Purdue University Chapter of Engineering World Health
Ceiling-Mount Surgical Lamp with Alternative Power Source
Fall 2021- Spring 2022

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Problem Statement

It is estimated that 8.1 million surgeries occur in low-income countries each year [1]. Specifically, an estimated 40% of surgeries have inadequate lighting, and 80% of surgeons believe their lighting provides a safety risk [2, 3]. 18% of surgeons have direct knowledge of the lighting causing patient harm [2, 3]. Therefore, it is believed improving the consistency of surgical lighting will reduce morbidity and increase surgical capacity [2, 3].

Additionally, it is estimated that every year at least 24 million patients are at risk of harm due to loss of lighting during surgery [2]. Almost half of the surgeons in low- or middle-income countries (LMIC) experience at least one power outage a week, and 58% will then rely on backup generators. However, these power outages can occur more frequently in rural settings. Dr. Steve Dorsey, a head clinician in rural Dominican Republic, says his location only has power from the grid for about 8 hours a day. While Dr. Dorsey does have backup power generators, he said these are not always reliable. One surgical facility in Uganda, 13% of operating days experienced power outages that averaged nearly 7 hours [3]. While backup generators are an option, one study found that in sub-Saharan Africa, less than 30% of backup generators work [2].

Therefore, the proposed solution is a ceiling mounting surgical lamp with an alternative power source. After insight from Dr. Dorsey on his practice and a virtual tour of his exam room, the team decided a ceiling mount would provide a more workable area around the surgical table over a traditional floor lamp. He said he once used a dental light track, which he liked, but it is no longer working. A picture from his procedure room can be seen in Figure 1.

To make a sufficient surgical lamp, the following performance specifications must be met. The lamp must weigh 45 kg or less, reduce cost by at least 50%, brightness between 40 – 160 klx, and light mobility to the head and toe of the patient [4, 5]. The lamp must also have a color rendition between 85 – 100 CRI, a color temperature of 3,000 – 6,700 K, and be shadowless [6]. In terms of the alternative power source, it must be able to provide power for up to 3 hours, which is the longest procedure length for Dr. Dorsey, and must have a recharge time of 8 hours or less. Additionally, the light bulb must have a lifespan of at least 25,000 hours at full brightness [7].

Figure 1: Dr. Dorsey’s Procedure Room

Statement of Impact in Developing World

Dr. Dorsey is a practicing surgeon in a rural community in the Dominican Republic. In his clinic, he performs low to moderate risk surgeries, some lasting upwards of three hours. On average, his clinic receives electricity from the electrical grid for only 8 hours a day. In emergencies when there is no electricity Dr. Dorsey has used a headlamp as a light source. Furthermore, his current surgical lamp is a floor lamp that provides the minimal amount of light needed for surgery. As a result of poor lighting, avoidable risks are taken during his surgeries.

Current solutions to improve lighting include surgeons wearing a headlight, but less than 10% of surgeons in LMIC do this [2]. Additionally, hospital grade current surgical lamps are expensive with the cost for incandescent lights ranging from $2,000 - $37,000 and LED lights ranging from $12,000 - $89,000 [4]. In order to further reduce costs, a less expensive LED will be used in-addition to low-cost materials such as PVC and 3D-printed materials.

Standard surgical lamps require electricity from an electrical grid, which are unreliable in LMIC [2]. As a result, low–powered, low-cost surgical lamps have been developed; however, fail to address all the needs of surgeons. LUMIS is a low-cost battery-operated surgical lamp powered by a 12-V car battery, but it cannot alternate between power sources [8]. As a result, surgeries are dictated by the amount of energy in the car battery at a given time. Conversely, the team's surgical lamp automatically switches between a standard electrical power source and a 12-V car battery power source. The automatic switch allows the surgeon to continue the procedure when the electricity goes out and the car battery energy is preserved.

Additionally, other low-powered, low-cost surgical lamps are free-standing, such as the lamp developed for Ethiopia [9], taking space away from the surgeons. As seen in Figure 1 above operating rooms have limited floor space. This purposed surgical lamp is ceiling mounted maximizing the floor space in the operating room and enabling the doctor to position the lamp at the beginning of surgery by using a sliding track and then leave it stationary for the full procedure.

While most of the design and its requirements were based off on conversations with Dr. Dorsey, this design could be implemented in other LMIC that experience intermittent electricity. Because the components are off-the-shelf, they could either be shipped or sourced locally. Additionally, a high-heat resistant plastic filament could be adopted, and other components could then be sourced to 3D-printers. However, variations in voltages in currents could result in variable design changes in the alternative power source. The actual ceiling-mount and supporting structure for the lamp, as described later, was designed to be adaptable to different ceiling supporting beam structures.

Therefore, there is still a need for a low-cost, low-powered surgical lamp. To use in rural communities, the surgical lamp should be easy to transport and assemble, with minimal need for maintenance. Lastly, it should be ceiling mounted to maximize space in the operating room. Improved lighting during surgery will decrease the number of avoidable deaths due to poor surgical conditions.

Required Performance Specifications

A standard surgical grade lamp must produce 40 – 160 klx, a color rendition between 85 – 100 CRI, and have a color temperature between 3,000 – 6,700 K. This enables the lighting to be shadowless to complete a successful surgery [5,6]. However, no more than 1000 W/m^2 of heat can be produced by the light to ensure the safety of the patient [5]. Additionally, Dr. Dorsey suggests the light field diameter should be between 30.48-20.32 cm and lightbulbs must be angled to diffuse light to provide additional shadow reduction [5]. To successfully create the light field, the light should be positioned 1 m from the shaft. The shaft should be 2 m from the ceiling mounted track to allow for easy movement of the lamp across the track. To account for different ceiling heights, the track should be adjustable for ceiling heights between 2.05 - 5.05 m since the typical surgical room height is 3.05 m [10]. Likewise, the ceiling mounted surgical lamp should have a track length of at least 1.83 m to allow for the positioning of the light at any section of a standard-length hospital bed [11]. Lastly, the surgical lamp should weigh no more than the average surgical lamp of 45 kg [12].

To create a cost-efficient surgical lamp, the lamp must have a cost reduction of 50% compared to current surgical lamps on the market, which range from $2,000 - $37,000 [4]. Likewise, materials should be easily replaceable by using locally sourced materials, such as a car battery, or shipping materials with minimal shipping costs. To maximize shelf life, all rust-free material should be used, the number of joints should be limited to avoid breakage, and LED lights that last up to 50,000 hours should be used [13].

Lastly, to successfully power the surgical light, an alternative, reusable power source is needed. The switch from the grid power to the alternative power source should be automatic to ensure surgeons can stay in a sterile working state. A flexible, easy to store power cord is needed to provide power to the lamp from the grid power and the alternative power supply. The power cord should be at least 3 m long to allow for adequate room around the surgical bed. Also, Dr. Dorsey estimates power outages that last up to 8 hours regularly occur in the Dominican Republic. Similarly, Dr. Dorsey estimates his longest surgeries in his rural clinical last roughly 3 hours. Thus, the alternative power supply must be able to run continuously for 3 hours and contain at least 8 hours of power supply before needed recharging.

Implementation of Prototype

Based on the team's conversations with Dr. Dorsey, it was determined that two lights may be desired. However, when asked about where above the bed the lights should be placed, he said it depends on the procedure, which is why dental lighting track was used. A versatile design was created where the track can be mounted either directly above the patient bed or off to either side of the bed as shown in Figure 2 in the appendix. Because two lights could be desired for use with just one track, a track with two slots, one for each light, was selected. Due to this and the strength and availability, an 80/20 beam was selected for the track.

Although the standard ceiling height in an operation room is 3.05 m, ceiling heights may not be regulated as well in rural clinics, and the surgical lamp needs to be adjustable. The track was mounted using I-hooks and chains so that the overall height could be easily adjusted for each location. This design would also work with variable ceiling support beam structures as some variance can be allowed between the I-hook locations. To keep the cord off the floor and from being a tripping hazard, cord clips for the ceiling and wall is included.

To enable easy positioning of the light, 3d-printed adapter pieces that slide into the 80/20 slots and support the weight of the lamp are used as shown in Figure 3. The adaptor is press fit into PVC piping and reinforced with the lamp shaft using PVC cement.

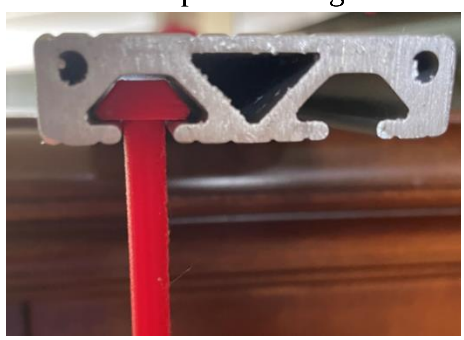

Figure 3: 3D-Printed Adapter in 80/20 Track

The lamp mount consists of a globe-like design, where a metal bowl encloses the light. A car headlight is used in this prototype. There are two pins on either side of the bowl to allow for tilt adjustments. A structural system sketch can be seen in Figure 4a and the prototype is shown in Figure 4b.

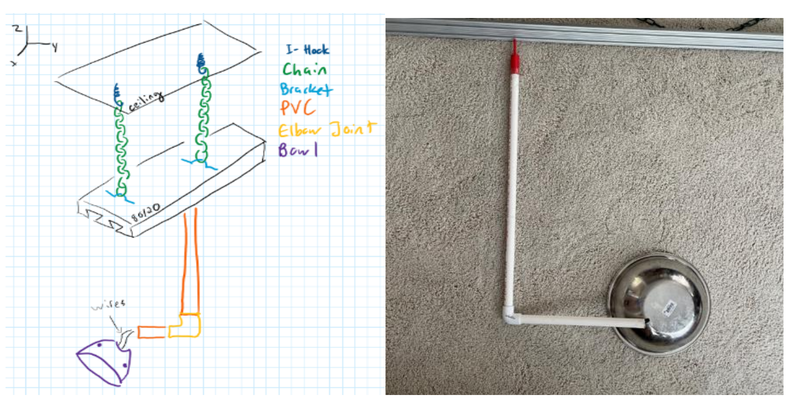

Figure 4: a. Structural System Sketch **b.** Prototype

To attain the cheapest alternative power source that is easily rechargeable and compatible with power loss detectors a 12V car battery was used. Other alternative power sources such as wind, water, and solar were considered, but implementation of the technology itself is much more expensive than the revenue in return. Hence, any type of rechargeable 12V car battery can be used for accurate and consistent power switching between the main power supply and the backup power supply. Figure 5 displays the circuit diagram to implement this automatic power supply.

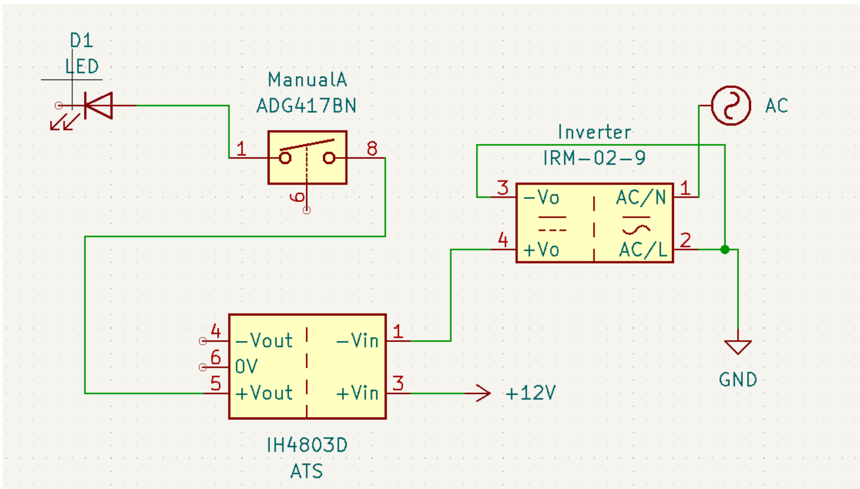

Figure 5. Compressed schematics of the surgical lamp without resistors and capacitors. Diagram shows the AC to DC inverter connected to the ATS where the output is connected to the manual switch of the surgical lamp [14].

An automatic Transfer Switch (ATS) is a device that automatically switches the power supply from the primary source to the backup source when it senses a power outage or failure [14]. The concept is rather simple, but the cost of implementation and the complexity of the circuits behind installation of the ATS was not easy. In addition to the ATS, a car battery inverter and an AC/DC inverter were investigated, but ultimately beyond the scope of the team's knowledge to implement.

Additionally, to use the ATS the transfer switch amps must match the main breaker in the electrical panel in the hospital or a technician must size the power switches according to the power requirements in the room of interest. Figure 6 in the appendix display a schematic for a general insulation of a transfer switch [15]. A different option for switching the power supplies is to use a microprocessor, such as an Arduino Uno.

To implement the Arduino Uno an algorithm that feeds in the power from the main electrical grid, measures the AC voltage, and converts the output to a DC supply is used. Depending on the amount of power measured by the Arduino Uno, it can switch on and off in relay to collect power from the 12V battery. The mechanism is also explained by the block diagram in Figure 7 in the appendix.

Proof of Performance

To test the overall strength of the structure, tensile testing was performed on the adapter piece shown in Figure 3 since it carries the load of the lamp. The results are shown below in Figure 8. Based on this, it is observed that there is no strain hardening, which reduces the risk of splintering as a clean break is more likely. The yield strength is also the ultimate strength, which was observed as 7.9658 MPa, which is equivalent to 1155.342 psi. The total weight of a singular lamp is 2.63 kg, which the adapter piece has proven strong enough to hold and is far below the average weight of a surgical lamp at 45 kg. Therefore, the possible failure modes result from the various press fits, which have been reenforced by PVC pipe cement.

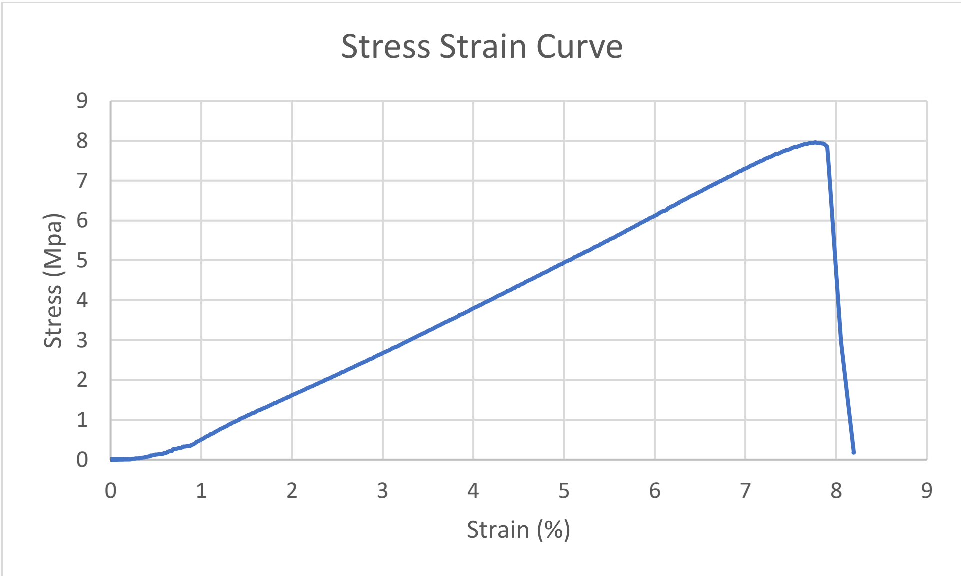

Figure 8: Stress Strain Curve for Track Adapter

To test the power of the lamp, the normal AC power supply is connected to an inverter and the lamp illuminated. The specifications of the headlight state its color rendition, color temperature, and heat production are within the specified ranges for a surgical lamp [16]. A lux meter was used to measure the strength of the light to be 55 klx, which is within the range needed for a surgical lamp and suggests the other specifications of the headlight are correct. Placing different items under the headlight at different heights demonstrated on average, there was minimal shadowing of the object at distances of 35.56 cm and smaller. When connecting the headlight to the 12V car battery, the headlight illuminated, suggesting 12V is enough to power the lamp.

For the safety of the team, the microprocessor using the Arduino Uno was not fully installed in the circuit. However, power from the power grid and car battery were provided through the ATS to ensure the circuit was functioning correctly. Figure 9 displays the illuminated light. Figure 10 displays the circuit containing the ATS [17].

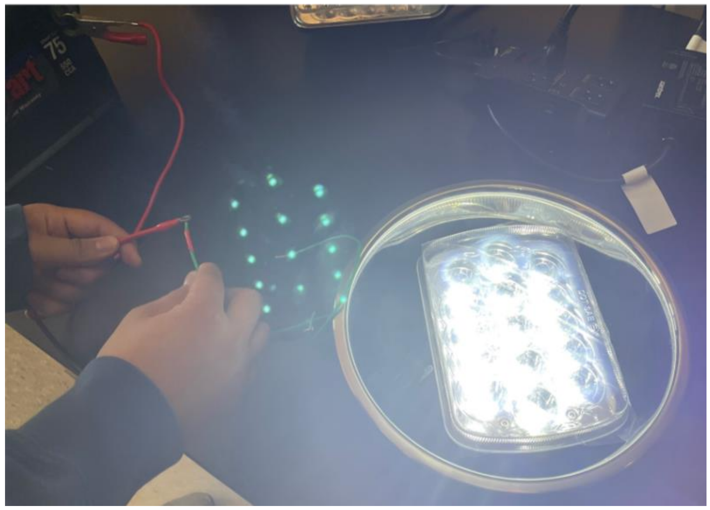
Figure 9. Illuminated headlight used for the surgical lamp

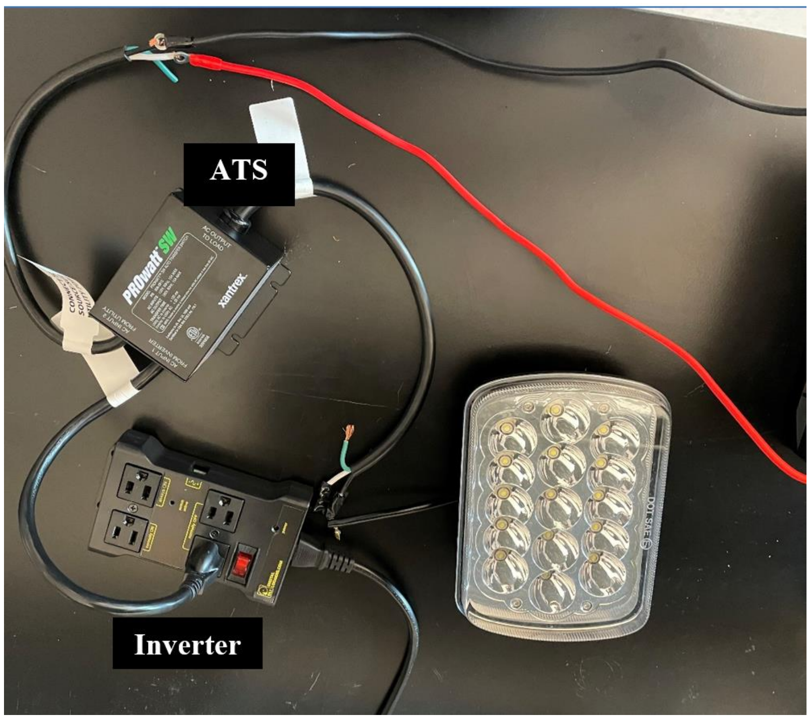

Figure 10. Built circuit containing the ATS

Business Plan for Manufacturing and Distribution of the Technology

As previously stated, 80% of surgeons in LMIC believe the lighting poses a safety risk during surgery [3]. The end users of this surgical lamp consist of rural clinicals and hospitals that preform minimally invasive surgeries. Other novel surgical lamps for LMIC include an uninterruptible surgical lamp developed by the EWH UNSW team in Australia [18]. However, as shown in Dr. Dorsey's image, there is minimal space in rural surgical rooms, which can affect the surgeon's performance. UNSW's surgical lamp requires a stand, taking away invaluable space around the patient. On the contrary, our surgical lamp is permanently ceiling mounting, providing access to the patient on all sides of the bed. Likewise, the alternative power supply enables surgeons to continue surgery without stopping when the power gride supply is shut off.

The surgical lamp contains three components- the wall mount, the lighting, and the alternative power supply. To build the prototype of the low-cost surgical lamp, a totally of $250.00 was spent; however, this cost includes shipping fees. It is estimated the surgical lamp would cost $162.78 to build using the most cost-effective materials. Table 1 shows the estimated cost of each material needed for the lamp. Instead of using a 3-d printed track adaptor and light holder, these mechanisms can be mass manufactured using a nonrusting material such as Polyvinyl chloride (PVC). On average, PVC takes at least 25 years before any damage should occur [19]. Likewise, buying the ATS and microprocessors directly from a manufacturer would decrease the cost even more. The minimal joint on the lamp decreases the likelihood of breakage and decrease the need to replace materials prematurely. Therefore, using more cost-effective materials will greatly decrease the cost of the lamp.

Table 1: Estimated Cost of Raw Materials

Material	Unit Cost	Total Cost ($)
80/20 metal [20]	0.23 $/inch	5.52
PVC [21]	0.61 $/lb	1.22
Wiring [22]	0.79 $/ft	23.70
Wire Crank [23]	$ 27.00	27.00
12V Car Battery [24]	$ 54.88	54.88
ATS [25]	$ 15.00	15.00
Microprocessor [26]	$ 17.98	17.98
I-hooks [27]	$ 5.41	10.82
Brackets [28]	$ 0.36	0.72
Ceiling Mount Chains [29]	1.98 $/ft	5.94

To ensure the safety of the patient, mass manufacturing the components in the United States and shipping kits to be assembled in LMIC will ensure the components of the surgical lamp are structurally sound. It is important that the electrical components are assembled properly, so sponsoring electricians to assemble the surgical lamp wiring is recommended. The surgical lamp can either be sold to surgeons in LMIC with clinics for a profit, or the lamp can be donated to hospitals and clinics in LMIC. Organizations, such as MedShare and American Medical Resources Foundation, can be used to aid in the manufacturing, distribution, and assembly of the surgical lamp in LMIC [30]. Since the surgical lamp costs very little to manufacture, it is plausible for an organization to sponsor the manufacturing and the technology needed to produce the lamp in full.

Likewise, the components of the surgical lamp cost very little to ship. Excluding the car battery, the prototype surgical lamp weighs 2.63 kg. To minimize shipping costs, assembly of the light portion of the lamp, including the wiring, will need to be threaded through the tubing and 80/20 upon arrival. Assuming the wiring and any mass manufactured PVC will be similar in weight, it would cost an estimate of $45.00 USD to ship the components to the U.S Virgin Islands and $65.00 USD to ship to any country in Africa [31]. Also, the lightweight enables transport to rural areas very easy and replacement pieces can easily be shipped.

With a car battery included, the cost of shipping will increase drastically. The weight of the car battery in the prototype is roughly typical 7.71 kg. As a result, it would cost between $86.00 and $120.00 USD to ship [32]. However, a standard 12V battery is used which can be found in any car. As a result, batteries can be found locally. The typical 12V battery contains two weeks' worth of energy before needing to be recharged and the typical shelf life of an unused car battery is 2.5 months before needing to be recharged [33]. Thus, the car battery is low maintenance and any maintenance for the battery can be completed locally.

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Appendix

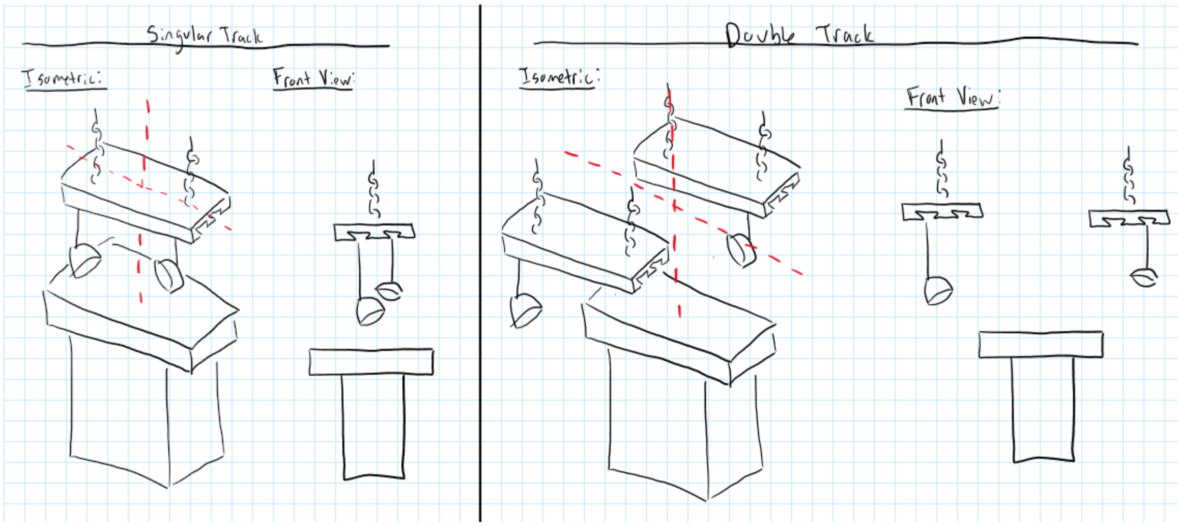

Figure 2: Track mounting options

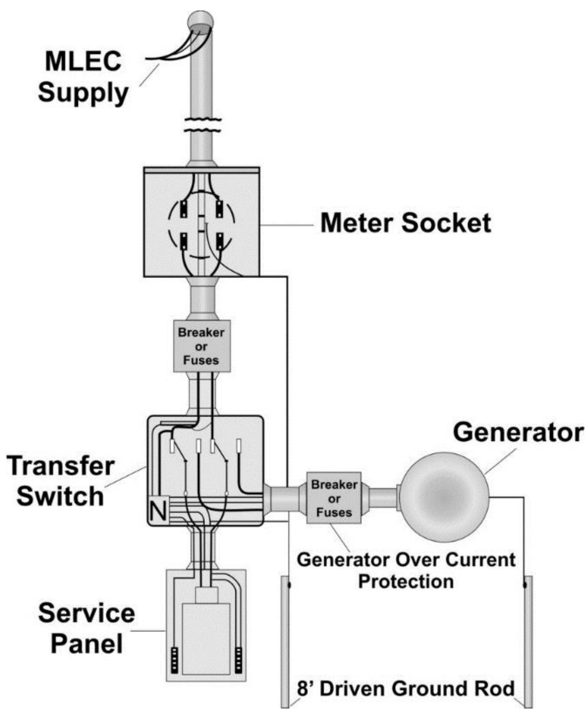

Figure 6: Schematic diagram of a generator transfer switch. Demonstrates how an electrician would normally install a transfer switch [15]

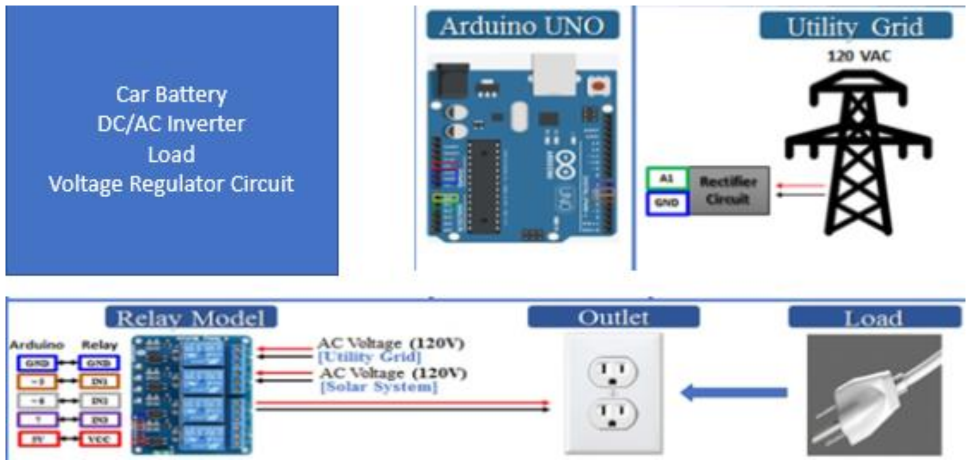

Figure 7: Block Diagram of Automatic Power switching with Arduino Uno [17]