A Location and Allocation Model in Determining Charging Station Facilities using Facility Fixed and Variable Costs: A Case Study

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Abstract

The development of technology is currently growing rapidly affecting several aspects of human life. One of the technological developments in the automotive world is vehicle electrification. It aims to reduce the impact caused by oil-fueled vehicles, namely air pollution. The Indonesian government has made regulations for electric vehicles, which shows that Indonesia will enter the era of electric vehicles. To support this regulation, it is necessary to plan the construction of supporting facilities for electric vehicles, namely charging stations. This study aims to determine the location of facilities and distribution of allocations by minimizing investment costs and mileage and can cover all requests, as well as analyzing investment feasibility. This study develops a mixed-integer linear programming (MILP) model that can determine the decision on the number and construction of charging station facilities and the number of allocations served. LINGO 18.0 software will be used for data processing. Based on the calculations obtained 29 market locations and 1 mall as a charging station location and the minimum amount of subsidy provided by the city government is 50% on CS devices for traditional market locations and 75% on CS devices for mall locations. The research succeeded in developing a supply chain network distribution system model for stakeholders. For investors (Solo Technopark), this model can be a reference in determining investment decisions for the establishment of a charging station facility. For the Surakarta City Government, this model can be used as an evaluation of subsidy policies to attract investors in the construction of charging station facilities. For consumers (e-trike users), the optimal cost and distance can make it easier for consumers to access the charging station facilities that will be built.

Keywords
Charging station, E-trike, Investment feasibility, Location and allocation model, MILP, Supply chain network.

1. Introduction
Becak is a traditional vehicle with a type of tricycle that has existed in Indonesia since the 1940s. This vehicle is quite popularly used to transport goods and passengers in daily life and is widely available around traditional markets. Along with the development of time, the number of rickshaws in Indonesia is increasing because rickshaws are also a source of income for some people in Indonesia. According to data from the Central Statistics Agency (BPS) in 2018, there were 4235 rickshaw units spread across various sub-districts in Solo City. So that makes rickshaws unable to compete with current four-wheeled or two-wheeled vehicles. The phenomenon of online transportation offers all the conveniences and practicalities that make rickshaws no longer a consumer choice. For this reason, it is necessary to modernize the rickshaw in order to compete with vehicles in today's modern era. The modernization of the rickshaw must be an environmentally friendly vehicle. According to the European Environment Agency (2010) the transportation sector is one of the largest contributors of carbon gas in the world. To reduce the impact of this, it is necessary to electrify motorcycles (Ahmad et al, 2018). According to Al-Alawi and Bradley (2013) electric vehicles can improve vehicle performance and can reduce the negative impact that occurs on the environment. Presidential Regulation No. 55 of 2019 concerning the Acceleration of the Battery Electric Vehicle Program for Road Transportation can encourage the use of electric vehicles in Indonesia. Technological innovations in electric vehicles and batteries can provide transportation solutions that are environmentally friendly, energy efficient, and have low operating and maintenance costs (Sutopo, et al. 2013).

E-trike is a battery-powered three-wheeled motorcycle vehicle, which has several advantages such as being able to transport passengers and goods, being more flexible, and being environmentally friendly. With all its advantages, e-trike can meet the criteria as a substitute vehicle for rickshaws. To support this discourse, it is necessary to build infrastructure facilities such as service centers and charging centers in order to encourage smoothness and convenience for e-trike users in the future. Determining the location of the charging station is important so that it can reach all e-trike users. The problem of charging stations is quite complex because it not only provides convenience for electric vehicle users but also the presence of the electric vehicle (Li et al, 2014). The construction of charging stations is also a form of encouraging the promotion of the presence of electric vehicles (Zhao and Li, 2014).

1.1 Objectives
The purpose of this study is to evaluate the feasibility of charging station facilities and to develop and integrate a model for determining the location and allocation as a decision-making tool for the construction of charging station facilities. The model for determining the location and allocation proposed in this study is expected to be useful for e-trike users so that they can reach charging station facilities easily. The investment cost minimization model carried out in this study is expected to help the Solo City Government as a policy maker for planning the construction of charging station facilities. In general, the model developed in this study can be used to answer questions related to: Where is the location for the construction of the charging station facility? Is the charging station investment worth it?

2. Literature Review
Electric vehicles are vehicles that are predicted to be a means of transportation in the future. According to Plotz et al (2014) electric vehicles have the potential to reduce local and global emissions and are expected to become a sales market in the future. E-trike or E-Tricycles is a three-wheeled motorcycle using electric power. The use of e-trike is still rare in Indonesia and is still a new type of vehicle.

Electric vehicles need a supporting facility such as a charging station so that they can be used continuously. Charging stations can be placed in public facilities or in residential areas. There are two types of charging stations, namely AC type and DC type. The AC type is usually used for housing which includes normal charging, while the DC type is used in public facilities including fast charging. Types of charging electric vehicles can be divided into several types, namely slow charge, normal charge, fast charge, and ultra-fast charge. Table 1. shows the types of electric vehicle charging.

Table 1. Types of electric vehicle charging

	Slow Charger	Normal Charger	Fast Charger	Ultra-fast Charger
Output Power	≤ 5 kW	5 – 50 kW	50 – 150 kW	≥ 150 kW
Application	Private	Public, parking/rest area	Public, parking/rest area	Public, fast charging patterns like gas stations

The E-trike is planned to be used in Surakarta City with the Mall/market as the destination point, so that passengers who want to use the E-trike can go directly to these points. The mall/market was chosen as the point point because the operation process or supply movement of the E-trike is a public facility for the mall/market. Due to the movement of supply from the E-trike, charging station facilities must be provided at each of these points. Supply chain management is important in the business world because it will have an impact on the competitiveness of the company. Companies cannot compete if they only rely on optimizing internal structures and infrastructure in business strategies (Landeghem and Maele, 2002). Therefore, companies must manage the supply chain well in order to be competitive and unique in the business system (Haizer and Render, 2001). Supply chain is a network of companies that work together to create and deliver a product into the hands of end users (Pujawan, 2005). So that supply chain management is a tool, method, or management of a supply chain. Supply chain network design is the process of building and modeling a supply chain that aims to save time and costs associated with the distribution of an item. According to Pujawan et al (2010), supply chain network design is a strategic activity carried out in supply chain management including decisions on the location, number, and capacity of production and distribution facilities in a supply chain.

3. Methods

This research is divided into three stages, namely the initial stage, the model development stage, and the analysis and conclusion stage. At the initial stage, explaining the preliminary stage carried out, namely the study of the object of study and literature study related to e-trike technology and charging station facilities. At the model development stage, a description of the system is carried out by making an influence diagram which will then be carried out by developing a mixed-integer linear programming (MILP) model, then data processing is carried out using the LINGO 18.0 software. Furthermore, at the analysis and conclusion stage, the researcher analyzes the output results of the model that has been made and draws conclusions to answer the objectives of the research conducted.

4. Data Collection

There are several data used in this study, namely the number and location of markets and malls, fixed costs and variable costs, charging station investment costs, electricity selling prices, basic electricity tariffs, set up and charging times, and charging station operational times. Table 2. shows the location of traditional markets and malls in Solo city.

Table 2. The location of traditional markets and malls in Solo City

No	Markets Name	Location
1	Market Elphabes	Banjarsari
2	Market Sidomulyo	Banjarsari
3	Market Triwindu	Banjarsari
4	Market Nongko	Banjarsari
5	Market Ngumbul	Banjarsari
6	Market Ngarsopuro	Banjarsari
7	Market Legi	Banjarsari
8	Market Depok	Banjarsari
9	Market Bangunharjo	Banjarsari
10	Market Bambu	Banjarsari
11	Market Ayu Balapan	Banjarsari
12	Market Meubel	Banjarsari
13	Solo Paragon Mall	Banjarsari
14	Market Tunggul Sari	Market Kliwon
15	Market Sangkrah	Market Kliwon
16	Market Notoharjo	Market Kliwon
17	Market Kliwon	Market Kliwon
18	Market Joglo	Market Kliwon
19	Market Gading	Market Kliwon
20	Market Cinderamata	Market Kliwon
21	Market Besi Tua	Market Kliwon
22	Market Ayam	Market Kliwon
23	Market Sidodadi	Laweyan
24	Market Purwosari	Laweyan
25	Market Penumping	Laweyan
26	Market Kembang	Laweyan

27	Market Kadipolo	Laweyan
28	Market Kabangan	Laweyan
29	Market Jongke	Laweyan
30	Solo Square	Laweyan
31	Solo Grand Mall	Laweyan
32	Market Hariodaksino	Serengan
33	Market Singosaren	Serengan
34	Market Tanggul	Jebres
35	Market Rejosari	Jebres
36	Market Pucangsawit	Jebres
37	Market Panggungrejo	Jebres
38	Market Nusukan	Jebres
39	Market Ngudi Rejeki Gilingan	Jebres
40	Market Ngemplak	Jebres
41	Market Mojosongo	Jebres
42	Market Ledoksari	Jebres
43	Market Jurug	Jebres
44	Market Jebres	Jebres
45	Market Gede	Jebres

Then data related to operational time, basic electricity tariff, selling price, etc. can be seen in Table 3.

Table 3. The data set used

No	**Item**	**Value**
1	Charging station operational time per day	10 hours (07:00 – 17:00)
2	Basic electricity tariff (Q = 0,8)	Rp. 566 /kWh
3	Selling price	Rp. 1650 /kWh
4	Cost of building a level 3 charging station facility (multiple plugs)	Rp. 800.000.000.,
5	Discount rate	10%
6	Lifetime	20 years
7	Number of e-trikes	500 unit
8	Set up time	10 minutes
9	Charging time	30 minutes

4.1 Charging Station Investment in Traditional Market

To build a charging station facility in a traditional market, it is necessary to know the investment costs, fixed costs and variable costs which are shown in Table 4.

Table 4. Investment cost of CS in traditional market

Item	Total	Cost per unit	Investment Cost
Construction cost	6 m	Rp. 2.000.000.,	Rp. 12.000.000.,
CS fast charging	2 unit	Rp. 800.000.000.,	Rp. 1.600.000.000.,
Total			Rp. 1.612.000.000.,

Table 5. shows fixed costs in traditional markets which include maintenance costs, overhead costs, employee salaries, and land rental costs.

Table 5. Fixed cost in traditional market

No	Item	Cost/Year (Rp/Year)
1	Maintenance	Rp. 1.000.000,00
2	Overhead Cost	Rp. 1.000.000,00
3	Employee Salary	Rp. 24.000.000,00
4	Land Rental Costs 6m	Rp. 1.800.000,00
Total		Rp. 27.800.000,00

Next, Table 6 shows the variable costs in traditional markets which include energy costs and assuming it can serve as many as 60 e-trike units per day, the service capacity reaches 21,600 units per year, so that the power requirement in a year is 28,080 kWh.

Table 6. Variable cost in traditional market

No	Item	Cost/kWh (Rp/kWh)	Power/Unit (kWh/unit)	Amount of Vehicles (Unit)	Power Requirement (kWh/tahun)
1	Energy Cost	Rp. 566,00	1,3	21.600	28.080
Total					Rp. 15.893.280,00

4.2 Charging Station Investment in Mall

To build a charging station facility in a mall, it is necessary to know the investment costs, fixed costs and variable costs which are shown in the Table 7.

Table 7. Investment cost of CS in mall

Item	Total	Cost per unit	Investment Cost
Construction Cost	6 m	Rp. 2.000.000.,	Rp. 12.000.000.,
CS fast charging	2 unit	Rp. 800.000.000.,	Rp. 1.600.000.000.,
Total			Rp. 1.612.000.000.,

Table 8 shows the fixed costs at the mall which include maintenance costs, overhead costs, employee salaries, and land rental costs.

Table 8. Fixed cost in mall

No	Item	Cost/Year (Rp/Year)	
1	Maintenance	Rp	1.000.000,00
2	Overhead Cost	Rp	2.000.000,00
3	Employee Salary	Rp	24.000.000,00
4	Land Rental Costs 6m	Rp	6.000.000,00
Total		Rp	33.000.000,00

Table 9 shows the variable costs at the mall which include energy costs and assuming the mall's operational time for 12 hours can serve as many as 72 e-trike units per day, the service capacity reaches 25,920 units per year, so the power requirement in a year is of 33,696 kWh.

Table 9. Variable cost in mall

No	Item	Cost/kWh (Rp/kWh)	Power/Unit (kWh/unit)	Amount of Vehicles (Unit)	Power Requirement (kWh/tahun)
1	Energy Cost	Rp. 566,00	1,3	25.920	33.696
Total					Rp. 19.071.936,00

4.3 Mathematical Model

This paper aims to determine the charging station facility location-allocation by fixed and variable cost. The relevant symbols are defined as follows:

i : index for market sources
j : index for destination from market
$trans_{ij}$: distance between source i and location j
$dist_{ij}$: allocation from source i to location j
D_i : demand on location i
m : index for mall sources
n : index for destination from mall

$trans_{mn}$: distance between source *m* and location *n*
$dist_{mn}$: allocation from source *m* to location *n*
D_m : demand on location *m*
Q_i : transportation costs at sources *i*
H_m : transportation costs at sources *m*
ICMarket: charging station investment cost at the market
ICMall : charging station investment cost at the mall
Pmax : maximum number of locations to be built
Pmin : minimum number of locations to be built
KMarket: charging station capacity at the market
Kmall : charging station capacity at the mall
X_i : $\begin{cases} 1, & \text{if market location } i \text{ selected} \\ 0, & \text{otherwise} \end{cases}$
Y_m : $\begin{cases} 1, & \text{if mall location } j \text{ selected} \\ 0, & \text{otherwise} \end{cases}$
$dist_{ij}$: $\begin{cases} 1, & \text{if sources } i \text{ can be served at location } j \\ 0, & \text{otherwise} \end{cases}$
$dist_{mn}$: $\begin{cases} 1, & \text{if sources } m \text{ can be served at location } n \\ 0, & \text{otherwise} \end{cases}$

Then, the mathematical model of the problem, in this case, is as follows:

Minimize total cost = [investment costs in the market + fixed costs in the market + variable costs in the market + transportastion costs in the market] + [investment costs in the mall + fixed costs in the mall + variable costs in the mall + transportation costs in the mall]

$$Min\ Z = [\sum_{i\in I} ICPasar_i X_i + \sum_{i\epsilon I} FCPasar X_i + \sum_{i\epsilon I} VCpasar X_i + \sum_{i\in I}\sum_{j\in J} Q_i trans_{ij} dist_{ij}] + [\sum_{m\in M} ICMall_m Y_m + \sum_{m\epsilon M} FCMall Y_m + \sum_{m\epsilon M} VCpasar Y_m + \sum_{m\in M}\sum_{n\in N} H_m trans_{mn} dist_{mn}] \quad (1)$$

Subject to:

$\sum_i X_i + \sum_j Y_j \leq Pmax$	$\forall\, i \in I, \forall\, j \in J$	(2)
$\sum_i X_i + \sum_j Y_j \geq Pmin$	$\forall\, i \in I, \forall\, j \in J$	(3)
$\sum_j dist_{ij} \geq 1$	$\forall\, i \in I$	(4)
$\sum_m dist_{mn} \geq 1$	$\forall\, m \in N$	(5)
$\sum_i D_i dist_{ij} \leq \sum_i Kpasar X_i + \sum_j Kmall Y_j$	$\forall\, j \in J$	(6)
$\sum_i D_m dist_{mn} \leq \sum_i Kpasar X_i + \sum_j Kmall Y_j$	$\forall\, m \in M$	(7)
$X_i \in \{0,1\}$	$\forall\, i \in I$	(8)
$Y_j \in \{0,1\}$	$\forall\, j \in J$	(9)
$dist_{ij} \in \{0,1\}$	$\forall\, i \in I, \forall\, j \in J$	(10)
$dist_{mn} \in \{0,1\}$	$\forall\, m \in M, \forall\, n \in N$	(11)

Equation (1) shows the objective function of the total cost minimization problem. Equations (2) and (3) show that each location for charging stations to be built in markets and malls is no more or less than the P value. Equations (4) and (5) show that consumers can be served by at least one charging station facility. Equations (6) and (7) the number of requests served by the facility does not exceed the capacity of the charging station facility. Equations (8), (9), (10) and (11) indicate the binary number of the selected location or not.

5. Results and Discussion

Based on the model that has been made, data processing is carried out using LINGO software. Assuming an operational time of 10 hours for traditional markets and 12 hours for malls, 29 selected market locations and 1 mall location must be opened for the construction of charging station facilities from 42 candidate locations. For demand allocation in market locations with a market capacity of 21600 vehicles per year and a capacity in malls of 25920 vehicles per year and assuming there are 500 e-trike units in Surakarta City, each market location can be served by all selected facility locations. Then from each mall location can also be served by all selected facility locations. The selected location candidates can be seen in the Table 10.

Table 10. Results of data processing for charging station facilities

No	Market Name
1	Market Sangkrah
2	Market Notoharjo
3	Market Kliwon
4	Market Joglo
5	Market Gading
6	Market Cinderamata
7	Market Besi Tua
8	Market Ayam
9	Market Sidodadi
10	Market Purwosari
11	Market Penumping
12	Market Kembang
13	Market Kadipolo
14	Market Kabangan
15	Market Jongke
16	Market Hariodaksino
17	Market Singosaren
18	Market Tanggul
19	Market Rejosari
20	Market Pucangsawit
21	Market Panggungrejo
22	Market Nusukan
23	Market Ngudi Rejeki Gilingan
24	Market Ngemplak
25	Market Mojosongo
26	Market Ledoksari
27	Market Jurug
28	Market Jebres
29	Market Gede
30	Solo Paragon Mall

5.1 Numerical Results

To find out whether an investment in a tool or item is feasible, it is necessary to conduct an investment feasibility analysis by calculating the Return on Investment, Payback Period, Break Even Point, and Net Present Value. The following are the results of the calculation of the feasibility of investing in the Market location with the assumption that there is a 100% subsidy on land rental costs:

$$\text{ROI} = \frac{\text{Net Profit}}{\text{Total investment}} \text{ x } 100\%$$
$$= \frac{\text{Rp. } 4.438.720 \text{ x } 20 \text{ years}}{\text{Rp. } 1.612.000.000} \text{ x } 100\%$$
$$= 5{,}5\ \%$$

$$\text{PP} = \frac{\text{initial investment}}{\text{Cash flow}} \text{ x 1 tahun}$$
$$= \frac{\text{Rp. } 1.621.000.000}{\text{Rp. } 4.438.720 \text{ x } 20 \text{ years}} \text{ x 1 tahun}$$
$$= 18 \text{ years}$$

$$\text{BEP} = \frac{\text{Fixed costs per year}}{\text{Cost per kWh - Variable costs per kWh}}$$
$$= \frac{\text{Rp. } 27.800.000}{\text{Rp. } 1.650 \text{-Rp. } 566}$$
$$= 25.646 \text{ kWh} \approx 19.728 \text{ unit}$$

$$\text{NPV} = PW_{income} \text{-} PW_{outcome}$$
$$= A\left(\frac{P}{A},i,n\right) \text{-[}A\ \left(\frac{P}{A},i,n\right) +P]$$
$$= \text{Rp. } 46.332.000\ (8{,}514) - \text{Rp. } 41.893.280\ (8{,}514) + \text{Rp.} 1.612.000.000$$
$$= \text{Rp. } 1.649.791.262.$$

If policy makers want a faster return on investment, a subsidy from the government is needed for charging station equipment. With the same calculations as done, Table 11 lists the results. Furthermore, using the same formula and method, the investment calculations at the mall location is also carried out and the results are shown in Table 12.

Table 11. Comparison of ROI, PP, and NPV values with subsidies in the market

	Subsidy 0%	Subsidy 25%	Subsidy 50%	Subsidy 75%
ROI	5,5%	7,3%	10,9%	21,5%
PP	18 years	13,6 years	9,1 years	4,6 years
NPV	Rp. 1.649.791.262.	Rp. 1.249.791.262.	Rp. 849.791.262.	Rp. 449.791.262.

Table 12. Comparison of ROI, PP, and NPV values with subsidies in mall

	Subsidy 0%	Subsidy 25%	Subsidy 50%	Subsidy 75%
ROI	4,4%	5,8%	8,7%	17,1%
PP	22,8 years	17,1 years	11,5 years	5,8 years
NPV	Rp. 1.198.683.851.	Rp. 1.242.024.314	Rp. 842.024.314.	Rp. 442.024.314

5.2 Graphical Results

Furthermore, researchers can analyze the effect if the selling price increases on the value of ROI, NPV, and B/C ratio. The following is a graph of the effect of selling price on the value of ROI, NPV, and B/C ratio for traditional market locations.

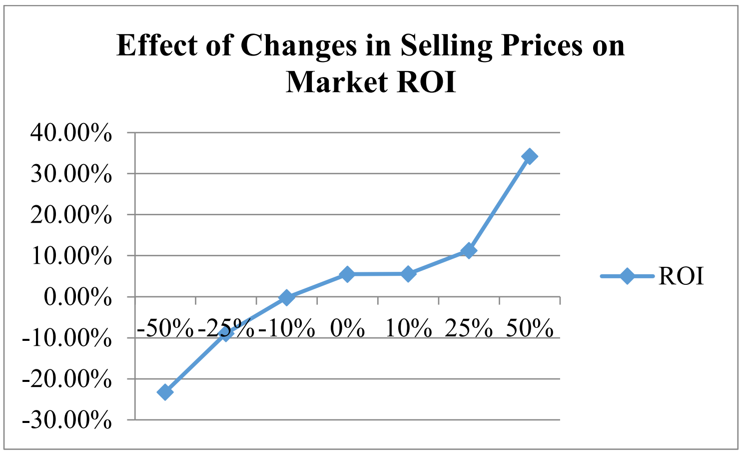

Figure 1. Graph of the effect of changes in selling prices on market ROI

Figure 1 shows a graph of the effect of changes in selling prices on market ROI.

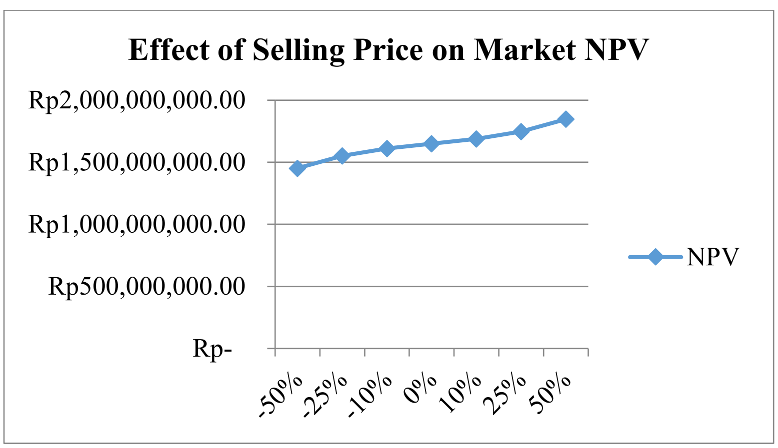

Figure 2. Graph of the effect of selling price on market NPV

Figure 2 shows a graph of the effect of selling price on market NPV. Furthermore, the graph of effect of selling price on B/C ratio market can be seen in Figure 3.

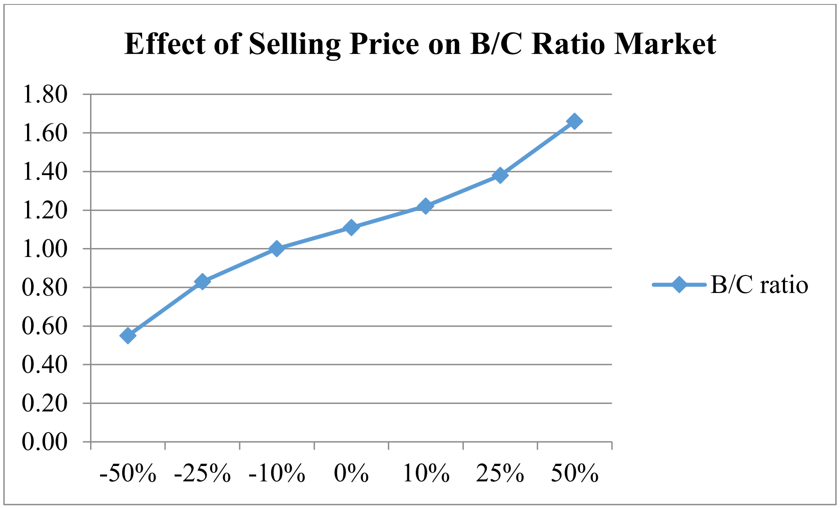

Figure 3. Graph of the effect of selling price on B/C ratio market

Furthermore, using the same method, an analysis related to ROI, NPV, and B/C ratio was also carried out for mall locations. The following is a graph of the effect of selling price on the value of ROI, NPV, and B/C ratio for mall locations.

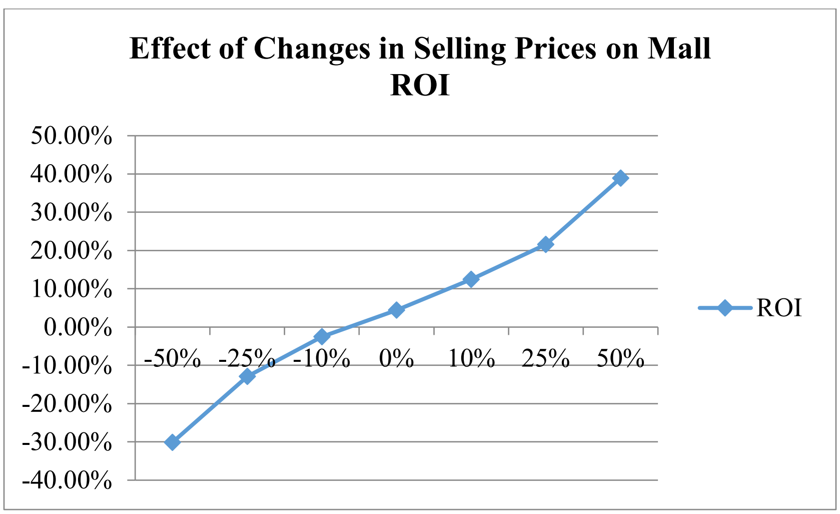

Figure 4. Graph of the effect of changes in selling prices on mall ROI

Figure 4 shows a graph of the effect of changes in selling prices on mall ROI. Figure 5 shows a graph of the effect of selling price on mall NPV. Furthermore, the graph of effect of selling price on B/C ratio mall can be seen in Figure 6.

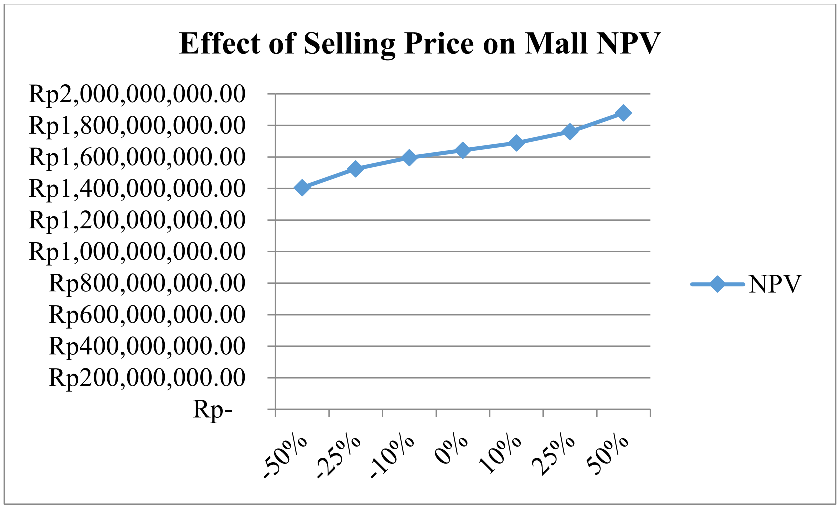

Figure 5. Graph of the effect of selling price on mall NPV

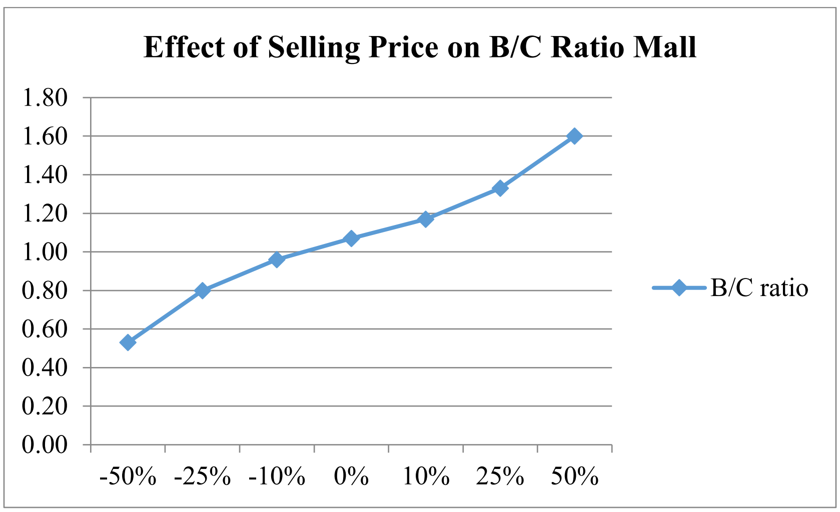

Figure 6. Graph of the Effect of Selling Price on B/C Ratio Mall

5.3 Proposed Improvements

This study has limitations of research time, so that the social aspects related to the behavior of the consumer needs to be studied further. This study only considers Markets and malls as candidate locations, further research needs to be done related to other public facilities to be used as location candidates.

6. Conclusions

Based on the calculation of the supply chain model of the charging station facility that has been carried out, conclusions can be drawn that can answer the objectives of this study, as follows: Based on the calculation of investment feasibility, if investors want to get a payback period of fewer than 10 years, then there is a minimum subsidy of 50% for charging stations for traditional markets and 75% for charging stations for malls. Furthermore, based on the calculations that have been made, 29 market locations and 1 mall have been selected as selected candidates.

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