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SYSM-5620 Final Paper: Photo Kiosk

S. M. McGee

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Sean McGee

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Introduction

Hiring a wedding photographer is one of the most expensive aspects of a wedding, and for good reason: where other expenses contribute to making the event as enjoyable as possible for the couple and their guests in the moment, the photography provides a lasting record. It is the lens (no pun intended) through which the event will be remembered for decades or more, by both those who attended and those who could not.

Professional wedding photographers are experts in capturing the sights, important moments, and feelings of a wedding, but there are limits to what they can produce. While staged group portraits of the couple's family and wedding parties are expected, other subgroups of guests are less likely to be photographed together by a professional photographer with a strict schedule to keep.

Additionally, while photographers commonly prompt subjects for a few informal shots ("Time for a silly one!"), this is still inherently limited by the fact that subjects know they are posing for a professional photographer. Even when the subjects, poses, and background of a photo are determined by the couple, the artistic authority of the photograph still belongs to the photographer: they determine how to frame the subjects, where to focus, and when to trigger the image capture. This is even more true for candid photos taken during the reception, where the photographer must not only capture *objectively* the people and events as they occurred, but the *subjective* feeling of being in the room.

Needs Statement

While wedding photographers take many high-quality staged and candid photos during a wedding, 60% of couples report that their favorite photo taken during their wedding was taken by a guest using a smartphone camera. Photos taken by guests are typically low-quality and may not be shared with the wedding couple. **There is a need for wedding couples to enable their guests to capture and share high-quality, emotionally authentic photos with creative autonomy during the wedding.** Wedding guests should feel encouraged to take fun, creative photos which will be shared with the wedding couple to supplement the photos taken by a professional photographer.

Current Situation

Current Systems and Operations

The current de facto solution is the use of smartphones to capture photos. Their ubiquity ensures that nearly every guest will have a smartphone camera with them at all times during the wedding. This allows guests to compose their own photos of the wedding, documenting the event from their perspective. From the perspective of a guest being photographed by another guest. this also puts the camera in the hands of a friend, allowing them to be more comfortable and spontaneous. While modern smartphones take high resolution photos, their dynamic range is lacking and their small image sensors generate significant noise which must be reduced by aggressive denoising algorithms. This results in photos that have reduced detail despite their resolution. Smartphone

cameras also produce images with lower bit-depth and dynamic range compared to professional cameras.

Another popular option is to provide guests with a small number of instant film cameras placed around the venue. This offers some of the same benefits as smartphone cameras: guests are made more comfortable by the fact that they are being photographed by someone they know. The promise of a nostalgic keepsake in the form of the developed photo encourages guests to photograph memorable moments, but every photo kept by a guest is necessarily not provided to the couple. Additionally, the image quality of such cameras is lower than that of smartphone cameras. At $10-20 per each, disposable film cameras provide a more affordable alternative to instant film cameras while also ensuring the wedding couple gets to keep the photos, but come at the cost of even lower image quality.

Rental photo booths are an option in this space that has seen a boom in popularity. Guests stand in front of the device which takes several sequential photos using its onboard camera. These photos are then printed out for guests to keep. This is a fun alternative to other solutions and makes taking larger group photos simpler. Like instant film cameras, though, photo strips kept by guests may not be shared with the wedding couple. The onboard cameras featured on most such systems are also not significantly higher quality than a typical smartphone camera.

Something all of these systems have in common is a deficiency of provided lighting. With most weddings occurring indoors and in the evening, a lack of natural lighting is to be expected. Since most of the above systems have reduced low-light performance, this lack of additional lighting exacerbates other issues with image quality.

Deficiencies and Opportunities

Current solutions excel in some areas, but there is a gap in their capabilities which can be targeted by a new system. This system should:

- Use a high-quality camera to improve noise, resolution, dynamic range, low-light performance, and editability
- Share all photos with guests as well as the wedding couple
- Provide a sufficient amount of high-CRI lighting in low-light conditions

Stakeholder Analysis

Stakeholder Identification

Active Stakeholders

WEDDING COUPLE: The wedding couple have the most obvious, direct stake in the system. They determine nearly all aspects of the system's operational environment, including its location, lighting, and when the system may be used. The body of photos produced by the system constitutes a substantial portion of the lasting record of their wedding.

Photographic Subjects: Wedding attendees who elect to be photographed by the system are doing so to contribute to the recorded memories of the wedding for the couple and for themselves. They expect to receive a copy of their photos. They should be given the latitude to arrange their own photos: who will accompany them, where and how they arrange themselves, and the emotional tone. They expect to know when the photo will be taken, and what will be in frame and in focus.

System Operator: The system operator is the individual actuating the functions of the system during use—typically, this will one of the photographic subjects triggering the capture of the image they are posing for. Because the system operator will have little to no training using the system prior to the event, system operation must be as simple and obvious as possible.

System Maintainer: The system maintainer is responsible for performing maintenance activities on the system to keep it functioning during use. They resolve any issues or errors encountered by users during the event.

System Transporter: The system transporter is responsible for delivering the system to the venue and setting it up for operation, as well as tearing it down and removing it from the venue. Damage to the system during delivery and setup may prevent its use altogether, so safe handling during these processes is critical.

Passive Stakeholders

Wedding Guests: Guests expect to be able to enjoy their loved ones' wedding with as few distractions as possible. As such, operation of the system must not interfere with their enjoyment of the event. Additionally, the system must not pose hazards (esp. tripping) to guests in its vicinity.

Wedding Photographer: The wedding photographer must be able to perform their duties without interruption due to the system. To this end, the system cannot interfere with the operation of the photographer's equipment or pose an eyesore in the background of photos.

Venue: Any damage to the premises caused by the system would be inflicted upon the property of the venue. Additionally, the venue may be held liable for injuries caused by the presence of the system during the event.

Stakeholder Requirements

See Table 1 in Appendix I: Tables.

Acceptance Criteria

AC1: The system must provide the wedding couple with digital copies of all photos.

The primary function of the system is to add to the cumulative body of photography from the couple's wedding. Failure to provide these photos to the wedding couple is a non-starter for any system concept.

AC2: The system must provide guests with digital or printed copies of their photos.

Encouraging guests to engage with the system will leave them with the impression that they will get to keep copies of their photos. Not making these will leave guests disappointed and discourage others from using the system, defeating its purpose.

AC3: The system must produce high-quality images.

The system is designed to provide a superior end product compared to existing systems. If the system cannot capture higher quality photos than a smartphone camera, its utility is significantly limited.

AC4: The system must not interfere with other wedding photography.

The system is not designed to replace the photos captured, curated, and edited by a professional wedding photographer. As such, the system must not interfere with any other methods of photography at the event.

Concept for the Proposed System

Concept Generation

There are a number of solutions to achieve each of the system's primary functions. These are broken down into the following categories.

Camera

Perhaps the most critical component of the system is a digital camera to capture images. Three options are considered:

WEBCAM: Webcams are a great solution for easily capturing and storing images over USB. High resolution webcams are available, but even these higher-end models generally feature poor low-light performance.

DSLR: A DSLR camera is an obvious choice where high quality images are required. Interchangeable lenses and compatibility with photographic flash systems are also advantageous. However, DSLRs do not integrate with external control as easily as other options.

CAMERA MODULE: A camera module (such as the Raspberry Pi High Quality Camera) are designed to be easily integrated into and interface with other electronic components. Image quality is roughly on par with webcams but offer lower-level control, interchangeable lenses, and reduced price point.

Control System

A control system forms the center of the design. It is responsible for tying all other components together and coordinating their functions. Three options are considered:

ARDUINO: Using an Arduino microcontroller board is a simple and cost-effective means of accepting user inputs and interfacing with electronic components. However, their processing power and memory are lacking compared to alternatives.

Raspberry Pi: Single-board computers (SBCs) like the Raspberry Pi 5 share some of the Arduino's flexibility in terms of programmable GPIO pins and feature significantly improved performance. Their small size and low price are also appealing.

Laptop: Using a laptop to interface with other components offers the greatest performance of any options under consideration. The integrated LCD display would greatly simplify creation of a user interface.

Lighting

Subjects must be sufficiently illuminated to be photographed. There are several possible methods of delivering that light.

Natural: Provided the system is equipped with a high-quality camera with sufficient low-light performance, it is feasible to use the light already present in the space to light subjects. However, this lighting may not be consistent in intensity over time, cast shadows on subjects, or may not be color-balanced for photography.

Flash: A camera flash for still photography can provide high quality lighting and easily integrated into the system if the camera chosen is a DSLR. Other camera systems will require additional equipment to trigger the flash. The strobing flash may prove distracting to guests.

LED Panels: Large, powerful LED panels are available with high color rendering index (CRI), commonly used for filming videos. These draw considerably more power than the flash mentioned above since they are not easily toggled on and off electronically, but the constant light output is considerably less distracting.

Trigger Mechanism

Operators of the system require some method of initiating the photo capture process. This method must be very quick and simple to explain and understand since operators will have no experience with the system before the event.

Shutter Release: A shutter release button attached to the system by a cable is a simple and effective solution featuring high reliability and easy implementation. Being attached to the system by cable introduces potential for guests to trip or snag the cable, pulling the system with it. The shutter release itself also must be held by the operator, meaning it will appear in all photos.

Motion: Making a recognizable gesture (e.g., waving, thumbs up) is a great solution for avoiding including cables and devices in photos. It is more difficult to implement, especially when high reliability is required.

Sound: Similar to motion activation, sound activation avoids the presence of a wired switch in all captured photos. It is more difficult to implement than a switch, but easier than motion activation.

Touchscreen: A touchscreen would allow the system to implement a highly intuitive interface to communicate with operators, and using this interface to trigger the image capture process would be simple. This requires the operator to approach the device, returning back to the frame during the countdown.

FOOTSWITCH: As an alternative to the handheld shutter release above, a footswitch can be placed on the ground so operators can step on it to begin the countdown. Placement of the footswitch near the focal plane also subtly hints to guests where they should stand to be in focus. Being near the bottom of the frame also makes the footswitch less visible than the handheld version.

Guest Access Method

While storing digital copies of photos is the only reasonable way of sharing photos with the wedding couple, wedding guests using the device are not as limited.

PRINT: Printing photos (similar to more conventional photo booths) makes the device very engaging and appealing for guests. Their photos contribute to the memories of the couple while also providing them with a keepsake of the event. The cost of the printer, photo paper, and ink make this a very costly addition to the system.

EMAIL: Emailing photos to guests is a very simple solution, but requiring every subject to enter their email addresses after every photo would dramatically reduce the throughput of the system.

MMS: Because phone numbers are shorter than email addresses, sending photos to guests via MMS message reduces the slowdown associated with guests entering email addresses. Photo size and quality may be limited by the message format.

QR CODE: Uploading photos to an online server allows guests to access them quickly and easily using their smartphones. This avoids the need to send many large files to dozens of guests over the course of the event.

Concept Selection

See Table 2, Table 3, Table 4, Table 5, and Table 6 in Appendix I: Tables.

System Context

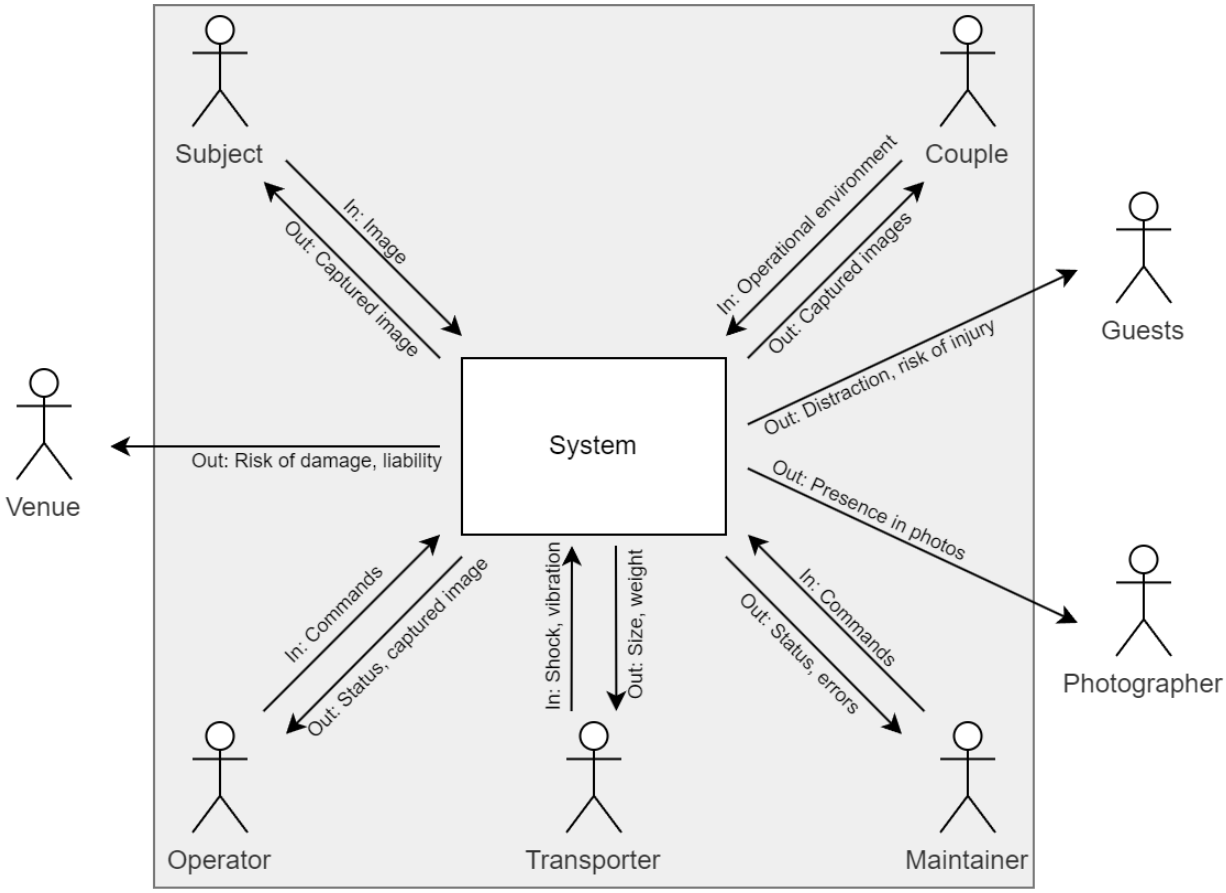

Figure 1: System context diagram

Operational Scenarios

Taking Photos

The primary function of the device is to take photos of groups of wedding guests. Guests arrange themselves in front of the kiosk, at which point one of them becomes the device operator by activating the footswitch. The kiosk begins a 5-second countdown which is displayed on the screen. At the end of the countdown, the kiosk captures the image, stores it on a local drive, and displays a preview of the image to the participants. The image is then uploaded to a remote server, and a link to access the server is displayed as a QR code so guests can download the photo on their own devices.

Retrieving Photos

Once the event has ended, the wedding couple may review all photos taken by the device. Upon reviewing them, they can select their favorites to download. These can be edited and reuploaded to the server, where they will be available to all wedding guests via QR code.

Performing Maintenance

Errors may occur which prevent the device from performing its functions, such as failing to communicate with the camera. In this case, the device displays a message which prompts the operator to seek out the maintainer to resolve the error. The maintainer can then enter a diagnostic mode, at which point the device will display an error code explaining more information about the error and some steps to take to alleviate the issue.

Use Case Model

See Figure 4 in Appendix II: Figures.

Use Case Specification

See Figure 5, Figure 6, Figure 7, and Figure 8 in Appendix II: Figures.

QFD Analysis

See Figure 9 in Appendix II: Figures.

System Requirements

See Table 7 in Appendix I: Tables.

Functional and Physical Architecture

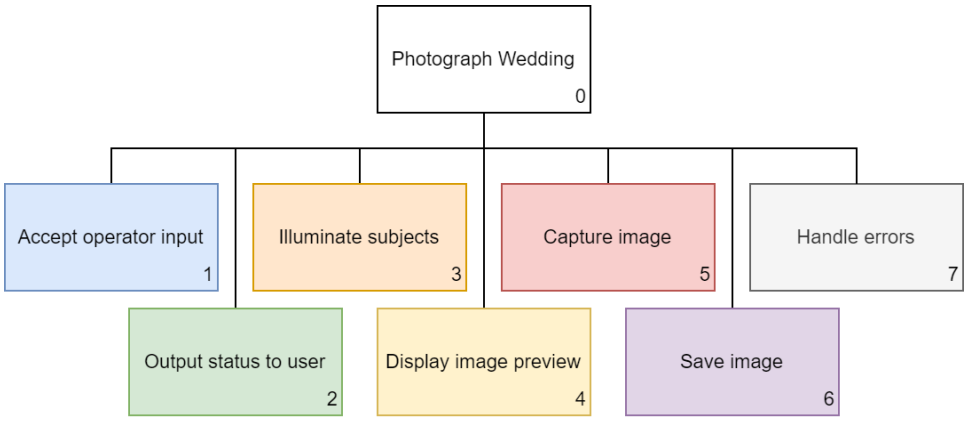

Figure 2: Functional decomposition

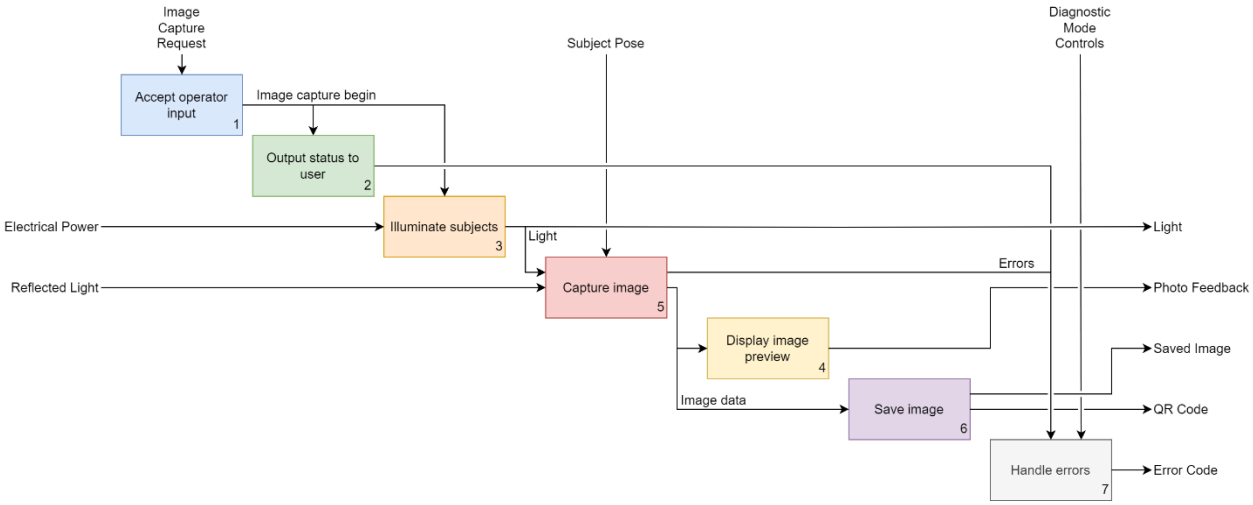

Figure 3: Functional architecture

Risk Assessment

Risk A: Internet Connection

RISK: The system requires an internet connection to execute all of its functions. As such, failing to make or maintain an internet connection during the wedding would constitute a very significant failure of the system.

MITIGATION PLAN:

1. Access the internet using both ethernet and Wi-Fi connections. If both are available at the venue, this provides a backup in case one is unreliable.
2. Store additional copies of all photos on a secondary local drive. Even if photos cannot be uploaded to a remote server, local backups can keep data safe even if the main storage system fails.

TECHNICAL PERFORMANCE MEASURES:

- Number of internet connection options
- Wi-Fi receiver sensitivity
- Proximity to internet access point

Risk B: Power Loss

RISK: The device will be powered by a standard 120 VAC outlet. If it loses power during operation, it will cease to perform its functions and may lose data in the process.

MITIGATION PLAN:

1. Equip the system with an uninterruptible power supply (UPS). This would permit the device to continue to function for a short time in the event of power loss from the wall outlet. If power returns quickly, the device can continue to function without interruption. If the power

loss is prolonged, the UPS will allow the system to be powered down gracefully, reducing the likelihood of losing data.
2. Equip the device with an extension cord. The number of power outlets and their locations within the venue are both unknown. If the loss of power is from a failure of the outlet itself, an extension cord would allow the system to be powered from a functioning outlet without having to move the device.

TECHNICAL PERFORMANCE MEASURES:

- UPS battery capacity
- System power consumption
- Power cable length
- Extension cord length
- Extension cord maximum current rating

Risk C: Excessive Maintenance

RISK: The system requiring frequent corrective actions from the maintainer creates a frustrating experience for the users and the maintainer.

MITIGATION PLAN:

1. Perform thorough testing of hardware and software during development and integration to reduce the probability of encountering errors during operation.
2. Reduce the amount and impact of custom code used in the system to reduce the likelihood of encountering confusing errors during operation. Where professional or well-vetted open-source code is available, it should be used instead.
3. Implement a simplified "safe mode" which can be utilized in the event of repeated errors. This mode should execute only bare minimum, required functionality. In the event optional functionality is the source of errors, this allows the system to continue to be used and serve its primary functions.

TECHNICAL PERFORMANCE MEASURES:

- Number of edge cases exercised in testing
- Number of code modules required for minimal functionality
- Number of custom-developed code modules

Conclusion

This process has produced a viable starting point for the design of the described system. Concept selection originally compared a few combinations of system components, but these failed to explore all viable system configurations. Comparing component options on individual Pugh charts allowed more permutations to be considered and ultimately led to a better system configuration.

Completing a QFD illuminated some unexpected system objectives. The stakeholder requirements made it clear that the system must prioritize maximizing image quality and data reliability, it was not immediately obvious how these requirements interacted. Images of the required quality are very large files, and minimizing the chances of losing data requires storing multiple copies in multiple places. This requires a nontrivial amount of data transfer speed, which was not clearly required before analysis.

The most glaring lesson learned from completing this process is the tangible benefit from performing it. Parts of the systems engineering process can feel like writing and rewriting the same information in different ways, requiring significant effort for no immediate benefit. Indeed, it can be very tempting to *just get started already*, but the work performed here paves the road for the simplest, cleanest design process possible. Making decisions ad-hoc during the design phase leads to failures in testing and integration, and an end product that is difficult to debug and fails to deliver on achievable goals. Spending the time to analyze and delineate *precisely* what is actually required of the system means the most intractable aspects of designing it are already complete.

Appendix I: Tables

Table 1: System requirements

Active Stakeholders

Wedding Couple

Capabilities

SHR 1.1.1 System shall provide couple with digital copies of all photos.

SHR 1.1.2 System shall automatically calculate exposure settings for all photos.

Characteristics

SHR 1.2.1 System internal structure and components shall be obscured from view when in use.

SHR 1.2.2 Outermost system surfaces shall use only colors listed in document ABC-123.

SHR 1.2.3 System shall be powered by a single standard 120 VAC outlet.

SHR 1.2.4 System image sensor must be at least 12 MP.

SHR 1.2.5 System image SNR shall be at least 4 at ISO <= 6400.

SHR 1.2.6 System shall occupy a footprint of less than 100 sq. ft. during operation.

Photo Subjects

Capabilities

SHR 2.1.1 System shall provide subjects with digital copies of all photos.

SHR 2.1.2 System shall provide subjects a live preview of the image leading up to the moment of capture.

SHR 2.1.3 System shall provide visual indication of image capture within ±0.1 s of capture.

SHR 2.1.4 System shall provide subjects with a visual 5 s countdown leading up to the moment of image capture.

SHR 2.1.5 System shall be ready to begin new image capture within 5 s of finishing image capture.

SHR 2.1.6 System shall support taking group photos of at least 10 people.

Characteristics

SHR 2.2.1 System shall capture and record images with a failure rate of less than 1%.

Operator

Capabilities

SHR 3.1.1 System shall require no input signal from operator after capturing an image to become ready for next image capture.

Characteristics

SHR 3.2.1 System shall provide instructions for triggering image capture.

SHR 3.2.2 System shall accept image capture trigger signals with a failure rate of less than 10%.

Maintainer

Capabilities

SHR 4.1.1 System shall backup all photos to remote server within fifteen minutes of capture.

SHR 4.1.2 System shall store redundant copies of all photos on a secondary local drive.

SHR 4.1.3 System shall provide a visual interface to support performing maintenance activities.

SHR 4.1.4 System shall provide a standard mouse and keyboard for performing maintenance activities.
SHR 4.1.5 System shall prompt operator to contact maintainer if an error is encountered.
SHR 4.1.6 System shall indicate errors using a standardized list of error codes.

Transporter

Capabilities

SHR 5.1.1 System must be collapsible to less than 12"x 18"x24" when not in use.
SHR 5.1.2 System setup and teardown shall require no tools.

Characteristics

SHR 5.2.1 System weight shall not exceed 25 lbs.
SHR 5.2.2 System setup by experienced transporter shall take less than 10 minutes.
SHR 5.2.3 System setup procedure shall require fewer than 10 operations.
SHR 5.2.4 System teardown by experienced transporter shall take less than 15 minutes.
SHR 5.2.5 System teardown procedure shall require fewer than 15 operations.
SHR 5.2.6 System shall survive 12" drop when packaged for transport.

Passive Stakeholders

Wedding Guests

Characteristics

SHR 6.2.1 System sounds shall be less than 30 dB as measured from 10' away.
SHR 6.2.2 System light output shall change by less than 100 lm/s

Photographer

Characteristics

SHR 7.2.1 System shall emit no signals in the 340-354 MHz range used by remote flash systems.

Venue Staff

Characteristics

SHR 8.2.1 System hardware components shall be positioned entirely within the system's footprint with no overhanging components.
SHR 8.2.2 System center of mass shall be less than 24" above ground.
SHR 8.2.3 System shall protect all cables extending beyond eternal covering per OSHA §1910.305.
SHR 8.2.4 System shall draw no more than 250 W during operation.
SHR 8.2.5 System shall use replaceable fuse to cut off power if input current exceeds 3A.

Table 2: Pugh chart comparing camera concepts

Traced to Stake. Req.	Criteria	Webcam	DSLR	Camera Module
SHR 1.2.4	High resolution	-1	1	0
SHR 1.2.5	Low noise	-1	1	-1
SHR 1.2.5	Good low-light performance	-1	1	-1
SHR 5.2.2	Ease of camera control	1	0	1
SHR 4.1.2	Ease of camera data transfer	1	0	1
	Overall Score	**-1**	**3**	**0**

Table 3: Pugh chart comparing control system concepts

Traced to Stake. Req.	Criteria	Arduino	Rasp. Pi	Laptop
SHR 2.1.5	Responsive	-1	0	1
SHR 4.1.1	Ease of internet connection	-1	1	1
SHR 2.2.1	Reliability	0	1	1
SHR 4.1.3	Ease of troubleshooting	0	1	1
SHR 5.2.1	Weight of control system	0	1	-1
	Overall Score	**-2**	**4**	**3**

Table 4: Pugh chart comparing lighting concepts

Traced to Stake. Req.	Criteria	Natural	Flash	LED Panels
SHR 1.2.6	Setup location flexibility	-1	-1	0
SHR 1.1.2	Low ambient light performance	-1	1	1
SHR 6.2.2	Low distraction to guests	1	-1	1
SHR 2.2.1	Ease of integration	1	0	1
SHR 8.2.4	Power consumption	1	0	-1
	Overall Score	**1**	**-1**	**2**

Table 5: Pugh chart comparing trigger mechanism concepts

Traced to Stake. Req.	Criteria	Shutter Release	Motion	Sound	Touch	Foot switch
SHR 8.2.1	Reduce risk of damage	-1	1	1	-1	1
SHR 3.2.1	Ease of instruction, learning	1	0	1	1	1
SHR 3.2.2	Reliability of actuation	1	-1	-1	0	1
SHR 2.1.2	Low impact on posing for photo	-1	0	1	-1	1
SHR 4.1.5	Ease of implementation	1	-1	-1	0	1
	Overall Score	**1**	**-1**	**1**	**-1**	**5**

Table 6: Pugh chart comparing guest photo access concepts

Traced to Stake. Req.	Criteria	Print	Email	MMS	QR Code
SHR 4.1.5	Difficulty of implementation	-1	1	1	1
SHR 2.1.1	Access reliability	-1	1	0	1
SHR 2.1.5	Guest throughput	0	1	1	0
SHR 4.1.1	Reduced bandwidth consumption	1	-1	-1	1
	Overall Score	**-1**	**2**	**1**	**3**

Table 7: Table of system requirements

Req #	Description
SR 1	**Input/Output**
SR 1.1	System shall display QR code for users to connect to remote server.
SR 1.2	System shall use a footswitch to activate image capture sequence.
SR 1.3	System shall accept commands from USB keyboard.
SR 1.4	System shall output shutter release signal to DSLR camera via USB.
SR 1.5	System shall receive image data from DSLR via USB.
SR 1.6	System shall output information to users on LCD display.
SR 1.7	System shall accept new image capture request within 5 sec. of previous image capture.
SR 1.8	System shall display instructions to operator.
SR 1.9	System shall output notification of image capture to operator.
SR 1.10	System shall upload photos to remote server within 15 min. of capture.
SR 1.11	System shall publish edited photos uploaded by wedding couple to remote server.
SR 1.12	System shall accept ethernet network connections.
SR 1.13	System shall accept 2.4 GHz Wi-Fi network connections.
	...
SR 2	**Functional**
SR 2.1	System shall take photos of wedding guests.
SR 2.2	System shall upload photos to remote server.
SR 2.3	System shall illuminate photo subjects.
SR 2.4	System shall display 5 sec. countdown prior to image capture.
SR 2.5	System shall save copies of all photos to secondary local drive.
SR 2.6	System shall collapse when not in use.
SR 2.7	System shall obscure internal structure and components from view when in use.
	...

[continued]	
SR 3	**Non-Functional**
SR 3.1	System shall be completed by Q4 2024.
SR 3.2	System shall cost less than $500.
SR 3.3	System shall weigh less than 25 lbs.
SR 3.4	System covering shall weight less than 32 oz.
SR 3.5	System shall provide 6 onboard 120 VAC outlets.
SR 3.6	System shall compress local image files according to ABC-123.
SR 3.7	System shall capture images with bit depth of 12-biut or greater.
SR 3.8	System shall capture images with resolution of 12 MP or greater.
SR 3.9	System shall use lens with aperture rating of f/2.0 or less.
SR 3.10	System shall use lens with focal length between 35mm and 50mm.
	...
SR 4	**Maintenance**
SR 4.1	System shall instruct operator to contact maintainer if an error is encountered.
SR 4.2	System shall communicate errors using code listed in ABC-123.
SR 4.3	System shall recognize CTRL-SPACE as signal to enter and exit diagnostic mode.
	...

Appendix II: Figures

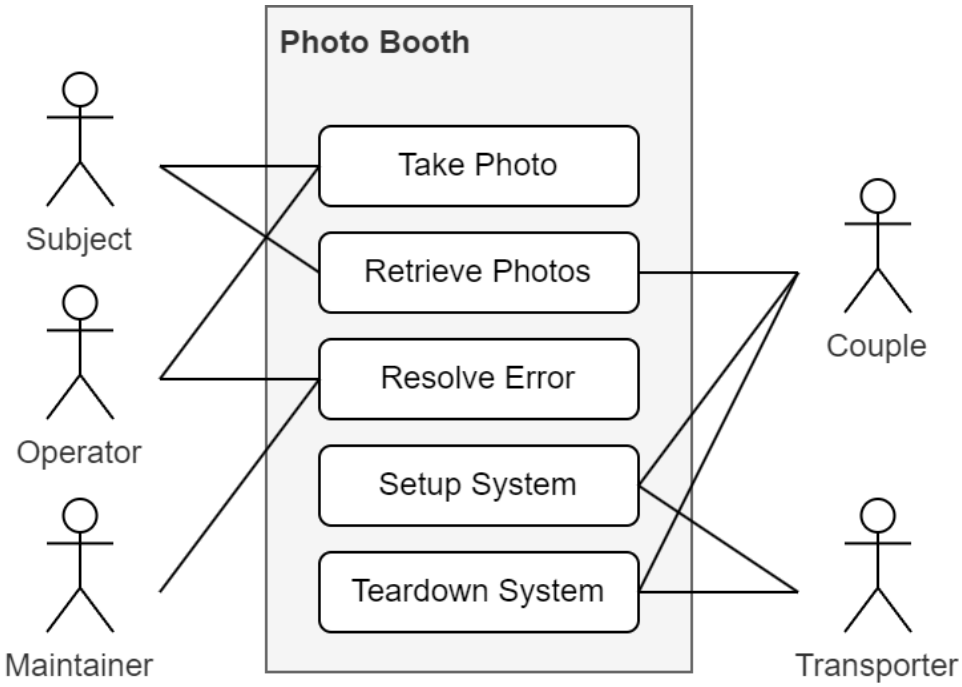

Figure 4: Use case model diagram

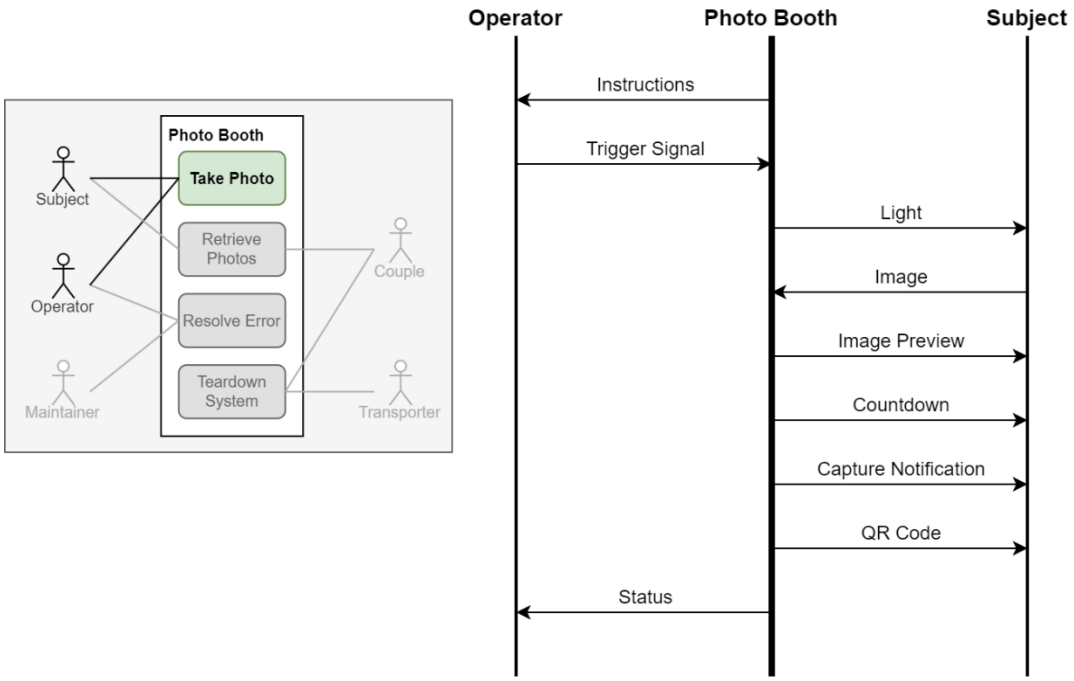

Figure 5: Sequence diagram for use case "Take Photo"

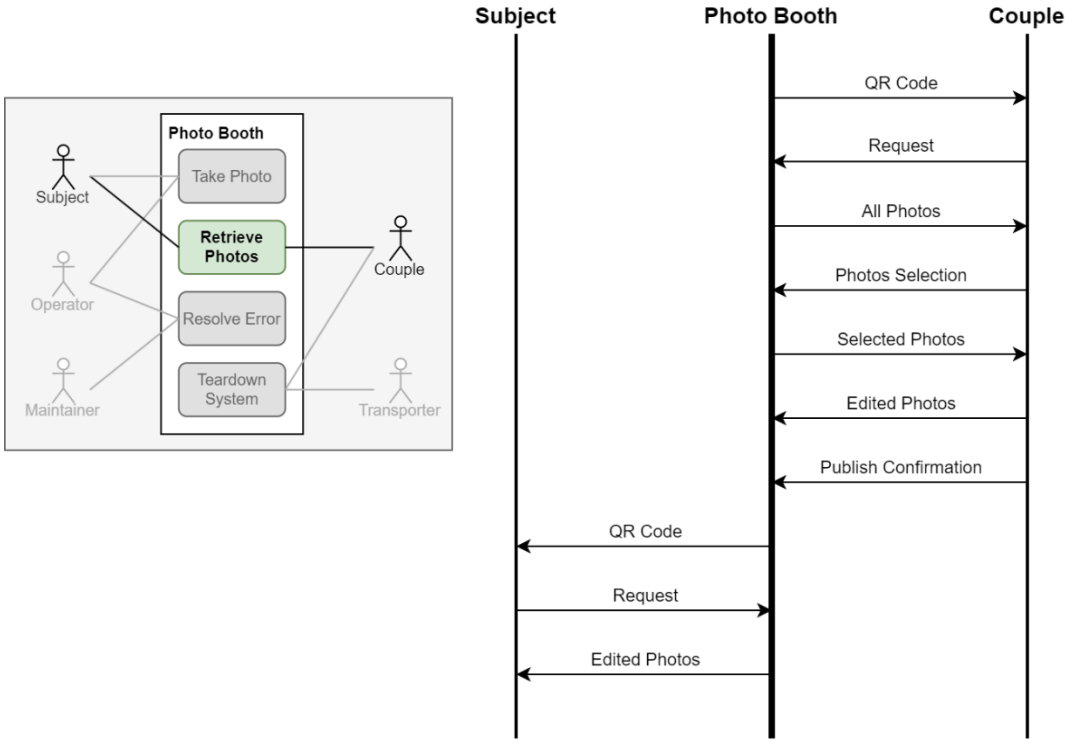

Figure 6: Sequence diagram for use case "Retrieve Photos"

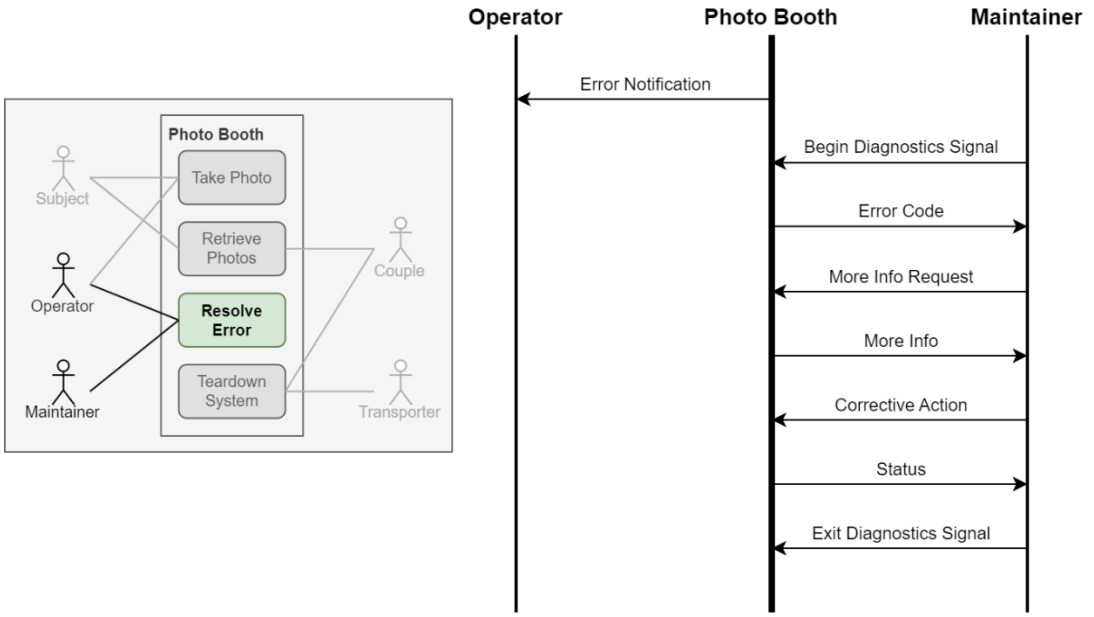

Figure 7: Sequence diagram for use case "Resolve Error"

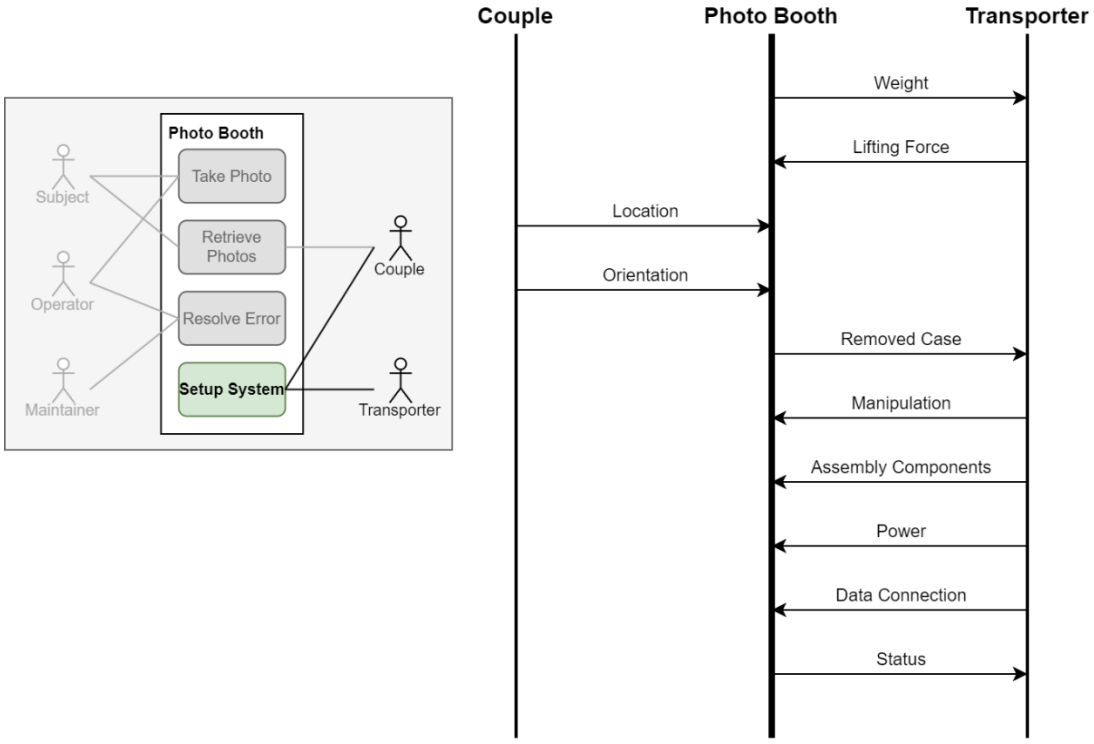

Figure 8: Sequence diagram for use case "Setup System"

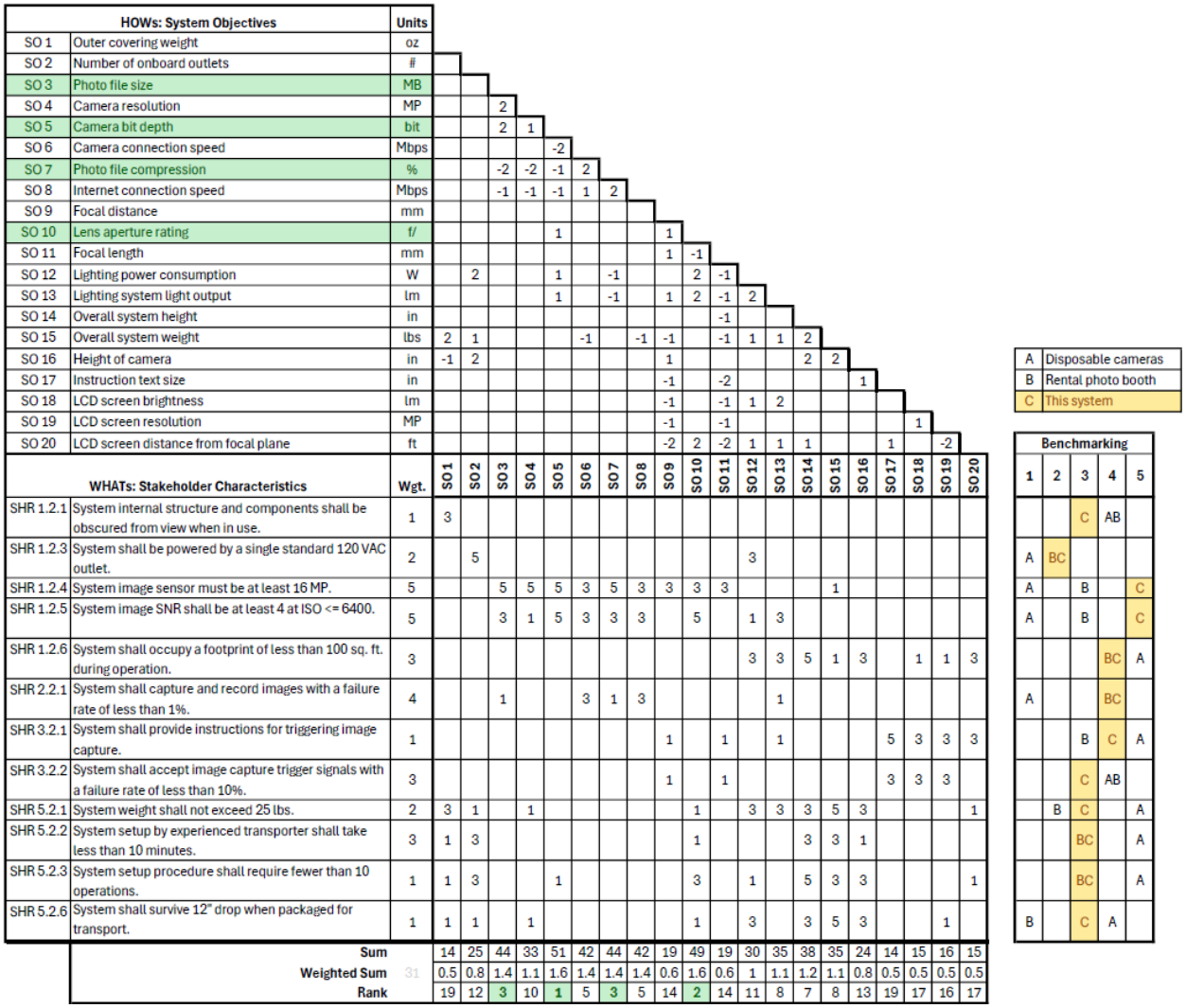

Figure 9: QFD analysis of stakeholder characteristics

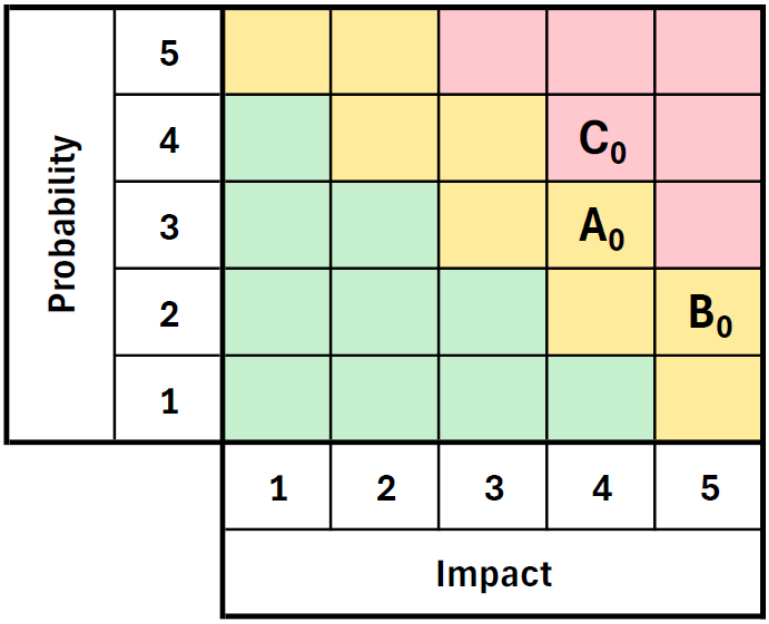

Figure 10: Initial positions of risks on risk matrix

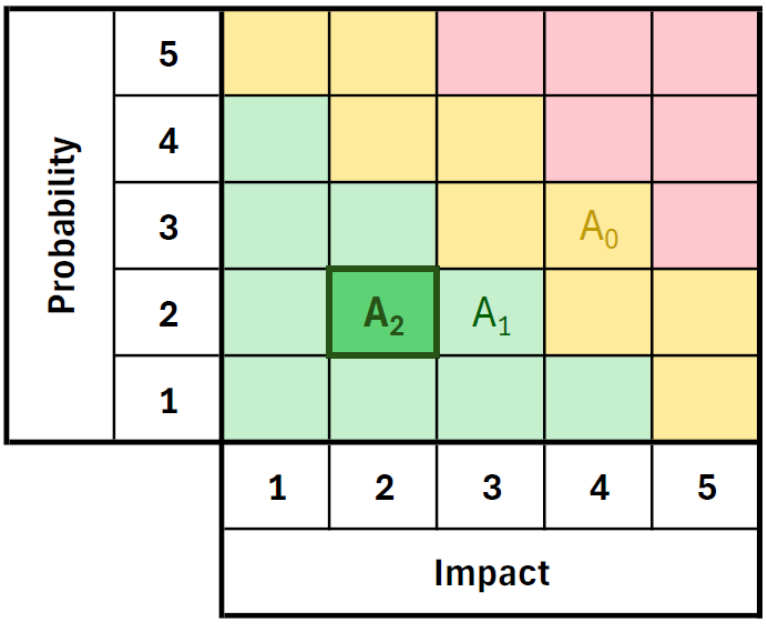

Figure 11: Effect of mitigation on risk of poor internet connection

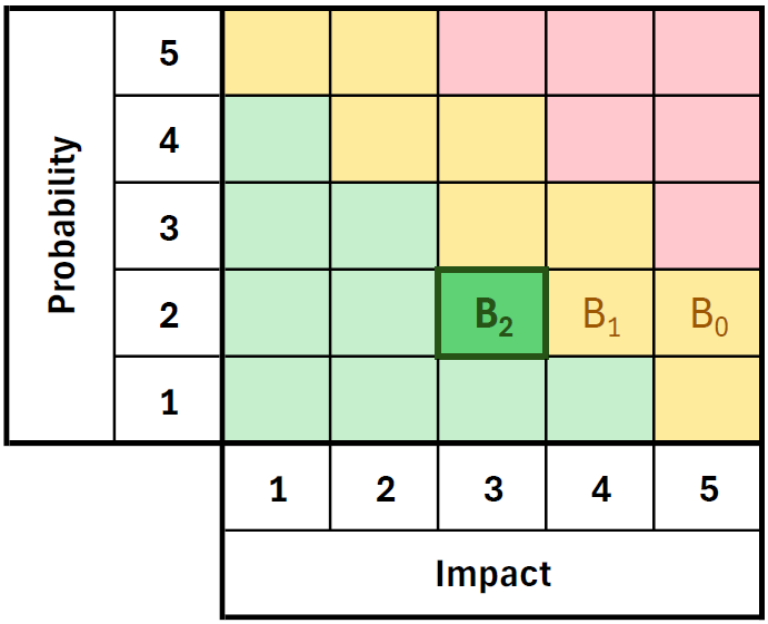

Figure 12: Effect of mitigation on risk of power loss

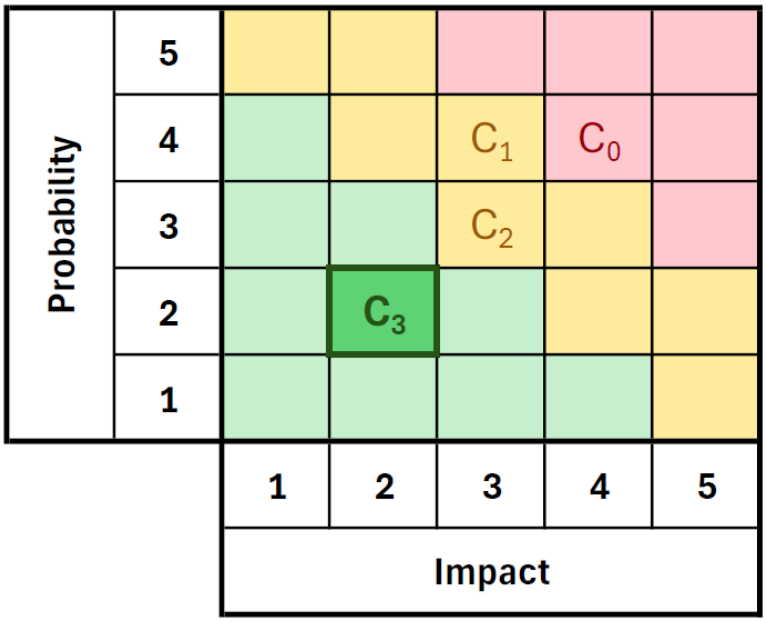

Figure 13: Effect of mitigation on risk of excessive maintenance