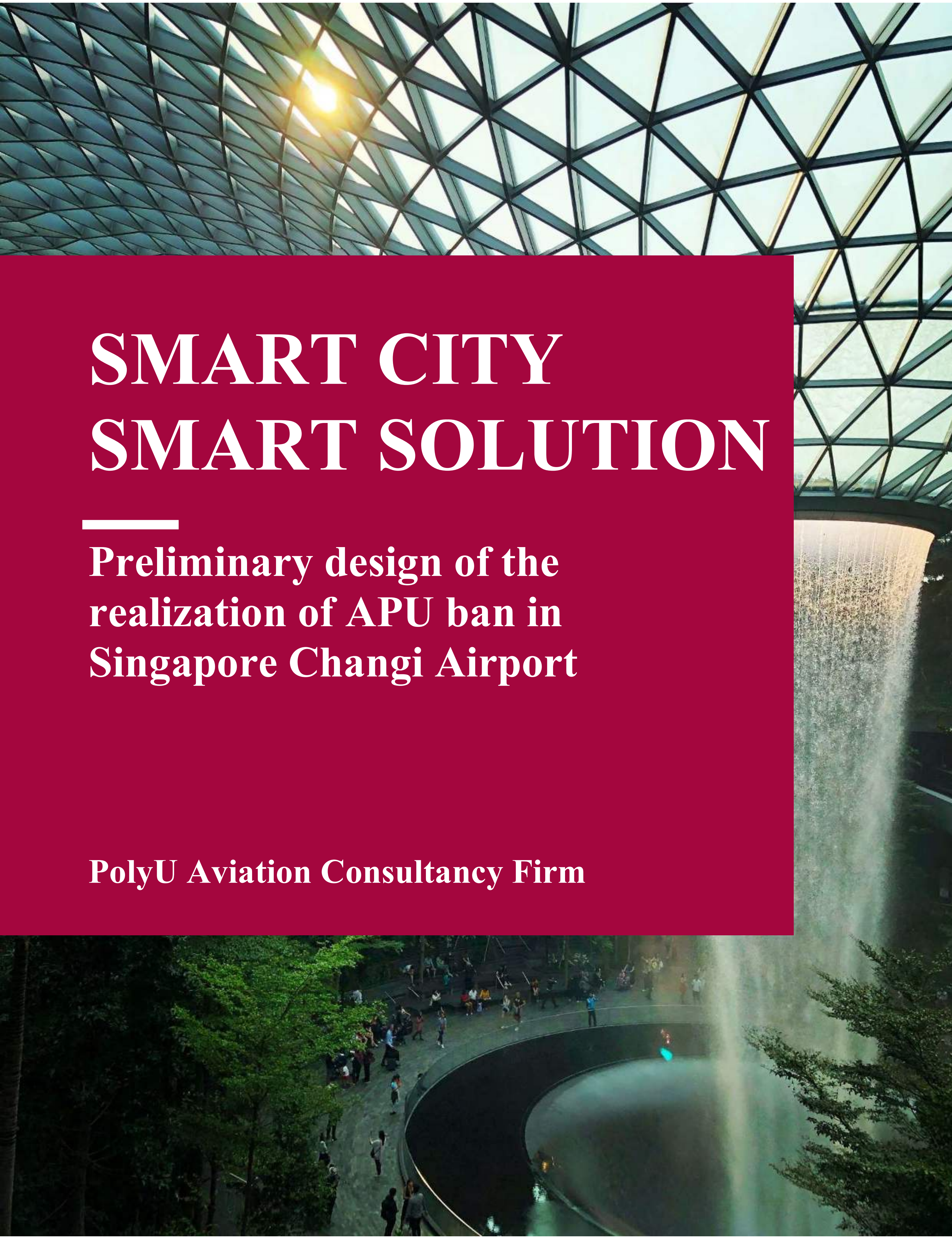

SMART CITY SMART SOLUTION

Preliminary design of the realization of APU ban in Singapore Changi Airport

PolyU Aviation Consultancy Firm

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Abstract

The Company's Background

The PolyU Aviation Consultancy Firm (PACF) is established in 2021 by a group of 10 aviation engineers from The Hong Kong Polytechnic University. It inaugurates consultancy services in aviation innovation and management. Its goal is to recommend an attainable, emission-free, and profitable solution to meet its clients' needs.

To achieve its goal, the PACF team conducts thorough research regarding its clients' problems. This research is consolidated with brainstorming, generating functional advice given to its clients.

Team members from PACF consists of the following founding members accountable for the proposed solution:

Introduction Team:

- LAM Ling Lee Sheena

Technical Team:

- LIN Ju
- TALADUA Ian Lorenzo
- QIN Qijun
- LIAN Jiarong

Budget Team:

- ANG Jershon Ainsleigh Entote
- KO Kwing Yu
- LUA Adrian Shalom

Persuasive Team:

- KAM Ho Pan
- KEUNG Yan Tung

With the preceding members, the PACF will continue to grow as they strive for an exceptional performance that could satisfy the client's demands. That way, PACF ensures productive counseling upon those in need.

Introduction

APU bans has been implemented in parts of the world, while also becoming the direction of the aviation industry. APU stands for 'Auxiliary Power Unit' - An engine used to provide electrical and mechanical power to the aircraft. Having an APU "banned" does not mean it is unutilized. An APU is banned for ground operations as it creates unnecessary noise and expenses within the process.

Singapore's Changi Airport is one of the world's busiest airports to implement the APU ban. Despite the challenges, the PACF suggests a cost-effective solution. This solution is the use of a Ground Power Unit as a replacement for APU on-ground operations.

Background

The Auxiliary Power Unit

The auxiliary power unit, also known as, "APU" is a turbine engine that is fixed on the empennage of the aircraft. It is essential for the electrical and mechanical functioning on powering the engine, air conditioning, shaft power, backup power, and ground operations [1].

The APU is mainly for the function of engine start-up, emergency source, and ground operation. Starting the engine, the APU compresses air, which generates bleed-air. When this bleed air reaches the main starter motor, it will spin every engine fan in the aircraft. Spinning these fans generates pressure that powers the other engine. After constant spinning is done by the other engine, the APU is turned off. This process is called, "cross-bleed" [2]. In a state of emergency - where an engine fails, the APU is useful to restart the engines [3]. It is because the APU supplies both powers to hydraulics and bleed-air to control the aircraft. In-ground operations, the APU can be used for providing power for the aircraft. It prepares the aircraft for take-off and generates propulsion for the aircraft on ground operations.

Figure 1 The Auxiliary Power Unit [11]

The APU consists of three sections: the power section, load compressor, and the gearbox. The power section generates power to the shaft, featuring a gas generator. The load compressor provides pneumatic pressure to the aircraft fixed on a shaft. Lastly, the gearbox is used to transfer energy from the APU to an electric generator [4].

Though it has been seen with significant functions, it causes noise pollution. This is a problem in aviation as it may cause health problems [5]. Experienced in daily life, it is evident that aircraft noises are a problem today. Another problem seen is the emissions that the APU has. According to Kinsey et. al. [6], the APU emissions include Sulfur Dioxide, Total Hydrocarbons, Carbon Monoxide, and Nitrogen Oxide.

The APU Ban

Various organizations act on reducing aircraft noise and emissions. This includes a limited usage of APU - the APU ban. The APU ban should be implemented due to the following reasons – safety, regulatory, air quality, noise level, and ramp congestion [7]. Due to these reasons, several airports implemented the APU ban. With this procedure, noise, and emissions will be reduced.

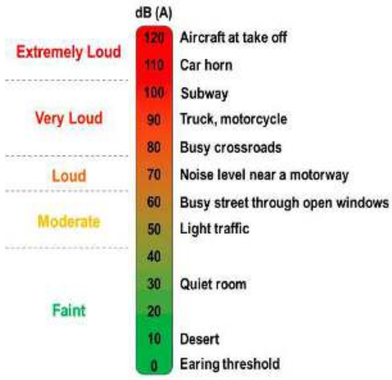

Figure 2 Noise Levels [12]

The Singapore Changi Airport

The Singapore's renowned Changi Airport is considered the world's best by Skytrax since the year 2013 – 2019. It accommodates over 100 airlines which flies to 400 cities worldwide [8]. It is constantly innovating and expanding as passengers increase in number. To sustain this growth, the Changi Airport utilizes Artificial Intelligence (AI) and the Internet of Things (IoT) [9]. With these innovations, the Singapore Changi Airport's sustainability report [10] shows that they reduced emissions from their previous years. Although they may have alleviated some emissions, their goal is to still minimize more emissions.

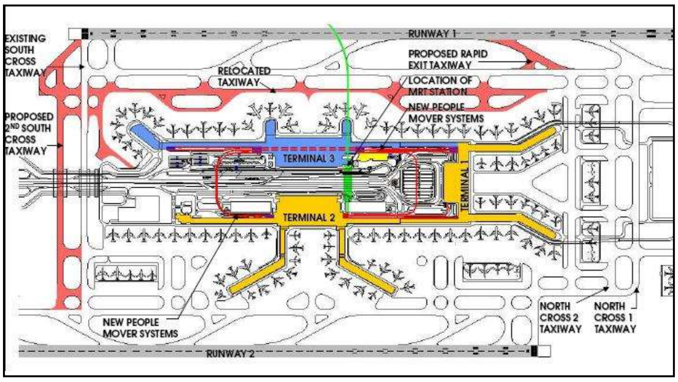

Figure 3 Singapore's Changi Airport Map [13]

Implementation Plan

To achieve the goal of energy saving, emission reduction, and environmental protection in the Singapore Changi Airport, our team experimented and simulated different methods for a long time. After tons of effort, we eventually designed the following innovative, ground-breaking, comprehensive, safe, and reliable solution to achieve this ambitious goal: No Auxiliary Power Unit (APU) is required in the aircraft's ground operation within the airport area.

Installed Equipment

To realize our plan, we have taken into account the existing facilities and other objective conditions of the airport and finally decided to improve or introduce the following equipment.

Air Start Unit

Aircraft engines will only start working when they are driven by strong power. Traditionally, the Auxiliary Power Unit (APU) is used to provide high pressure airflow to the engine to start the aircraft engine, but this causes noise pollution on the ground, and emits large amounts of greenhouse gases and inefficiently consumes large amounts of fuel [14]. In this plan, the Air Start Unit (ASU) replaces the role of APU to provide the initial movement and rotation of large aircraft turbine engines [15].

Figure 4 AIRSTART of IAE engine with Air Starter Unit (ASU) - LATAM Airbus A320 [16]

Smart Aircraft Tug Unit

Smart Aircraft Tug Units (SATU) are able to provide the power to move the aircrafts by "uprising the front gear" without operation or power from the turbine engines. In fact, Changi Airport is currently equipped with small tugs with remote control as shown on the right, and this tug is planned to be upgraded to provide several additional functions as listed below:

Figure 5 Ground crews remotely controlled the aircraft tug to push back the A320 at Changi Airport [17].

1. The front end of the aircraft tugs incorporates an integral connection component that allows them to be connected to Ground Power Unit (GPU). This component guarantees the aircraft's stable power connection during the push-back procedure. The connection between the tug and the GPU as well as the power connection between the GPU and the aircraft will be cut off manually after one engine has been started.

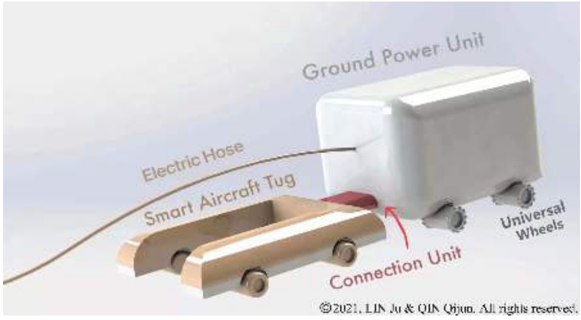

Figure 6 Concept diagram for Smart Multi-functional Tug

2. These smart aircraft tugs use IoT technology for route planning to transport aircraft safely and efficiently to the Runway Taxi-Holding Position (RTHP) and return automatically.

3. They have sensors installed around them to achieve obstacle avoidance through intelligent analysis.

4. Wireless charging modules have been added to allow tugs to charge themselves at the nearest charging base when low battery status is detected.

5. This SATUs are equipped with ultra-high accuracy positioning systems and can identify signs on the ground. As an exemplification, it can recognize RTHP markers, aiding its performance in positioning.

400Hz Ground Power Unit

A Ground Power Unit (GPU) is usually a vehicle capable of supplying power to aircraft parked on the ground. However, it can also be installed in the jet bridge for operation when the aircrafts are parked in the terminal. For this plan, we will equip the airport with both of it to facilitate the electricity supply before any engine is started.


Figure 7 400Hz Ground Power Units powering an aircraft [18]

Similarly, we updated the GPU vehicles to guarantee reliability and safety. For instance, we plan to import an integrated connection component to the rear of the GPU that can be combined with the front end of the ASU. With this component, the GPU can power the electrical system of the aircraft during push-back phase, ensuring that the aircraft can start its normal functions even before the engine is started. Since that the power supply port of aircrafts are located in the lower part of the front of the aircrafts, if the relative positions of the GPU and the aircrafts are changeable during the push-back procedure, it is possible to result in serious safety concerns including the situation when the overly long hoses are caught in the front wheels or engines. We believe that this new design can help solve this problem when this design use fixed structure to ensure the relative positions of both objects.

Equally important, the wheels of Ground Power Unit vehicles have also been improved with universal wheels, an upgrade that allows this component to steer more properly[1].

After the Air Start Unit starts either side of the turbine engines, the vehicle will break the connection from the aircraft when appropriate and be driven away the safe area manually.

DC Charging Piles

The design of the DC Charging Piles is inspired by smart home sweepers and fast charging protocols for cell phones. The charging piles are fixedly installed close to each jet bridge and parking spot. The piles provide two types of charging modes, which are wireless charging and wired charging. The wireless charging facilitates the SATUs to charge themselves when low battery status is detected. Meanwhile, wired DC charging uses high power for efficient and safe charging of SATUs.

Standard Operating Procedures (SOP)

After introducing the newly installed equipment according to our plan, the following content, combined with the objective situation in Changi Airport, presents you the detailed operating procedures of the realization of APU ban.

Take-off Operating Procedures (TOP)

The whole TOP is further divided into two main parts. The first part is from the start of push-back procedure to the First Stop Site (see *Figure 9*), and the second part is from the First Stop Site to an appropriate position close to the RTHP.

[1] The component couldn't steer properly without this upgrade since the turning steers are located in one set of the SATU's wheels that are closer to the Connection Unit.

When an aircraft is permitted to leave the jet bridge, the ground crews will cut off its connection with the Air Conditioning Unit and the Ground Power Unit sourced from the jet bridge. Then, the GPU vehicle will assembly the SATU through an integrated connection component and power the aircraft. The assembly (SATU+GPU) then pushes back the airplane from its parking position.

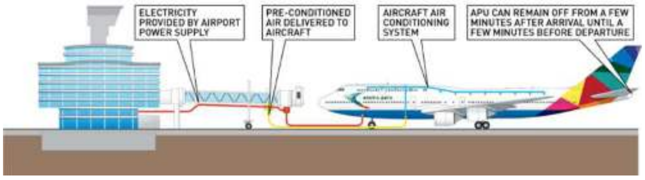

Figure 8 Basic layout of aircraft ground energy systems [19]

When the aircraft being pushed back to the First Stop Site, the component will stop the further movement of the aircraft. Subsequently, the ASU will arrive and provide the initial movement and rotation of either side of the aircraft's turbine engines in accordance with the specific model of the engine. After one engine is started and the started engine is put to a phase where the electric system of the aircraft is operating normally, and the air compressed is enough for aircraft operation and maintaining cabin pressure, the ground crews will cut off the connection of the GPU after the captain switches the power source from the GPU to the engine. Then, the ground crews will drive the GPU and ASU back to the terminal, only leaving the aircraft tug holding the aircraft's front gear up.

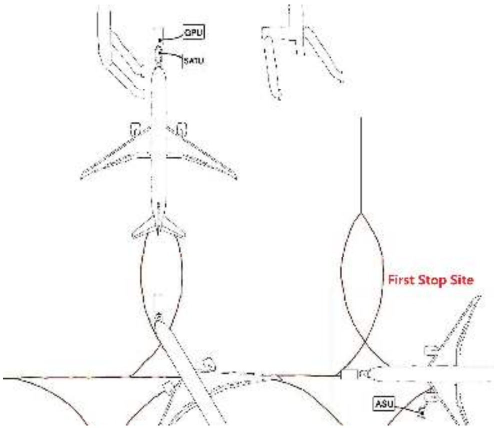

Figure 9 Diagram of the First Stop Site

After other Ground Support Equipment except the SATU is uninstalled, the rest of the process was carried out unattended. With the support of IoT techniques and obstacle avoidance algorithm, the SATU then takes the aircraft to a position where is close to the RTHP through an effective route planning. When ATC and tower determine that the aircraft can enter the runway and take off in a relatively short period of time, the pilot can use the already started engine to start the other engines that are not started yet, which is also regarded as cross-bleeding, and check the engines' performance in the meantime. When everything is set, the SATU automatically detaches from the aircraft and follows the automatically generated route back to the departure jet bridge to prepare for the next flight.

It is worth noting that the separation of the SATU and the aircraft occurs when close to the RTHP as the SATU cannot get too close to the aircraft whose engines are pushed to full speed in the runway. In addition, cross-bleeding generally occurs while the SATU is in transit and the aircraft can take off without queueing, even when the aircraft encounter air traffic control and require a longer wait, the SATU will wait with the aircraft and won't break until the other engines are started successfully and the condition is normal.

Figure 10 Schematic Diagram of TOP

Landing Operating Procedures (LOP)

After an aircraft landed on the runway, it will be required to exit from the appropriate runway exit without delay to ensure runway clearance. After the aircraft finishes exiting the runway, it will follow a generated route to its assigned parking position with its own engine power. After it arrives at the destinated spot, one side of its engines will be turned off. Ground crews then connect the aircraft to the GPU that is installed in the jet bridge (or from a vehicle when the aircraft is not parked against the jet bridge). Subsequent to the pilot's switching the power source from engines to GPU, all the engines will then be turned off. The following operations are the same as usual.

Figure 11 Schematic Diagram of LOP

Technical Details

The proposed revised Standardized Operating Procedures takes advantage of current multi-engine transport aircrafts' systems ability to run on only one engine, thus limiting the air and noise pollution produced by the aircraft, whilst keeping the aircraft's systems running with no ground equipment.

A multi-engine aircraft's electrical system consists of alternating current (AC) and direct current (DC) bus/es, in which each is powered by at least one generator, and at least one battery, in addition to units that convert DC to AC and vice-versa. While in most times, the generators would power their respective buses in a split-bus configuration, in times when a generator is unable to supply power to its respective bus, pilots can supply power to the affected bus by opening the respective bus ties, in turn, changing the configuration of the aircraft's electric system into a parallel bus configuration.

To start the engines, the aircraft uses air from the pneumatic system to drive the engine starter. The air from the pneumatic system can be sourced from three sources: ground equipment, specifically the ASU, APU, or another engine [20]. In the revised Standardized Operating Procedures for departing aircraft, after the aircraft has finished its pushback, the ground crew would connect the ASU to the aircraft, giving the aircraft the necessary pneumatic pressure and volume to start one of its engines. After the engine has completed spooling up, the ground crew would disconnect the ASU. At about the same time, the pilots would open the crossfeed valves so that when the aircraft is to start the remaining engines, the air that will be used to drive the engine starters will be sourced from the bleed air of the operating engine.

While most commercial aircraft rely on a bleed air pneumatic system to start up their engines, a special case has to discuss with regards to aircraft with a no-bleed systems architecture, in other words, the Boeing 787 family (B787). As a replacement to the pneumatically driven engine starter, the B787 uses its generators in the engine to start the aircraft through a start converter. In addition, after the engine-start phase, these start generators will serve as controllers for the cabin pressurization motors [21].

Alternative Taxiing Procedures

While aircraft engines are very efficient in flight, it is relatively not efficient when it is on the ground and taxiing, considering the greenhouse gas emissions and amount of noise generated when using the engines to propel the aircraft during taxi. As part of the team's proposal is for departing aircraft to taxi from the departing stand to the runway using a tow instead of relying on the aircraft's engine power, one must explore various alternative taxiing procedures to understand why the group decided that it is best to taxi with aid from a tow.

Taxiing Using a Tow

A possible solution would be to use a pushback tow to pull the aircraft forward as it taxies to the runway, disconnecting just before the aircraft will enter its assigned departing runway. Amsterdam Schiphol International Airport has experimented with this technique with a special towing vehicle called Taxibot. Unlike normal towing vehicles, Taxibot is not driven by the driver of the towing vehicle, but by the pilot. The vehicle will only provide the movement of the aircraft at about 41 km/h, while the pilots will provide the steering and braking. When the aircraft reaches the runway, the towing vehicle will unlink from the aircraft and return to the terminal, while the aircraft would continue in its departure procedures [22].

The experiment was run on Boeing 737-700s and -800s, which resulted in a 50-65% increase in fuel savings, with also a 50-65% decrease in CO2 and oxides of nitrogen emissions. However, it was pointed out by the authors that there are certain requirements before this procedure is to be implemented on an airport-wide level, such as the need for modifying current and building new infrastructure to support a procedure like this such as additional roads to points where the aircraft is going to unlink from the towing vehicle, enabling the towing vehicle's compatibility with other aircraft, and updating procedures and training of pushback drivers and pilots [22].

Taxiing With Only One Engine

Another method that has been discussed is the use of single-engine taxiing procedures. While it is less experimental compared to its towing counterpart, its logic is that it is possible to only use one engine for taxi operations, minimizing noise, greenhouse gas emissions, and fuel consumption.

This method of taxiing was experimented in a study in collaboration with London Heathrow International Airport and an unnamed airline, where after the aircraft would complete its post-landing checks at a constant thrust setting, the pilots would then shut down the secondary engine for taxi-in operations. It should be noted that this experiment does not cover taxi-out operations. However, the authors infer that trends seen in the data for taxi-in operations could also be similarly seen for taxi-out operations. On twin jets, the pilots would shut down the engine on one side when initiating single-engine operations, while on quad jets, pilots would only shut down two engines on one side of the wing to begin single-engine operations [23].

The results of the study reveal that there is a 50% increase in fuel consumption and emissions if pilots do not use single-engine taxi procedures. In taxi-in operations, it was concluded that reducing the time before pilots shut down the necessary engines to begin single-engine operations reduces the fuel consumption and greenhouse gas emissions by 7-14% [23].

While the authors of the paper have recommended mandatory implementation of single-engine operations in many airports [23], authors discussing the sustainable taxi experiment in Amsterdam Schiphol have discussed against its implementation due to a more intense jet blast, which endangers passengers, ground personnel, and equipment when the. In addition, single-engine taxiing creates an issue of aircraft maneuverability for pilots when taxiing. When the twinjet, for example, taxies with all of its engines on, the aircraft can taxi in a symmetrical thrust setting and can use asymmetrical thrust settings should need be. In single-engine taxi operations, however, the aircraft will always have an asymmetrical thrust setting and will tend to turn, which will have to be counteracted by the pilot's corrections through the aircraft's tiller steering [24]. The fuel savings have also been pointed out to be lower when compared to sustainable taxiing with the Schipol authors estimating a 30% increase in fuel savings for single-engine taxiing to the 50% to 65% increase in fuel savings for sustainable taxiing [22].

Conclusion

As a result, it is generally agreed that despite the necessary cost to the changes that would be in place to execute the operations, it is agreed that sustainable taxiing, through the SATU, would be a better option due to the higher fuel savings that could be achieved and lower air and noise pollution due to the aircraft not needing to use its engines for propulsion, all without the aircraft having to experience a tendency to turn, which would be seen if the aircraft is to use single-engine taxi.

Application of Internet of Things

Internet of Things (IoT) is a network that extends and expands on the basis of the Internet, forming a huge network by combining various information sensing devices with the Internet to realize the interconnection of people, machines and things at any time and any place [25].

Background

General Description

Nowadays, the IoT is a very extensive technology in the world. It has a wide range of applications, covering industry, agriculture, transportation, energy, smart cities and many other fields. It collects and organizes all kinds of information into the Internet cloud, and with the excellent computing performance of computers, it can complete the integrated planning in a very short time, enabling all industries to operate efficiently and stably. Therefore, IoT technology is widely supported and favored by various industries like Express Industry using IoT robot to sort couriers, or the smart quay using IoT.

In addition, most IoT technologies have matured including cloud computing technologies, IoT platforms, related chips, and wireless connectivity communications. These technology providers include AWS, Aliyun, Intel, Entech, Apple, etc. [26], which have formed a large and mature industrial chain.

IoT in Changi Airport

Based on the Smart Nation Policy of Singapore, Changi Airport has launched the Smart Airport construction plan. Currently, Changi Airport has adopted IoT technology in many areas, which is supported by the Living Lab Program. The airport already owns kiosk check-in, automated bag drop and boarding which are self-service; biometric technology that makes a smooth trip for passengers; Cameras and technology that detect and identify

Figure 12 Self-service Kiosk Check-in [27]

incoming planes; 'Smart Tower' that enables air traffic controllers; Laser-guided autonomous aerobridge; Automated vehicle ramps; Autonomous Container Trailer (ACT); etc. [28]. These smart IoT facilities provide passengers with a profound travel experience, while providing a good technical foundation for smart airport construction. And of course, this provides a superior infrastructure for our smart solution to APU ban [27].

Figure 13 Autonomous Container Trailer [27]

Scheme Design

General

In order to realize the automation function of Smart Aircraft Tug Units (SATU), we need to design an architecture that interconnects SATU with the Internet system and merges it into the original IoT framework so that the data from the SATU can be transmitted to the Internet, through integrated computer planning, and the commands can be return to the SATU and executed.

Therefore, we considered 4 parts: SATU Data Collector, SATU-IoT Communication Module, IoT Cloud Data Processing and SATU Execution Mechanism.

SATU Data Collector

This part includes various sensors (such as infrared, laser-guidance, camera), ground operation feedback device and, most importantly, the Positioning System. After all the data are collected, they will be packaged and sent to the communication module, and then sent out periodically.

Since Changi Airport itself has a self-driving vehicle similar to ACT, with mature equipment in terms of sensors and position systems, we just need to use the same equipment as it has.

SATU-IoT Communication Module

The communication module is the link between the Device Layer and the Application Layer. We realize the data interaction between the Device Layer and the Application Layer by transferring the sensing data or Application Layer data from the wireless transmission module to the existing Network Layer of Changi Airport through certain protocols, and then distributing it to the Application Layer or the Execution Mechanism.

IoT Cloud Data Processing

In the Application Layer, the IoT cloud computer will receive data collected from SATU, including basic ground obstacle information, ground handling operation information, vehicle positioning information, and also receive instructions from ATC.

After the ground sends a push back or taxi signal to the computer in the Application Layer, the computer will judge the back push and taxi timing based on the airport traffic recorded in the cloud, and at the same time use the path algorithm to automatically calculate the best taxi-route for push back or taxi to Runway Taxi-Holding Position. After the calculation is completed, the cloud will send the corresponding instruction to SATU to execute.

During taxiing, the computer also determines when the aircraft is expected to reach Runway-Holding Position and automatically alerts the pilot to the timing of starting the other engine via a specific radio frequency.

When the aircraft reaches the Runway-Holding Position, SATU will automatically disconnect from the wheel and send data to the cloud, and then the cloud will calculate a safe route back to the original Ramp/Jetway via the vehicle lane. Of course, the cloud will also make a comprehensive allocation of SATU when needed.

SATU Execution Mechanism

The Execution Mechanism mainly processes the received commands and assigns the commands to the actuators through the chip to make the SATU do the actions.

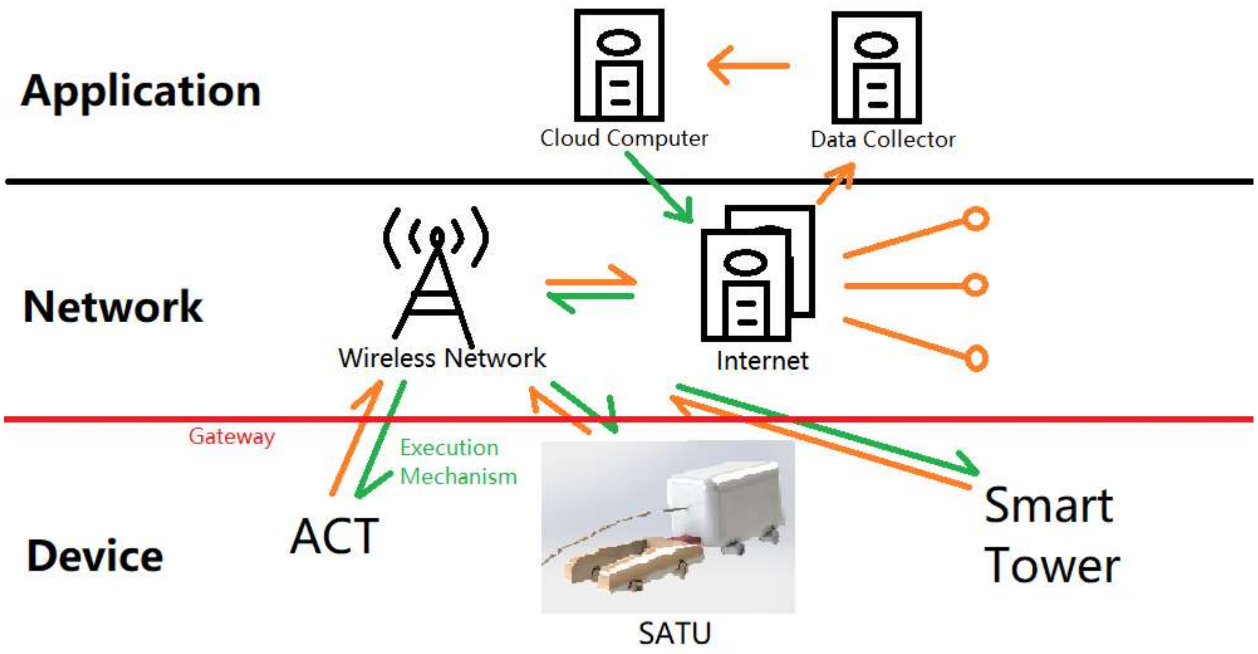

Figure 14 IoT Structure Schematic

Security & Safety

There are two potential forms of security issues, one is IoT data security on network level, and the other is SATU technology safety on execution level.

Network Security

Network security is one of the most important aspects of IoT. It includes the stability of the network, the capacity to carry data at scale, and the ability to defend against network attacks.

In this aspect, Changi Airport's technical team has already established a mature IoT system, so the network security can be well guaranteed.

SATU Traffic Safety

While airports already have self-driving vehicles similar to ACT, SATU is different. Because SATU operates on taxiways close to the runway, there may be some problems such as signal instability due to long distance transmission and sudden false stops on distant taxiways.

Therefore, we need to design emergency avoidance procedures. When a SATU loses its signal en route or has a sudden shutdown, the IoT will detect the problem in time and immediately re-route all SATUs at the airport and signal the rescue station.

Beneficial Highlights

Among so many teams working on how to ban the APU use in the Singapore Changi Airport, our team have some special and highly efficient highlights to better solve the current pollution problems as well as provide a possible solution for the new trend of smart operation in Airport. A greener future is all we wish and keep fighting for.

Emergency Response Mechanism

As we all know that all mechanical things have the possibility of failure, so having some redundancy may avoid potential operation problems. So, it is very important to have some redundancy.

SATU

If one of the SATUs fails while performing its task, the SATU immediately notifies the Emergency Response Team (ERT) and the IoT system about the essential information such as location. The IoT network then notifies nearby devices and plans a route for other devices to be unaffected by the failure. After receiving the response, the ERT will travel to the failure location to further address the unexpected situation. Prior to this, the IoT system automatically plans a safe route for it (note that this route is planned in collaboration with other devices within the IoT network to ensure its safety).

We also prepared four extra SATUs. In case one device fails, the alternate device will take over its original role.

Network

Network like the IoT highly rely on the computers, if the computer failed, the IoT may result in chaos. So have a redundancy of the internet things is very important too.

As our team has planned, we will build a mirror server to the airport, which will have the same computers, the same data, the same operational logic but with different electricity resources. This will let the airport continues to operate in case of sudden electricity cut.

Environmental Friendliness

Aiming to improve the airport's service and to response the call of reducing the operating emissions, our team provides some suggesting changes to the normal airport operations, also sets some new standards for the ground crews and the airliners' managers, which will make the Singapore Changi Airport to be more environmentally friendly.

Energy Saving

In our designed taxing, taking off and landing procedures, saving more energy is of the second priority just behind the safety. To achieve this energy saving goal, we adopt several new operation rules.

Firstly, we choose to use the ASU instead of the APU to start the engine. K.A. Friedrich and R. Henne [29] illustrate that the APU creates up to 20% of the aircraft ground-based emission and cost a lot of fuel. As a fact that the APU is not build for ground operation, it is more focus on the high attitude operation, is not an efficient way to use APU to start the engines and to create electricity all time on the ground. To solve this serious issue, we decide to use the ASU to start the engine. The ASU is a specially built engine unit that only focus on starting the engine, so it is easy to make the ASU more energy-efficient and to save energy during the engine-starting period.

Figure 15 A car carrying jet fuel [30]

Secondly, in the taxing period, as we designed, the aircraft only start one engine and make it to idle position. The idling engine is mainly to generate electricity for the electricity consuming devices onboard such as the flight control systems, the air condition system and the entertainment systems. There is a big problem in Singapore Changi Airport that due to the heavy air traffic, the airplanes need to wait on the taxi way more than 15 minutes before they can approach to the runway and taking off. In traditional practice, the airplanes have to start their two engines (some may be four engines) all the way through taxing, this is a huge energy lost for the aircrafts. However, as our team planed, the airplanes only need to start one engine to generate electricity almost all the time of the taxing. They even don’t need to add more power to move the aircraft, because the SATU can automatically lead the aircrafts to follow the aircraft ahead. This energy saving plan really works in the busy airport like the Singapore Changi Airport.

Thirdly, our team will use the Internet of Things technology (IoT) and artificial intelligence technology (AI) to better plan the taxi routes and the push back time for airplanes. This kind of technology is a future trend for fuel efficiency and time efficiency operation. By the calculation of the main computer in the airport and the big data analyse, the system can provide a command to the SATU to avoid the potential traffic jam. This again, will help the Singapore Changi Airport to be more efficient.

Also, all kinds of the ground service vehicles will be gradually changed to the electricity powered vehicles. Singapore Changi Airport seldom face an extreme cold weather, so the power weaken in the battery will not affect the airport’s daily operation so much. Through using the electricity to power the vehicles, the airport will reduce much more emissions and can make the operation cost to be much lower.

Noise Reduction

Apart from the heavy emission, the big noise caused by aircrafts’ engines is also disturbing citizens around the airport. According to World Health Organization (WTO) [31], exposing to the loud noise like jet engines for a long time may be harmful to human beings hearing and the mental health. In our designed aircraft operation, only one idling engine per aircraft is needed in the taxing period, which will greatly reduce the noise caused by jet engines. This will be more friendly to the citizens around the airport, also, will be more friendly to the ground crews.

Figure 16 A ground crew wearing a headphone to protect himself [32]

Time Saving

Saving time to travel from one place to another is a big advantage for aircrafts that they can fly almost a straight line in the sky with a high speed. However, nowadays, a long-time delay for aircrafts is a common thing. Sometime, the bad weather caused the delay, but in most of the time, the low-efficiency management of the airport caused the delay. Based on this, our team arranged some ways to make the airplanes operate more smoothly.

1. After checking in all the passengers, the airplanes will send a message to the terminal and the main computer in the terminal, the terminal will automatically calculate the fastest path and guide the SATU to follow it. If the system analyse that the airplane needs to wait and cannot directly be guided to the taxi way, the plane will be told to stay in the terminal and use the GPU to support the whole airplane that could avoid the potential emissions. If when it is time to leading the aircraft to the terminal, the aircraft will cost little time on taxing and can take off smoothly.

2. The airplanes that just landed will have the highest priority to taxi back to the terminal. When the sensors captured which exit the airplane have exited, it will directly report it to the main computer to avoid the potential collisions with other airplanes. This will also save a lot of time.

Linkage to the Future

It is a common agreement that our world is changing very quickly, so the plan our team delivered is not only focus on present, but also focusing on the future updates and next generation products.

Internet of Things

Our team plans to link everything connect to the internet, even the passengers' luggage. With this technology applied, the management of the whole airport will be easier and more efficient. Also, the airport operating manage system is an open system, which means that if the airport wants to add some new vehicles or some other equipment for other purpose, they can join the current system without any boundary.

Adoption for Next Generation Aircrafts

With the development of modern technology, the aircrafts changes in a fast speed, so it is very important for the huge airport like Singapore Changi Airport to keep adopting the newly exited aircrafts. When a new airplane exits and need to use a special linkage to transport passengers from the terminal to the aircraft, the airport only needs to build a few new linkages for them and the SATU will automatically guide the aircraft to the special terminal, this is a low-cost way to achieve that goal.

Cost-gain Balancing

Although so many methods can achieve this kind of operations, but our team more focus on balancing the cost and the gain of the airport. We pursue spending less money and achieve better performance. Therefore, we also ruled out many impractical solutions in the process of consideration. We will then list one typical example of those innovative but irrational plans.

Building Underground Track

We have thought about building underground roads for the SATU, however, after deeply considering about, our team finally choose not to this kind of method. Reasons are listed as follows:

1. Building underground roads for the SATU is very expensive. Comparing to building roads on the ground, the underground operation may cost extra money.
2. Building underground roads for the SATU is time-consuming. It is widely agreed that the Singapore Changi Airport is one of the busiest airports in the world, even during the pandemic time. If our team wants to build an underground for the SATU, it needs to close the runway to do the construction. This will take a long time and it is a disturbance to the normal operation to the airport.
3. Building underground roads for the SATU is not flexible. The airport is changing quickly, we cannot promise that the airport won't expand its size. However, the underground roads can't be change or reschedule easily, which means that the underground roads may be a boundary for the airport in the future.
4. Building underground roads for the SATU may affect the stability of the runway. The runway needs to be strong enough to ensure a safe landing. Building roads under it may cause potential risks to it.

Budget

To ensure that the mentioned solutions can be properly and realistically implemented, the team has come up with the budget plan of the said solutions for Singapore Changi Airport (SIN) to use as reference.

Equipment Expenditures

The equipment expenditures consist of equipment purchasing and maintenance costs. The following costs were calculated assuming SIN did not have the equipment. This assumption was done because SIN does not reveal how much of each equipment is available in the airport. It must therefore be noted that these costs would have to be the maximum possible costs for this project, and may vary depending on how much equipment SIN currently has.

Equipment Purchasing

To determine equipment costs, the first thing that needs to be done is to determine the total number of jet bridges and remote parking bays of Singapore Changi Airport (SIN). To do this, the estimated number of parking bays in Terminal 5 must first be estimated. The total number of jet bridges was first calculated by obtaining the average ratio of the maximum passenger capacity and the number of jet bridges per terminal. This ratio was then multiplied to the expected passenger capacity of the fifth terminal, in which 66 parking bays were calculated. The total number of parking bays was then calculated by first obtaining the floor area of the fifth terminal. This was done by getting the average ratio between the floor area and maximum passenger capacity of each terminal, which was then multiplied to the expected capacity of Terminal 5, resulting in a floor area of 688,491 sq ft. This number was then multiplied to the average ratio between the total number of parking bays to the floor area of each terminal, resulting in a total of 89 parking bays for Terminal 5. The number of remote parking bays for this terminal would then be 23, resulting in a total of 248 parking bays (206 jet bridges and 42 remote parking bays) [33] for SIN.

Air Starter Unit

The specific price of the Air Starter Unit is indeterminate as the supplier requested for an official order enquiry before being able to access the price quote of the product. As this plan is currently only a proposal, no official enquiry could be made yet, and hence, estimation would be needed. According to online markets [34], a caterpillar air starter (for cars and diesel engines) costs around 16,000 HKD.

The ratio of the median price of an airliner ($100M) [35] to the median price of an automobile ($41,000) [36] is approximately 2,439.02 or 24.39x. Using this ratio, the cost of an air starter for aircraft would be 16,000 x 24.39 = HKD 390,243 . Hence , the estimated cost of an Air Starter Unit (ASU) is HKD 390,243. The amount of air starter units needed will be equal to the amount of jet bridges. This means that in total, SIN would need 206 ASUs. The total expense of the Air Starter Units would then be HKD 80,390,243.9.

Smart Aircraft Tug Unit

Smart Aircraft Tug Units (SATUs) cost approximately USD 214,000, or HKD 1,667,276.14 [37], inclusive of the data processing chip, anti-interference modules, lidar sensors, etc. The amount of Smart Aircraft Tug Units depends on the average number of flights per hour. Based on data acquired [38], there are on average 22 flights per hour in SIN. On average, pushback takes 10 minutes, and so splitting the 22 flights into 10-minute intervals, there would be around 4 flights every 10 minute interval of pushback. This means that at least 4 SATUs need to be operational at the same time. To account for redundancy and delay possibilities, 12 SATUs that operate at the same time would be needed. Hence, the airport would need 12 different SATUs. This means that the total cost for SATUs required would be HKD 20,007,312.

Because these smart tugs need to be connected to the Ground Power Units to function properly, the cost for a connecting unit would also need to be accounted for. More specifically, aircraft towbars can be used to serve as the connecting unit. A Narrow Body Interchangeable Multi-Head Towbar costs HKD 24,520 [39]. In total, the cost for the towbars would be HKD 294,240.

As for the wireless charging unit, there is currently only one company that provides services for installing wireless chargers on electric vehicles (EVs), Plugless Power. This company currently offers an average of USD 3,000 or HKD 23,373.03 for installation in one vehicle [40]. With this, the total cost for the 12 SATUs to be used would be around USD 36,000 or HKD 280,476.36.

400Hz Ground Power Unit

According to market inquiry, the cost for each 400Hz Ground Power Unit (GPU) would be around HKD 550,000. One GPU is required per jet bridge (206). This would mean that the required cost of GPUs to completely ban the use of APUs would be HKD 113,300,000.

Universal wheels, which would promote easier maneuverability and handling, will cost around HKD 270 for a set of 4, so the total cost for the upgrade would be HKD 55,620.

DC Charging Piles

DC Charging Piles have three different levels, depending on the required charging voltage. For this case level 2 would be sufficient enough to charge the Smart Aircraft Tug Unit, based on the required voltage of different SATU brands. Compared to level 3, which is only available for commercial use, level 2 charging piles would be more cost efficient as the difference in cost for both levels differ significantly with the level 2 charging unit costing around USD 5,500 and level 3 costing USD 100,000 [41]. This is because for the same number of charging piles and costs, using level 2 charging piles would allow SIN to purchase 109 additional SATUs.

The cost for one level 2 charging unit costs around HKD 17,140.22, with installation costs of around HKD 25,710.33, totaling around HKD 42.850.56 [41]. Since there must be one charging port in each parking bay, the total cost for one charging pile would have to be multiplied to the total number of parking bays (248), resulting in a total cost of around HKD 10,626,937.64.

Additional to this, a wireless charger per station must also be installed. Wireless charging stations cost around USD 3,000 per unit and around USD 500 per installation [42]. This means that the total cost for these installations would be USD 868,000 or HKD 6,762,596.68.

Total Equipment Costs

Table 1 The total equipment costs

Equipment	Quantity	Price per Unit (HKD)	Total Cost (HKD)
Air Starter Unit	206	390,243	80,390,243.90
Smart Aircraft Tug Unit	12	1,667,276.14	20,007,312.00
Towbar	12	24,520.00	294,240.00

SATU Wireless Chargers	12	23,373.03	280,476.36
Wireless Charging Station	248	27,271.79	6,762,596.68
Universal Wheels	206	270.00	55,620.00
Ground Power Units	206	550,000.00	113,300,000.00
DC Charging Piles	248	42.850.56	10,626,937.64
Total			**231,717,426.58**

Operations Costs

Standard Operating Procedures (SOP)

SOP are the frameworks that are usually set out by the airline for its own common procedures which support pilots in operating a commercial aircraft consistently. It ensures the task and operation of the aircraft to be done correctly, SOP's are essential and fundamental to facilitate our implementation plan of having the newly installed equipment to be officially used in the
Singapore Changi Airport. To prove that our implementation plan is highly achievable, the estimated operation cost of the SOP per hour (which is assumed and calculated by the operation cost of TOP+LOP) will be listed in details below.

Estimated operation cost for TOP/hr.: HKD 849.98 +1.88

Estimated operation cost for LOP/hr.: HKD 832.2

- ➔ **Total estimated SOP/hr. operation cost: 849.98 + 1.88 + 832.2**

  = ***<u>HKD 1684.06</u>***

Take-off Operating Procedures (TOP)

As mentioned in the implementation plan, the whole TOP is divided into two main parts. To ensure effective expression, all operation costs of the newly installed equipment used in both parts will be clearly listed with two tables respectively.

For the first part, ground energy systems, GPU vehicle, Smart Aircraft Tug Unit and Air Start Unit will be used to start the push-back procedure to the First Stop Site. The estimated operation cost for the push-back procedure is illustrated by the following table.

Table 2 Estimation of operation cost used in the push-back procedure (HKD)

Equipment Used	Estimated Operation Cost
Ground energy systems	$832.20/hr
GPU vehicle	$3.43/hr
Smart Aircraft Tug Unit	$1.88/hr
Air Start Unit	$12.47/hr
	Total cost: $849.98/hr

For the second part, only the Smart Aircraft Tug Unit is used to allow the aircraft to reach the appropriate position close to the RTHP. The estimated operation cost for the approach is illustrated in Table 3.

Table 3 Estimation of operation cost used to reach the appropriate position (HKD)

Equipment Used	Estimated Operation Cost
Smart Aircraft Tug Unit	$1.88/hr
	Total cost: $ 1.88/hr

Landing Operating Procedures (LOP)

From the implementation plan, after the aircraft is landed, it will exit the runway and taxi to the assigned parking position with its own engine power. The only new installed equipment will be used is the GPU that provides electricity for the aircraft operation after it reaches the jet bridge with all engines turned off. The estimated operation cost for the GPU operation is stated in Table 4.

Table 4 Estimation of operation cost or the GPU operation in LOP (HKD)

Equipment Used	Estimated Operation Cost
Ground Power Unit	$832.20/hr
	Total cost: $ 832.20/hr

All estimated operation cost is calculated by taking 25.8 cents per kWh, stated by the Energy Market Authority of Singapore [43].

Conclusion

Taking into account the objective situation of Changi Airport and based on the direction of unmanned and intelligent development of Changi Airport, we selected this most feasible solution from various alternatives. This solution, i.e., the design of the SATU system and the interconnection of various facilities in conjunction with Changi Airport's existing IoT system, is the solution that maximizes the benefits for all airport stakeholders. The specific implementation and technical details of this solution have been stated above. In the next section, we will summarize its outstanding advantages beyond the technical aspects.

Airlines

If Singapore Changi airport uses different ground equipment to provide electricity to the aircraft, airlines save the cost on fuel to operate APU during turnaround time and the maintenance cost of repairing the APU.

Fuel Saving

As APU need to burn fuel to operate, it will generate an extra cost for airlines annually. Marina [49] point out that APU will burn about 2-2.5% when operating. Also, airline operates 50 single aisle aircraft and 10,000 flights a month would burn more than 10,000 tons of fuel if the APU is operating during the turnaround time. Moreover, Table 6 [49] listed APU consumption for different aircraft types and Table 7 [52] showed the estimated fuel savings when using ground-based equipment to replace APU. Figure 17 [48] also presented the fuel burn on different aircraft size. Therefore, more than 11 million gallons of fuel and 30 million US dollars can be saved for the airlines. As fuel is the second highest cost in airline operation, fuel can be saved per flight which will attract airlines willing to set a route to Singapore Changi Airport.

Table 6: The standard APU consumption of various aircraft types [49]

Aircraft Type	APU consumption (kg/hour)
A320	126
A330	210
B737	110
B777	312

Table 7: Estimated fuel savings [52]

Fuel Consumption and cost	APU	Ground-based equipment	Annual Savings
Fuel Consumption (gallons)	11,681,000	56,407	11,680,000
Fuel Cost (US$)	29,203,000	1,140,000	29,089,000

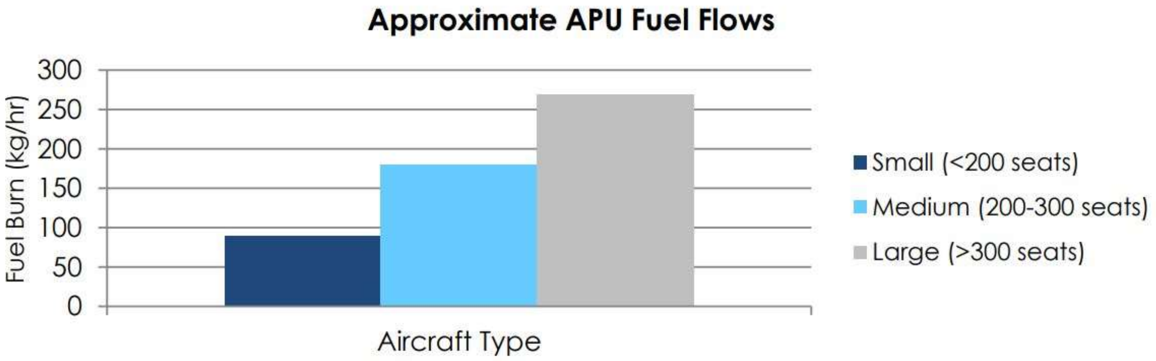

Figure 17 Approximate APU fuel flows by aircraft size [48]

APU's Extended Service Life

On the other hand, APU is prohibited to operate in Singapore Changi Airport, the service life of APU can be extended as each APU has their own service life. For example, APS3200 APU is one of the auxiliary power units for the Airbus A320 family. Its manufacturer, Pratt & Whitney Canada, indicated the fixed life limit in the Engine Manual such as 50,000 cycles for the load compressor impeller and the power section impeller and 32,000 cycles for the first stage and second-stage turbine disk [46]. Therefore, using APU in less time can reduce the cost for maintenance to replace APU per year. Moreover, using ground power equipment to replace the use of APU can also attract airlines willing to Singapore Changi Airport as the cost can be reduced per year for maintenance.

Singapore Changi Airport

APU operating cost mainly focus on airlines and airports need to invest huge money for installing those fixed and mobile ground power units and pre-conditioned air units. For example, Hong Kong International Airport banned the use of APU by aircraft in 2014 and invested over 7.8 million for upgrading all fixed ground power and pre-conditioned air system [47]. However, airports can benefit from it such as less pollution will be produced and revenue from charging airlines electricity fees.

Environmental Friendliness

Nowadays, many airlines and airport are planning to achieve goal for becoming a green airport. For example, reducing pollution on noise and air generated by aircraft. However, APU is one of the pollutant sources which produce noise and carbon dioxide during operation. Table 8 [49] showed the benefits of APU mitigation option of Zurich airport emissions. Table 8 can conclude that there are less pollutants produced on carbon dioxide and compound on nitrogen and oxygen such as nitric oxide. Moreover, Nice Côte d'Azur Airport has reduced by 416 tonnes carbon dioxide emission annually after installed the ground power system for its general aviation departing area in 2014 [47]. As a result, there can be one of the elements to put Singapore Changi Airport as a greener airport.

Table 8: The benefits of APU mitigation option (of the total Zurich airport emissions) [49]

	Variation in operations (concentration relevant emission perimeter only)					
Scenario	no AGES / GPU avail. (full APU operations only)		AGES / GPU as it is today at Zurich Airport		APU for MES only (rest is AGES only)	
NOx 2016						
Total Airport 2016 (1,000m)	909 t	100%	802 t	100%	786 t	100%
APU	128 t		17 t		5 t	
GPU	0 t		3 t		0 t	
APU+GPU	128 t	14.1%	20 t	2.5%	5 t	0.6%
CO_2 2016						
APU	50,066 t		7,896 t		2,131 t	
GPU	0 t		1,050 t		0 t	
APU+GPU	50,066 t		8,945 t		2,131 t	

On the other hand, APU will produce noise pollution during operation. Therefore, prohibited the use of APU can protect the people working on the apron. The reason is people working in a loud environment for a longer time will be harmful to human beings. Scoot [52] indicated prohibited the use of APU can have noise reduction about 15-25 decibels typically quieter when using the ground-based equipment. This number is a significant number on noise reduction which can protect the health of those people who work on apron longer time. As a result, Singapore Changi Airport can also protect their people who work in the airport although it is a huge investment in the first year.

Revenue from Charging Airlines Electricity Fees

Singapore Changi Airport can charge airlines electricity fees when airlines use it. The reason is airport will benefit from a quick return on investment of about three to four years by charging as little as forty euros per hour for a narrow-body aircraft while wide-body aircraft can charge more fees [50]. The electricity fees charged to airlines is much lower than the cost of burning fuel to operate APU and the maintenance cost on it. Therefore, airlines are willing to pay electricity fees on powering the necessary equipment on the ground which Singapore Changi Airport can follow.

Passengers

As the number of passengers increased in 2017, the expectations for comfort have also risen [50]. Pre-conditioned air units can provide passengers with a better experience when they travel by aircraft. Nowadays, pre-conditioned air units can operate in different weather situations for heating and cooling planes with high quality air. Also, passenger experience depends greatly on the temperature inside the plane [50]. For example, 2 degrees temperature change inside the cabin with an increase of humidity, the passengers may feel uncomfortable quickly. In addition, Dublin Airport handled more than 15.5 million passengers in the first six months of 2019 and there is a 6% increase on the same period last year [51]. As a result, more passengers may be willing to travel to Singapore and the airport can provide a better experience for their leisure or business trip.

Green Sense

Since Changi Airport is the symbol of Singapore, the image of it is quite important to the country. As our team has introduced, using APU in the airport is not environmentally friendly since it would emit a large number of air pollutant that may be harmful to the environment. While using GPU instead of using APU could ameliorate the situation. GPU is greener comparing to APU. The airport may become more environmentally friendly with using of GPU. It could not only give a better image of Changi Airport, also for Singapore, but also could give a green sense to the citizens to raise their awareness of protecting the environment.

Alters of the Airport

Applying GPU instead of using APU needs the changes of the airport. The major difference of APU and GPU is that APU is installed in the aircraft that do not reliance on ground support equipment, but GPU is fixed or mobile unit that could be connected to the electric system of different aircrafts that rely on the ground supports. Therefore, while we are banning the APU and using GPU, there are the following alters need to be made in airport.

Hardware

Using GPU instead of APU, first change of the airport is that the airport needs to install the ground support equipment for GPU, such as Air Start Unit, Smart Aircraft Tug Unit and 400Hz Ground Power Units, and DC charging Piles which our team have already introduced. Deploying the communication power cable which connect the ground power to the aircraft and air-conditioning ducts would occupy the space. Therefore, using GPU need to reserve the space for installing the above equipment.

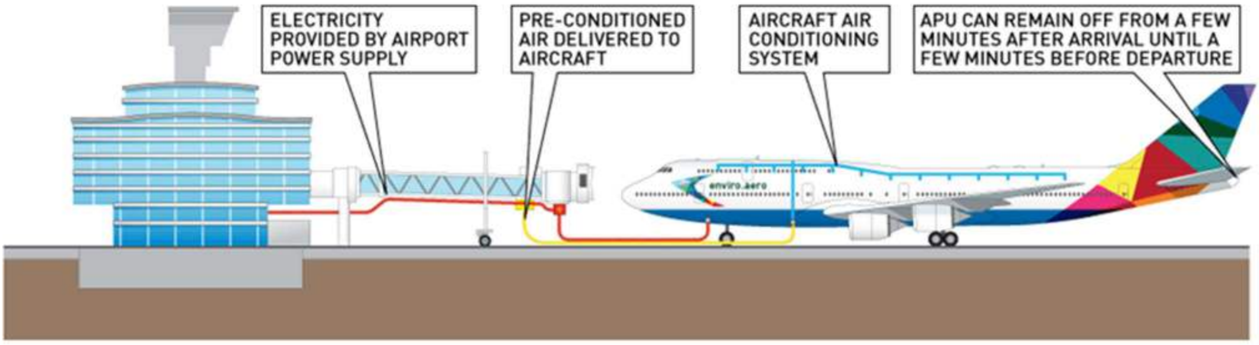

Figure 18 Basic layout of aircraft ground energy systems [47]

Ground Management

Using GPU need to use extensive of ground-powered vehicles and air-conditioned vehicles. The vehicle may cause the confusion in operation and the management. Therefore, there should be a well preparation of the transporting planning the vehicle including the aircraft and the cars.

Figure 19 Ground Power Unit Vehicles [45]

Figure 20 Air Conditioning Unit [44]

Human Resources

Using GPU needs to connect the aircraft with the ground support equipment, so, the engineers or the worker should know how to control the panel and connect them. At the beginning of changing to use of

GPU, the staffs in the airport should spend time to learn and will experience a period of time of unfamiliar with the system. And the airport should provide the training course for the engineer or the worker to familiar with the system in order to comfort the disbelief of the collaborator of the airport.

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