Executive Summary

In October 2018, Energisation Ltd. introduced their autonomous battery swapping station that offered Batt-R-E batteries while the swapping system supplied by Lifts and Things Ltd. In April 2020, the photocell was found to be out of service. Tony Best, the operator of the station, was using the emergency override button to initiate the battery swapping process. After 2 years of service, Batt-R-E put a new variant of batteries in circulation. Unfortunately, after a few days, an explosion occurred while a customer, John Taylor, was having his car's battery swapped.

From various investigations, a few problems were observed. John Taylor was found to be swapping to the Ultimate battery that weighed 810kg before the explosion happened. The lift system that the station had at the time was not capable to handle the weight. As a result, the key within the gear system was detected to have come loose although the loosen key was tightened in the previous service. Consequently, the chains broke due to the misalignment of the sprockets and layshaft. It is concluded that a battery was dropped from a height and exploded.

There were inflictions in terms of operations and legalities that potentially caused the explosion. From the letters between BATT-R-E and Energisation Ltd, Energisation Ltd was informed to use the stronger lift that can handle the new battery. However, the lift installed by Lifts & Things Ltd. after the incident was a different model. Therefore, there may have been a miscommunication between Lifts & Things Ltd. and Energisation Ltd. on the models. Furthermore, Tony Best has been using the override button in response to the broken photocells which is against the user manual. In conclusion, it is concluded that both Lifts & Things Limited and Energisation Ltd. are responsible for this incident.

Background

Timeline

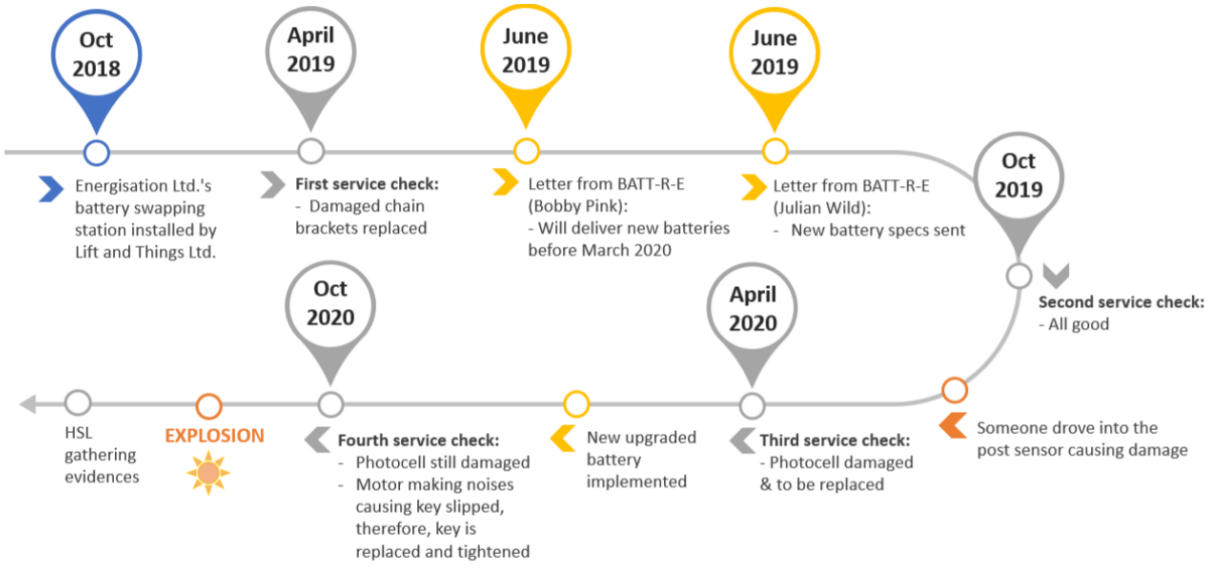

FIGURE 1: TIMELINE LEADING TO THE INCIDENT

Party	Notable Names	Explanation
User	John Taylor	Electric Car owner
Lifts and Things Ltd	Director	Manufacturer & Maintenance
	Engineer	
Energisation Ltd	Pamela Rodgers	Battery Swapping Service Provider
	Tony Best (employee at station)	

Batt-R-E	Julian Wild (head of strategy) Bobby Pink	Battery Provider
Link-Controls	-	Electric motor and gearbox supplier for L&T
Sedis	-	Roller chain supplier for L&T

TABLE 1: PARTIES INVOLVED

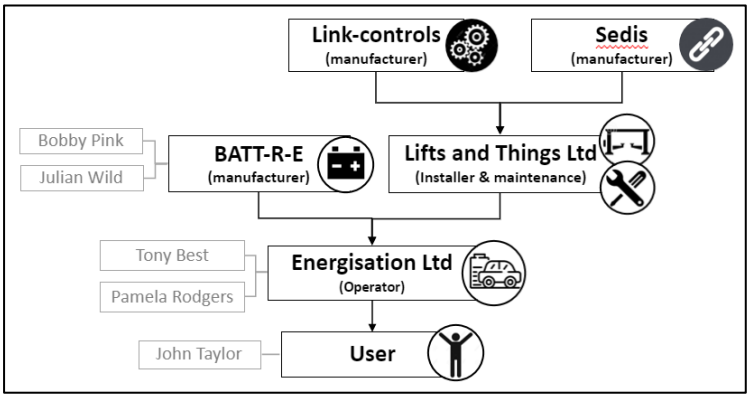

FIGURE 2: THE CONNECTION BETWEEN ALL PARTIES

Sequence of Failures

As the CCTV camera was broken long before the explosion incident, the sequence of failures could not easily be determined. Therefore, a professional team of the Health and Safety Laboratory (HSL) was hired to gather more evidence.

Prior to the explosion, John Taylor went to the swapping station to replace the battery on his electric vehicle. It is deduced that John was swapping to the 'Ultimate' variant option during the accident. After the accident, BATT-R-E company claimed that without the isolation point technology, the explosion would be more catastrophic. This technology has only been implemented for the 'Ultimate' variant of batteries in circulation (see **TABLE 2**).

	City	Standard	Extender	Ultimate
Range (quoted)	80 miles	200 miles	400 miles	600 miles
Capacity (useful)	26 kWh	65 kWh	130 kWh	195 kWh
Weight	208 kg	385 kg	540 kg	810 kg
Length	1.8 m	1.8 m	1.8 m	1.8 m
Width	0.9 m	0.9 m	0.9 m	0.9 m
Depth	0.1 m	0.1 m	0.1 m	0.1 m
Charge time HV	2 hours	2 hours	3 hours	4 hours
Charge time LV	7 hrs	8 hrs	10 hrs	12 hrs
Safety	Normal	Normal	Normal	Isolation cells
Storage	Individual charging cabinet	Individual charging cabinet	Individual charging cabinet	Individual charging cabinet

TABLE 2: TECHNICAL DATA FOR THE BATTERIES

It was found that the wrong specification of the lift-system was installed. The lift-system found at the scene was LANDT_XX002A, which has a maximum load capacity of 600 kg (see **TABLE 3**). However, the specification found from the records of Energisation Ltd noted by the BATT-R-E company was LANDT_XX002C which has a maximum load of 1000 kg. The 'Ultimate' variant of batteries which weighs 810 kg (see **TABLE 2**), shows that the lift-system was overloaded by more than 30 percent of its maximum load.

	LANDT_XX002A	LANDT_XX002C
Limit load	600 kg	1000 kg
Lifting time	12 seconds	13 seconds
Lowering time	14 seconds	16 seconds
Max Height	2.2 m	2.2 m
Height of the Structures	1.6 m	1.6 m
Width of the Structures	1.2 m	1.2 m
Length of the Structures	2.6 m	2.6 m
Width of the Platform	1.1 m	1.1 m
Length of the Platform	2.2 m	2.2 m
Drive (Link Controls)	2x3 Phase 1.1kW	2x3 Phase 1.1kW
Anti-drop safety (Link Controls)	Yes	Yes

TABLE 3: TECHNICAL DATA FOR THE LIFT SYSTEMS

The marks on the surface of the key and drive shaft indicate that the grub screws were used as set screws to restrict the movement of the components using friction. Because of overloading, the grub screws and the sprockets are subjected to higher stress than its intended value. It is believed that the grub screws were loosened over time due to this.

The fainting mark of the grub screw along the key suggests that the friction between the grub screw and surface of the key was insufficient to hold the key in place and resulted in the slip of the key towards the casing (**FIGURE 3**) as mentioned on the 4th service report. This argument is further strengthened by the circular mark on the face of the left casing, which has the same width as the key (**FIGURE 4**). Consequently, it caused a small local movement and resulted in a small wallowing indentation in the middle of the keyway (**FIGURE 5A & 5B**). However, due to the uneven loading, only one side of the keyway was indented.

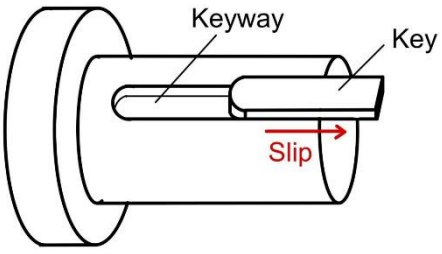

FIGURE 3

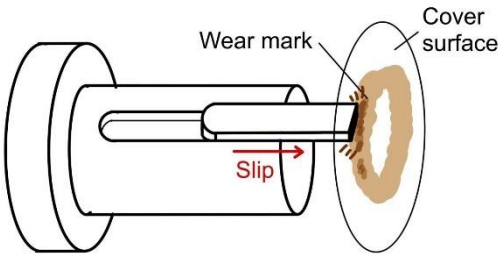

FIGURE 4

View from the top of the keyway

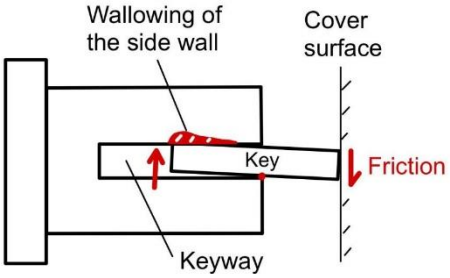

FIGURE 5(A)

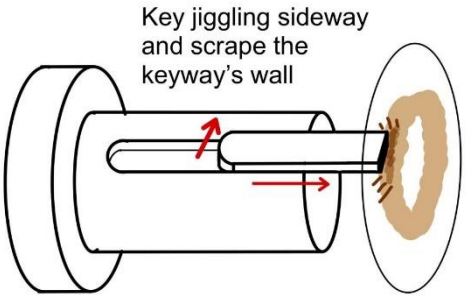

FIGURE 5(B)

Even though this key was replaced in recent service, as mentioned in the maintenance log dated October 2020, the keyway was slightly enlarged due to the vibration effect. This resulted in the new key to slip through easier as the swapping procedure went on. The subsequent slipping of the new key then caused the sprocket of the driveshaft and the sprocket of the lay shaft to misalign (**FIGURE 6**). Consequently, this made the pulling force acting on the chain to be at an angle and

opposite to each other (**FIGURE 7**). Hence, it puts greater stress at the weak spot of the chain. Together with the old and rusty chain, the chain components: outer plates and pin, get detached from each other. In turns, the load distribution changed due to one of the chains detach, putting more load through the other 3 chains. Thus, this resulted in a fractured chain on the right-hand side due to overloading (see **Appendix 1**).

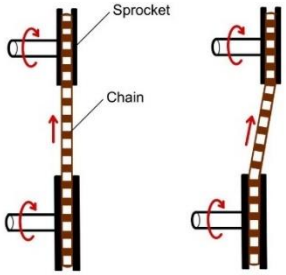

FIGURE 6

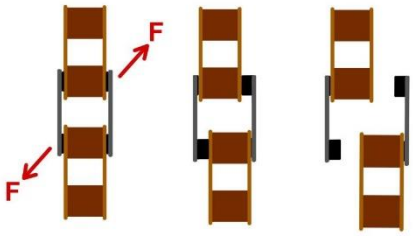

FIGURE 7

Once the two single-roller chains of the same side broke, the platform where the battery is rested tipped over. The battery was then dropped from the platform at height which damaged the battery which led to the explosion.

Assessment of Current Design

The specification for the lift (as shown in **TABLE 3**) in the swapping station was LANDT_XX002A, designed by Lifts and Things Ltd, which can carry a maximum load of 600 kilograms. The platform is made of 12 mm stainless steel plate welded to a square tubular structure. The system uses two three-phase motors rated at 1.1kW and two gearboxes, supplied by Link Controls. A motor and a gearbox are placed at each end of the platform. Also, each motor is connected to two single-roller chains (CA1N04B000), manufactured by Sedis, as shown in the diagram (as shown in **FIGURE 8**).

FIGURE 8: SIMPLIFIED SCHEMATIC OF LIFT PLATFORM (HSL - Examination Report, 2020)

The drive shafts and layshafts of the lift are directly attached to the wall of the battery swapping bay, this does not provide any structural support to the lifting platform, hence the platform has no solid movement constraints. This causes the platform to move around if the single-roller chains are slagging.

This lift is designed for full automation in cooperation with sets of photocells, also made by Link Controls, exclusively for changing cars' batteries that are placed around the battery swapping bay. As shown in the HLS analysis, the photocells are attached to short posts. This poses a risk to these photocells as external circumstances may break them. This was evident when a driver drove into these posts, breaking the photocells which is an integral component in the system.

The key was placed into a tight open-ended keyway locating along the drive shaft. The sprocket was friction fitted onto the shaft using two Allen screws, one above the key, pressing down the key, and another directly onto the shaft. This is thought to be the main point of failures of this incident as concluded in the previous part. The layshaft has its sprocket welded onto the surface which is much stronger than the friction fitted.

Each motor was also fitted with an integral safety gear that would engage under unusual circumstances. This was found not to be engaged after the accident. It is deduced that; such a safety feature was implemented to prevent a sudden uncontrollable increase in velocity of the gears; however, it was not effective against the incident. Furthermore, an override button was available for operators strictly in case of emergency. It was intended for lowering down the platform in case fault was detected.

Lastly, according to the HSE guidelines on battery storing, if batteries are charged too quickly or too long, the pressure relief valves in batteries will open and let gases escape. This causes a gas pressure build up and would likely cause an explosion if it is close to an ignition source such as a spark. Also, water vapour can be built up from this process and will rust metallic components such as the drive train and chains as shown from the HSL analysis. From any of these documents, there is no indication that a ventilation system is set in place to counter this problem, which makes the station hazardous.

Assessment of Current Maintenance and Operation Procedures

1. From the evidence provided and the analysis of sequences of failures, it was deduced that the new batteries must have been implemented a couple of days before the 4th service. Although it is not a requirement, the machines should be inspected or tested for compatibility before the new products are commissioned.

2. The replacement of the key in the 4th service suggests that faults of the key and keyway were realised. However, it is concerning that the engineer and the inspector didn't fix the problem entirely. This potentially shows the incompetence of the inspector or the maintenance individual where they did not consider the defect of the keyway and they only replaced the old key.
3. The Photocell sensors were damaged before the 3rd service. However, they were not replaced in the 3rd and 4th service. It is apprehensive that the swapping procedures took place many times before the explosion happened, which is against the owner's manual instruction, "If the lift is used in conjunction with sensors for auto functions, ensure all sensors are working". This breach in the operating regulations suggests that the incident could have been prevented if maintenance for the sensors were done in time and in an appropriate manner by the engineer.

4. Without the photocell, the operator (Tony Best) used the override function on a control panel situated in the operative kiosk to initiate the battery swapping. This, however, should strictly only be used under emergency circumstances as stated in the user manual of the lift.

5. The broken CCTV covered the view of the battery swapping area where the worker in the store supervises the battery swapping operations. In the employee statement, Tony Best mentioned that he pressed the override button to start the battery swapping process as soon as he heard the alarm went off without having seen the battery swap area. Although it is not possible to deduce that the accident was caused by operational errors, it is definite that supervision on the operation is one of the safety procedures needed in the battery swapping process. Thus, the CCTV must always be in good condition as the station worker is always expected to be in the store. Otherwise, a supervisor can be assigned in each battery swapping bay to supervise the battery swapping process.

6. According to the figures in the HSL Incident Report, rust is present on the chains and drive shaft. Rust affects metals by making them weaker and causes metal parts to get stuck when they are supposed to slide over each other. Lubrication in general should prevent rusting and this proves that the engineer did not lubricate these components as specified in the user manual under the drive shaft and chain drive section.

Legal Issues Involved and Regulation Compliances:

1. Possible breach of agreement (Dates for battery delivery): BATT-R-E

BATT-R-E agreed with Energisation Ltd. that the new batteries are expected to be delivered to the station by the end of the first quarter of 2020 (from the email by Bobby Pink). However, there are two pieces of evidence suggesting that the delivery of batteries may have arrived later than the initial agreement which include:

i. According to the employee statement, the accident occurred a couple of days after the new batteries were put into circulation.
ii. The latest inspection service (by Lifts and Things Ltd.) before the accident occurred took place during October 2020.

These evidences show that the new batteries must have arrived either 6 months later than the initial agreement or they arrived on time but were implemented 6 months after the arrival. This indicates that if it is the case where the batteries arrived late, there was a **breach of agreement** by BATT-R-E company.

2. Negligence (in the operative regulations and safety procedures): Energisation Ltd.

There are number of proofs (from the Petrol Station Employee Statement and HSL Report) that Tony Best from Energisation Ltd. failed to follow the regulations of the Lifts and Things Ltd. Owner's Manual:

i. 'Operation requires supervision at all times' (from Lifts and Things Owners' Manual) but Tony was not supervising the station when the explosion happened, and Energisation Ltd failed to provide the equipment for this (CCTV).
ii. 'If a lift is used in conjunction with sensors for auto functions, ensure all sensors are working' (from Lifts and Things Owners' Manual) but the swapping station allowed to operate during the period when the photosensor is broken.
iii. 'Override button should only be used in emergency' (from Lifts and Things Owners' Manual) but the override button was used to initiate the swapping processes since the damage of the photocell.
iv. The user was required to leave the car and wait in the designated area during the swapping process; however, many users choose to remain in the car throughout the process and Tony admitted he did not ask them to leave.
v. In the employee statement, Tony Best mentions that the entire station has not been following the proper process, which implies that no formal training was conducted for their employees.

These evidences suggest that Energisation Ltd. was negligent in providing adequate training to their employees which led to Tony Best's violations of operative procedures and providing the equipment needed for this (CCTV).

3. Incompetence (Insufficient maintenance): Lifts and Things Ltd

Maintenance conducted by Lifts and Things Ltd was incomplete which led to the failure of the system. This is supported by the following evidence:

i. The failure to follow up the noise caused by the motor in the latest service report.
ii. The failure to replace photocell sensor even after a period of 6 months, as the April 2020 service report has already noted down the broken sensors.
iii. Insufficient instructions in the user manual, such as lacking instructions to perform checking on the keyway which ultimately led to the slipping of the key, then the breakage of the chains.

The failure to replace broken components and follow up on glaring issues such as the noise demonstrates the incompetence of the individual sent to maintain the system. In addition, the lack of certain crucial instructions on the manual can be viewed as Lifts and Things Ltd.'s negligence to properly train their employees and define a comprehensive maintenance procedure.

4. Fraud (Lift model offered and delivered): Lifts and Things Ltd

There are two conflicting evidence that might indicate possible fraud by Lifts and Things Ltd. which are:

i. The BATT-R-E company quoting their record of the lifting platform used by Energisation Ltd.'s swapping station is the LANDT_XX002C model in an email.
ii. However, from the after-incident investigation by HSL, they found that the actual lifting platform in practice was the LANDT_XX002A model, a different model to the above statement.

As the model present at the station is not the same as the records, with limited information, it was deduced that Lifts and Things had installed the wrong model. Although no official document was found to have stated the model used by Energisation Ltd.'s swapping station, the only evidence about the model to be installed is BATT-R-E's email. Thus, we can conclude that in this situation Lifts and Things Ltd has committed fraud against Energisation Ltd.

Final Verdict

These findings have led us to deduce 4 possible legal issues:

- **Breach of agreement by Batt-R-E.** where Batt-R-E had not delivered the new variants of the batteries before that agreed dates.
- **Negligence by Energisation Ltd.** by not being compliant with the operating instructions stated in the Lifts and Things Ltd. Owner's Manual.
- **Incompetence by Lifts and Things Ltd.** where Lifts and Things Ltd. failed to maintain the system up to standards and neglected training their employees properly.
- **Fraud by Lifts and Things Ltd.** where Lifts and Things Ltd. intentionally installed the LANDT_XX002A model despite agreeing to install the LANDT_XX002C model.

In our final analysis, Energisation Ltd is not the main party liable for the accident but they still hold responsibility for:

1. Not training the station operator (Mr Tony Best) up to standard and not providing clear instructions on the operative regulations and procedure for the swapping process that led to the malpractice of Mr Best which then led to the accident

On the other hand, Lifts and Things Ltd. is the most accountable for the incident due to:

1. Installation of the incorrect model which led to the overloading of the system.
2. Incompetence in making sure that the machine is operating safely and soundly. The evidence gathered showed that their maintenance was not up to standards and failed to identify and rectify certain major faults.

Hence, we concluded that Energisation Ltd holds liability for the accident due to violation of the regulations and procedures which endangered the users, but they are not the main party who is solely

accountable for the entire incident. The breach of agreement committed by installing the wrong model and incompetency in maintaining the system is enough to ensure that Lifts and Things Ltd is the main party accountable for the incident, even though Lifts and Things Ltd are not supposed to hold any liability due to the malpractices of the operator of Energisation Ltd.

New Product Design Specifications: Battery Swapping System

Aspect	Objective	Criteria	Test Conditions
Safety	High	**o** Should be able to swap batteries safely without causing damage to both the battery and components of the system, with precautions in case of failure **o** Have safety mechanisms that would operate when components fail. (such as the override function) **o** All delicate equipment must be kept within a safe enclosure. **o** Able to ventilate the battery storage and removing highly volatile gases and controlling humidity levels.	**o** Move the platform up and down with the maximum load **o** Hold the platform at mid-point for a few seconds with x1.25 maximum load with a fail-safe function in place. **o** All safety features will be randomly turned on to test whether it can work anytime. **o** Extreme cases (such as free falling of the platform) should be tested to ensure all safety features are engaged in such situations **o** Test that the sensor measurements are accurate, and the ventilation system can remove unwanted gases, which will be shown by a change in sensors' readings.
Ease of maintenance	Easy for engineers to repair or replace components if needed.	Faults should be easily identified, and repairs can be done with ease	Check suppliers to make sure spare or new parts can easily be obtained. The time taken to replace broken components should not take too long that can cause the swapping station to close.
Ease of operation	Easy enough for a trained worker to operate	Operations should not include complicated procedures or hard algorithms where it would take a significant amount of time for the operator to figure out how to operate the machine in every cycle of operation	The design will be consulted with skilled operation workers and a team of engineers to ensure that the system is easy to use.
Performance	Fast swapping	The swapping procedure must be within 5 minutes	Able to perform the process completely within 5 minutes.

TABLE 4: PRODUCT DESIGN SPECIFICATION (PDS): FROM MOST IMPORTANT TO LEAST

Evidence and reasoning for the PDS

1) **Safety**
   To prevent such an incident from happening in the future, this aspect must be the most important feature. This includes:

a. The platform must withstand a load that is x1.2 of the maximum load for a short amount of time with a failsafe in place so that if a heavier battery were to be used such as during the explosion, the platform will not drop the battery.
b. Stationary components such as the key and the grub screw should be tightened and secured and should not experience any unintended motion.
c. Delicate equipment such as the photocell must be in a safe location to prevent any damages due to human error.

2) Ease of Maintenance

From the service sheets and HSL analysis, it is evident that some parts of the system were not considered for service and repair. This resulted in reoccurring problems even after maintenance such as the key becoming loose after tightening, due to the indentation in the keyway.

3) Ease of Operation

From Tony Best's statement, this system was fully autonomous unless a problem occurs.

4) Performance

It is stated in Tony Best's statement that 'John Taylor seemed in a rush' when the incident happened, thus in our new PDS we included time of swapping as our performance criteria so that the time to swap batteries would not be a concern for the user in the new design.

<u>Proposed improved design and operative procedures</u>

The improved design (**FIGURE 9**) will be based around the original design where motors and chains are used to lift the platform. In this new design, some adjustments will be made to the previous design: the driveshaft locking mechanism and photocells. Also, new safety components will be added: guided poles, hydraulic damper, and the ventilation system. These will be explained in more details below:

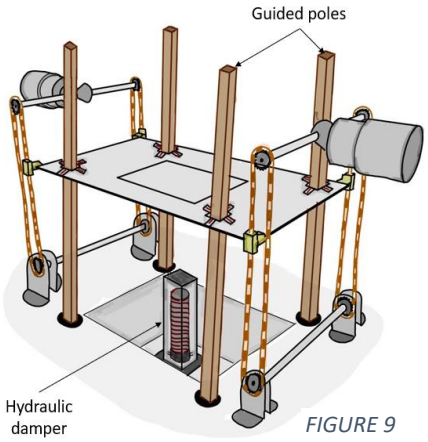

FIGURE 9

- **Driveshaft**

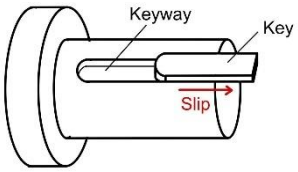

FIGURE 10

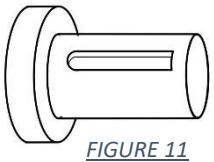
FIGURE 11

  - The current design (**FIGURE 10**) shows that the open-ended keyway poses risk in the key slipping out. In improved design (**FIGURE 11**), the keyway is designed to enclose the key, to reduce the risk of the key slipping out of place. The key must be tightly fitted into the slot to minimise the movement of the sprocket, hence the tolerant should be extremely small.
  - The driveshaft and the sprocket should be locked in place using a lock sleeve mechanism (**FIGURE 12**). The lock sleeve is directly bolted to the sprocket itself; this works the same way as a door stopper, which should provide sufficient friction to hold the sprocket in place.

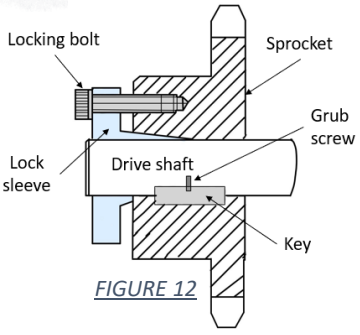

FIGURE 12

- **Guided Poles/rail**

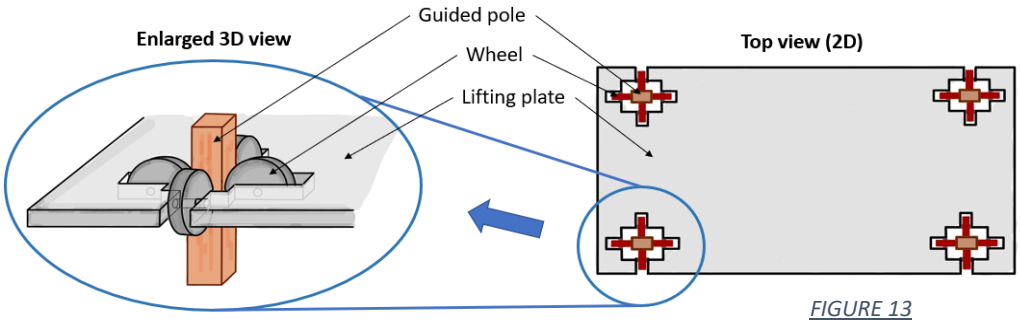

FIGURE 13

  - To further ensure that the platform does not tilt and drop the battery during an emergency, 4 guided poles structure is placed within the design much like a lift.
  - Should one of the sprockets or chains fail, the rotation or tilting of the platform would be constrained by the geometry of the platform and the guided poles. The platform is perfectly aligned with the guided poles; hence one side of the platform is prevented from being imbalanced from the level of the other side should one side collapses.

- **Hydraulic-spring damper**
  - In the case of an emergency where the motors or the chains failed and caused the platform to fall, the hydraulic-spring damper will absorb the energy of the impact, which minimises the possibility of the battery being damaged or causing an explosion.

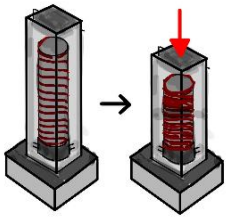

FIGURE 14

- **Photocell**
  - Initially, the photocell sensors are attached to the post in front of the entrance. This exposure of the sensors increases the risk of damage due to external factors thus it is suggested that the improved design should embed the sensors in the wall and on the ground of the battery swapping bay to enable some level of protection for the sensors.

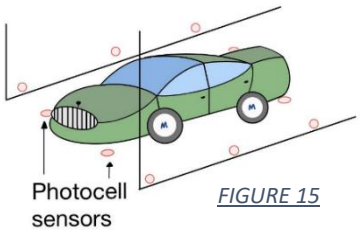

FIGURE 15

- **Ventilation**
  - The ventilation system should be implemented onto the battery storage unit to improve the airflow and control the humidity of the storage and operation units. This is to prevent further rusting and improve the standard in compliance with the HSE's regulation in battery keeping.

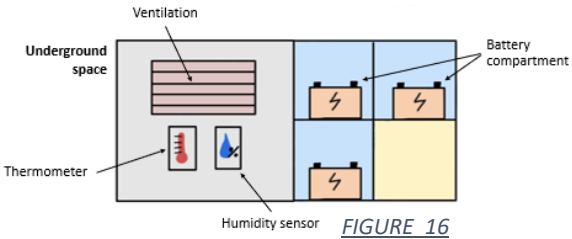

FIGURE 16

- **Maintenance & Operation**
  - Maintenance should be done every 3 months instead of 6 months
  - Engineers should be trained annually to perform proper maintenance.
  - Checking of components for wallowing should be added to the maintenance procedure.
  - Battery swapping operators should be trained to operate the station appropriately. The operators must understand that:
    - This operation must be always supervised.
    - Verification that nothing is in the way of the mechanisms is essential.
    - All sensors must work during operation.
    - The override button must only be used to lift the platform to ground level if the auto sensors are broken during operation and call for maintenance.
  - Cease operations if protocols are not up to standard.

Appendix 1

Calculation of loads in the single-roller chain:

According to the specification sheet of CA1N04B000 single-roller chain, its ultimate tensile strength is rated for 3.20kN (Sedis, 2019).

Max load per chain

$$L_{C,MAX} = \frac{3.20 \times 10^3}{9.81} = 326.19\ kg$$

Hence, theoretically, a lift with four chains attached could bear a maximum load of:

$$L_{L,MAX} = 4 \times L_{C,MAX} = 4 \times 326.19 = 1304.79kg$$

Since one of the chains broke due to misalignment as explained, its maximum load decreases to

$$L_{L,MAX} = 3 \times L_{C,MAX} = 3 \times 326.19 = 978.59kg$$

With the platform mass of $307kg$ therefore, the load capacity reduces to $978.59 - 307 = 671.59kg$ which is not enough to handle the mass of the $810kg$ ultimate variant hence the failure in structure.

The lift was overloaded by

$$\frac{810 - 671.59}{671.59} \times 100 = 20.6\%$$

Appendix 2

Risk Assessment for the new and improved design

Identification	Function	Failure Modes	Failure Effect		Failure Detection Method	Compensating Provisions	Severity * Likelihood	Remarks
			Local effect	System Effect				
Gearbox and Platform	Lifting battery from lower ground battery storage compartment up to the level of the Electric Vehicle where the platform must be at zero degrees in angle to the horizontal level at all times	Key breaks or misaligns	Drive shaft and sprocket can unlock and disengage from each other. The angle of the sprocket will be misaligned with the chain and the lay shaft sprocket.	The sprocket and drive shaft disengage from each other which will result in the sprocket rotating uncontrollably. Uneven distributed directional forces at the chain causing the disconnection or breakage of the chain.	An optical absolute shaft encoder can be integrated into the sprockets to ensure that the difference between the rotation speeds for each sprocket does not exceed a certain limit.	1) Frequent replacement of the key 2) Stronger material for the key can be used 3) Enclosed the keyway and make sure that the key fits in seamlessly into the keyway	4 x 4 = 16	Severity=2, Likelihood = 4 Severity: 1 will be the key breaking which leads to the collapse of the entire system, 5 = Lift system stop functioning but does not collapse
		Chains become disconnected	The lifting platform cannot operate and will be stuck.	The platform can collapse and a battery on the platform can drop from a height.	Use strain gauges to measure the tension in the chains. The tension will be zero when a chain breaks apart.	Firstly, remove any objects that lie on top of the platform manually. Then bring the platform down to the ground.	2 x 5 = 10	Severity = 2 Likelihood = 4 Severity could be 1 if the emergency braking system wasn't put in place and the guided poles does not restrict the tilting of the platform and battery still falls
		The locking feature of the drive shaft and the sprocket become loosen.	The sprocket can become misaligned and put more stress on the chain.	The chain can break if stress is acting at a weak spot of the chain	Laser system which aligns with the vertical angle of the sprocket to ensure that the sprockets do not misaligns	Stop the swapping procedure as soon as possible the tighten the screws or replace the lock sleeve to line-up the chain properly.	4 x 5 = 20	Severity = 2 Likelihood = 4 Severity: 2 if the locking mechanism fails along with the grub screw which results in the loosen sprocket
Sensor and detection systems	Make sure that both the vehicle and components are in their correct places before the swapping procedure takes place.	Photocell sensors break	The vehicle will not be in the correct place before the swapping procedure happens.	Both the vehicle and swapping components can be damaged. This can lead to an explosion of the battery if the swapping tools hit the battery's critical parts.	The warning alarm should be turned on to warn the operating team before starting the operation.	An emergency button should be used to stop the procedure as soon as possible and must be fixed by a maintenance team before using.	3 x 4 =12	Severity = 3, Likelihood = 4, The likelihood could be higher if the sensor wasn't built inside the pole.
Ventilation systems	Remove harmful gases that are produced by batteries when they are overcharged.	The ventilation system cannot expel the toxic gas from the storage compartment.	Harmful gases will be spread around the battery storage compartment	An explosion can occur if the temperature is raised by the over-charging of batteries or sparks	Use a thermometer to measure the temperature in the charging compartment.	Open all doors and windows to let fresh air into the compartment and to remove any flammable gases produced by batteries.	5 x 2 = 10	Severity = 5, Likelihood = 2, the severity could be 3 or 4 if the new batteries didn't have the isolation point technology.
Lift system's tower brackets	Sustain the full load of all components including gearbox, battery, platform and platform bracket.	The collapse of the entire lift mechanism	The collapse of one or multiple beams for the tower body	The collapse of the entire lift system which will result in 1) Dropping of battery which will lead to explosion 2) Damage of platform and gearbox due to fall 3) Human fatalities due to the fall heavy components	1) Strain gauges can be attached to every beam to ensure there're no overloading of beams 2) Measure each beam's natural frequency by attaching an accelerometer and striking the beams with a hammer to ensure the limits of buckling loads are not exceeded	All operations must be stopped if any of the beams fail and it is unlikely to be able to compensate for a collapsing tower bracket.	1 x 5 = 5	Severity = 1, Likelihood = 5 Severity: 1 will be the entire body of the lifting system collapsing and 5 would be everything will be still intact although one or more beams were bent

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