-	-	-	-	-	-	-	-	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1
Prediction	-	-	-	-	-	-	-	-	-	-	1	-	1	1	-	1	-	1	1	1	1	-	1	1	1
**Note*	"-" No feedback							"0" Disagree									"1" Agree								

Figure. 5. Projection design criteria.

For instance, as reported by the participants, they found it hard to predict the type of system fault that could occur in the prototype. Participants suggested providing a short message informing users on types of system fault that could happen at any time. Providing such information will help the users to analyse the problems and for them to come up with possible solutions (Dix et. al, 2004).

In order to give meaningful simulation, two participants suggested that symbols or images used in the system design should use engineering standard symbols for system or machines in order to avoid confusion among users. Unambiguous symbols in the system will help users to have a clearer picture on how the system works (Norman, 1986).

Feedback, guidelines, solutions, short notes, and pop up messages will help users to have a quick analysis on the next actions that they need to take in dealing with the system. In this study, all the participants were satisfied with the concept of continuity embedded into the system. By highlighting important information at the earlier stage of the simulation process, it is able to attract user attention to the system. As people tend to lose focus at the end of a particular situation, important information should be highlighted at the earlier stage of system design (Chance, 2008).

Additionally, to represent similar meaning and command to user mental model, designer can combine the information in displaying warning to attract user's attention, integrate the information in designing signage, or incorporate the information in logo to make the identification process faster. As a whole, in this study, the participants showed rising growth of agreement towards the end of the final stage of prototype development process. The participants were able to use the system smoothly and the incorporated cognitive criteria helped them in handling the system..

CONCLUSIONS

This paper describes the importance of cognitive awareness criteria incorporated in the prototype interface system design. The prototype was evaluated in stages by the participants in order to enhance the interface system design. Ideas and comments from the participants were essential to the researcher as these ideas and comments were useful in improving the powder handling simulation system for further research analysis.

In general, it was rather a challenging task to incorporate the cognitive awareness criteria in the prototype system design. Progress in developing the prototype was expanding moderately and the prototype was improved after each stage of evaluation process. From the perception criteria feedback, three criteria that have to be given more time to design in designing a system were affordance, consistency, and visibility criteria. System users need information that is able to evoke their memory so that they can select and react accordingly while handling the system. Similar to consistency, it is important to keep the design consistent in order to avoid ambiguous feeling to users while they are interacting with the system.

As for comprehension criteria, a system that supports users' learnability process allows users to own the skills in controlling the system. If problems occur, they will be able to act automatically and think precisely on the actions that they need to take while handling the situations. It is a challenge to provide information that meets users' cognitive requirements. Therefore, active contributions from the participants in designing the system were essential to make sure that users' cognitive needs were incorporated in interface system design.

In order to help users to perform well in their decision making, system designer needs to focus more on ways to design feedback and meaningful projection criteria in system design. Due to human abstract thinking, system designer also needs to design a system that helps users to understand the system and situations around them. Appropriate and useful information are thus crucial to system users as the information will be observed and analysed by them in order to select the best actions while interacting with the system. It is hoped that cognitive criteria will help users to enhance their performance in using the system and help them to minimise human error at workplace.

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