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Designing User Interface Elements for Remotely Operated Ship-to-shore Cranes

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The graphical user interfaces (GUIs) for operating cranes differ greatly even among the same type of cranes because the various crane manufacturers and their third-party suppliers offer distinct GUIs. This situation requires operators to train themselves whenever they use GUIs from another manufacturer, since their knowledge from using one GUI may not be applicable to other GUIs. Furthermore, distinct GUIs may have specific rules or mechanisms that operators must follow, thereby increasing the potential for human errors. Therefore, there is a need for a coherent and intuitive design system that crane manufacturers and their third-party suppliers can use or refer to when developing their GUIs. Since there are many types of cranes, this paper focuses on describing the process of designing and evaluating user interface elements for operating remote ship-to-shore (STS) cranes, which are offered as part of the OpenCrane Design System.

graphical user interface, crane, remote operation, design system, human-centered design

1. INTRODUCTION

Modern heavy machinery, ranging from mobile machines like excavators to stationary machines like tower cranes, is usually equipped with digital systems that present supportive information to operators via a graphical user interface (GUI) (Sitompul 2022c). However, the GUIs have distinct ways of presenting information even among the same type of machines, depending on which machine manufacturers or third-party suppliers that develop the GUIs (Wallmyr 2020). Operators need to train themselves whenever they use GUIs from another crane manufacturer or third-party supplier, since different GUIs may have different rules or mechanisms that operators must follow. To reduce the risk of human errors and improve the consistency of the GUIs across different machine manufacturers and third-party suppliers, there is a demand for a design system that the developers can use or refer to when developing their GUIs (Nordby et al. 2019).

In this paper, we present the process of developing an open-source design system called OpenCrane Design System, which provides user interface (UI) elements for operating different types of cranes. We hope the open-source UI elements would improve design consistency, since various crane manufacturers and third-party suppliers have a design system that they can use or refer to. Since cranes can be large or small, mobile or stationary, on-site or remotely operated, and have other characteristics, this paper focuses on designing UI elements for the GUI of remote ship-to-shore (STS) cranes, also known as quay cranes (see Figure 1 for an example). STS cranes are commonly used to load and unload containers on container ships. The majority of STS cranes is controlled on-site by operators who are located inside the crane's cabin, but more modern STS cranes can also now be controlled remotely by operators working from a remote operation centre (Majoral et al. 2023). The trend of moving from on-site to remote operation is due to the consideration of greater risks to the safety and wellbeing of operators when working from on-site cabins (Sitompul 2022b). Additionally, working in remote control rooms also offers advantages in terms of productivity, as operators can instantly control any cranes within the port.

Since operators of remote STS cranes are unable to directly receive information through their senses, they are highly dependent on videos and sensor data presented in the GUI to perceive the remote environment and operate the crane accurately (Karvonen et al. 2012). Therefore, it is important to design UI elements with a high match between the visual design and the context of use. This approach

Figure 1: *The examples of ship-to-shore cranes used for loading and unloading containers to and from ships.*

aids in reducing the cognitive effort required to process the presented information while doing the task, which would then enable operators to respond to dangerous situations accordingly (Fang et al. 2018). The following research questions were defined to address the requirement of designing UI elements that match the contextual needs of operators of remote STS cranes:

1. Which UI elements should be provided in the design system?
2. How can the various operations of remote STS cranes be designed as UI elements?
3. How do operators of STS cranes perceive and understand the proposed UI elements?

The remainder of this paper is split into five sections. Section 2 presents prior studies that propose GUIs for remote crane operations. Section 3 describes the activities that we did to design and evaluate the UI elements for remote STS cranes, as well as to answer the research questions presented above. Section 4 presents the UI elements for remote STS cranes that we have designed, as well as the findings that we obtained from the evaluation activities with crane operators. We present our reflection after designing and evaluating the UI elements in Section 5. Finally, Section 6 concludes the study presented in this paper.

2. RELATED WORK

Remote crane operators are highly dependent on the video streams and the GUIs displayed on their monitors to control their cranes accurately, as mentioned in Section 1. There are prior studies that propose GUIs that could be used for remote crane operation of cranes. The proposed GUIs greatly differ among the studies due to the different types of cranes to be operated remotely and the fidelity level of the prototype (see Sitompul (2022a) for the complete review).

Kim (2006) proposed a GUI that could be used for operating a remote gantry crane. The proposed GUI consisted of two video camera views; one showing the cabin view and the other showing the spreader view. In addition, the GUI also showed buttons to operate the gantry crane and some UI elements that show different states of the gantry crane. The proposed GUI was designed to operate a remote gantry crane in a simulated environment. However, since the study does not report any user evaluation, it is unclear whether the proposed GUI could be used for operating real remote gantry cranes.

Singhose et al. (2011) designed three types of GUIs for remotely operating an all-terrain crane, a bridge crane, and a tower crane, respectively. However, the GUIs were not designed for real remote operation, but rather as an education tool for students to learn about crane mechanisms. Students were able to operate mini replicas of the cranes using the GUIs. This study also does not report any user evaluation. Therefore, it is unclear how the proposed GUIs would be applicable for operating real remote cranes.

Similar to Kim (2006), Karvonen et al. (2014) also designed a GUI for operating a remote gantry crane. Their GUI supported two camera setups, in which one setup offered a 2-camera view and the other offered a 4-camera view, along with UI elements that represent various states of the gantry crane. Six crane operators were recruited to evaluate the proposed GUI, but the evaluation only focused on the preference between the two camera setups, rather than the design of UI elements. The results show that the operators preferred the 2-camera view, since they considered video size in the 4-camera view too small. This study provided insights regarding the organization and size of camera views, but the study did not investigate the suitability of the other UI elements in the proposed GUI.

Chen et al. (2016) proposed two GUIs that could be used for operating a tower crane prototype remotely. The first GUI comprised multiple camera views only, while the second GUI contained multiple camera views plus UI elements showing different states of the tower crane prototype. Both GUIs were evaluated by 30 non-operator participants and the results pointed that the participants faced fewer dangerous situations when they used the second GUI, which also contained the UI elements for showing the states of the tower crane prototype. The results of this study indicate that the presence of the UI elements helped the participants to perform more

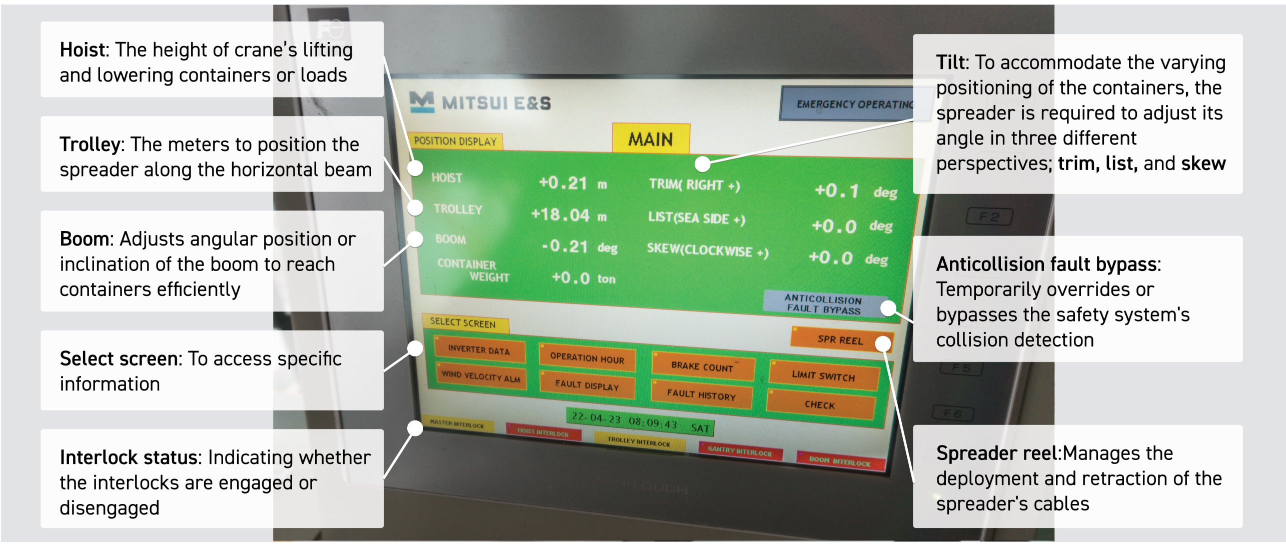


Figure 2: *An example of how we inspected every UI element that exists in the GUI used for operating STS cranes.*

safely, but it does not describe how each of the UI elements helped achieving the safer performance.

Lastly, Yu et al. (2021) designed a GUI for controlling a bridge crane prototype remotely. The GUI consisted of four camera views, buttons to control the crane prototype, and four clickable icons to change the input techniques. The evaluation was done by involving by 21 non-operator participants and 11 crane operators. However, the evaluation focused on comparing the effectiveness of the input techniques, rather than investigating the suitability of the UI elements that exist in the proposed GUI. Therefore, it is unclear to what extent the proposed GUI would be applicable for the remote operation of real bridge cranes.

While the number of related work is still limited, the review indicates that the designs of GUIs for operating cranes remotely are diverse and have low consistency. The low consistency could increase the risk of human error, since each GUI may have different mental models, rules, or interaction techniques that need to be followed by crane operators (Nielsen 1989). Although all the studies reviewed here are all published and the proposed GUIs are available as the source of inspiration for other designers and developers, it is difficult to determine which of the UI elements that should or should not be adapted, since none of the studies reviewed here examined the suitability of each UI element in their proposed GUIs. Considering the severe damage of crane-related accidents to life, property, and the environment (Milazzo et al. 2017), it is important to have UI elements that have been assessed thoroughly with respect to the context of use (ISO 2019). Hence, it is necessary to develop a design system that not only offers UI elements that crane manufacturers and third-party suppliers can adopt when developing their GUIs, but also provides UI elements that have been evaluated based on the tasks that operators need to perform.

3. METHODS

In this section, we describe the process of designing and evaluating the UI elements for operating remote STS cranes.

3.1. Creating a List of UI Elements for the Design System

When developing a design system, one of the first steps is to make a list of UI elements that should be made available in the design system Vesselov and Davis (2019). This is essential to know which UI elements to be designed. To determine which UI elements to be made available in the design system, we reviewed existing GUIs for operating STS cranes. We performed two activities to review existing GUIs for operating STS cranes: (1) a field study at a port that employed STS cranes and (2) the analysis of online videos uploaded by crane manufacturers that fully or partially show the GUIs for remote STS cranes. These two activities are relevant to discover the answer to the first research question "Which UI elements should be provided in the design system?" mentioned in Section 1.

3.1.1. A Field Study to Analyze Existing GUIs for STS Cranes

Since the focus of this study was remote STS cranes, it would be ideal to visit a port that employs remote STS cranes. However, since remote STS cranes are still relatively new, there are still very few ports that use them. Nonetheless, we conducted a field study at a port that employed conventional STS cranes that still need to be operated on-site from inside the cabin (see Figure 1 for an example). Although this approach did not allow us to see the example of GUIs for operating remote STS cranes, it still provided insights into what kind of GUIs that exist inside the crane's cabin. During the field study, we took photos of the GUI that existed inside the cabin of STS cranes. We analyzed the photos manually by inspecting each UI element shown on the display (see Figure 2 for an example of this activity). We also asked the crane operators for clarification if there were UI elements shown on the display, which we did not understand.

3.1.2. Analysis of Online Videos Uploaded by Crane Manufacturers

After conducting the field study described in Section 3.1.1, we had an initial list of UI elements for conventional STS cranes. To make sure that our list of UI elements also covered GUIs used for operating remote STS cranes, we analyzed online videos uploaded on YouTube by two manufacturers of remote STS cranes[1 2]. To the best of our knowledge, only these two manufacturers currently produce remote STS cranes. Out of 1525 videos that these two manufacturers have uploaded at the time of this study, only six videos fully or partially showed the GUIs for operating remote STS cranes.

The analysis started by observing the six videos and taking screenshots whenever the GUIs were visible in the videos. After that, we manually analyzed the screenshots by examining every UI element that was visible in the videos. This task was similar to what we did when analyzing the photos taken from the field study (see Figure 2). This approach allowed us to derive examples of existing GUIs for operating remote STS cranes. The combined results from the field study and the video analysis generated a list of UI elements that should be made available in the design system.

3.2. Designing UI Elements through Three Design Workshops

The next phase was to generate design ideas to visualize the list of UI elements that we have gathered from reviewing existing GUIs for STS cranes. We conducted three design workshops, where each workshop consisted of different activities. Conducting the design workshops also served as the method to find the answer to the second research question "How can the various operations of remote STS cranes be designed as UI elements?" mentioned in Section 1.

[1]www.youtube.com/c/abbmarineandports/videos
[2]www.youtube.com/@LiebherrGroup

3.2.1. Workshop 1: Designing the UI Elements

The goal for first design workshop was to generate design ideas for the list of UI elements that we have gathered from reviewing existing GUIs for STS cranes. The first design workshop was done by each of the authors individually in order to allow the freedom to generate unique ideas without being influenced by each other.

3.2.2. Workshop 2: Revising the UI Elements

The second design workshop was conducted several days after the first design workshop. During the second design workshop session, we presented, compared, and integrated the design ideas that each of us had developed individually. This included a discussion about the suitability of the generated design ideas. Subsequently, we chose several design concepts that we all deemed appropriate. These selected concepts were then further refined into UI elements using Figma [3].

3.2.3. Workshop 3: Getting Feedback from Design System Experts

The third design workshop was conducted a couple of weeks after the second workshop by engaging three experts from the OpenBridge Design System[4]. The goal of the third design workshop was to collect feedback from experts who had experience in designing and maintaining a design system. During the third design workshop, we reviewed every UI element generated from the second design workshop and collected feedback on how well they accomplished the criteria of consistency and scalability. In this context, consistency means to what extent the UI elements were designed according to the same visual style, while scalability means to what extent they could be adapted into different sizes. We then modified the design of our UI elements according to the feedback from the design system experts.

3.3. Involving Crane Operators to Evaluate the Generated UI Elements

After carrying out design workshops mentioned in Section 3.2, we produced three groups of UI elements that could be relevant for operating remote STS cranes. Note that, as shown in Figure 2, GUIs for STS cranes contain a lot more functionalities than what we could possibly covered in our first attempt to develop a design system. For this first attempt, we decided to stick with three groups of UI elements shown in the top-row images of Figure 3, since these UI elements are essential for operating STS cranes. According to the human-centered design approach (ISO 2019), the involvement of end users is crucial when evaluating the design solutions to

[3]www.figma.com
[4]www.openbridge.no/

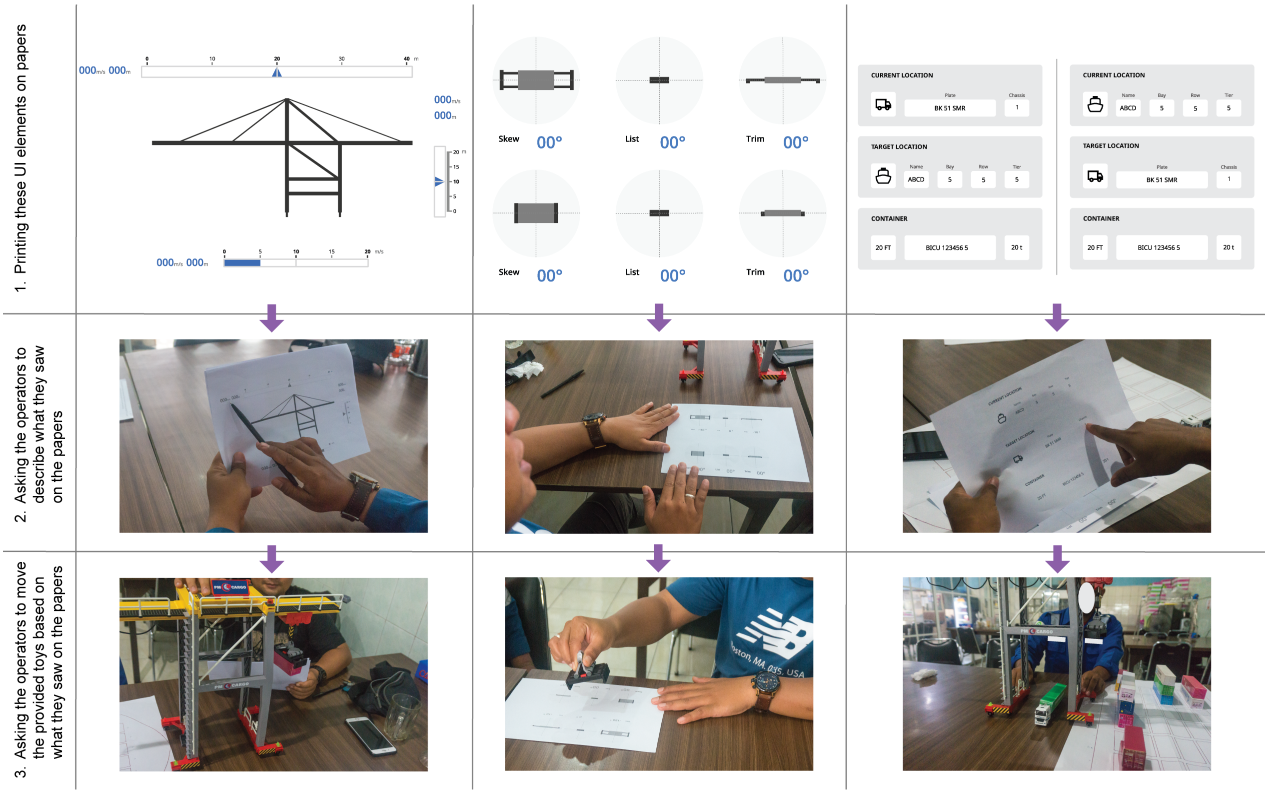


Figure 3: *The images that show how the proposed UI elements were evaluated. The top-row images show three groups of UI elements that were printed on paper. The middle-row images show the operators verbally described their understanding on the meaning of the printed UI elements. The bottom-row images show the operators moved the given toys based on the printed UI elements.*

investigate the suitability of the solutions for both end users and the tasks that they need to perform. In this context, evaluating the proposed UI elements with crane operators was also necessary to find the answer to the third research question "How do operators of STS cranes perceive and understand the proposed UI elements?" mentioned in Section 1.

We involved nine operators of conventional STS cranes, which still need to be operated on-site from inside the cabin, to evaluate the proposed UI elements. The participants were aged between 24 and 33 years old. All of them had more than three years of experience as operators of conventional STS cranes. Since there are still very few ports that employ remote STS cranes, we did not manage to recruit participants who have experience as operators of remote STS cranes. Nevertheless, involving operators of conventional STS cranes still provided insights on how well operators of STS cranes in general could understand the proposed UI elements. The evaluation consisted of two activities, which are described in the following Sections (see Sections 3.3.1 and 3.3.2) and the entire evaluation took up to two hours for each participant. The protocol of the evaluation was reviewed and approved by the Norwegian Agency for Shared Services in Education and Research (No. 782630). The operators provided their written informed consent before participating in the evaluation. Each participant received a gift card worth around USD 15 as a token of appreciation for their involvement in the evaluation.

3.3.1. Asking the Operators to Guess the Meaning of the UI Elements

The first evaluation activity was done to investigate how well the operators could understand the meaning of the proposed UI elements without receiving prior instruction or training. We printed the UI elements produced from the design workshops (see the top-row images in Figure 3) and provided the prints to the operators. Without providing any information, we asked the operators to think aloud while guessing the meaning of every UI element shown on the papers (see the middle-row images in Figure 3). The process was repeated until the operators had guessed the meaning of every UI element shown in the top-row images in Figure 3.

3.3.2. Evaluating the Operators' Understanding on the UI Elements

The second evaluation activity was done to discover whether the operators fully understood the meaning of the proposed UI elements. In this activity, the operators were required to move the given toys (see Figure 4) based on the UI elements that they saw on paper. This activity allowed us to review our interpretation of the verbal description given by the operators in the previous activity (see Section 3.3.1) since we could explicitly see the operators' understanding based on their interaction with the toys. This approach has also been found effective for evaluating low-fidelity UI prototypes for operating excavators (Sitompul et al. 2020) and mobile cranes (Sitompul et al. 2020).

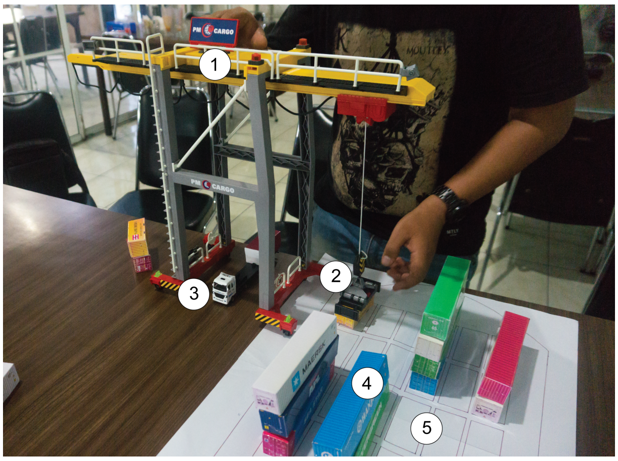


Figure 4: *The toys that we used in the evaluation activities consist of (1) an STS crane replica that can be moved by pressing buttons on top of it, (2) a spreader replica, (3) a truck replica, (4) multiple container replicas, and (5) a white paper that represents the ship's stacking area.*

The evaluation proceeded by presenting the operators with a printout that showed one of the three groups of UI elements (see the top-row images in Figure 3). We then requested the operators to move the provided toys according to the values shown on the printed UI elements (see the bottom-row images in Figure 3 for the examples of this activity). Once the operators had moved the toys to the positions that they considered correct, we changed the values shown on the printed UI elements and asked the operators to move the toys again with respect to the updated values. We changed the values shown on the printout four times for each group of UI elements. After changing the values for times, it became evident whether the operators had correctly understood the meaning of the UI elements. Once we finished with evaluating the first group of UI elements, we evaluated the second group of UI elements using the same procedure. The evaluation ended after all three groups of UI elements had been evaluated four times.

4. RESULTS

This section presents the list of UI elements to be be made available in the OpenCrane design system, how the various operations of remote STS cranes should be visualized as UI elements, and the feedback that we obtained from the operators. The information presented in this section also serves as the answers to the three research questions mentioned in Section 1.

4.1. UI Elements that Visualize Trolley, Gantry, and Hoist Movements

The first group of UI elements that we produced from the design workshops is the UI elements that represent trolley, hoist, and gantry movements of remote STS cranes. Based on the first evaluation activity (see Section 3.3.1), all the operators correctly guessed the meaning of the UI elements in this group and moved the STS crane replica and the spreader replica as we predicted, except for the UI elements that indicate the gantry speed and its location in the quay (see No. 7, 8, and 9 in Figure 5), as expressed by the quote below:

> These (while pointing to the top) are for trolley. These indicate the trolley speed and its location on the boom. These (while pointing to the right) are for hoist. These indicate the hoist speed and how high the spreader is lifted from the ground. These (while pointing to the bottom), I do not understand what are these [P5].

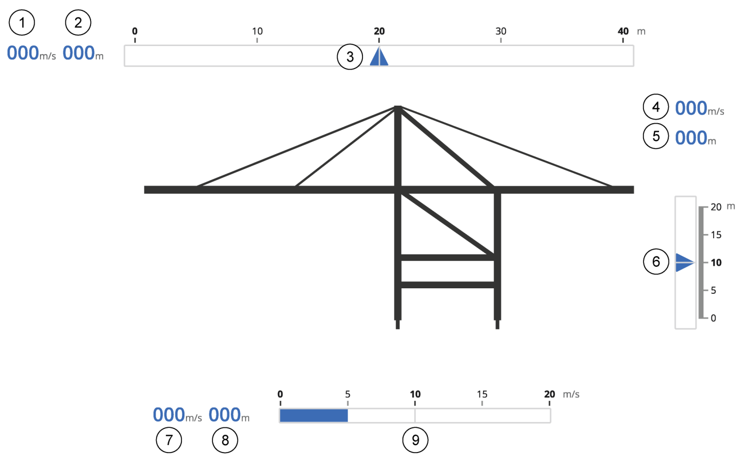
Three operators were able to correctly guess the meaning of the UI elements shown with No. 7, 8, and 9 in Figure 5 as the gantry speed and its location in the quay, but not because of the design of the UI elements. Instead, those three operators managed to guess correctly by thinking about what kind of information that they have not guessed yet, as suggested by the quote below:

> If these (while pointing to the top) are for trolley and these (while pointing to the right) are for hoist, then these (while pointing to the bottom) must be for gantry. Yeah, I think these are for gantry, because the basic crane movements are only trolley, hoist, and gantry [P6].

One of the operators hinted to exclude the UI elements shown with No. 7, 8, 9 in Figure 5 because they are not appropriate to represent the gantry speed and its location in the quay with respect to the crane image that was used, as explained by the quote below:

> I think it does not make sense to have these (pointing to the bottom) for gantry. If the crane image is like this, then the gantry movement should be either getting closer toward us or getting farther from us. It makes sense to visualize trolley and hoist like these, but not for gantry [P9].

Lastly, as shown with No. 2 and 3 in Figure 5, the value of trolley location can be anywhere between



The intended meaning of every UI element in this figure

1. Trolley speed
2. Trolley location
3. Indicator of the trolley location with respect to the boom
4. Hoist speed
5. Hoist height
6. Indicator of the spreader height from the ground
7. Gantry speed
8. Gantry location in the quay
9. The bar that indicates the gantry speed

Figure 5: *The left image shows the UI elements that represent information about trolley, hoist, and gantry movements. Each UI element is numbered from 1 to 9. The meaning for each UI element can be seen on the right side of this figure.*

0 m and 40 m along the boom. Although all the operators were able to correctly guess the UI elements shown with No. 2 and 3 in Figure 5) as the trolley location, they commented that the way to measure the trolley location is different in their STS cranes. They commented that in their cranes, the value of 0 m is defined based on the parking position of the spreader (see Figure 6 for an illustration). The trolley location is negative from the parking position toward the sea and positive from the parking position backward, as described in the quote below:

> In our STS cranes, the value of 0 m for trolley location is based on the spreader's parking position. From the parking position toward the sea, the value of the trolley location is negative. From the parking position backward, the value of the trolley location is positive. But this is probably something that depends on the crane manufacturer. In our STS cranes, the measurement is done like that, but it could be different in other STS cranes [P2].

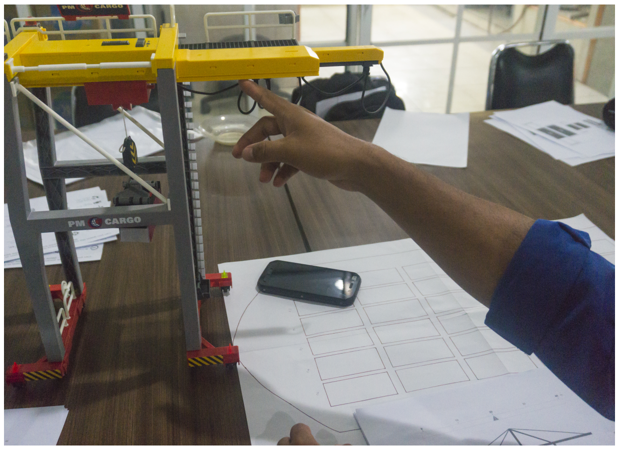


Figure 6: *The operator pointed to a specific part of the STS replica to indicate the location of the spreader's parking position, where the value of 0 m for trolley location is defined.*

4.2. UI Elements that Visualize the Rotation of the Spreader

The second group of the proposed UI elements is the UI elements that visualize the rotation of the spreader based on three different axes (see Figure 7). All the operators correctly guessed the meaning of the UI elements, as expressed by the quote below:

> The left ones are for skew. Skew is if the spreader's rotation is seen from the top view. The middle ones are list. List is if the spreader is tilted forward or backward. The right ones are trim. Trim is if the spreader's rotation is seen from the side view. Usually the values are positive if the rotation is to the right and negative if the rotation is to the left. The top images are for when the spreader is extended to 40 feet, while the bottom images are for when the spreader is retracted to 20 feet [P1].

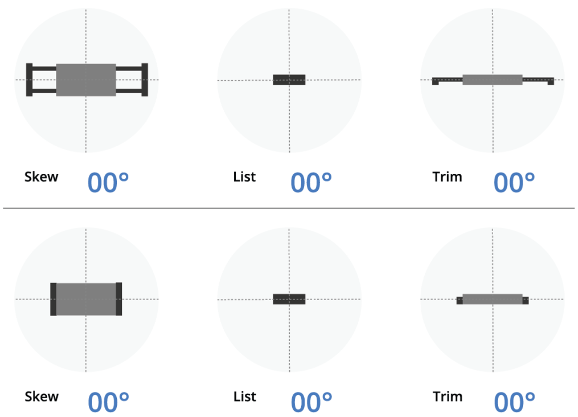


Figure 7: *The images that show the UI elements for visualizing the spreader's rotation based on different axes. The top images are shown if the spreader is in the 40-foot mode, while the bottom images are shown if the spreader is in the 20-foot mode.*

Based on our observation in the second evaluation activity (see Section 3.3.2), all the operators also moved the spreader replica according to what they saw on paper, as what we predicted. However, there were two operators who suggested to modify these elements to improve their understandability. One operator suggested to add indicators to show which direction the positive or negative values will rotate to, as explained in the quote below:

> Although these are easy to understand, I think it would be better if we also know to which direction the rotation is, for example, if the value is negative or positive. Therefore, we could understand them a lot more easily [P4].

The other operator suggested to improve the understandability by rotating the spreader image according to the angle's value, as expressed by the quote value:

> I think these are good enough. However, if I may add, I think it would be better if the spreader images would also rotate depending on the angle's value. It would be much easier for us to grasp the information [P8].

4.3. UI Elements that Show the Current Position and Destination of the Target Container

The third group of the proposed UI elements the UI elements that show the current location and the destination of the target container. The UI elements in this group are presented differently based on whether it is a loading operation, i.e, moving a container from a truck to the ship (see the left images in Figure 8) or an unloading operation, i.e., moving a container from the ship to a truck (see the right images in Figure 8).

When we presented the printout that showed the right images in Figure 8, all the operators were able to correctly guess the meaning of these UI elements

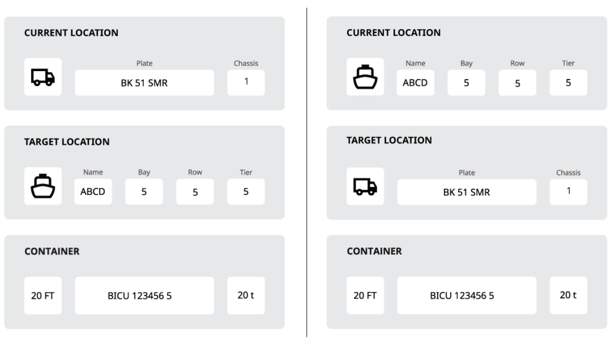


Figure 8: *The left images are shown when the operation is to move a container from a truck to the ship, while the right images are shown when the operation is to move a container from the ship to a truck.*

as an unloading operation, as indicated by the quote below:

> These images seem like an operation to move a container from the ship to a truck. The ship's name is ABCD and the container is currently located at bay 5, row 5, and tier 5. We should place the container onto this truck. The truck's plate number is BK 51 SMR and the container should be placed on chassis No. 1. The container is 20 feet, the number is BCU 123456 5, and the weight is 20 tonnes. [P7].

The operators also correctly guessed the meaning of the UI elements as a loading operation when we presented a printout that showed the left images in Figure 8, as suggested by the quote below:

> The top ones are the information about the truck that brings the container. This is the ship and we should place the container at bay 5, row 5, and tier 5 on the ship. Below is the information about the container that should be moved. These images indicate an operation to move the container from this truck to this ship [P3].

Lastly, although all the operators correctly guessed the meaning of the UI elements shown in Figure 8 without any problems and also agreed that those kinds of information would be sufficient in normal conditions, two operators expressed an example of situation, where it would not be enough to have this kind of information only. One such situation is due to the ship's poor condition, as explained by the quote below:

> In some ships, the markings of bays or rows are not visible anymore because the paint has faded. In this case, we cannot rely on the numbers of bays and rows only. We need to use references in this case, like, whether it is on the land side or the sea side. For example, unloading a container from bay 5, fifth row from the sea side, and tier 5 [P7].

5. DISCUSSION

As mentioned in Section 3.1, we analyzed videos uploaded by crane manufacturers that fully or partially showed the GUIs for remote STS cranes in order to create the list of UI elements, since there are still very few ports that employ remote STS cranes. The opportunity to conduct a field study that used conventional STS cranes and talked to the operators allowed us to obtain a lot of information about the operation of STS cranes. Having such knowledge was really useful when inspecting every UI element that was visible in the online videos. We could imagine that it would be difficult to analyze the online videos without having such prior knowledge.

As described in Section 4, the operators gave a total of five comments on how the proposed

UI elements should be modified to improve their understandability. The UI elements that we generated from the design workshops have been designed by considering modifiability to a certain extent. In Section 4.1, an operator hinted to exlude the UI elements that indicate the gantry speed and its location in the quay (see No. 7, 8, and 9 in Figure 5). Removing these UI elements can be done without affecting the understandability of the remaining UI elements. As described in Section 4.1, all the operators commented about how the measurement of the trolley location was done differenty in their STS cranes (see Section 4.1). The UI elements shown in Figure 5 can be modified to address this need by changing the numbers in the top-part of Figure 5. In Section 4.2, one operator requested to add an indicator for whether the positive or negative values indicate left or right rotation. This request can also be accommodated without significantly changing the remaining UI elements, for example, by adding "right +" or "left -" next to the texts of skew, list, and trim. The UI elements shown in Figure 7 can also be modified to accommodate the request from one operator that the spreader images should also rotate according to the angle's value. In this case, developers simply need to program so that the spreader images shown in Figure 7 will also rotate according to the angle's value. However, the present UI elements cannot accommodate the comment about improper marking of bays or rows, since the ship's sea side and land side always change depending on which side the ship is berthed.

As described in Section 1, the GUIs used to operate heavy machinery, such as cranes, can greatly differ based on which crane manufacturers and third-party suppliers that develop the GUIs (Wallmyr 2020). Although sharing open-source UI elements that others can use or refer to can enhance the design consistency across various machine manufacturers (Nordby et al. 2019), it could be argued that the UI elements described in this paper provide additional diversity to the already-diverse GUIs for crane operations. While this argument might be true, we see at least two primary justifications for reusing the UI elements described in this paper. Firstly, although the participants to evaluate the proposed UI elements were operators of conventional STS cranes, they were were able to accurately describe almost all the UI elements presented in this paper without receiving any prior instruction or training from us (see Section 4). This suggests that nearly all the UI elements presented in this paper were easy to comprehend and crane operators would not require additional training to use them. Secondly, with this paper, we have made the process of designing and evaluation these UI elements transparent. Hence, allowing others to make informed decisions whether reusing any of the proposed UI elements.

Although this paper presents the UI elements that depict various states and operations of remote STS cranes, along with how they were designed and evaluated, it is important to note that the UI elements described in Section 4 are not final. Firstly, as mentioned in Section 3.3, the GUIs for operating STS cranes have a lot more functionalities than what we could not cover in this first attempt to develop a design system. Secondly, UI elements in a design system are usually improved over time (Vesselov and Davis 2019). Hence, the UI elements presented in this paper should be regarded as the first draft rather than the final version. All the crane operators that we recruited to evaluate the proposed UI elements had the same nationality, worked at the same port, and used STS cranes produced by one manufacturer. Therefore, it would also be relevant to repeat the evaluation described in this paper with operators who work with STS cranes manufactured by different companies in different countries. Doing so would allow us to investigate to what extent the findings described in Section 4 remain applicable. In the near future, we intend to make these UI elements publicly available to allow different stakeholders to have access to them. Consequently, we expect to receive additional feedback on these UI elements beyond what we have obtained from this study.

6. CONCLUSION

In this paper, we have presented the process of designing and evaluating UI elements for operating remote STS cranes that crane manufacturers and third-supliers can use or refer to when developing their GUIs. The design process started by creating a list of UI elements that should be designed later. To create the list of UI elements, we conducted a field study at a port that used conventional STS cranes and analyzed online videos uploaded by manufactures of remote STS cranes. After that, we conducted three design workshops to generate and refine design ideas for every UI element in our list. We then involved nine participants who worked as operators of conventional STS cranes to evaluate the proposed UI elements by involving nine participants. The results suggest that the proposed UI elements were easy to understand because (1) the operators correctly guessed the meaning of nearly all the UI elements without receiving prior instruction or training from us and (2) they also moved the given toys according to what we predicted. However, considering UI elements in a design system is usually changing over time, the UI elements presented in this paper should be considered as the first draft, and not as the final version.

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