## Research Proposal

## Research Title

## The Design and Development of a sports stadium monitoring and management system to provide early threat detection and prevention of cyber threats to Cyber Physical Systems (CPS).

## Supervisors

* First Supervisor: Cathryn Peoples
* Second Supervisor: Doug Millward

## Background

Currently, there exists risks to data confidentiality, integrity and availability (CIA) and to human life within sports stadiums (Benslimane, 2022; Wan et al. 2021). Internet of Things (IoT) connected devices are growing in numbers globally, however the security measures in sports stadiums in which to protect them are not keeping pace (Baker, 2020). Manufacturers and sports organisations are producing these effective and efficient devices, including CCTV cameras, access control systems, and alarm systems, without having sufficient foresight to the consequences of them being breached. In a sports stadium, where many people gather, the results could be devastating. Breached devices could be maliciously used to lure crowds into danger, unauthorised access to turnstiles could result in them being locked, keeping patrons in a bottle necked area, making it easier to launch a subsequent terrorist attack. Video boards, PA systems, or fire alarm systems could be leveraged to spread panic causing thousands of spectators to blindly run into physical traps. Denial of Service (DoS) attacks could be launched to render systems inoperable, causing loss of revenue, dissatisfaction amongst fans and reputational damage to the organisation. Compromise of in-game IoT technology could be used to influence the outcome of a game, and insecure apps and networks could result in patron data being compromised or identity fraud, leading to heavy fines for the organisation.

Attackers able to successfully breach a sport stadium device, data or network, could potentially access any other device connected to that network (Melander, 2017), or even the corporate network from such a foothold. Corporate networks in sports stadiums are generally much better protected than IoT, Operational Technology (OT) or CPS networks (NCSC, 2020), as the effects of malicious activity is well understood and documented. While this is important, it is equally necessary to protect the IoT that controls physical devices.

Sports stadiums are particularly vulnerable targets due to their capacity to hold several thousand people at once in a relatively concentrated area. Additionally, sports mega events are often televised and international tournaments may bring increased attention from hacktivists and provoke politically driven attacks from nation states (Benslimane, 2022).

The National Center for Spectator Sports Safety and Security (NCS4), an academic organisation dedicated to protecting spectators of sport (NCS4, N.D.), have teamed with the Cybersecurity and Infrastructure Security Agency (CISA, N.D.) to provide a diagram where twelve example sports stadium vulnerabilities are described (CISA, N.D.).

These vulnerabilities are listed in Appendix A, with proposed mitigations to be implemented in the prototype model that will be developed through this project. Proposed security controls include:

* Firewalls – To be applied by using an Ubuntu base image and then configuring iptables for that device. Iptables are suitable due their lightweightness. It would be difficult to install a HIPS or software firewall on a small IoT device, and physical firewalls are not feasible for the project.
* Segregated subnets – These will be applied on Docker Desktop as two separate custom bridges. This is to simulate devices of particular importance being isolated from the rest of the network, providing an additional level of protection for specific devices, or providing secure access to the public without compromising the security of the main network. Common implementations of these in the real world would be by employing extranets, demilitarised zones (DMZ), virtual local area networks (VLAN) or guest networks, and could be achieved using firewalls and switches.
* Encrypted data links – Data will be sent between the devices using MQTT. This will include connection messages to check if a device has gone offline, and when it is back online, and will also include distress signals and meter readings. MQTT is a lightweight protocol designed for IoT use and messages will be encrypted using a key generated by the Fernet python module which uses the Advanced Encryption Standard (AES) 128-bit encryption in cipher block chaining (CBC) mode. The data will encrypt the message before sending to the monitor via a public broker. The public broker is a recognised limitation, and in the real world a broker on the local network would more likely be used. Although data encryption is listed only by two or three examples in the diagram, due to a stadium’s relatively small size it makes sense that all traffic within a stadium network is encrypted, especially when any breach of data transmissions could result in the whole network being compromised.
* Firmware upgrade utility – This will be simulated by a text file fetched from a GitHub repository, replacing an existing text file stored in the container.
* Local logins for firmware – Hashed secure passwords will be stored locally in text files within specific containers, and decrypted and compared during log ins.
* Domain-simulated network log ins for software – User details will be stored in an online MySQL database. When attempting to log in, details will be fetched from the database upon entry of a correct username and password combination. These fields will have input validation applied to protect against injection attacks.
* SSH capability for specific users – A Python app will be mounted on an Ubuntu image. SSH capability will be enabled and only users who are permitted access will be allowed to use.
* Monitoring capabilities – A monitoring device will be created to watch continuously for important events across the other devices, so that security personnel can be alerted in real time.

The proposed model of mitigations, as displayed, is to be created using containers built and stored in Docker Desktop. The apps will be coded in Python, and the data transmitted using Message Queuing Telemetry Transport (MQTT), a messaging protocol which allows for low bandwidth and power consumption. MQTT uses a publish / subscribe pattern, sending messages (publish) from a device (client) to a broker, via a network. Subscribing devices then consistently poll the broker for messages.

Devices send and receive the binary data without extra processing, maximising transmission speed across the network, however it is not implicitly secure, therefore additional encryption is required.

MQTT is an available library in Python, is cheap, lightweight, scalable and highly compatible, making it suitable for IoT, and is TCP/IP-based so can guarantee delivery of messages (Solovev & Petrova, 2020).

Where required, Ubuntu base images will be used to provide additional functionality. The containers will be organised as shown in the following network diagram (Figure 1):

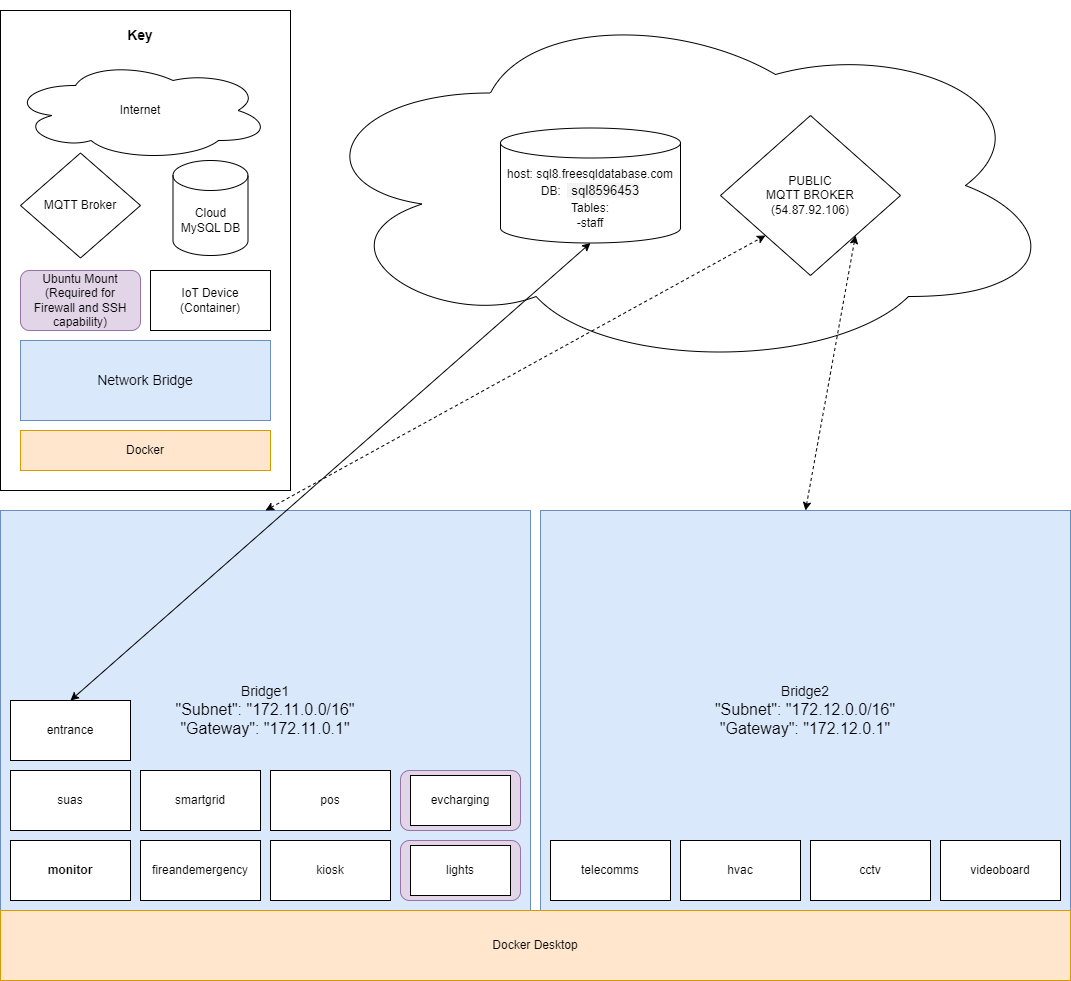


Figure 1: Network diagram

More inter-connected devices make for a more immersive patron experience, however it also increases the attack surface for the stadium network. Therefore, it is imperative they are protected in line with such expansion.

Several methods have been put forward to protect sports stadium IoT devices. Wan et al. (2021) propose an AI-CPS system, based on anomaly detection. This gives good results and may have its uses, however is not 100% efficient and could be argued that human decisions are still necessary where CPS systems, and human safety are at risk. Additionally, artificial intelligence (AI) technology is not always affordable for smaller stadiums and so alternative solutions are required. For larger stadiums, AI could be useful to work in tandem with a monitoring model such as the one proposed through this project.

IoT systems often do not have sufficient processing power or memory to carry out transactions locally, meaning the data are often pushed off over the network connection to computers with higher computational bandwidth (Darling, 2021). Therefore, locally installed security mechanisms such as antivirus are often not useful, however data encryption protection remains paramount.

A study by Khalifa (2020) provided recommendations to invest in data protection technologies in stadiums, including the use of online databases and hiring competent specialists in the field of cybersecurity, and encouraging cyber security awareness campaigns for fans to support efforts.

There seems to be very little regulation for providing cybersecurity measures amongst sports clubs.

Roberts (2019) states that until recently, awareness of dangers around cyber-attacks in stadiums has been lacking and that, with CPS, often the cyber component is not the ultimate target, however is compromised initially in order to carry out a physical attack.

Roberts gives examples of previous attacks, such as the one in 2017 where a fire-alarm system at an American Football Conference (AFC) National Football League match was hijacked, resulting in the fire alarm being sounded causing the Media to evacuate the stadium, and another which disrupted the 2018 Pyeongchang Winter Olympics opening ceremony which brought down Internet access, affected broadcasting, took the official website offline, and resulted in low attendance when fans were prevented from printing out tickets.

A third example is that of a hacker who disrupted CCTV cameras at the Singapore Sports Hub prior to the 2015 South East Asian games closing ceremony.

Nate Evans from the U.S. Department of Energy’s (DOE) Argonne National Laboratory confirms attackers no longer solely use cyberattacks to cause damage to the cyber network, however they use them to inflict physical damage or put people in areas where they can be placed at maximum risk.

The laboratory allows stadium owners to attain credentials for the Department of Homeland Security’s Safety Act program, giving opportunities for strengthening physical and cyber defences, and affording legal protection in the event of an incident (Bukey, 2020).

Evans highlights the importance of physically isolating the controls to each CPS, and understanding systems that are dependent on others.

The above is what has led to the proposal for the Capstone Project, and after this initial review, there does not seem to be a sufficient model in literature to produce an IoT monitoring system to ensure the safe and reliable operation of CPS in sports stadiums.

## Research Questions

1. How can the safety and security of IoT-dependent cyber-physical systems in sports stadiums be ensured.
2. Can the safety of patrons at sports events be ensured by detecting attacks to Cyber-Physical Systems in sports stadiums
3. Can the safety of patrons at sports events be ensured by preventing attacks to Cyber-Physical Systems in sports stadiums
4. How can the above be ensured using IOT technologies and protocols

## Aim

## To design and develop a prototype model which monitors IoT devices in sports stadiums and provides pre-emptive protection against cyber attacks.

## Objectives

* To protect the CPS against DOS attacks and compromise within the sports stadium domain
* To create a prototype of the model, producing mitigations to the twelve risk examples listed in NCS4 and CISA’s integrated security considerations diagram.
* To create a detailed report on the findings of the research

The model will be designed in accordance with the twelve example vulnerabilities, and as a result will provide a mechanism for early detection of the following types of attacks:

* Denial of Service (DOS) / Distributed Denial of Service (DDOS)

The majority of the security issues related to CPS in sports stadiums relate to DOS attacks. This is highlighted by the twelve examples of vulnerable devices listed in CISA and NSC4’s diagram. CPS devices often do not contain data that attackers will want to access. More crucially it is critical they remain available and operating in a safe and proper way to ensure the safety of patrons in and around the stadium. Therefore, DOS attacks are a major concern for smart sports stadiums.

Detection of DOS attacks will be achieved through the monitoring facility to detect when remote IoT-controlled devices are offline or otherwise not reporting properly.

The prototype will prevent the following attacks:

* Man in the Middle (MITM) – by encrypting the data in transit
* Sniffing – by encrypting the data in transit
* Password Cracking – by enforcing secure passwords
* Vulnerability Exploits – by providing a firmware update facility, firewall functions, and several other mitigations
* Denial of Service (DOS) / Distributed Denial of Service (DDOS) – which can also be prevented through a combination of all mitigations employed, as well as network segregation to prevent intruders accessing sensitive system controls
* Identify theft – prevented in the case of the electric vehicle charging station by implementing a local firewall

Additional bonus features which are not necessarily related to the twelve examples include prevention of the following attacks:

* SQL Injection

Literature Review

The literature review is intended to follow a structure similar to the following:

# Introduction (1250 words)

* An introduction to IoT and its types
* IoT’s use in the modern world
* IoT’s use in relation to Cyber Physical Systems (CPS)

# Smart stadiums & Cyber Security (1250 words)

* Which devices in a stadium are smart
* Consequences of compromise
* Examples of historic compromise

# IoT Technology and Cyber Security in sports (1500 words)

* The various current uses and deployment methods of IoT technology
* The importance of securing IoT in sports stadiums
* How IoT is currently secured in sports stadiums?
* Ways in which IoT is lacking security in sports stadiums, and why

# Word count

Total estimated: (4000 words)

Methodology

Because the artefact will be created using software tools, the project will be carried out using the scientific method (Figure 2), will require deductive reasoning and quantitative data will be used to test the hypothesis (Miessler, 2020).

The project will be delivered using the Lean Software Development method. This is beneficial for solo projects, which facilitates regular communication and feedback with supervisors, possible changing requirements, small teams, and minimises waste by creating one piece of quality work at a time and minimising delays (MHZ Studio, 2021).

Although the planning approach will follow an Agile philosophy, a GANTT chart has also been created to help map the project’s progress, and work packages and milestones included to break the project into more manageable chunks (UOEO, N.D.).

An extensive literature review will then be undertaken to understand the extent of the problem and current state of the art. Once this is complete, the artefact will be more focused.



Figure 2: Scientific Method (sciencenotes.org, 2023)

The following tasks will need to be executed:

1. Provide an overview of the subject area
2. State the problem
3. List the requirements of the software
4. Design the software
5. Implement the software
6. Test the software
7. Write the report.

## Hypothesis

That a successful model is created with sample data to monitor the status of IoT devices deployed in sports stadiums, using secure transmissions, providing an early warning of possible threats or malfunction, and mitigations to the defined vulnerabilities.

## Risks

Project risks include:

## Insufficient knowledge of the technologies required to create a working model. In order to counteract this, substantial research into the technologies likely to be used will be conducted, focusing on areas which are applicable to the project. This will be achieved using video learning sites such as LinkedIn Learning and YouTube, and the Internet.

## Insufficient time to complete either the model or report. To counteract this:

## A project plan in the form of a Gantt chart will be created. This will help keep the project on track, and act as a reminder for any remaining work. It will help to project manage and combat any procrastination.

## A work / study / life balance will need to be achieved. For this, a strict regime will need to be followed, allowing for breaks and daily domestic duties. Redundant time will be used where possible to focus on completing the project in good time.

## Misinterpretation of the requirements. To counteract this, regular contact with the assigned supervisors, who have invaluable experience and expertise of what is required, will be maintained.

## Not enough information to create the report. This will likely mean that the research is not likely to meet the requirements of a master’s level dissertation. Obvious counteractions to this would be to:

## Carry out more research

## Make use of the available capstone project resources

## Regularly consult with the assigned supervisors

1. Data loss. To counteract for this, regular backups of the data will be made.

## Project Breakdown

The project will be organised into work packages as shown in Figure 3.

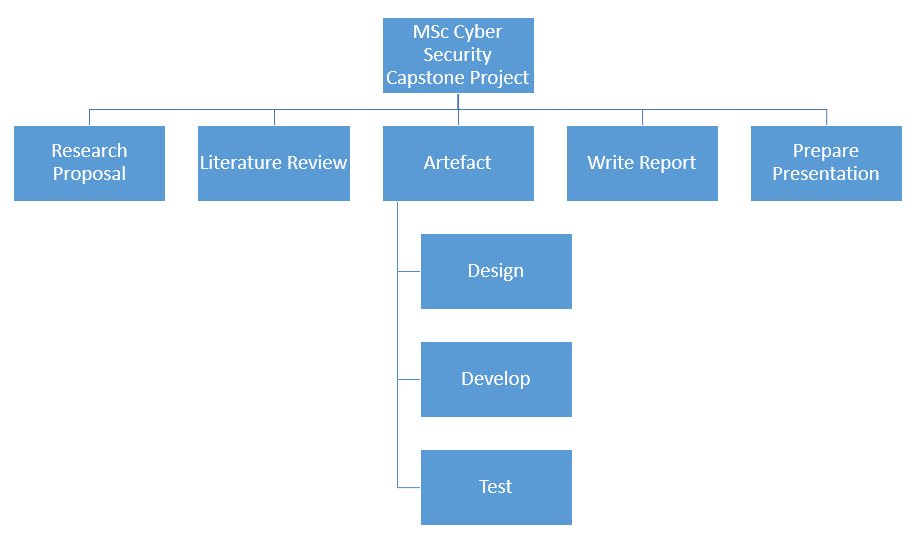


Figure 3: Project Work Packages

Artefact

The artefact will be produced using a mixture of technologies including Python and MQTT, and encapsulated in containers held on Docker Desktop to simulate the various IoT-connected devices within a stadium. UML diagrams and a network diagram will be used for the design. The model will include a variety of security controls which aim to mitigate each of the twelve vulnerabilities described by the NCS4 and CISA in their integrated security considerations diagram. The prototype model will also include a central monitoring node to check all systems are reporting ok, and all data sent between devices and the central monitoring screen will be encrypted.

It is possible that only some examples will be taken from the full quota of twelve, due to likely time constraints. The decisions on which vulnerabilities will be mitigated in the prototype model will be chosen using the MoSCoW approach (Monday, 2022).

As this module requires a computing artefact to be created, the type of project will therefore be software development (UOEO, N.D.).

A test plan will be created to test the quality of the code, the effectiveness of the security controls and the system as a whole. This will be recorded to video once complete and uploaded with the rest of the documentation.

Finally, the project will be critically evaluated, and then written up with full conclusions and referenced using the Harvard referencing style.

## Project Timeline

Both the 13,000-word report and artefact are expected to take approximately ten weeks each. The project timeline is shown in Appendix B.

## CyBOK

This project research aims to help further the Infrastructure Security CyBOK Category and the associated Cyber-Physical Systems Security Knowledge Area (NCSC, 2019).

## References

Baker, P. (2020) The Rise of Cyberthreats in Sports. Available from: <https://professional.uchicago.edu/stories/master-science-threat-and-response-management/rise-cyberthreats-sports> [Accessed 06 March 2023].

Benslimane, K. (2022) Protecting global stadiums and events with Self-Learning AI. Available from: <https://darktrace.com/blog/protecting-global-stadiums-and-events-with-self-learning-ai> [Accessed 27 February 2023].

Bukey, D. (2020) Argonne scientists lead push to strengthen cybersecurity in sports stadiums. Available from: https://www.anl.gov/article/argonne-scientists-lead-push-to-strengthen-cybersecurity-in-sports-stadiums [Accessed 18 February 2023].

Cybersecurity & Infrastructure Security Agency. (N.D.) About CISA. Available from: <https://www.cisa.gov/about> [Accessed 06 March 2023].

Cybersecurity & Infrastructure Security Agency. (N.D.) STADIUM SPOTLIGHT: CONNECTED DEVICES AND INTEGRATED SECURITY CONSIDERATIONS. Available from: <https://www.cisa.gov/stadium-spotlight-connected-devices-and-integrated-security-considerations> [Accessed 06 February 2023].

Darling, G. (2021) IoT vs. Edge Computing: What’s the difference?. Available from: <https://developer.ibm.com/articles/iot-vs-edge-computing> [Accessed 18 February 2023].

Khalifa, N.A (2020) IDENTIFICATION AND PREVENTION OF EXPECTED CYBERSECURITY THREATS DURING 2022 FIFA WORLD CUP IN QATAR. Journal of Poverty, Investment and Development. 5(1): 49-84. DOI: <https://doi.org/10.47604/jpid.1135>

Melander, B. A. (2017). Smart stadiums: An illustration of how the “Internet of things” is revolutionizing the world. *Sports & Entertainment Law Journal Arizona State University.* 6(2): 350-382. Available from: <https://asuselj.org/wp-content/uploads/2017/08/Melander-Smart-Stadiums.pdf> [Accessed 18 February 2023].

MHZ Studio. (2021) Applying Lean in Software Development. Available from: <https://www.youtube.com/watch?v=uZ_uG28ZQSM> [Accessed 25 February 2023].

Miessler, D. (2020) The Difference Between Deductive and Inductive Reasoning. Available from: <https://danielmiessler.com/blog/the-difference-between-deductive-and-inductive-reasoning> [Accessed 14 February 2023].

Monday.com. (2022) The MoSCoW prioritization method explained. 22 September 2022. *project-management.* Available from: https://monday.com/blog/project-management/moscow-prioritization-method/#:~:text=The%20acronym%20MoSCoW%20stands%20for,to%20resolve%20conflicts%20between%20stakeholders. [Accessed 14 February 2023].

NCS4. (N.D.) National Center for Spectator Sports Safety and Security. Available from: <https://ncs4.usm.edu> [Accessed 06 March 2023].

NCSC. (2019) CyBOK The Cyber Security Body of Knowledge. <https://www.cybok.org/media/downloads/CyBOK-version-1.0.pdf> [Accessed 14 February 2023].

NCSC. (2020) The Cyber Threat to Sports Organisations. Available from: https://www.ncsc.gov.uk/files/Cyber-threat-to-sports-organisations.pdf [Accessed 06 March 2023].

Roberts, F. S. (2019) From Football to Oil Rigs: Risk Assessment for Combined Cyber and Physical Attacks. *Journal of Benefit-Cost Analysis.* 10(2): 251 - 273. DOI: https://doi.org/10.1017/bca.2019.15

Sciencenotes.org. (2023) Steps of the Scientific Method. Available from: <https://sciencenotes.org/steps-scientific-method> [Accessed 14 February 2023].

Solovev, A. & Petrova, A. (2020) Reasons and Peculiarities of Choosing MQTT Protocol for Your IoT Devices. September 10, 2020. *Integra Sources Blog.* Available from: <https://www.integrasources.com/blog/mqtt-protocol-iot-devices> [Accessed 06 March 2023].

University of Essex Online. (UOEO) (N.D.) Software Development. Available from: <https://www.my-course.co.uk/Computing/Cyber%20Security/CYSPROJ/CYSPROJ%20Lecturecast%204/content/index.html#/lessons/b-geZlb5JM4I0hp9xRVXjcGltldoYPCD> [Accessed 14 February 2023].

University of Essex Online. (UOEO) (N.D.) Work Packages. Available from: <https://www.my-course.co.uk/Computing/Cyber%20Security/CYSPROJ/CYSPROJ%20Lecturecast%203/content/index.html#/lessons/lnP5c3GVPaYQjzvjuFbnhrI_P5BpWCKZ> [Accessed 14 February 2023].

Wan, B., Xu, C., Prasad Mahapatra, R. & Selvaraj, P. (2021) Understanding the Cyber‑Physical System in International Stadiums for Security in the Network from Cyber‑Attacks and Adversaries using AI. *Wireless Personal Communications*. 127: 1207-1224. DOI: <https://doi.org/10.1007/s11277-021-08573-2>

## Appendices

## Appendix A: Vulnerability List

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| # | Name | IoT Device | Vulnerability | Consequence | Mitigation | Network | Test Success |
| 0 | monitor | Central Control Monitor | No way to detect devices, such as online status | > Availability issues AND delays in detecting an attack | Provide a monitoring screen which displays key events from other critical devices | Bridge 1 | Display any alerts (such as up / down / distress) from other nodes |
| 1 | pos | Point of Sale (POS) | Outdated and unpatched firmware / software | > Attacker disables POS systems, resulting in loss of revenue and dissatisfaction among patrons | Mechanism to update firmware, simulated by updating text files locally in container | Bridge 1 | Firmware can be updated to latest |
| 2 | kiosk | Stadium Kiosk | No password to software / firmware | > Attacker shuts down ticketing system, causing unrest among patrons due to the inability to purchase tickets or be granted admission | Set to require a password to access the device's firmware | Bridge 1 | Access only granted with correct password |
| 3 | entrance | Stadium Entrance Equipment | Device software lacks strong password protection | > Attacker hacks into control system and locks turnstiles, preventing entrance into the stadium. This causes mass gathering that makes the crowd vulnerable to a mass attack such as a bombing or an active gunman | Apply secure passwords for login | Bridge 1 | Strong password for access that meets certain standards. All other access attempts are denied. |
| 4 | cctv | CCTV | No segmented access controls and ACL | > Attacker disrupts CCTV and telecommunications, impairing communications with emergency services | Segment device to a new subnet (bridge2) AND segregated access controls provided by a domain (simulated by an online database) | Bridge 2 | Connection is not possible from devices in bridge1 AND access is only granted to those specified in domain (database) |
| 5 | telecomms | Telecommunications | Not segmented | > Attacker disrupts telecommunications with emergency services resulting in delayed response times | Segment to new subnet (bridge2) | Bridge 2 | Connect is not possible from those in bridge1 |
| 6 | hvac | Heating, Ventilation, and Air-Conditioning (HVAC) | Not segmented | > Attacker raises temperature in server room causing servers to become overheated and shutdown | Segment to new subnet (bridge2) | Bridge 2 | Connect is not possible from those in bridge1 |
| 7 | suas | Small Unmanned Aircraft System (sUAS) | No encrypted data link AND weak/no encryption keys | > Attacker introduces malware that distributes DOS attack, congesting networks and rendering dependent systems inoperable | Encrypt data in transit, simulated by sending encrypted data to and from a public MQTT broker | Bridge 1 | Data in transit is encrypted - Test with Wireshark or print() function. Data can be read successfully with encryption key |
| 8 | smartgrid | Smart Grid | Smart grid meter memory, containing admin credentials, lacks encryption | > Attacker manipulates meter settings resulting in power outage (stadium / critical systems) | Encrypt data in transit, simulated by sending encrypted data to and from a public MQTT broker | Bridge 1 | Data in transit is encrypted - Test with Wireshark or print() function. Data can be read successfully with encryption key |
| 9 | videoboard | Video Board and Public Address (PA) System | Control system is unsecured, leaving its video boards and PA system vulnerable | > Attacker displays or announces a threatening message, causing crowds to panic | Segregate to bridge2, and encrypt traffic | Bridge 2 | Connection is not possible from devices in bridge1 AND traffic to and from broker is encrypted |
| 10 | fireandemergency | Fire and Emergency Management | Unmonitored | > Hacker sets off fire alarm system, causing patrons to panic and rush out of stadium | Monitor events on monitor screen | Bridge 1 | Monitor device displays events on screen |
| 11 | lights | Automated Lighting Controls | Fails to restrict remote access authorization to a need-to-have basis | > Attacker shuts down lighting in stadium causing patrons to rush out of the stadium, endangering lives | Implement SSH capability only for selected admin user(s) | Bridge 1 | That SSH function works with valid credentials |
| 12 | evcharging | Electric Vehicle Charging Station | No firewall | > Attacker steals patrons' credit card information > Displays threatening message on charging station, causing patrons to panic | implement firewall in the form of iptables which only allow the monitor to communicate with it | Bridge 1 (Firewall Required) | That only traffic from 1 x IP address is allowed and all else is denied |

## Appendix B: Project Timeline

