Performance Analysis of Electric-Rubber Tired Gantries from a Green Container Terminal Perspective

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Abstract: This study investigates the performance of electrically-powered rubber tired gantry cranes versus that of diesel-powered versions, and analyzes and compares rubber tired gantries (RTGs) and electric rubber tired gantries (E-RTGs) at a case study company from the perspective of energy saving and CO2 reduction. This study discovered that (1) the fuel costs, noise and exhaust produced by diesel-driven rubber tired gantry cranes do not comply with current operational and environmental requirements, and old equipment should therefore be modified or replaced with new equipment. (2) E-RTG cranes offer a significant performance improvement compared with older equipment, and can achieve 86.60% energy savings and a 67.79% reduction in CO2 emissions. (3) E-RTG cranes are expected to have an individual payback period of 2.2 years, and are not only friendly to the environment, but also ease the impact of diesel oil price hikes.

Key Words: Sea port, Maritime Logistics, Green Container Terminal

1. INTRODUCTION

Owing to the effect of the global financial crisis and high oil prices, every shipping company is endeavoring to explore and seek optimal solutions that will minimize operating costs and improve port pollution. Gantry cranes used in container yard and container terminals include rubber tired gantry cranes (RTGs) and rail mounted gantry cranes (RMGCs). The former are powered by diesel fuel, and the latter are electrically powered. While there are no significant differences in handling efficiency between the two types, there are clear differences in energy savings and CO_2 reduction, and a comparison of the two is therefore is worthy of in-depth exploration.

The majority of container handling equipment in existing container terminals and container yards at the port of Kaohsiung consist of RTGs. The fact that high energy consumption, high-pollution RTGs are operating around the clock at the port of Kaohsiung entails a high cost burden for terminal operators and causes serious environmental pollution in nearby port areas. In order to lessen operating costs, strengthen business competitiveness, and alleviate environmental pollution, container terminal operators should formulate appropriate strategies for changing from diesel to electric RTGs to achieve the goals of energy conservation and reduced carbon emissions.

In the wake of severe energy shortages and higher energy costs around the world, some equipment (such as RTGs and straddle carriers) with large operating costs are being phased out in favor of handling facilities offering energy savings, environmental friendliness, and electric power systems (Yang and Sam, 2009). E-RTG cranes offer maintenance and repair costs that are 30% lower than for standard diesel RTGs, and also provide additional fuel cost savings of as much as 70%. The use of E-RTGs can reduce CO_2 emissions by 60~80% compared with conventional diesel-powered RTGs, which can result in overall terminal CO_2 emissions decreasing by 20% per TEU handled, and the retrofitting of the majority of the existing 400-unit APM terminal RTG fleet with electrical systems will reduce CO_2 emissions by 70,000 tons annually (APM, 2011)

In spite of their drawbacks of high energy consumption, high pollution, and high noise, the majority of shipping companies and container yards still employ diesel RTGs for container handling. When assessing cost savings and environmental protection measures, shipping companies and terminal operators should consider the possibility of converting RTGs from diesel to electric power in order to achieve the goals of energy saving, noise abatement, and CO_2 reduction.

Newly-built container yards and container terminals typically choose electrically-powered rail mounted gantry cranes (RMGCs) as container handling equipment. While a majority of container terminals and container yards at the port of Kaohsiung use conventional diesel rubber tired gantry cranes (RTGs), finding ways of reducing operating costs and alleviating environmental pollution has become an urgent issue for a terminal operators and managers in the present era of high oil prices and strict environmental regulations. This paper consequently focuses on the conversion of RTGs from diesel power to electric power, compares RTG performance between before and after conversion, and analyzes the advantages and disadvantages, operational limitations, energy savings, and CO_2 reduction benefits of the two types of RTG.

More than 200 RTGs are used by container terminals and container yards in the port of Kaohsiung, and this equipment consumes vast amounts of fuel oil and produces tremendous exhaust emissions, leading to heavy operating costs and environmental pollution. Now that the "green port" concept has prevailed at the international level over the past decade, the government of Taiwan should act promptly to lessen carbon emissions in keeping with international standards.

A container terminal is a distinctive and complex operating area which is composed of a gate, container yard, and shipside areas, and where several types of equipment (such as tractors, RTGs, RMGs, straddle carriers, and gantry cranes, etc.) bear responsibility for handling containers in the three areas. Although there is significant linkage among handling efficiency, operational performance, and cost, in order to achieve better focus and research effectiveness, this paper primarily compares RTGs and E-RTGs in container yards, and neglects the remaining types of equipment in the other two container terminal areas.

Motivated by the need to lower container terminal operating costs, improve air quality in the port area, decrease pollutant emissions, and protect the physical health of personnel, converting diesel RTGs to electric power has become a vitally important issue. This paper consequently seeks to determine the changes in physical performance occurring as a result of converting RTGs to E-RTGs, compares energy savings and CO_2 reduction performance based on a green container terminal perspective, reviews three different conversion systems (cable reel, bus bar, and touch wire systems) at the case study company, and finally present conclusions and recommendations.

The goals of this paper can be summarized as follows: (1) To examine the operating models of container terminals at the port of Kaohsiung and review the E-RTG conversion project at the case study company. (2) To compare RTGs and E-RTGs in terms of energy saving and CO_2 reduction performance. (3) To present conclusions and suggestions for terminal operators and shipping companies assessing the possibility conversion to E-RTGs in compliance with green terminal concept.

This paper consists of five sections: The first section is an introduction stating the motivations, goals, and framework of the study. The second section contains a review of the literature concerning container terminals and green container terminals, and the third section examines the E-RTG conversion project at the case study company, including the RTG to E-RTG conversion process. The fourth section performs a performance analysis of the E-RTG conversion project at the case study company based on analysis of energy savings and CO_2 emission reduction. The final sections present conclusions and implications for shipping companies and terminal operators, and suggest possible directions for future research.

2. LITERATURE REVIEW

2.1 Container terminals

Different terminals, with their unique combinations of liner services, yard layouts, and equipment configurations, may find that different yard planning strategies work better for their circumstances (Ku, et. al, 2010). As human operators drive equipment at traditional terminals, there is no need for computer control of the movement of equipment. When automated equipment is used, however, every movement must be directed, the traffic of vehicles must be controlled, and movement of equipment must be synchronized (Kim *et al*., 2004).

Container terminal systems consist of three subsystems: the gate, container yard, and berths. Container handling equipment in these systems includes transfer cranes, gantry cranes, yard tractors, and trailers (Yun and Choi, 1999). The four main subsystems/operations in a container terminal system are ship to shore, transfer, storage, and delivery/receiving. Container terminal operations involve very complicated operating systems, which must be evaluated from the perspective of CT operating performance to assess a CT's competitiveness.

Container handling equipment in a container yard performs the functions of moving and lifting containers, and stevedoring trailers. The choice of a terminal operating system can influence the performance of a container terminal. A container terminal can improve its productivity by increasing the efficiency and effectiveness of cargo handling and storage equipment. The most common types of yard crane comprise rail mounted gantry cranes (RMGCs), rubber tired gantry crane (RTGs), straddle carriers, reach stackers, and chassis-based transporters. However, only RMG cranes are suited for fully automated container handling (Gunther and Kim, 2006; Lin and Chang, 2006).

A container yard serves as a buffer area for the loading, unloading, and transshipping of containers, and is typically divided into blocks: Each container block is served by one or more yard cranes, which can be rubber-tired or rail-mounted (RTG/RMG), and straddle carriers (SCs). Straddle carriers, automatic guided vehicles, and trucks are commonly used to transport containers between quayside and yard, and between yard and gates, and to relocate containers within the yard (Vacca *et al*., 2007; Hsu, 2007).

There are a total of 26 container terminals at the port of Kaohsiung, and these terminals are managed by ten container terminal operators (Evergreen, Yang Ming, Wan Hai, OOCL, APL, NYK, Han Jin, Hyun Dai, Kao Ming, and Lien Hai). The container terminals have four types of cargo handling equipment, namely straddle carriers (such as Han Jin), RTGs (such as APL, NYK, Evergreen, Hyun Dai), RMGCs (such as OOCL, Wan Hai, Yang Ming, Lien Hai), and A-RMGs (such as Evergreen and Kao Ming) (see table. 1).

Table 1. Container terminal operating models at the port of Kaohsiung

Company Name	Wharf No.	Operating Model	Waterside vehicle
Lien Hai	41W/42W	RMG	Tractor
Wan Hai	63W/64W	RMG	Tractor
OOCL	65W/66W	RMG	Tractor
APL	68W/69W	RTG	Tractor
Yang Ming	70W	RMG	Tractor
Kao Ming	108W/109W	Auto RMG	Tractor
Evergreen	79W~81W	RTG and E-RTG	Tractor
	115W~117W	Auto RMG and RMG	Tractor
Han Jin	76W~78W	SC	SC
Hyun Dai	118W/119W	RTG	Tractor
NYK	121W	RTG	Tractor

2.2 Green container terminals

Control of logistics operations at container terminals is an extremely complex task (Grunow *et al.*, 2006). Effective deployment of material handling equipment at container terminals is crucial in enhancing overall container handling efficiency and performance during the import, export, and transshipment of containers (Lau and Zhao, 2008). In designing a container terminal, one must weigh the value of certain types of storage and retrieval equipment by performing feasibility and economic analysis (Vis, 2006). Sisson (2006) suggested that the features of a state-of-the-art green terminal comprise cold ironing of vessels with rapid automated berthing, automated transport vehicles with low emission technology, electric end-loaded yard cranes, and electric cranes serving the on-terminal rail yard. Pedrick (2006) proposed that the features of green terminals include beneficial site planning, lower water usage, greater energy efficiency, better materials and systems, and improved environmental quality.

Clarke (2006) argued that the requirements of green container terminals include minimum impact on the local environment (for instance, via air pollution mitigation, noise pollution reduction, and lower utilization of lighting), minimum impact on the macro environment (for instance, via lower energy consumption and lower land and water resource utilization). Automated container terminal equipment meets the chief requirements of green container terminals, which comprise lower greenhouse emissions, lower energy consumption, container damage reduction, air emission control, noise pollution mitigation, operating efficiency control, and lower climate impact.

Pedrick (2006) proposed that green terminals should be designed in harmony with their locations, promote high efficiency, improve economics, enhance overall infrastructure, and provide a link to the community. Sisson (2006) asserted that the features of green terminals should include electricity for vessels at berth, automated mooring to reduce vessel idling, electric dock cranes, automated low emission transport vehicles, end-loaded electric yard cranes, the requirement that street trucks turn off their engines while awaiting service, and gate appointments to minimize waiting time for street trucks.

Watanabe (2004) believes that competition between mega container ports is gradually intensifying, and this trend is likely to intensify further. To ease the resulting situation, international agreements should require container terminal operators to make reasonable payments proportional to their CO2 emissions volume.

Geerlings and Duin (2010) used the port of Rotterdam as an example to illustrate the optimal layout of a container terminal, which can, in the case of Rotterdam, reduce CO2 emission volume by approximately 70%. These researchers further proposed two alternatives for CO2 reduction: The former is for the government to implement a policy requiring terminal operators to replace old equipment; this approach can reduce CO2 emissions by 20% and increase working efficiency by 20% if diesel cargo stevedoring equipment is replaced by electric equipment. The latter is to mix diesel fuel with biofuel, which can reduce CO2 emissions at a container terminal by 13%~26% and reduce CO2 emissions per container by 21%. In addition, the use of diesel fuel blended with biofuel can reduce energy consumption by 30%.

Storage yards at container terminals serve as temporary buffers for inbound and outbound containers, and RTGs are the most frequently-used container handling equipment in yards (Zhang, et.

al, 2002). An E-RTG conversion project is one way for port operators to reduce fuel consumption and CO_2 emissions. Diesel RTGs often account for half of CO_2 emissions generated by terminal operations, and the economic and environmental effects of conversion are correspondingly large (Conductix, 2011). The advantages of E-RTG use include (1) reduced CO_2 and NO_x emissions, reduced noise pollution, reduced maintenance costs and downtime, and reduced fuel costs (CAVOtec, 2011). The chief advantages of RTGs are as follows: (1) Owing to their high efficiency, RTGs can handle successive lifting, lowering, and stacking operations for a larger number of containers. (2) There is a high container space utilization ratio in cross-block operations. (3) Thanks to the good mobility of RTGs, storage blocks can be used in a complementary fashion to promote operating efficiency.

However, RTGs also have some shortcomings, which include (1) diesel generator operation can lead to a high mechanical breakdown rate and high maintenance costs; (2) heavy fuel consumption can increase operating costs, and (3) exhaust emissions and noise can cause environmental pollution.

Table 2 provides a brief comparison of the three main operating systems (RTG, E-RTG, and RMG) based on information collected through personal interviews and on-file studies of several container terminal operators at the Port of Kaohsiung, including Evergreen, Yang Ming, Wan Hai, APL, OOCL and NYK, from May to June of 2011.

This paper believes that the green container terminal concept will guide future port development. The green terminal concept aims to ensure that ports embody the characteristics of environmental health, ecological protection, rational use of various resources, low energy consumption, and low pollution. Another aim is to ensure harmony between container terminal operations and human health, while fostering sustainable development of the port.

Table 2. Comparison of the operating performance of different types of handling equipment

Item	RTG	E-RTG	RMG
Mobility	Average	Average	Poor
Safety	Average	Average	Good
Operating system integration method	Wireless transmission system	Wireless transmission system	Fiber transmission system
Stability of Signal	Unstable	Unstable	Stable
Breakdown frequency	Average	Average	Low
Mechanical method	Hydraulic	Hydraulic	Electric control
Repair and maintenance time	Average	Average	Short
Energy source	Diesel	Diesel/Electric	Electric
Maintenance cost	High	High	Low
Air pollution	Severe	Zero	Zero

3. CASE STUDY OF AN E-RTG CONVERSION PROJECT

The ABC company is in charge of wharves No. 79~81 at Terminal No. 4 in the port of Kaohsiung. This company had assessed two container handling equipment alternatives, namely the replacement of RTGs with RMGs, and an E-RTG conversion project employing a bus bar system. The disadvantages of the first alternative include (1) impact on terminal operation: Since Terminal No. 4 contains old wharves, the replacement of RTGs with RMGCs would require the establishment of new rail tracks and the reinforcement of the pile-supported wharves to provide adequate support for the track. This, however, would entail an excessively long construction period and impact ongoing operations. (2) High capital investment: In comparison with conversion of old equipment, the installation of new equipment would require huge capital investment and have a long payback period. This approach consequently would not provide optimal economic benefit. (3) Poor operational mobility: The scope of RMG motion is restricted by a fixed track route, and RMGs therefore cannot move cargo to different storage blocks. Moreover, a RMG will impact the operation of other equipment along the same tracks if it breaks down. After reviewing the shortcomings of the RMG installation project and considering the construction period and budget constraints, ABC company made the final decision to implement an E-RTG conversion project employing a bus bar system.

Conversion methods can provide E-RTG equipment with an electric supply system employing both city power and power from a diesel generator. Switching between electric and diesel power can provide the equipment with flexibility. For instance, the equipment can run on electric power while handling containers, and then switch from city power to its diesel generator when working across different storage blocks (Wang and Liu, 2009).

E-RTGs are light-type electric rubber tired gantry cranes, and can improve on the disadvantages of traditional RTGs, which include high purchase price, high maintenance costs, and huge energy consumption, while offering good economic and environmental efficiency. Moreover, since the operating power of E-RTGs is provided by an external electric power supply, instead of a large diesel generator, this will not only reduce purchase cost and largely eliminate maintenance costs, but also enhance environmental protection. The case study company adopted light E-RTGs with four-roller control technology for hoist lifting and trolley traveling functions; these E-RTGs were equipped with hybrid electric/diesel motors (the E-RTGs also had small diesel generators for traveling between blocks).

3.1 Conversion of E-RTG systems

E-RTGs combine several advantages of RTGs and RMGs; not only does electric drive reduce fuel costs, but the E-RTGs' light diesel generators allow travel across different blocks to meet terminal operating needs. At present, E-RTG conversion methods consist of the bus bar, touch wire, and cable reel systems.

(1) Bus Bar System

In a bus bar system, power supply lines in the form of rigid slide rails are installed in the container yard. When E-RTGs are operating in the storage area, their diesel generators are switched off, and power is transmitted from the slide rails to the RTGs via current collecting devices. In contrast, when an RTG must move to another working area, it will switch off electric power and turn on its diesel generator to supply the power; after returning from the other blocks, it will switch off its diesel generator and resume use of electric power. Bus bar-powered RTGs equipped with online braking can reduce energy consumption by up to 60% and reduce local emissions by up to 95%. RTGs chiefly run on electricity drawn from the local grid, not from a diesel generator. The installation of bus bar-powered RTGs offers the advantages of a small project scale, low investment cost, and simple configuration (Duan, 2009).

(2) Overhead conductor system

RTGs can also access city power through an overhead conductor system, which is a concept adopted from electric trains. This type of system enables RTGs to obtain electric power from an overhead cable instead of a diesel engine, but an RTG can also start up its diesel engine so that it can operate while electric power is off. The advantages of this system include convenient inter-block operation, high mobility, and flexibility, while disadvantages include large investment costs during the conversion period and the need to consider the threat of lightning .（Zhou and Chen, 2009)

(3) Cable Reel System

Cable reel RTGs employ cable reels, control systems, cable brackets, electric supply cables, cable plugs, ground switch boxes, and other components. When an RTG travels along a traffic lane, the cable reel control system coordinates the speed of the cable reel with the speed of the RTG through frequency conversion control based on tension in the cable, and this tension control model also maintains the safety of the cable reel. When an RTG must travel to another block, the operator must first turn off the electric junction box safety switch, cutting the RTG's connection with city power, and then carefully pull out the plug connecting the equipment with city power. After the RTG has returned from the other block, the operator must plug in the electric junction box and resume operation in the city power mode.

RTG power cables can be installed through cable guides in underground trenches or aboveground cement trenches. An RTG can be moved from one container route to another by disconnecting the cable plug after switching off the power source, and the cable reel can be retracted using a small crane-mounted auxiliary engine (Wang and Ye, 2008).

The advantages of a cable reel approach include a high degree of flexibility, a logical, user-friendly interface, minimal infrastructure investment, low maintenance costs, manual connection and disconnection, ability to use an MV power supply, cost effectiveness, and unrivalled electrical connection safety (CAVOtec, 2011).

Table 3. Comparative analysis of RTG conversion systems

	Overhead conductor system	Cable reel system	Bus bar system
Purchase cost	Relatively low cost due to simple design, use of common conductor bases, and provision of power on two sides.	Relatively high cost due to need for cable reel, cable bracket, electric supply cable, and ground switch box.	Relatively low cost due to the fact that only additional cable plugs are needed and conversion work can be contracted out.
Installation	Longer construction period affects container storage in the terminal. Fixed operating model restricts working procedures	Container yard must be emptied during construction period, cable trenches and drainage pipelines must be installed at the start of work, hence will affect existing container operations.	1. Use of modular steel frame and cement blocks ensures easy construction. 2. Vertical conductor frames are installed directly on cement piles, hence space requirements are low.
Lightning protection	Simple design easily incurs lighting strikes.	Low probability of lightning strikes	Low probability of lightning strikes.
Engineering inspection	Not needed	Original manufacturer has to provide calculation report for redesign configuration and apply for re-inspection due to the 7-ton weight increase caused by the cable reels and cable brackets.	Not needed
Convenience of maintenance and repair	Damage may affect the entire power supply system and have a major impact on operations.	Simple	Simple
Maintenance cost	Relatively low cost	Cable reels have a service life of roughly 5~8 years; maintenance costs are relatively high.	Carbon brush must be changed every two years; maintenance procedures are simple and costs are low.

3.2 Assessment of conversion of E-RTG systems

RTG power supply systems can be converted via overhead conductor, cable reel, and bus bar system approaches. The advantage of conversion via these three types of systems is that they do not require changes to existing equipment functions and characteristics. The case study company performed conversion to a bus bar system after careful review of various factors (including purchase cost, installation cost, lightning protection, engineering examination, maintenance convenience, and repair cost) by the company's upper management (refer to table 3).

The chief design parameters of the E-RTGs at the case study company included an equipment weight without spreader of 30.5 tons, stacking height of 5+1 tiers, span of 23.5 meters, lifting speed (heavy lifting/empty lifting) of 18/28m/min, trolley travel speed of 60m/min, gantry travel speed of 70m/min, working electric power consisting of three-phase 380V/50Hz AC power, and electric control employing an AC variable frequency drive system.

3.3 E-RTG Conversion process

The case study company had leased three exclusive container berths in container terminal No. 4 at the port of Kaohsiung, and had an RTG working area comprising 25 blocks. Being the first conversion case in Taiwan, the terminal operator selected 19 blocks as the scope of construction work, which allowed it to maintain good coordination and smooth container movement. Four new E-RTGs produced by ZMPC (Shanghai Zhenhua Port Machinery Company) were equipped with low-powered diesel engines, which are used solely to move the E-RTGs between blocks and move away malfunctioning equipment, and are not used in ordinary container handling operations.

Terminal conversion work was completed in the two steps of installing bus bars along the container storage stacks, and fitting the connector arms to the individual RTG units (APM, 2011).

The following tasks were performed during each stage of the conversion project: Mechanical and electrical engineers reviewed electric regulations, assessed advantages and disadvantages of the power supply system, determined the electric voltage, and designed high-voltage transmission lines and a power substation. (1) Mechanical engineers reviewed electric technology regulations, designed an optimal system after comparative analysis of power supply systems, and performed high-voltage line and substation design. (2) To ensure no interruption of terminal operations, reorganization and re-painting of lines was performed in the storage area before the start of construction. Land preparation and installation of water drainage system, steel frame, and cement blocks were also performed. (3) Installation of buried pipelines, substation, electrical panel foundation, and electrical boxes. (4) Installation of transformer and electric boxes; inspection of electrical instruments. (5) Installation of electric junction boxes and safety rails. (6) Modification of old RTG power lines by establishing automatic on/off switches and connecting plugs and sockets. (7) Inspection of power distribution equipment, transformer, cables, rated voltage, electric current, and frequency; operating motion testing, breakdown voltage testing, and operation (See Figure 1).

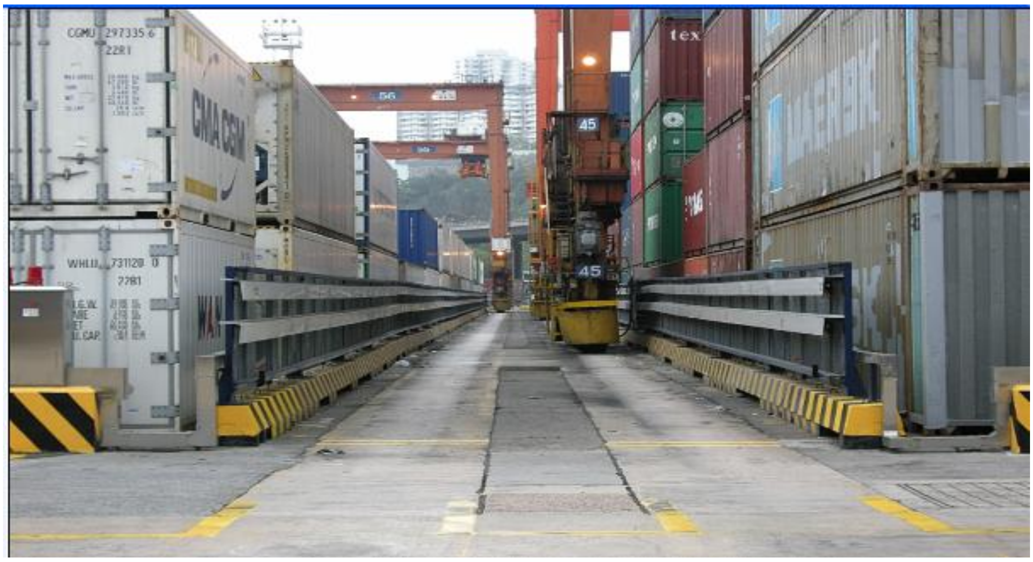


Figure 1. Illustration of a bus bar system

4. PERFORMANCE OF E-RTG CONVERSION PROJECT

4.1 Energy consumption before and after conversion project

Energy saving and CO2 emission performance values were calculated using internal data and formulas provided by the ABC company. This paper compared RTGs and E-RTGs from an energy saving and CO2 emission perspective. The ABC company had 25 RTGs responsible for container yard container handling tasks, and these RTGs performed approximately 1 million moves annually. Average annual fuel consumption in 2005 and 2006, before the RTG conversion project, exceeded 2.2 million liters. The huge cost of this fuel, as well as severe exhaust and noise pollution, motivated the case study company to assess conversion of its RTGs to electric power.

Table 4. Energy consumption of RTGs at the ABC company

Item/year	2005	2006	Average
Total fuel consumption (liters)	2,363,915	2,139,739	2,251,827
Total number of operating shifts	17,705	17,896	17,800
Total number of moves	1,068,705	1,030,925	1,049,815
Average move number handling per shift	60	58	59
Diesel fuel consumption per shift	134	120	127
Diesel consumption per move (liters)	2.21	2.08	2.14

According to the RTG energy consumption statistics for 2005 and 2006 shown in Table 4, annual average diesel consumption was 2,251,827 liters and diesel consumption per container was 2.14 liters. According to annual reports concerning the average price of high-grade diesel fuel in the Kaohsiung area issued by the Bureau of Energy, Ministry of Economic Affairs, the average diesel price during the foregoing two years was TWD 21.02 per liter, and the total annual cost of diesel fuel used at the terminal was therefore TWD 47,333,404. When various maintenance expenses are added, the total annual cost of maintenance and diesel fuel would have surpassed TWD 50 million (approximately USD 1.67 million).According to annual total operation statistics at the case study company for 2010, the conversion of RTGs from diesel to electrical power saved TWD 53 million in maintenance and diesel costs each year. If the E-RTG conversion investment cost was TWD 120 million, the E-RTG conversion investment payback period based on energy consumption expenditure is expected to about 2.2 years, which is a remarkable result (Table 5).

As shown in Table 6, energy consumption based on diesel fuel and electric power usage can be calculated as follows:
Mathematic formula is depicted as below:

$$TE = WT \times EM \times EE$$

Where TE=Total energy expenses(TWD)
WT=Total number of moves
EM=Energy cost per move(Kwh/move or Liter/move)
EE=Energy expenses(TWD/Kwh or TWD/Liter)

(1) Calculation of total annual fuel consumption expenses for diesel fuel:

1,199,543 moves/year × 2.21 liters/move = 2,650,990 liters/year

2,650,990 liters/year × TWD 24.16/liter = TWD 64,047,918/year

(2) Calculation of total annual power consumption expenses for electric power:

1,199,543 moves/year × 3.02 kWh/move = 3,622,619 kWh/year

3,622,619 kWh/year × NT$ 2.38/kWh = NT$ 8,621,833/year

Assuming that total handling volume remained the same, the amount of annual energy savings can be calculated by comparing diesel fuel and electric power costs.

TWD 64,047,918/year-Liter − TWD 8,621,833/year-Kwh = TWD 55,526,085

Table 5. Maintenance and diesel fuel costs of the ABC company in 2006

Unit: TWD

Item	Maintenance/diesel fuel cost
Tire replacement expenses	1,425,000
Diesel engine maintenance expenses	644,000
Machinery maintenance expenses	3,478,711
Electric machinery maintenance expenses	938,665
Diesel consumption expenses	47,333,404
Total annual cost	53,819,780

Table 6. Energy saving of RTGs and E-RTGs

Item	E-RTG	RTG
Total number of moves	1,199,543	1,199,543
Total energy consumption (by Kwh or by liter)	3,622,619	2,650,990
Energy cost per move	3.02	2.21
Energy expenses (TWD/Kwh or TWD/liter)	2.38	24.16
Energy cost per move (TWD)	7.16	53.42
Total energy costs (TWD)	8,621,833	64,047,918
Difference		(55,526,085)

4.2 Performance analysis from a carbon reduction perspective

According to a bulletin issued by the Chinese Petroleum Corporation, the CO2 emission coefficient of diesel fuel is 2.7 kg/liter, and the CO2 emission coefficient of electric power is 0.637 kg/kWh. Based on the total cargo handling volume of the case study company in 2010, annual CO2 emissions were reduced by 4,850,065 kg (Table 7).

Mathematic formula is depicted as below:

$$CO = EC \times CC$$

Where CO= Annual carbon emissions (KG)

EC=Energy consumption based on fuel or electricity (Liter/Kwh)

CC= Co2 emission coefficients (KG)

(1) Annual CO2 emissions attributable to diesel fuel

2,650,990 liters/year × 2.7 kg/liter ＝ 7,157,673 kg/year

(2) Annual CO2 emissions attributable to electric power

3,622,619 kWh/year × 0.637 kg/kWh ＝ 2,307,608 kg/year

Assuming that operating volume remained constant, annual CO2 emissions can be reduced through the use of city power. The ratio of CO2 emissions per container attributable to diesel fuel and electric power use is 3.1: 1.
7,157,673 kg/year － 2,307,608 kg/year ＝ 4,850,065 kg/year

Table 7. CO_2 emission statistics for RTGs and E-RTGs in 2010

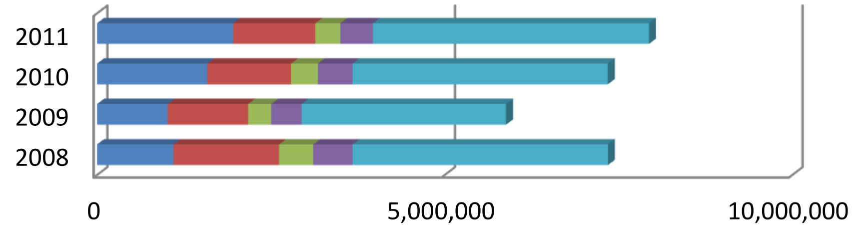
Equipment type	RTG	E-RTG
Fuel consumption/electrical consumption	2,650,990(Liters)	3,622,619(Kwh)
Total containers handled	1,199,543	1,199,543
Average fuel consumption/electrical consumption	2.21(liter)	3.02(Kwh)
Carbon emissions per container	5.96 KG	1.92 KG
Annual carbon emissions	7,157,673KG	2,308,197
Difference	(4,850,065KG)	

4.3 Comparative analysis of RTGs and E-RTGs at the port of Kaohsiung

As seen from Fig. 2, the four shipping companies APL, Evergreen, NYK, and Hyun Dai all employ RTG operating models. APL's container handling throughput increased from 1,099,138 TEU in 2008 to 1,957,670 TEU in 2011, for a growth rate of 78.11% during that period. Evergreen's handling throughput fell from 1,519,174 TEU in 2008 to 1,182,698 TEU in 2011, for a growth rate of -22.15%. The handling throughput of Hyun Dai and NYK similarly declined from 491,056 TEU and 564,608 TEU in 2008 to 358,736 TEU and 470,427 TEU in 2011, for growth rates of -26.95% and -16.68% respectively. The total container handling throughput of these four shipping companies at the port of Kaohsiung consequently increased from 3,673,9766 TEU in 2008 to 3,969,531 TEU in 2011, for a growth ratio of 8.04% from 2008 to 2011. The paper applied the argument of Yang and Lin(2013) claimed energy consumption is computed by energy cost and container handling volume.

According to 2011 data, conversion of RTGs to E-RTGs saved TWD 183,630,504.1 in energy costs, which was obtained by subtracting E-RTG energy consumption of TWD 28,421,841.96 (3,969,531 TEU x TWD 7.16/kWh) from RTG energy consumption of TWD 212,052,346 (3,969,531 TEU x TWD 53.42/liter). As a result, conversion to E-RTGs yielded an energy saving performance of 86.60%, which is higher than the 70% suggested by APM (2011). This result can be considered a remarkable achievement for the port logistics sector (Fig. 3).

As shown in Fig. 4, based on 2011 data, conversion of RTGs to E-RTGs reduced CO2 emissions by the equivalent of 16,036,905.24 kg, which was obtained by subtracting E-RTG CO2 emissions of 7,621,499.52 kg (3,969,531 TEU x1.92kg/TEU) from RTG CO2 emissions of 23,658,404.76 kg (3,969,531 TEU x 5.96kg/TEU). As a result, conversion to E-RTGs yielded a CO2 emission reduction of 67.79%. This figure is within the 60%~80% range claimed by APM (2011), and represents a significant CO2 reduction achievement.



	2008	2009	2010	2011
APL	1,099,138	1,016,331	1,585,453	1,957,670
Evergreen	1,519,174	1,155,975	1,204,094	1,182,698
Hyun Dai	491,056	333,347	387,276	358,736
NYK	564,608	435,963	496,596	470,427
Total	3,673,976	2,941,616	3,673,419	3,969,531

Source: Port of Kaohsiung, Taiwan International Ports Corporation (2012).

Figure 2. Total container handling throughput of tenant companies using RTGs in the port of Kaohsiung, 2008~2011

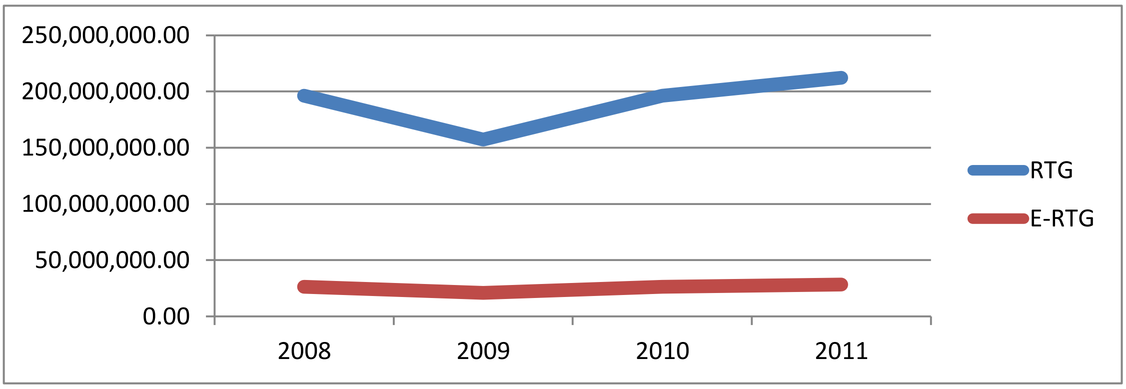


Figure 3. Comparison of total energy consumption cost between RTGs and E-RTGs in the port of Kaohsiung by 2008~2010

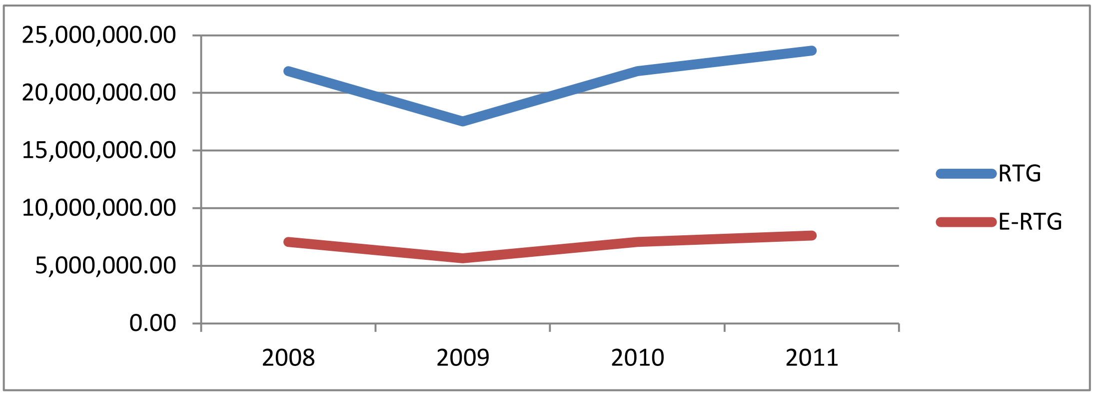


Figure 4. Comparison of total CO2 emissions of RTGs and E-RTGs in the port of Kaohsiung

5. CONCLUSIONS

The shipping industry underwent a period of recovery and prosperity after 2003, which was followed by severe retrenchment in the wake of the global financial crisis in 2008. Container terminals currently confront many major challenges, including how to deal with increasing energy costs and the requirement that they meet even stricter environmental standards, while striving to realize the green port vision. Since over 200 diesel RTGs are still in use at the port of Kaohsiung, terminal operators continue to look for means of reducing energy expenses and improve emissions in this time of high oil prices and tightening environment regulations. This paper therefore focuses on the conversion of RTGs, and examines such issues as performance before and after conversion, advantage and disadvantage of E-RTGs, operational constraints, and energy savings and carbon reduction.

This paper examines a case study of E-RTG conversion by the ABC company, which implemented the first conversion project at the port of Kaohsiung, and attempts to analyze the performance of the conversion project from the perspective of energy savings and carbon reduction. This paper obtained several conclusions and recommendations for terminal operators and shipping companies with regard to the use of E-RTGs in compliance with the green terminal concept.

The following findings were obtained: (1) High fuel oil price are forcing container terminal operators to bear heavy operating expenses. After comparative analysis of the capital payback period and physical performance of RTGs and E-RTGs, we found that container terminals and shipping companies can justify the conversion of existing equipment from diesel fuel to electric power in view of the resulting 86.60% energy savings and 67.79% reduction in CO2 emissions. (2) Diesel-powered RTGs produce large amounts of engine noise and exhaust emissions during operation, have long constituted a serious pollution source in the port area, and also severely impact the physical and mental health of container terminal workers. This paper suggests that container terminal operators and shipping companies should review all handling equipment and then assess the feasibility of either a conversion project or acquisition of new handling equipment (such as RMGCs, automatic RMGCs, and automatic stacking cranes) in compliance with environmental protection requirements.

(3) Owing to the growing operating cost burden caused by increasing international oil prices, conversion to E-RTGs is expected to become a mainstream alternative for the port logistics industry. Shipping companies and terminal operators should therefore pay close attention to this yard crane trend, which complies with the green container terminal and eco terminal goals. (4) Conversion of RTG power supply systems may employ an overhead conductor, cable reel, or bus bar system. This paper found that the bus bar system is the optimal RTG conversion system owing to such advantages as short construction period, less disruption of terminal operations, and lower installation and maintenance expenses. (5) CO_2 emissions generated by RTGs used by the four major shipping companies at the port of Kaohsiung have increased from 21,896,896.96kg in 2008 to 23,658,404.76kg in 2011, which represents a growth rate of 8.04%. The Taiwan International Ports Corporation should therefore formulate appropriate regulations or provide incentive measures to encourage the four terminal operators to upgrade their handling equipment or perform E-RTG conversion projects paralleling the case of the Port of Rotterdam. The port of Kaohsiung has the opportunity to become a successful model green port, and CO_2 emissions will gradually fall if the foregoing measures can be implemented.

In addition, this paper proposes the following suggestions for practical workers and academic researchers: (1)Based on the shipping company case study, this paper found that conversion of diesel RTGs to electric power can save a total of TWD 55 million annually. If investment cost is TWD 120 million, the investment payback period was expected to about 2.2 years. This indicates that an RTG conversion project is not only beneficial for the environment, but is also an optimal means of avoiding the impact of high diesel fuel prices in the shipping industry. (2) RTGs constitute the majority of handling equipment at the port of Kaohsiung, and the decision to perform conversion or acquire new equipment may be based on a shipping company's or container terminal operator's business strategy and operating guidelines. In addition to the E-RTG conversion model, various systems have been proposed by academic researchers for use in equipment conversion, such as hyper-electric systems with diesel and natural gas engines. (3) This research focused on conversion of RTGs to E-RTGs without considering human factors. What influence do management personnel have on the operating efficiency of handling equipment? In order to shed more light on this issue, further research may therefore examine the physical performance of E-RTG cranes from the perspective of human factors or management-level considerations. (4) The scope of this paper was restricted to a comparative analysis of the performance of RTGs and E-RTGs from the perspective of energy savings and CO_2 reduction based on the conversion project of the case study company. Further research may not only extend its focus to other types of cargo handling equipment at container terminals and container yards, but also probe the issue of how to upgrade energy systems and equipment in order to achieve operating cost savings and environmental improvement.

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