CENTER FOR EDUCATION + RESEARCH IN CONSTRUCTION
DEPARTMENT OF CONSTRUCTION MANAGEMENT

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Virtual Reality as a Training Tool for Building Operators

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This is an applied research consortia project at the Center for Education and Research in Construction, Department of Construction Management University of Washington, and Mortenson Construction. This work validates the feasibility of the use of Virtual Reality for building operations training.

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INTRODUCTION

The past decade has seen a technological revolution in the construction industry. With the introduction and large-scale commercial application of Building Information Modeling (BIM), construction industry processes have turned towards digitization trends to increase efficiency and collaboration. BIM helps organize data sets of information and integrates this information into 3D or 4D models. These models help workers throughout processes of project visualization, development, and interpretation. In turn, the design phase has shifted from an on-paper approach to a digitized approach. Virtual Reality (VR) is another digital technology that has now emerged in the construction industry that has the capacity to enhance data visualization work and the coordination of components in day to day construction work.

VR can help bridge the gap between the virtual world and the real world. VR systems are generally composed of four elements: 1) a 3D virtual environment (VE), 2) geometric data, 3) computer hardware, and 4) an interface system (e.g., headset). These four elements work together to provide a first-hand experience for the user. The 3D VE is crucial to VR as it is the foundation upon which data, hardware, and interface provide input. The data and computing elements provide the necessary parameters that shape the 3D VE. Presentation hardware, such as Head Mounted Devices (HMD), are the final element that interface with the user's movements and actions in VR and provide the VE with input on these activities. VR provides an advantage to other digital technologies due to its ability to provide a realistic and life-sized spatial context of a digital representation (e.g., a building, a construction site).

There have been many studies that show the benefits of VR technologies in the construction industry. However, this study analyzes the potential value proposition of VR for operations staff training. VR systems are a potentially powerful tool for training people to perform tasks that may be expensive or dangerous to duplicate in the real world. This idea is not new: flight simulators have been used for decades to train pilots for both commercial and military aviation and are now integral to both the design and the operation of modern aircraft. This research aimed at leveraging these VR characteristics of real world scenario simulation while ensuring worker safety in building operations training (Adams et al. 2001).

In this study, we developed a VE for the West Campus Utility Plant on the University of Washington's Seattle campus. This study focuses on the application of VR for facilitate management training. We sought to study the value of VR from the facilities management perspective. In this work, facilities management personnel found a particularly strong value proposition for VR. The VR of the West Campus Utility Plant allowed operators working at the Central Utility Plant to virtually tour the plant and become familiar with the layout and systems, even though they were not able to physically visit the plant on a regular basis. Consequently, VR was seen as valuable for facilities management training as it familiarized workers with building systems they do not frequently visit. VR operations staff training could be used for rooftop, tunnel, or other difficult to reach areas. This type of VR application may also support emergency response training—a VR of the campus may allow emergency response crew personnel to practice routes and access procedures without physically disrupting campus buildings, students, and staff.

1 LITERATURE REVIEW

Background

The 'traditional' construction industry has been challenged to improve its operations staff training practices during the commissioning and handover of buildings (Goulding et al. 2011). Furthermore, the construction industry lags behind other industries in terms of leveraging new technologies and innovative practices, which can improve safety, cost effectiveness, quality of life, competitiveness, and productivity (DFEE 2000). The research team for this project took it upon themselves to bring about a change in this status quo and look at how VR implementation can help with different tasks in a construction environment. The specific area of our VR research was operations training. Our team developed a VR environment for the Switchgear room of the West Central Utility Plant that was being built by Mortenson Construction on the University of Washington Campus.

Training is a major expense in system operations. The time and resources associated with the development of competence in controllers and maintenance personnel represent a substantial component of overall costs. Maintenance itself requires down-time periods, which impact the use of facilities and decreases end user productivity. Consequently, alternative and improved methods of training, which also provide augmented support for operations, promise to provide a significant return on investment (Flexman and Stark 1987). The emerging properties of virtual reality provide an opportunity for immersion in three-dimensional, computer-generated worlds and hence a new opportunity to address the problem of operator training for disruptive or dangerous events (Kozak et al. 1993).

For the West Campus Utility Plant VR study, the Switchgear VR environment we developed was a 'scenario-based' interactive learning experience. From a training perspective, taking advantage of a VR interactive environment can often provide the means to get learners to experience the training objectives (Magerko et al. 2002), which supports learning transfer as well as accelerate learning (Jarvis et al. 2009). Thus, an 'ideal' VR interactive training environment should appear realistic to its real-world counterparts with specific set of actions available to the learner, thus simulating the experience as though it is experienced firsthand.

Each time the learner enters the environment, different instructions and interactions would lead to different experiences and outcomes, thereby maximizing the learning experience. Moreover, the inherent cost related to VR is the hardware, software, and the development of the interactive VE needed to conduct training. VR removes the financial dangers involved if something physical happens to the actual building equipment during training. Therefore, VR has a potentially greater return on investment (ROI) than traditional training practices in the field used in training for infrequent disruptive events.

The following table below summarizes the literature on training in Virtual Reality. The value and benefit for VR training varies as per the types of tasks and training scenarios. One conclusion to draw from this literature is that VR-based training needs to be strategically designed for the desired learning outcomes:

No	Title	Author, Year	Results
1	**Construction Industry Offsite Production: A virtual reality interactive training environment prototype**	Goulding et al., 2011	The VR environment did not aim to resolve problems, rather it aimed to allow 'things to go wrong.' Consequently, VR allowed users to 'experience' the resulting implications of mistakes *and* to reflect on those implications as a part of the learning process.
2	**Transfer of Training from Virtual Reality**	Kozak et al., 1993	When reporting learning, there was no significant difference between a virtual reality training group and a group that received no training on a task. However, the group that received real-world training performed significantly better.
3	**Construction Safety Training Using Immersive Virtual Reality**	Sacks et al., 2013	Significant advantages were found for VR training on stone cladding work and for cast-in-situ concrete work, but not for general site safety. VR training was more effective in terms of maintaining trainees' attention and concentration, and was more effective over time.
4	**Transfer of Learning in Virtual Environments: A new challenge?**	Bossard et al., 2008	Research in cognitive psychology and education has shown that learning is linked to the initial context providing a challenge for virtual reality in education or training.
5	**Transfer of Training from Virtual Reality Environments**	Hamblin, 2005	Virtual environments can be effective training simulators for complex assembly tasks although they are less efficient than real-world training. Individual differences such as general intelligence, spatial aptitude, and computer user self-efficacy influence one's ability to learn in a virtual environment.
6	**Virtual Training for a Manual Assembly Task**	Adams et al, 2001	Subjects trained with force feedback performed significantly better than those who received no training.
7	**The Effectiveness of Virtual Reality for Administering Spatial Navigation Training to Firefighters**	Bliss et al., 1997	Virtual reality training, if constructed and implemented properly, may provide an effective alternative to current navigation training methods.

Table 1. Summary of Literature for VR-based Training.

2 RESEARCH METHODOLOGY

This VR training study focused on comparing conventional switchgear training with VR switchgear training. The conventional training included training through in-person sessions and videos. For the VR training, we conducted a pilot study where operators wore the VR headset and completed VR-based switchgear training that our team developed. Each operator's interactions and movements in the virtual environment were monitored as they completed the training. During the VR training, our team also used a talk out-loud script and asked the operator questions about the VR experience. After the training, operators were asked for their recommendations for VR training and we requested that the operators complete a learning matrix.

Four operators participated in the VR lock out tag out pilot training. As the operators needed to stay in the Central Plant building during their shift, the research team set up the VR system in the Central Plant building. During VR training, researchers recorded each operator's movement, interactions, and comments with the help of a GoPro. The study used a "talk out loud" approach to have the operators talk about what they were seeing and thinking about. This captured their reactions while they were interacting with the virtual world and training sequence. After the VR training exercise, operators were asked to fill out an individual experience survey.

Figure 1. Research Process.

VR Development

Developing realistic content for VR is time consuming. Fortunately, construction companies can leverage the use of BIM to create virtual environments. A typical timeline for developing a VR environment is about two weeks if the 3D models for a building are already developed through other design activities.

The building used in our pilot study was the West Central Utility Plant, under construction by Mortenson on the University of Washington Campus. The utility plant is an emergency power and cooling distribution plant serving buildings on the west and south part of the campus when the main Central Utility Plant on the campus is offline. Different scenarios were considered for implementing VR at different stages of construction. After our discussions with the operators and taking into consideration their values and concerns, we embarked upon developing training on the LOTO (Lock out and Tag out) procedure for a switchgear assembly. We chose the LOTO procedure for the switchgear assembly because it is critical to the overall operations of the plant; however, the procedure is conducted infrequently, leading to a need for continuing training. Furthermore, the operators will not visit the WCUP on a regular basis, so VR training would provide a method for them to periodically review the WCUP layout and procedures. In addition, mistakes made during the LOTO procedure can lead to serious physical harm making this a good procedure to practice in VR.

The work flow for developing the virtual environment is shown below:

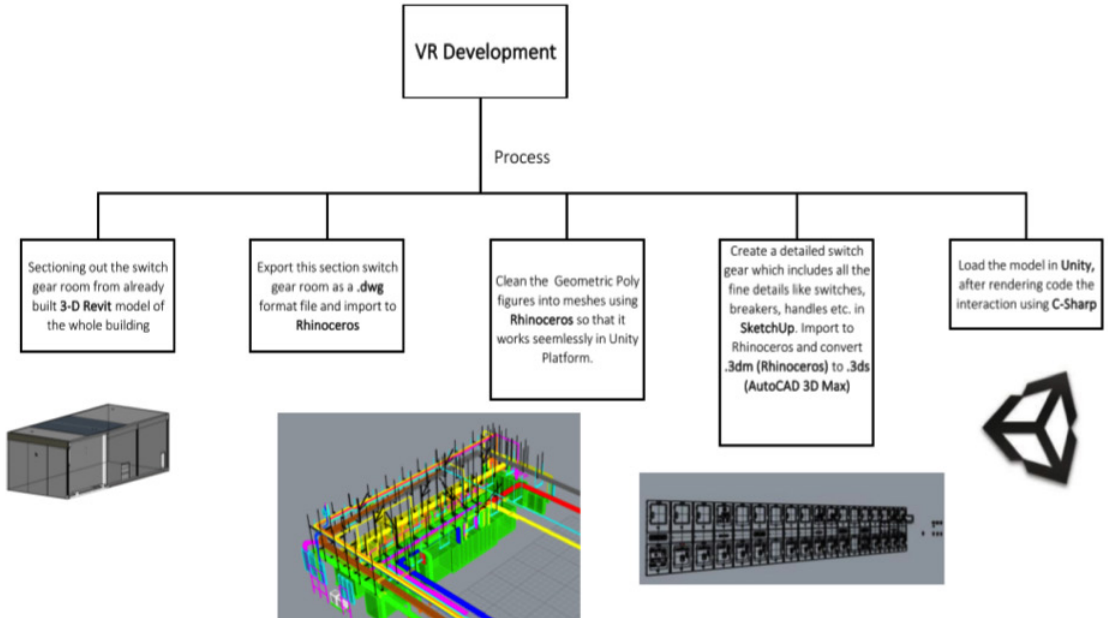

Figure 2. VR Development Work Flow.

Data Collection

For data collection, our team implemented the pilot study followed by the survey. Four operators participated in the survey. We sought to include twelve operators in this study but on the VR study day only six of them were present. Of those six, only four people participated to experience the VR training pilot study and fill out the survey.

3 VR PILOT STUDY RESULTS & RECOMMENDATIONS

The following presents our pilot study's results and analysis. First we conducted an orientation and observed VR interaction. Second, we report on the survey results.

VR Interaction (Talk out loud and VR questions)

The first step in the VR interaction was to orientate the facilities management staff to the VR tools. They were provided instructions on how the environment was set up, how the headset and hand controls worked, and the task that they would perform in the environment. Throughout this interaction, the staff where asked to talk about their experiences in VR. Some of these responses included the following reactions:

"WOW!! This is great. I can see the value proposition of this being used as a training tool. For me VR training would be a complement in use for low risk and more frequent operations and replacement for high risk and less frequent operations" - Operator

"Ohh Whoaa, this is amazing. VR as a tool will be great help for me to use to tour facilities and being familiar with them because I don't usually leave the Central Utility Plant" - Operator & Plant Manager

In terms of the VR experience, the majority of operators found the VR training valuable (see Figure 3 below).

- Operators had a good experience with VR training and they saw its value proposition being used in the future. Three out of four of the operators found the VR training tool as valuable and having a lot of potential. Two of them found it to be informative, while the other two preferred their in-person training to VR.
- Operators expressed diverse comments on what was important to get right in the virtual environment. One operator felt that the rendering was very important to make it look life-like. Two of the operators valued getting the spatial understanding and experience right and two valued getting the step by step process right as it was the most important part of the training.
- Two of participants agreed that VR training could be used as a supplement and enhancement to in-person training, rather than VR taking over the in-person training completely. Also, two of them valued it being used for learning new operations in a safe and accident-free environment.

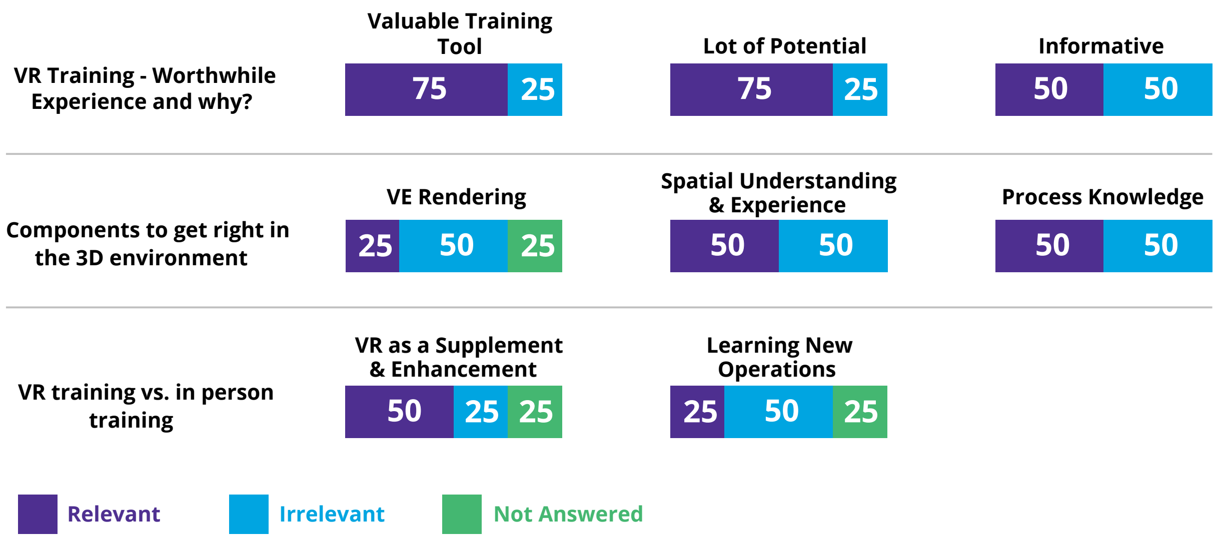

Figure 3. Value of VR Training for West Campus Utility Plant.

Survey Section 1 (Testing base knowledge after completing training)

The results of the talk out loud VR experience indicated that VR training may indeed be beneficial for gaining and retaining knowledge during training. The survey measured what the operators learned while in VR. This section contained the following six technical questions about the operations procedure of Lock out and Tag out:

1. **What is the first step to open Bus B for maintenance?**
2. **If you wanted to take out of service, the B bus terminal what procedure would you follow?**
3. **When closing Bus B, what does the red light on the switchgear breaker control panel indicate? If it is on, what is your next step?**
4. **If the green light on the switchgear breaker control panel is on, what does that indicate? If it is on, what is your next step?**
5. **What is different on the main breaker CBSC switch on the VTWGC - MAIN as compared to the other switches?**
6. **Why is the main breaker (WGC – Main) different?**

One caveat to our results indicating that VR might be beneficial were the responses to question six of the survey. For this question, one operator had an incorrect response and two operators did not answer the question. The research team had considered question six to be the most important since it was a step in the training that was different from traditional plant operations of a switchgear. As we centered the VR training on this question, we expected the learning outcome to be high. However, despite this result, the responses to the other five questions indicate that VR training did help these operators increase their knowledge base and retain knowledge around operations procedures. It should be noted that the operators taking the VR training did not have prior training on West Campus Utility Plant operations and therefore did not have prior knowledge of these operations procedures.

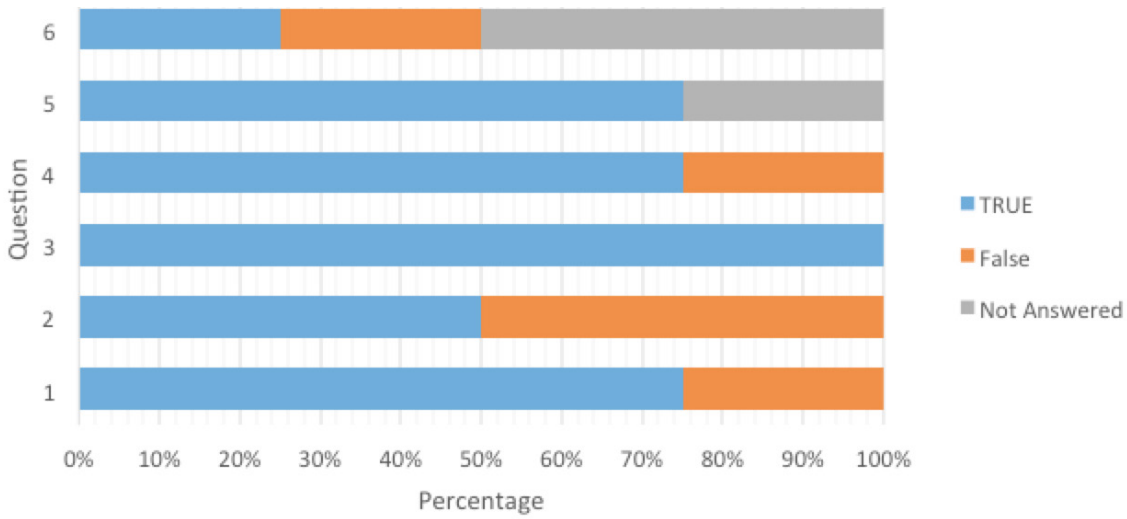

Figure 4. Staff Learning from the VR Training.

- Three of the operators answered the first question correctly, indicating that they fully understood the first steps of the procedure after successfully completing the VR training.
- Two of the operators had a correct response to the second question, while the other two were incorrect. This indicated that the knowledge retained during the training for this specific process was average.
- All of the participants were correct on question three, indicating that they fully understood what was being conveyed.
- Three of the participants answered the fourth question correctly indicating an above average learning for that particular part of the switchgear procedure.
- The operators who completed the fifth question answered it correctly, indicating above average learning for that particular part of the process.
- The sixth question only received one correct response. One operator provided an incorrect response, while half did not answer the question. The low level of response rate to this question may be due to the operators not fully understanding the question.

Survey Section 2 (Future Recommendations)

The following list represents operator recommendations for improving the VR training experience:

- Rendering of human hands instead of the blocks at the front of the controller in the VE.
- Having a wireless HMD VR system.
- Better key-pad arrangement and more detailed steps for the procedure.
- Haptic feedback to know the feel of a breaker switch being tripped.

Survey Section 3 (Learning Matrix)

The learning matrix was developed to better understand the impact of VR training. This matrix asked operators to rate their own knowledge and experience gained in VR training. We then calculated the mean value across the completed learning matrices (see table below). The data for this section of the survey indicates that prior knowledge of the system was low. Then, operators indicated that they had had significant increase in learning from the VR training. This signifies that VR training has the potential to be a successful learning tool.

Prior Knowledge		**Mean**
	Relationship between the main bus and individual breakers	**1**
	Connect to paralleling gear	**0.75**
	Difference between CBSC switches	**1.5**
	Bus systems	**0.25**
	Safety procedures (safely operating switchgear)	**0**
	Meanings of the different light signals	**0**
VR Training	Relationship between the main bus and individual breakers	**3.25**
	Connect to paralleling gear	**3.25**
	Difference between CBSC switches	**2.25**
	Bus systems	**2**
	Safety procedures (safely operating switchgear)	**2.5**
	Meanings of the different light signals	**2**

Table 2. The Learning Matrix.

4 CONCLUSION

Team Building and Partnership

This research project aimed at validating the possibility of using VR in the construction industry, especially as a training tool for the operators on a site. The results were sometimes mixed in regards to VR's learning outcomes, however self-rated learning outcomes indicate a significant advantage for VR. Furthermore, its advantage as a safe virtual space to make—and learn from—mistakes means it has significant potential to be an effective supplemental training tool.

The results of the pilot study and survey does have its limitations in drawing direct causal links between VR training and successful educational outcomes and learning retention. Specifically, our sample size in this research was too small to make conclusive remarks. Future studies with Mortenson and the University of Washington should focus VR training on a work activity or procedure that could potentially be used/operated by a larger number of people. This would increase the potential participant pool and data sample size. Another method of increasing the sample size would be to focus on a type of building that had larger numbers of potential operators involved.

Despite these limitations, this pilot study explored a new dimension of VR for construction practices and training. The value of VR training for building operations would be for training operators on infrequent operations and potentially dangerous activities. This allows operators to practice to both be familiar with the building layout and components as well as practice dangerous activities in a safe way. It shows that there is a strong potential for VR to play an important role in training and to do so in way that educates operators effectively, efficiently, and—most importantly— in a safe working environment.

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6 APPENDIX

Talk Out Loud Session

- **Step 1:** Provide orientation to the VR interface including headset and hand controls
- **Step 2:** First Guided walk through then test scenario: Ask them to conduct a lock out tag out a breaker (question asked within VR). Ask them to Talk Out Loud throughout.
- **Step 3:** In VR questions:
    1. Has the VR training presented a worthwhile experience to you and why?
    2. Thinking about graphical accuracy – what components do you think are important to get right in the 3D world?
    3. What will drive you to use VR training over the in-person training?

Survey

Section 1: Training Procedures

(Refer to Appendix for pictures of the switchgear)

1. What is the first step to open Bus B for maintenance?
2. If you wanted to take out of service, the B bus terminal what procedure would you follow?
3. When closing Bus B, what does the red light on the switchgear breaker control panel indicate? If it is on, what is your next step?
4. If the green light on the switchgear breaker control panel is on, what does that indicate? If it is on, what is your next step?
5. What is different on the main breaker CBSC switch on the VTWGC - MAIN as compared to the other switches?
6. Why is the main breaker (WGC – Main) different?

Section 1: Response

Question #	True	False	Not Answered
1	3	1	0
2	2	2	0
3	4	0	0
4	3	1	0
5	3	0	1
6	1	1	2

Section 2: What are future recommendations?

1. What would you like to improve in the VR training experience with regards to process (sequence of operations)?
    a. With regards to System (which breaker, elements, visual signals)?
    b. With regards to Safety?
2. What more technical information related to the training would you like to see in VR? e.g. access to training manual in VR
3. Would you recommend the VR training as complement or as a substitute to the in-person training? Why?

Section 3: Matrix for VR vs In-person Training

(Rate your learning based on a Likert scale)

1: don't get it yet 2: a little learning 3: some learning 4: more learning
5: completely understand KT: knew from prior experience with plant operations

Rating	**1**	**2**	**3**	**4**	**5**	**KT**
Relationship between the main bus and individual breakers						
Connect to paralleling gear						
Difference between CBSC switches						
Bus systems						
Safety procedures (safely operating switchgear)						
Meanings of the different light signals						
Relationship between the main bus and individual breakers						
Connect to paralleling gear						
Difference between CBSC switches						
Bus systems						
Safety procedures (safely operating switchgear)						
Meanings of the different light signals						

Section 3: Response

	Person 1	Person 2	Person 3	Person 4
In-Person				
Relationship between the main bus and individual breakers	1	2	0	1
Connect to paralleling gear	1	1	0	1
Difference between CBSC switches	1	1	1	3
Bus systems	0	1	0	0
Safety procedures (safely operating switchgear)	0	0	0	0
Meanings of the different light signals	0	0	0	0
VR-Training				
Relationship between the main bus and individual breakers	1	3	5	4
Connect to paralleling gear	1	2	5	5
Difference between CBSC switches	1	4	1	3
Bus systems	0	3	1	4
Safety procedures (safely operating switchgear)	0	2	5	3
Meanings of the different light signals	0	3	5	0

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