Abstract

Xiluo produce market is the largest wholesale market which supplies one-third fruit and vegetable demand in Taiwan. However, each day more than 800 diesel-powered tricycles running at the market result in serious air and noise pollution. In order to solve the pollution problem, since 2010, the Environment Protection Administration (EPA) has implemented a plan to replace the diesel-powered tricycles with electric trucks. Besides, EPA also integrates efforts with local manufactures to develop appropriate electric trucks which can accommodate the requirements of usage. On July 3, 2013, EPA further announced a subsidization program, namely "the Regulations Covering Subsidies for Electric Produce Transporters at Xiluo Produce Market". According to the program, the subsidy covers the purchasing cost of electric trucks (excluding battery) and rental fees of the power batteries. At the same time, a battery management operator will be selected to provide service of maintaining battery. In addition, EPA drew up the verification specification as the vehicles' testing standard to ensure the function and safety of the electric trucks. The target is to eliminate all diesel-powered tricycles out of the Xiluo produce market before 2018 and the air quality improvement is in line with Taiwan's indoor air quality standards.

Taiwan's government hopes to electrify all diesel vehicles currently in the other similar wholesale markets basing on the experience of promotion, so as to build clean trading environment for all wholesale markets in the future. This paper will discuss this vehicle electrification case study in detail and share the experience.

Keywords: EPA, produce market, diesel-powered tricycles, electric trucks

1 Introduction

The Xiluo produce market is the largest fruit and vegetable wholesale market in Taiwan and supplies over one-third of Taiwan's daily consumptions. Over 3000 transport vehicles of different types run on the Market everyday. Of which, diesel-powered tricycles are the major transporters. Since the Market building is a large steel structure with poor ventilation, numerous diesel-powered tricycle carrying not only loads of produce but also exhausting gases
and noise inside the market [1]. The situation is threatening the health of people who work in the market. Therefore, a solution must be sought to overcome this problem.

In order to improve environment in the Xiluo produce market, the Environmental Protection Administration (EPA) of Taiwan has, since 2007, initiated plans to replace all old diesel-powered tricycles with electric trucks. Investigations at the market began with collecting data on the status of using old diesel-powered tricycles. The electric truck specification were established which were based on the requirements from dealer and data collected from the diesel-powered tricycle tests. At the same time, the EPA had rented six electric powered pallet trucks from sellers and provided the rented vehicles to local dealers for actual use tests and evaluation. Since the electric powered pallet trucks did not offer stable performance and quality, dealers' acceptance was not good, but the zero emissions and low noise of the vehicles had been appreciated.

In order to improve upon the issue of poor vehicle performance, the Industrial Technology Research Institute (ITRI) gave assistance to various manufacturers and established electric power conversion technologies of old diesel-powered tricycle in order to reduce the cost for establishing a fleet of electric trucks. At the same time, to ensure vehicle usage performance and safety, "Verification Specification for transportation of electric truck suited to the fruit and vegetables market of Xiluo" [2] (hereinafter referred to as "the Verification Specification ") has been stipulated. Since 2010 to 2012, sixteen electric trucks exceeding 45,000 km mileage had undergone performance and functional tests. As vehicle performance and reliability improve, local users have become willing to drive electric trucks.

In addition to using the method described above to ensure that the electric trucks would meet market requirements, the EPA has also released "the Regulations Covering Subsidies for Electric Produce Transporters at Xiluo Produce Market" on July 3rd, 2013 which provided subsidies for dealers on vehicle purchase and battery rental. Benefits include battery companies in charge of the battery rental plans to ensure the quality of battery maintenance and provide incentives for electric trucks dealers to accelerate the popularization of electric trucks.

The objective of this project is to replace all diesel-powered tricycles and greatly improve the unclean environmental within the Xiluo produce market. The Xiluo produce market is expected to be set up an example for other wholesale market in Taiwan.

2 Establishment of Electric trucks

2.1 Usage of Trucks in the Xiluo wholesale produce market

Figure 1 shows the areas and usage environments of produce trucks in the Xiluo wholesale produce market. Large trucks are mainly used for long range transport, while smaller trucks and diesel-powered tricycles are mainly used for short range transport. Diesel-powered tricycles serve mainly to transport produce from the dealers' warehouse to the Market for sale. The following is the vehicle usage evaluations:

- Purpose: Transport produce between the market and the warehouse / farm.
- Over 800 diesel-powered tricycles pass through the Market to deliver produce everyday.
- Range (round trip): About 2-4 km
- Usage time: 08:00–20:00, Peak time: Twice a day from 09:00 to 11:30 and from 16:00 to 18:30. Each peak period lasts 2.5 hours for a total of 5 hours of peak usage.
- Load: 500-2000 kg.
- Speed: 25-50 kph.
- Daily usage is below 50 km

![Figure 1: Usage of Produce Trucks in the Xiluo produce market](image-url)
2.2 Specifications required of electric trucks for particular use in the Xiluo produce market

To stipulate electric truck specifications suitable for the Market usage conditions and investigation of dealer requirements for produce transport in the whole market was summarized in Table 1. The following provides detailed descriptions:

- Cruising range using a fully charged battery: The electric trucks are mainly used to transport produce within the Market as well as between the Market and the dealers' warehouses. Cruising range of the vehicle is dependent on battery capacity, but increasing battery capacity will also increase vehicle operating costs. After considering both battery costs and the dealers' practical requirements, the minimum cruising range on a fully recharged battery for the electric trucks must reach 50 km.

- Speed: The maximum speed of electric trucks is based upon actual speed measurements of the diesel-powered tricycles. Considering the standards and safety of commercial electric trucks, the maximum speed of the electric trucks must be 40 km/h and 25 km/h when loaded 1000kg produce at least.

- Climbing ability: The climbing ability of the electric trucks must be able to overcome the ground surface environment of the Xiluo produce market. The minimum climbing ability of the vehicle is set at 8 degrees.

- Loading platform specifications: Loading platform dimensions of the electric trucks must satisfy the dealers' produce transportation requirements. Dimensions are stipulated according to vehicle load:
  - 1-ton vehicle: Length ≥ 2424mm, width ≥ 1212mm.
  - 2-ton vehicle: Length ≥ 3030mm, width ≥ 1515mm.

- Standard accessories: The electric trucks must include necessary accessories that ensure vehicle safety.

| Table 1: Specifications of the electric trucks |
|------------------------------------------------|
| **Items** | **Specifications** |
|-----------------|------------------|
| Cruising range  | ≥ 50 km          |
| Speed           | ≥ 40 kph (no load) |
|                 | ≥ 25 kph (when loaded 1000kg) |
| Climbing ability| 8 degrees@10 kph  |
| Platform specification | 1-ton vehicle: Length ≥ 2424mm, width ≥ 1212mm |
|                  | 2-ton vehicle: Length ≥ 3030mm, width ≥ 1515mm |
| Standard accessories | speedometer, fuel gage, Reversing buzzer, horn, headlamp, lamps, brake light, rear-view mirror |

2.3 Electric power conversions of the diesel-powered tricycles

The actual operation of the electric trucks investigated in the preliminary phase of policy, dealers have frequently reflected that four wheel electric trucks currently sold in the market have performance and quality issues and felt that they are less manoeuvrable and unsuitable. Additionally, most four wheel electric trucks provided by the manufacturers are smaller vehicles with smaller loading platforms, resulting less flexible than the diesel-powered tricycles. Furthermore, new electric trucks also cost higher. Hence, dealers believed that converting diesel-powered tricycles into electric powered vehicles would be easier met the produce transport requirements of the Xiluo produce market.

Due to poor quality control and subsequent repairs, vehicle manufacturers lack incentives to invest electric power conversions of diesel-powered tricycles. Once the policy is implemented, a solution for disposing of the obsolete vehicles must be found as well because it will prohibit the use of diesel-powered tricycles. This is a compounded issue on subsequent vehicle repairs and maintenance as well as the survival of the original manufacturers of the diesel-powered tricycles. In order to remove resistance against the policy and solve the issues as described above, the ITRI has proceeded with electric power conversion designs for the diesel-powered tricycles and worked with local manufacturers to do vehicle conversions. Local diesel-powered tricycles manufacturers have been encouraged to become service stations with facilities be able to do vehicle
In order to ensure that the electric trucks are capable of meeting dealer usage and vehicle safety requirements, the EPA has stipulated the Verification Specification which is applies to various electric trucks. When dealers purchase electric truck that has passed the tests stipulated in the Verification Specification, they may apply for vehicle purchase subsidies provided by the government. Thus, those electric trucks from original diesel-powered tricycles must satisfy various provisions within the Verification Specification and pass the relevant tests.

Figure 2 shows the problems that must be overcome to convert diesel-powered tricycles into three wheels electric trucks. The main requirements are that the resulting three wheels electric trucks must satisfy vehicle performance, operational safety, and electrical safety requirements stipulated within the Verification Specification. Details are provided in the following:

1. Vehicle performance: The key regulations are the specifications and performance of the electric trucks that include vehicle dimensions, loading requirements, maximum speed requirements, climbing ability, and cruising range using a fully charged battery.
2. Operational safety: Mainly specifies the safety requirements when operating the electric trucks. These include drive-train activation / deactivation procedures, driving, vehicle reversing, parking, on-board and off-board electric supply devices.
3. Electrical safety: Mainly specifies electrical protection and recharging requirements of the electric trucks. Electrical protection includes protection against direct contact and indirect contact, RESS cable insulation resistances, cable insulation resistance, potential balance, and waterproof protection.

ITRI, with advanced technologies and experiences in developing various electric vehicles, has first used electric vehicle system compatibility designs and structural modifications for diesel powered tricycles conversions and vehicle system architecture planning. Besides, ITRI is synchronizing vehicle performance indicators which are applied to analyze the drive-train specifications required by the electric trucks to ensure that the three wheels electric trucks are capable of satisfying vehicle performance requirements stipulated in the Verification Specification. For operational and electrical safety requirements, the ITRI is good at electric trucks safety control designs to establish an all-vehicle electrical control system architecture and wiring schematic to ensure vehicle usage safety.

2.3.1 Compatibility designs of the electric vehicle systems

In order to satisfy the performance requirements stipulated by the Verification Specification, the drive-train compatibility must first be solved on electric power conversions. Current diesel powered tricycles with a variety of specifications such as gross vehicle weight ratings, tire dimensions, and rear axles have no standard vehicle designs. Hence, a systematic estimate must be made to analyze drive-train specifications and ensure that all converted three wheels electric trucks are capable of meeting the Verification Specification.

Figure 3 shows the drive-train compatibility analysis procedure for the electric power conversion of diesel-powered tricycles. The procedure include (1) parameter settings; (2) estimates of vehicle power requirements; (3) drive-train specifications evaluation; (4) estimates of
motor requirements and specifications; (5) selection of a suitable motor. Detailed descriptions are provided below:

**Parameters Setting**

| Parameter                     | Value           |
|-------------------------------|-----------------|
| Speed (mph)                   | 100             |
| Tire Speed (rpm)              | 180             |
| Driving Torque (Nm)           | 398.25          |
| Motor Output Power (kW)       | 94              |
| Total Driving Torque (Nm)     | 237.13          |

**Performance of the three-wheels electric truck**

- Gross Weight ≤ 1900 kg
- Maximum Weight ≤ 4000 kg
- Tire Diameter = 560mm/600mm/650mm
- Reduction ratio of Rear Axle: 4.0–4.8

**Estimates of Motor Requirements and Specifications**

**Estimates of Vehicle Power Requirements**

**Drive-Train Specification evaluation**

**Selection of a Suitable Motor**

Figure 3: Procedure for the drive-train system compatibility analysis

(1) Parameter settings: Parameters influencing electric truck power specifications include vehicle performance requirements, vehicle weight, tire diameter, and rear-axle ratio. Tire diameter and rear-axle reduction ratio are based on actual investigations of existing
2.3.2 Electric vehicle system compatibility design

The three wheels electric trucks are made by converting diesel powered tricycles. In order to avoid excessive vehicle chassis modification that may lead to large conversion expenses, vehicle system of the three wheels electric trucks must be compatible to existing three wheels vehicle chassis. Figure 4 shows the vehicle-wide system architecture of the three wheels electric trucks, with details listed in the following:

(1) In order to retain the rear-axle of the original diesel-powered tricycles and to provide enough driving torque to the vehicle at the same time, the drive-train of the three wheels electric trucks shall be composed of a drive motor, a transmission case, a drive axle, and a rear axle. Motor power output shall undergo two speed reductions by the transmission case and rear axle respectively to increase the final output driving torque.

(2) The battery system is composed of 16 serially linked 6V lead acid batteries. However, restrictions posed by the original chassis of the three wheels vehicle meant that the batteries must be distributed into 4 secondary battery modules located the front left, front right, rear left, and rear right. Waterproof connectors and extraction structures have been used to retrieve and replace each module individually, giving battery exchange features to the electric trucks.

(3) Air brakes in the original diesel-powered tricycle used the diesel engine to drive an air pump to compress air. After converting the vehicle to a three wheels electric truck, an air compressor is used to provide sufficient pressure to the air brakes.

(4) A 12V auxiliary battery shall provide power to the vehicle dashboard, lights, and air compressor. A DC-DC converter is used to transform output from the 96 V drive batteries to 12V to recharge the 12V auxiliary battery.

(5) In order to reduce the vehicle conversion costs and simplify system architecture, this vehicle has been designed with a control box composed of multiple solenoid switches to control the activation / deactivation of vehicle functions and battery recharging. This will ensure that the vehicle is compatible with the operational safety requirements stipulated by the Verification Specification.

Figure 4: Vehicle-wide system architecture of the three wheels electric trucks

2.3.3 Operational safety control designs of the electric trucks

In order to ensure usage safety of the electric trucks in the Xiluo produce market, vehicle system wiring schematic of the electric power conversion of diesel-powered tricycles have been specifically designed to meet safety requirements. Figure 5 shows the vehicle-wide control wiring schematic of the electric trucks. Considerations have been made for subsequent vehicle production and repairs by the manufacturer, hence ITRI has abandoned control wiring schematics based upon vehicle control unit. Instead, multiple sets of single or double contact relays were used to provide control over vehicle operations and functions. Meanwhile, to enhance the convenience in wiring
failure inspections and troubleshooting, ITRI has placed every relay used for vehicle controls within a single control box. The manufacturer may first assemble the control box in order to reduce difficulties in wiring installation.

2.3.4 Test and operations

To assist the government in promoting the use of electric trucks, the ITRI has currently completed the conversion of a number of diesel-powered tricycles and the converted trucks have been deployed in actual use in the Xiluo produce market. At the same time, after the EPA has formally released the Verification Specification, testing was carried out according to the stipulated Verification Specification. The converted vehicles have passed the test, making them Taiwan's first electric trucks to satisfy the Verification Specification. Additionally, power consumption and cruising range tests of converted three wheels electric trucks were also performed in order to verify the actual performance of the vehicles. Table 2 shows the specifications and performance of one of the three wheels electric trucks.

Table 2: Specifications and performance of the three wheels electric trucks

| Specifications                  | V         | Dock dimension (mm) | Gross Weight (kg) | Max. payload (kg) | Gear box | Performances  |
|--------------------------------|----------|---------------------|-------------------|-------------------|----------|---------------|
| Vehicle dimension (mm)         | 5000 (L) / 1550 (W) / 1960 (H) | 3270 (L) / 1550 (W) | 1822              | 2500               | High gear/Low gear | ≥ 55 kph [gross weight/high gear] |
|                               |          |                     |                   |                   |          | ≥ 40 kph [(gross weight + 1000kg payload) /low gear] |
| Climbing capacity              | 140@17.3 kph |
| Mileage                        | 54.1 km [(gross weight + 1000kg payload) /low gear] | 81.6 km [gross weight /high gear] |

2.4 Supply of electric trucks

The electric power trucks conversion on diesel powered tricycles to by ITRI has satisfied EPA specifications. Technologies and experience established during the vehicle construction and conversion processes were applied to help manufacturers to develop and improve electric trucks. Four local manufacturers are now capable of providing electric trucks that meet EPA specifications as shown in Table 3.

Table 3: Electric trucks capable of satisfying EPA specifications

| Maker                              | Model |
|------------------------------------|-------|
| BEI LI Electric MOTION ENTERPRISE CO., LTD | VLM-303 |
| SU WEI MACHINE FACTORY CO., LTD     | PH-503 |
| NOVELTEK INDUSTRIAL MANUFACTURING INC | ET-35A |
| DATO AGRICULTURE MACHINERY CORP.    | ET-2000 |
3 Formulation of Subsidies

Battery expenses and battery reliability are key factors to influence the dealers' willingness to use electric trucks. Hence, the EPA has formulated separate subsidies for the vehicle and the batteries. A separate vehicle and battery operation model based on the users' perspectives is carried out according to the Separate Vehicle and Battery Subsidies Framework shown in Figure 6. Dealers intending to purchase electric trucks (without the battery) only need to pay almost the same price as the diesel powered tricycles. Dealers may rent batteries from battery operators who are in charge of leasing batteries as well as battery maintenance. The government provides subsidies for vehicle purchasing costs and battery rental subsidies as well. It is hoped that such measures will encourage dealers to convert existing vehicles or purchase new electric vehicles. The following lists the advantages of the subsidies plan:

![Figure 6: Framework for the separated vehicle and battery operational model](image)

(1) Dealers using electric vehicles will be guaranteed.
(2) Dealers will always have good batteries and need not worry about battery life.
(3) Improvements in battery management operations will help enhance battery life without increasing dealer expenses.
(4) After receiving government subsidies for vehicle, the purchasing cost of electric trucks will be the same as the diesel powered tricycles.
(5) After receiving government subsidies for battery rental, the monthly payments for battery rents will be lower than that of refuelling costs for diesel powered tricycles.

4 Implementation and Future Development

(a) After actual testing, it was found that the electric trucks not only provide the advantages of zero emissions and low noise, but also improved effectiveness compared to diesel-powered tricycles (as shown in Table 4).
(b) Universal power modules, Verification Specification, and certification procedures have been established in order to safeguard the quality of the electric trucks and resolve issues of electric trucks performance and safety concerns.
(c) Currently, nearly 50 electric trucks have been provided to the dealers for use. Vehicle numbers are expected to increase as the number of participating vendors increase.
(d) The EPA shall continue to provide vehicle purchasing subsidies until 2018. Subsidies for battery rental shall continue after the vehicle subsidies have expired.

Table 4: Comparing the effectiveness of electric trucks and diesel-powered tricycles.

| Item                          | Electric trucks | Diesel-powered tricycle |
|-------------------------------|-----------------|-------------------------|
| Power consumption (1)         | 3.5~4.5 km / kWh| 7.0~10.0 km /L          |
| Energy cost (2)               | NTD 2.1~4.4 / kWh| NTD 30~35 / L           |
| Operational costs per km (3)  | NTD 0.5~1.2 / km| NTD 3.0~5.0 / km        |
| Usage costs                   | NTD 500~1200 / month| NTD 3000~5000 / month |
| Battery rent (4)              | NTD 5000 / month| NTD 0 / month           |
| Total usage costs             | NTD 5500~6200 / month| NTD 3000~5000 / month |
| Monthly usage costs           | NTD 2000~2700 / month| NTD 3000~5000 / month |

(1) Considerations made for differences in vehicle load and vehicle status.
(2) Piecewise pricing for electricity; fluctuating gas prices.
(3) Based upon monthly usage of 1000 km.
(4) Including the EPA battery subsidy of NTD 3500 / month.
5 Conclusion

In order to solve the serious air and noise pollution caused by diesel-powered tricycles in the Xiluo produce market, the government has promoted the replacement of diesel-powered tricycles with electric trucks. The following methods have been implemented to gradually achieve the relevant objectives:

(a) ITRI has used technologies and experiences gained from electric vehicle development to help suppliers improve their electric trucks and ensure that the trucks are capable of meeting market requirements.

(b) The vehicle inspection agency has performed vehicle inspection according to “Verification Specification for transportation of electric truck suited to the fruit and vegetables market of Xiluo” released by the EPA to ensure vehicle quality and usage safety.

(c) Battery operators are responsible for battery rentals and repair to ensure power provision and normal performance of the electric trucks.

(d) Subsidies formulated by the EPA shall provide dealers support when purchasing vehicles and renting batteries, offering additional incentives for the dealers to use electric trucks.

(e) In 2018, Local governments shall enforce the replacement of diesel-powered tricycles in compliance to the administrative order of completely prohibiting the use of diesel-powered tricycles in the Xiluo produce market.

Due to limits in the preliminary phase of the project, lack of support from the dealers, low orders as well as poor supplier production capacity, the replacement of diesel-powered tricycles in Xiluo produce market still cannot be implemented fast enough. The government is thus currently promoting and carrying out relevant policies to accelerate the popularization of electric trucks.

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References
[1] http://taqm.epa.gov.tw/data/car/
[2] http://ivy5.epa.gov.tw/
[3] http://ivy5.epa.gov.tw/

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