Technical and Financial Analysis on Trolley and Electric Bus in Phitsanulok, Thailand

Sittichoke Pookpunt[1,*], Ananchai Ukaew[1], Pongpun Othaganont[1],
and Pakchira Nugbanleng[2]

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A B S T R A C T

This paper aims to demonstrate the transformations of public space in Vientiane Capital, focusing on Nam Phu (Fountain) Park as a case study to understand the urbanization process impact on the urban social spaces. The Lao government has been actively involved in urban management of public spaces since the early year 2000s, following its decree to turn land into a capital (TLIC) in 2006. Public spaces and assets have been transformed in order to facilitate this transfer of "capital", which has been driven by both foreign direct investment (FDI) and domestic direct investment (DDI). The Nam Phu Park is one of public spaces that have been privatized by the DDI, in order to develop it as a modern place to attract tourists. Leading to direct negative impact on community in the form of being restricted from access to Nam Phu Park that they had previously used. Nam Phu is a case that the Lao government and the capitalist class have collaborated together in the transformation of public space into privatization. They have been able to achieve this by obtaining legitimation from residents through the promotion of a 'modernity and beautification' discourse, which attempts to convince national residents that they have the duty to develop the country and sacrifice their individual interests to the common good. This changing phenomenon concerning public space transformed the meaning of space from 'state-owned, public space' to 'commodified space', which is meant to facilitate economic growth. This privatization of state land has led to many negative impacts on surrounding communities. To understand the process of transformation of Nam Phu Park, the author applies the qualitative method including observation, in-depth interviews of key informants, as well as a critical literature review to investigate the urbanisation process of public space in Laos and the implications for the powers of exclusion the community from the Nam Phu Park.

1. INTRODUCTION

Phitsanulok locates at the lower north of Thailand, developed the Indochina Intersection project since 2007 and planned as the economic corridor of the Greater Mekong subregional-GMS including Thailand, Myanmar, Lao, Cambodia, Vietnam and China (Yunnan). Moreover, Phase 1 of the Northern High-speed Railway Project between Bangkok and Chiang Mai will start to operate in Phitsanulok within 2024 [1]. Additionally, the strategic plan "Phisanulok 2020" provided the direction and developed The Mass Transit Master Plan [2] aimed to improve the quality of public transportation. The master plan of Public transportation development would include available technology to use with existing infrastructure and a financial plan considered one of the important parts of a project as a decision-making tool to decide whether a project is feasible or not. The financial plan/model is necessary for a project leader to allocate the funding sources from both the private and government sectors.

First, the demand for public transportation was forecasted to design eight different transportation routes in Phitsanulok area. Only two feasible routes were chosen and one route with the highest estimated number of passengers is discussed in this paper. Because of the high investment per distance on the Overhead Wire (OH) system of trolley, the other long-distance routes showed large capital investment when implemented with trolley infrastructure. Based on the 'Green City' concept, this study focused on the highest transit demand and the shortest distance route designed passing over the downtown area (the red line in master plan [2]). The study compared a cost and benefit between 2 scenarios which are traveling via trolley and traveling via battery electric bus (BEB).

This study shows technical and financial analysis of 2 scenarios either implementing a trolley bus or BEB. The chosen option will be implemented as a part of the

[1]*Social Science (International Program), Faculty of Social Sciences, Chiang Mai University, P.O. Box 50200, Thailand..*
**Corresponding author:* Phone: +66-99-296-2964; E-mail: kesone2009@gmail.com.

transportation policy study [3]. The annual passenger demand used for choosing the route was obtained from the city transportation master plan [2]. To begin with, the driving pattern and energy required per trip are calculated to determine the battery capacity of trolley and BEB. Additionally, revenue for both trolley and the electric bus is calculated based on the fixed fare rate. The capital and operational cost are determined based on future passenger demand. With the bus driving pattern, the electricity required to operate a vehicle is calculated. Then, the cost to benefit ratio is applied for economic analysis for comparing a cost and benefit from traveling by trolley bus and BEB. Finally, sensitivity analysis and scenario tests are applied to determine risk in financial analysis.

2. MATHEMATICAL MODEL

2.1 Energy Model

The energy and power model are used to determine the transportation range and optimal battery capacity in a bus service route. Bus driving power including driving force, transmission losses and auxiliary requirement are as following,

$$P_E = (F_I + F_R + F_A + F_P)V + P_L \quad (1)$$

where, P_E is the total driving power requirement, F_I is driving force required to accelerate the bus, F_R is rolling resistance, F_A is aerodynamics resistance force, F_P is friction from pantograph on overhead (OH) wire, P_L is auxiliary required power and V is bus velocity. Detail of calculation extending to the total power requirement can be determined as shown in Eq.(2).

$$P_E = \left\{ \left(m\dot{V} + C_R mg + \frac{1}{2}\rho C_D A V^2 + C_C N_C \right) V + P_L \right\} \Big/ \eta \quad (2)$$

where, m is total mass of vehicle, $\dot{V}$ is acceleration need, C_R is coefficient of rolling resistance, ρ is air density, C_D is coefficient of air resistance, A is bus fatal area, C_C and N_C are the coefficients between pantograph on OH wire and its compressed force, and η is total transmission efficiency. Then the driving energy could be obtained from:

$$E = \sum_{i=0}^{n} P_{E,i} \quad (3)$$

where, E is total energy requirement and i is service time on the route.

2.2 Financial Model

2.2.1 Cash flow (CF)

Cash flow represents the stream of cash generated through project lifetime from the initial year (year 0) to the terminal year (year T). It includes an initial investment (CF_0), the annual after tax operation cash flow (CF_t) and the terminal-year after tax non-operating cash flow ($TNOCF$). CF_0 is considered as the $CAPEX$ plus initial networking capital (NWC_0) including research and design, initial project operation and management as in Eq.(4). CF_t is a stream of cash while operating a project including revenue, operation expense, depreciation (Dp_t), interest and tax (Tax_t) as shown in Eq.(5) where t is the number of operated years. $TNOCF$ is collected cash in the terminal year of the project including forecasted salvage value (Sal_T) and net working capital (NWC_T) as in Eq. (6).

$$CF_0 = CAPEX + NWC_0 \quad (4)$$

$$CF_t = (Rev_t - CAPEX_t - Exp_t - Dp_t) \times (1 - Tax_t) + Dp_t \quad (5)$$

$$TNOCF = Sal_T - (Sal_T - BV_T) \times Tax_T + NWC_T \quad (6)$$

where, $CAPEX_t$ refers to buses purchase depending on demand and battery replacement every 5 years. NWC_0 and NWC_T are 5% add over the cash flow, while NWC_t assumes to zero during the operation.

Table 1. Trolley and electric bus specification

Specification lists	value
Total mas including passengers (Mg)	18.0
Aerodynamics coefficient	0.66
Coefficient of rolling friction	0.0075
Friction of pantograph to OH wire (N) [4, 5]	12.0
Wheel radius (m)	0.5
Bus fatal area (m^2)	6.4
Air density (km/m^3)	1.25
Total transmission efficiency (%)	87%
Auxiliary power (kW)	5.0
Regenerative Braking efficiency	30%

2.2.2 Net Present Value (NPV)

The different benefits and costs as yearly cash flow over project lifetime are discounted using a 10% discount rate (defined by EGAT) or expected return on investment. The total of net cash flow minus initial investment called *NPV* uses to measure and compare the return before investing in the project, shown in Eq.(7), where d is the discount rate specified by the Electricity Generating Authority of Thailand (EGAT), the sponsorship in this study [3]. In general, the positive *NPV* induces the investors, while the negative *NPV* defects the project attractiveness. However, the mass transit project should be accountable for both financial and economic benefits.

$$NPV = \sum_{t=1}^{T-1} \frac{CF_t}{(1+d)^t} + \frac{CT_T + TNOCF}{(1+d)^T} - CF_0 \quad (7)$$

given *d* = 10% and *T* = 20 years.

While the revenue is used to determine CF and NPV in financial analysis, the economic benefits including the vehicle operating costs saving (VOC), the valuation of travel time saving (VOT) and the accident cost saving (ACC) which is mentioned in a master plan are used to determine the social benefit in term of economics internal rate of return (EIRR). Note that, VOC is the vehicle operating cost saving referred to the saving cost relatively vehicle operation including vehicle purchase, O&M and replacement maintenance when the project would be implemented. VOT, the valuation of travel time saving referred to time saving of the passenger, would increase in the value of working time. ACC is the accident cost saving referred to the cost of accident and it relatively decreases due to less number of vehicle on the road travel.

3. METHOD

The red line route designs for 25.2 kilometers of a round trip between Central Plaza Phitsanulok to Phitsanulok University with 15 bus stops as shown in Fig.1. By scheduling with average 382 passengers per hour per direction, a bus runs 16 round trips per day or about 200 km/day, then around 66,051 km/year. The average speed and duration of the trip are 26 km/h and 58 min/trip.

3.1 Financial Schematic Model

The mass transit investment is seen as long-term investment hence a project cash flow is determined and discounted to the NPV. The project revenue could be obtained using the demand forecast (number of passengers) and a fixed fare rate. The capital investment (CAPEX) is an investment in infrastructure located on the chosen route including vehicle, depot, substation and overhead wire for trolley, charging station and battery pack for BEB while the operational expenditure (OPEX) is calculated based on the demand of mass transportation from the estimated number of passengers and headway design. The cost of running the operation of the trolley divides into fixed and variable costs. The cost of electric power used for the driven motor, operation cost, and maintenance cost is distant related. While the cost of hiring drivers, depot staffs, and back-office staffs depend on the number of vehicles used. Cost also includes fixed annual payment on insurance, land rental, registration and concession. The schematic of the financial model is shown in Figure 2.

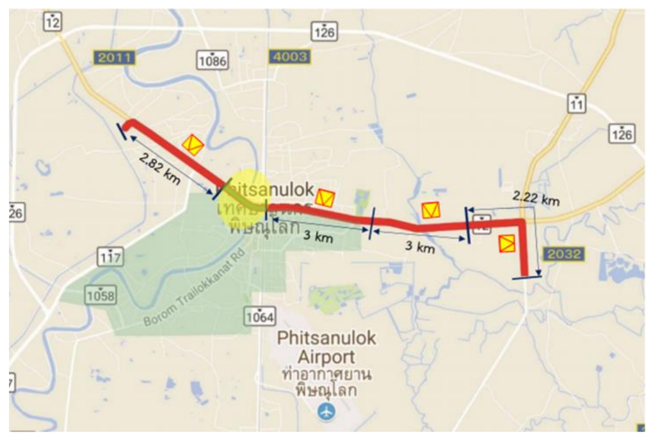

Fig. 1. The red line route designed for 25.2 km round trip with 15 bus stops and 4 substations for trolley [3].

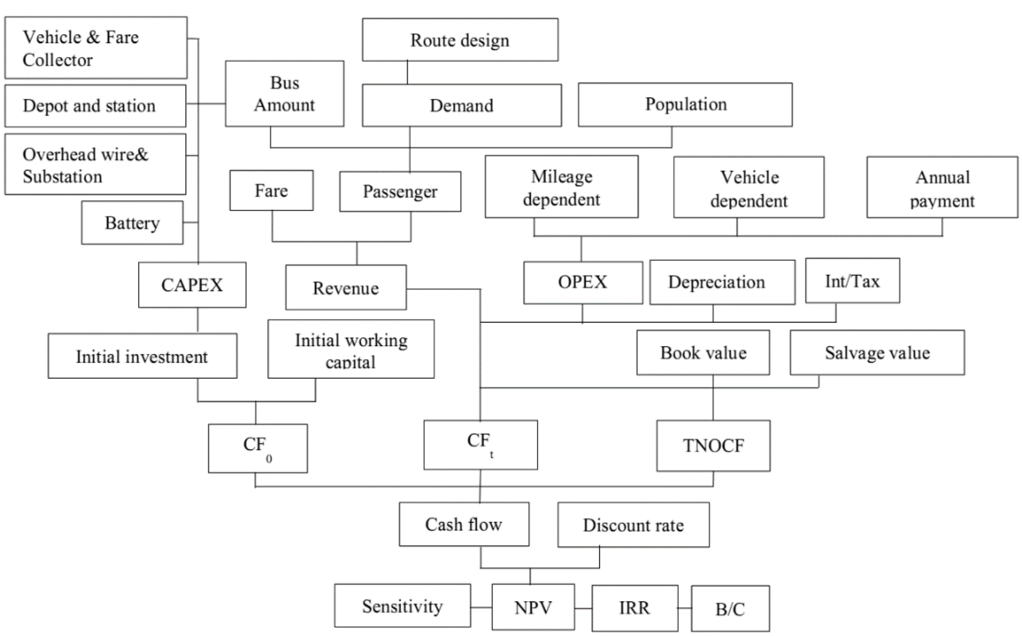

Fig. 2. Schematic of financial model.

3.2 Revenue and Benefit

The direct benefit comes from transportation service called box fare revenue, while the non-box fare revenue is from advertisement, commercial lease cost, salvage cost and others. In this study, the demand estimation of passengers from the case of HST project development in phase 1 was used with the fixed fare price at 25 baht per trip to calculate revenue. Figure 3 shows the demand of passengers per day and revenue on both trolley and BEB during 25 years of project from 2022 to 2047. The salvage cost of the battery in BEB shows a little different between both technologies. While the Figure 4 shows the similar benefit of mass transit system between trolley and BEB including VOT, VOC and ACC.

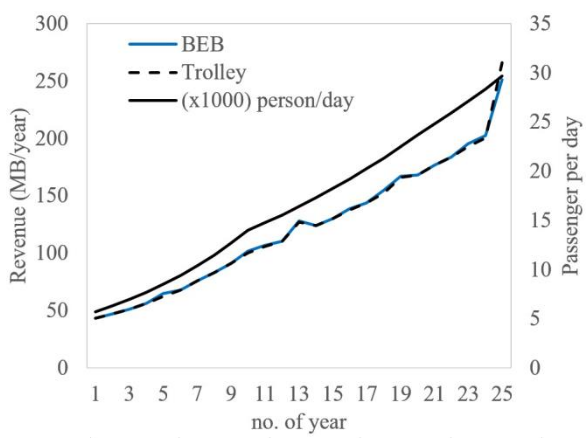

Fig. 3. The passenger per day estimated by the Master plan and revenue between trolley and BEB.

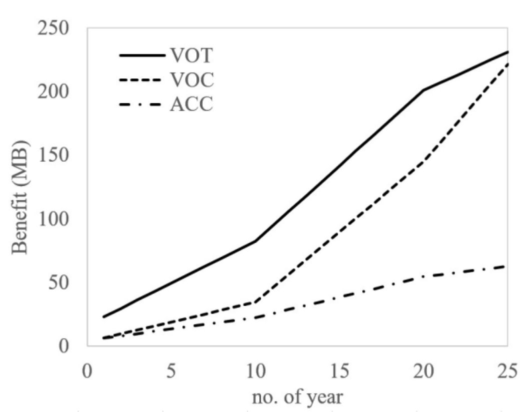

Fig. 4. The similar benefit of mass transit between trolley and BEB.

3.3 Capital Expenditure (CAPEX)

CAPEX is the money spent on the improvement or purchase of fixed assets. In this study, CAPEX is an initial fund used to acquire assets including vehicles, depot and office building, bus station, OH wire and structure, substation, security and transportation management system (TMS) and equipment as shown in Eq.(8) and annualized form is shown in Eq.(9).

$$CAPEX = Vehicle + Depot + (Substation, OH\ wire)_{trolley} + (Battery, Charger)_{BEB} + TMS \quad (8)$$

$$\text{Annualized} = \text{CAPEX} \times \left(\frac{d(1+d)^T}{(1+d)^T - 1} \right) \quad (9)$$

3.3.1 Vehicle Procurement

The initial vehicle procurement plan and process considers both the estimated number of passengers and technology selection. The amount of bus fleets depends on headway, bus schedule on weekdays and estimated passenger (as in shown Eq.(10)), given LF_c as a capacity load factor needed for the recirculated bus. Bus specification such as bus capacity, fare collection system, emission standard and safety system depend on the purchasing price. Buses used in this project will be imported and the investment decision will be considered fewer than 2 circumstances; bus with imported tax and without imported tax. A lifetime of the bus is 12.5 years or about 1 million kilometers on service. To reduce investment risk, the bus would be purchased every 6.5 years. The bus needed and the number of buses purchased is shown in Figure 5.

$$\text{Bus need} = \frac{\text{passenger per day}}{\text{services hour} \times \text{bus capacity} \times LF_C} \quad (10)$$

Table 2 Initial investment comparison between trolley and BEB

CAPEX	Trolley (MB)	BEB (MB)
Depot and office building	40.80	40.80
Bus stop	1.50	1.50
GPS and TMS	2.10	2.10
OH wire system	158.05	-
Substation along the route	46.28	-
BEB charging station	-	17.01
Initial bus purchasing (no import tax)	109.47	123.46
Total	358.21	184.87
Annualized (MB/year)	52.6	35.2

3.3.2 Depot and Office Building

Depot is used to park and maintain the fleets. Space and area needed for construction depend on the fleets size and the number of staffs working in a depot. Bus specification in this study is 12 meters bus with 75 seats. One bus requires, at least, a 100 m^2 space in a depot. While office space in the depot requires 9.3 m^2 per working staff [7]. With the high cost of land in the downtown area, the depot location is supported by the local government with long term land leasing contracts to reduce the initial investment and project risk. Expenditure for depot and office building includes construction cost, cost of equipment needed for bus maintenance e.g. mechanic device, bus painting unit, charging device, and electrical system maintenance unit as shown in Table 2.

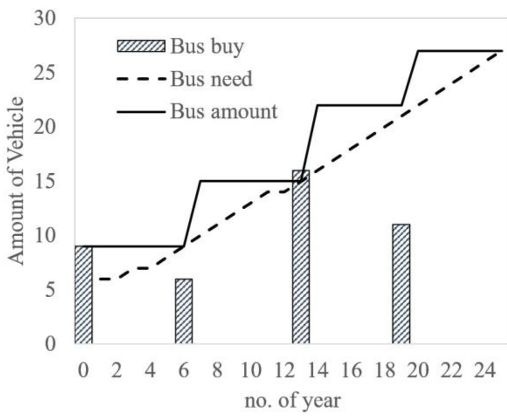

Fig. 5. Number of buses purchased and bus procurement.

3.3.3 Overhead Wire and Substation

For trolley, the substation should be constructed in every 3 kilometers to invert 22kVAC transmission line to the 600-700 VDC to the catenary wire along the route to depot. The construction cost used in this study was reviewed from cost per unit data of 15 sections over North America and European countries [8, 9]. While BEB uses batteries that store enough energy for a one-day service length and the buses will be charged at the depot when they are not in service. Manufactures Unit Values (MUV) refers to a price index (in the U.S. dollar) of an imported product. This index is used for calculating the cost of imported products that bought in an initial year of a project. For domestic cost adjustment, a consumer price index (CPI) is used to measure the average change over time of the domestic price level. In this study, MUV is 1.8% and CPI is 1.6%.

3.3.4 Battery Replacement

In general, the battery life depends on the manufacturer warranty; however, every 5 years replacement is used in this study. Trolley uses 34 kWh Lithium Titanium Oxide (LTO) battery charged via the overhead wire. While BEB uses 324 kWh Lithium iron phosphate (LFP) battery and needs the charging station at the depot during off-service at night time because of the discounted energy price without the demand charge period (10 pm to 9 am in the next day) [10]. The forecast price model of battery capacity [11] is used to decrease the replacement cost within the expired project year as shown in Figure 6.

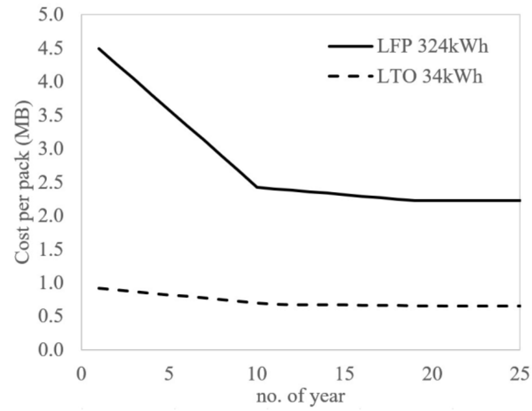

Fig.6 The forecast battery price per pack.

3.4 Operational Expenditure (OPEX)

OPEX is the expense to run the business during the operation period including the cost of operating service, cost of vehicle and annual payment. The mileage dependent cost is mainly electricity cost. Electricity used for both vehicle types is 1.54 kWh/km for a trolley and 1.09 kWh/km for BEB. The higher consumption on trolley is because of the losses from the transmission line to the motor drive. Additional, tire replacement and general maintenance are considered as the cost per kilometer.

Vehicle dependent costs mostly relate to the number of staffs including the bus driver, mechanic and electric staff in depot, back office staff and management team. The detail of this expense follows the BRT guideline [6] and rebalances to the minimum wage in Phitsanulok. Finally, the annual payment as fixed cost except for those two groups including depot and on-route infrastructure maintenance cost, concession, insurance, registration fee and etc. are compared between trolley and BEB as shown in Table 2.

4. RESULTS and DISCUSSION

4.1 Energy Consumption

For the 12.6 kilometers one-way route of the red line, fifteen bus stops will be designed on the route using the population density in each location while the bus on services, the acceleration is assumed as 0.75 m/s^2 because of driving comfort. The bus velocity and power demand and energy consumption during service could be determined between each bus stop by changing average bus velocity ranging from 23.4, 26 and 28.6 km/h. The simulation shows that the higher average speed leading to the higher power demand and energy consumption as shown in Figure 7(i)-7(iii), respectively.

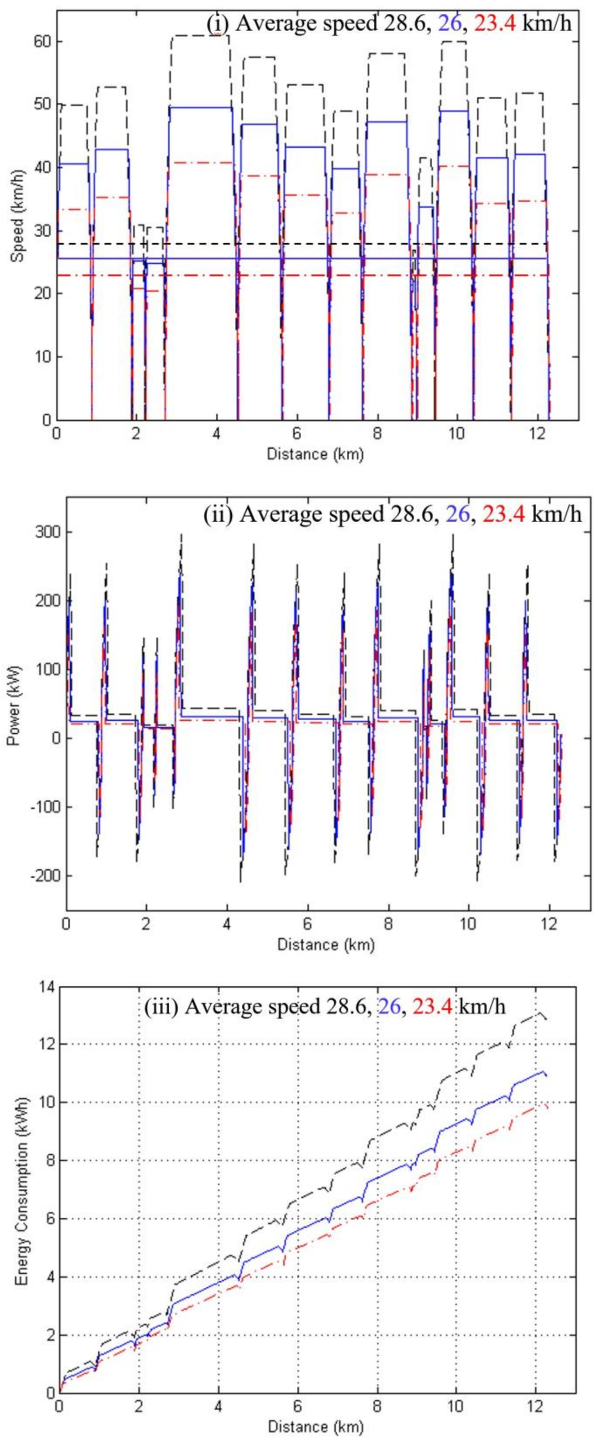

Fig. 7. Comparison between different average speed with (i) speed between bus stop, (ii) power demand and (iii) energy consumption.

4.2 Cost of Transportation

Table 2 compared the initial investment both on the trolley and BEB project. The same amount invests on a depot and small different on both vehicle types; however, the trolley would double invest more than BEB because of the OH wire and substation along the route. In another way, the operation cost would be increased year after year because of the larger fleet and staff to support the higher demand. Then, Table 3 compared the annualized operational expense showing not so much different in total operating expense between trolley and BEB.

Table 3 annualized operational expense comparison between trolley and BEB

Annualized OPEX	Trolley (MB/year)	BEB (MB/year)
Electricity cost	5.6	4.0
Vehicle maintenance	4.4	4.4
Insurance and registration	0.5	0.5
Battery replacement	1.4	8.0
Personnel	18.3	18.3
Land lease cost	1.7	1.2
Infrastructure maintenance	6.0	0.9
Total (MB/year)	36.9	37.3

In summarizing the cost of transportation, the initial investment cost would be annualized along with the project considering time. While the year by year increasing revenue would be discounted and annualized as the same as the operating expense. The cost of transportation per passenger, cost per distance and cost per person per kilometer could be determined as shown in Table 4. The small difference in revenue is due to the battery salvage cost when replaced. The cost of transportation of trolley higher than BEB because of the higher in initial investment.

Table 4. The transportation cost comparison between trolley and BEB

	Trolley	BEB	
Revenue	89.2	89.5	MB/year
Annualized expense	89.5	72.5	MB/year
Cost per passenger	27.9	21.8	THB/person
Cost per distance	96.8	75.7	THB/km
Cost of transportation	3.33	2.60	THB/person-km

4.3 Financial Analysis

When discount all cash flow to the present value, trolley cash flow provided minus along the considering project time. However, BEB cash flow turned to plus from year 14 and so on as shown in Figure 8. The results show the negative NPV on the trolley and the positive NPV on BEB because of the double investment amount for the trolley, while there are not different in both revenue and operating expense. Moreover, considering the IRR together with B/C ratio, BEB presented the more attractive for investment in this route. When considering the economics benefit including the vehicle operating cost saving (VOC), the valuation of travel time saving (VOT) and the accident cost saving (ACC), both mass transit technology provided reasonable economics return for the local government to support this project as shown in Table 5.

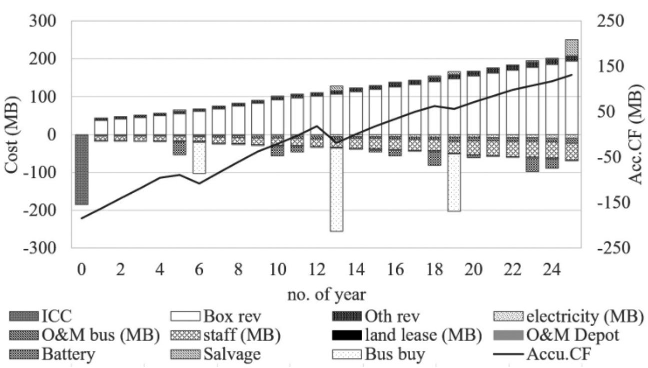

Fig.8. Discount cash flow on both revenue and expense of BEB

Table 5 Financial and economics analysis of the red line project

		Trolley	BEB
Financial analysis	NPV (MB)	-38.4	131.6
	IRR	9.0%	16.0%
	B/C	0.56	0.95
Economics analysis	EIRR	18.1%	26.6%

4.4 Sensitivity Analysis

Variation of independent factors ranging from -20% to 20% showed the NPV range of estimation. Sensitivity analysis considered a range lowering 10% of the initial investment. Both technologies showed the most sensitive factor related to the revenue including fare price and occupied load factor of passenger amount. Increasing fare prices, increase project return more attractive; however, these losses convince to the passenger. The import factors including import tax, exchange rate, OH wire system and vehicle price defected the project NPV. Additional, the discount rate as expected return rate and debt to equity ratio also disturb the attractive of investment as shown in Figure 9. BEB showed similar sensitive factors characteristics except for the OH wire system. The more NPV range for import and debt to equity ratio because of the higher import price of BEB. However, all deficit factors still made positive NPV on BEB project, then it showed a more attractive return on investment than trolley in financial analysis.

4.5 Indirect Benefit

The indirect benefits when using electrical power sources instead of conventional diesel bus could reduce oil import and tailpipe emission including CO_2, CO, HC, PM10, NOx and SOx. However, the CO_2 was generally compared becasue the diesel after-treatment technology following EURO 4 standard was enforced to eliminate the harmful organic both in fuel and emission. Table 6 showed the decreasing amount of import kilo-ton crude oil equivalent (ktoe) as 52.6% in the trolley and 65.5% in BEB comparing to a diesel bus. Moreover, trolley and BEB could lower CO_2 emission by 5% and 31% than a diesel bus, respectively.

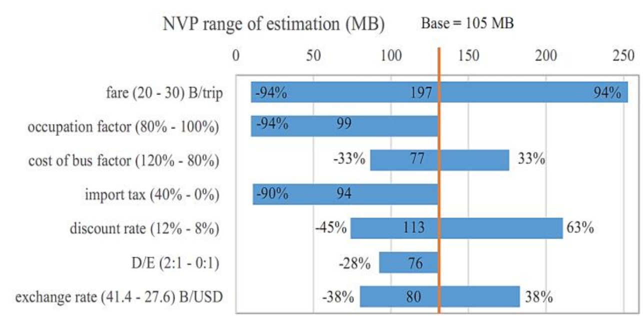

Fig. 9. Sensitivity analysis for BEB.

Table 6 Indirect benefit comparison between bus technologies and crude oil equivalent

Indirect benefit				Crude oil eq.	
Total distance	30.6	M.km			
Trolley	45.9	GWh	=	3.94	ktoe[1]
BEB	33.3	GWh	=	2.87	ktoe
Diesel	9.2	M.liter	=	8.33	ktoe
CO_2 diesel[2]	24.2	M.kgCO_2			
CO_2 trolley	22.9	M.kgCO_2			
CO_2 BEB	16.7	M.kgCO_2			

[1] IEA : 1 toe = 11.63 MWh = 41.868 GJ
[2] NTSDA: Diesel bus consumption = 0.3 L/km
Diesel CO_2 emission = 2.64 kgCO_2/L
Electric CO_2 emission = 0.5 kgCO_2/kWh
Diesel HHV = 38 MJ/L

5. CONCLUSION

Phitsanulok, as the Indochina Intersection, has developed Mass Transit Master plan to serve the economic corridor of the Greater Mekong subregional-GMS and Phase 1 of North High-Speed Train to Chiang Mai. This study presented a comparison of two mass transit technologies, the trolley and BEB, both in technical and financial analysis. Because of the high investment per distance of the trolley overhead wire (OH) system, the shortest route passing through downtown, as the red line predicted the highest passenger demand in the Master plan, was selected to be analyzed. To compare with BEB, the trolley required higher energy consumption because of transmission loss. Even though both technologies had not much different both revenue and operating expenses but trolley presented the higher cost of transportation as it has a higher total annualized cost from the initial investment. Moreover, BEB could provide the non-box revenue by managing the charter bus on a special route event. However, the trolley infrastructure in this study was assumed for 25 years which was shorter than their actual lifetime. Besides, this study did not consider economies of scale when buying OH wire, which could provide better NPV of this project. In terms of Economic returns, investment in both technologies, trolley and BEB, becomes more attractive for the government as this could increase economic activities in a particular area where is mass transit service provided. Good mass transportation can also increase a number of tourists. These economic activities can increase the level of consumption as this investment can increase employment hence income per capita expecting a higher Gross Provincial Product (GPP) and a better quality of life in an area of investment.

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REFERENCES

[1] Wanwisad, W. 2013. *The Path to Development of High Speed Rail Project in Thailand*: The Secretariat of the Senate.

[2] OTP. 2016. *Feasibility Study and Preliminary Design of Phitsanulok Transit System.* The Office of Transport and Traffic Policy and Planning : Ministry of Transportation.

[3] Ukaew, A. et al. 2018. *Policy Study of Potential Electric Bus Employment for Transportation Using Phitsanulok Urban Area as Case* : National Science and Technology Development Agency.

[4] Ding, T., et al. 2012. *Friction and Wear Behavior of Pantograph Strips Sliding Against Copper Contact Wire with Electric Current.* AASRI Procedia : p. 288-292.

[5] Wu, G., et al. 2018. *Characteristics of the Sliding Electric Contact of Pantograph/Contact Wire Systems in Electric Railways.* Energies. 11(17).

[6] ITDP. 2017. *The BRT Planning Guide*. 4th ed. Newyork: Institute for Transportation & Development Policy.

[7] NFPA. 2019. *NFPA 101 2009 Edition Life Safety Code*.

[8] Dunoye, D. and Diewald, D. 1996. *Trolley bus and motor coach operational cost comparisons utilizing section 15 data.* Transportation Research Record.

[9] C.E. Programme, 2013. *Take-up guide for the replacement of urban diesel buses by trolley buses.* European Regional Development Fund : European Union.

[10] PEA. 2015. *PEA Classification of Electric rate* : Provincial Electricity Authority of Thailand. Retrieved September 14, 2018 from the World Wide Web: https://www.pea.co.th/en/Electricity-Tariffs.

[11] C.A.R. 2016. *Advanced Clean Transit Battery Cost for Heavy-Duty Electric Vehicles* : The California Air Resources Board.