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Allocation Optimization of An Electrical Vehicle Charging Station Using Ant Colony Algorithm

Sulistyo Prabowo Adhi Karno, Agus Ristono and Apriani Soepardi
Department of Industrial Engineering
Faculty of Industrial Engineering
Universitas Pembangunan Nasional Veteran, Yogyakarta, Indonesia
PT. Keramika Indonesia Assosiasi
Jakarta, Indonesia
apriani.soepardi@upnyk.ac.id

Abstract

Limited energy sourced from fossil fuels and world climate change is a challenge for energy security because the provision of adequate and affordable energy sources is imperative to support sustainable growth and development. In 2021, the largest energy consumption is in the transportation sector, which is or 33 percent of the total national energy consumption. World climate change and fluctuations in the cost of fossil energy make the demand for electric vehicles one of the alternative choices in driving with the reason to reduce carbon dioxide gas emissions. The purpose of this study is to develop a model based on ant colony algorithm to determine the number of charging stations and locate them that minimize total setup cost, namely the initial cost of developing and the total power capacity of prospective charging stations, index of active power reduction, reactive power loss reduction and voltage profile improvement, and the probability of electric vehicles arrivals using ant colony algorithms. Objective functions are founded from weighting of function elements by Analytical Network Process. The location of the study was carried out by applying a model to the real case, namely the Trans Java toll road section which is the longest and most populous toll road section in Java, stretching between Jakarta to Surabaya, with a road length of about 1200 KM and daily traffic density of 688,000 vehicles.

Keywords
AHP, Ant colony algorithm, Charging station, Electric vehicle, Location optimization

1. Introduction
The average population growth of 1.6% each year contributes to the increasing demand for energy, specifically for fossil fuels (Huang et al., 2021). Additionally, the use of these fuels, which significantly contributes to global climate change, presents certain challenges to energy resilience [Sheng 1]. This means there is a need to provide sufficient and affordable energy to support sustainable growth and development. Moreover, the transportation sector was reported to have consumed the highest volume of energy in 2021, accounting for 388.42 million barrels of oil equivalent (MBOe) or 33% of the total national energy consumption. The report further showed that fossil energy was ranked first with 27.8% of national energy consumption (MEMRRI, 2022).

The focus on global climate change and fluctuations in fossil energy costs was found to have increased the demand for electric vehicles (EV) as a choice to reduce carbon dioxide emissions (Parker et al., 2021). This is associated with the lower operational cost of electric vehicles compared to fossil fuel-powered cars (Zhu et al., 2021). The affordability is based on the development of lithium-ion battery technology, which has higher power and energy density in the range of 0.9-2.63 MJ/L compared to older battery types such as lead-acid batteries with 0.36 MJ/L.

The National Electricity Company (PLN), which is a stakeholder in the provision of electric vehicle infrastructure, is targeting the production of 16,000 units by 2025 and 65,000 units by 2030. This increasing number of electric vehicles requires the provision of more reliable charging stations with short charging times. Zeb et al. (2020) reported that this charging time usually ranges from 20 to 30 minutes per vehicle. This is further confirmed by the PLN data, that the rate at Public Electric Vehicle Charging Stations (SPKLU) is 30 minutes for fast and 15 minutes for very fast charging (MEMRRI, 2020).
The PLN data also shows that there are currently 21 SPKLU units along the Trans Java toll road. Meanwhile, according to The Central Statistics Agency (BPS) reported that the Jakarta-Cikampek toll road which spans 73 km is the busiest route on the Trans Java toll road because 138,365,987 vehicles passed through in 2020, averaging 688,020 vehicle per day. This potential imbalance between SPKLU facilities and the number of electric vehicles on this road poses risks to safety and driving comfort which are the essential parameters associated with the successful adoption of these vehicle as stated in the policy instruments.

The objective of this research to determine the optimal number and location of SPKLU along the Trans Java toll road by considering the initial development cost, total power capacity, active power reduction index, reactive power loss reduction index, voltage profile improvement index, and the probability of electric vehicle charging at SPKLU. In the proposed model, a probability factor, or the rate of arrival of electric vehicle users who will charge at charging stations is added. With this factor involved, the output of the model obtained not only the optimal location, but the number of charging stations can be determined. The use of ant colony algorithms in the proposed model is more beneficial than other *metaheuristic* approaches because the ant colony algorithm can be continuous in *real time,* so it is more suitable for determining the optimal route between vehicles and charging station locations. In addition, in determining the criteria for selecting the optimal SPKLU location, the use of ant colony algorithms in the proposed model will be integrated with the Analytical Network Process (ANP) approach which is a multi-criteria decision-making model that is relatively simple but can provide accurate criteria weighting results.

2. Literature Review

2.1 Research Position

Add research objectives here. Make All the research conducted by Pazouki et al. (2013), Su et al. (2013), Xiang et al. (2016), Zhu et al. (2016), Awasthi et al. (2017), Mohsenzadeh et al. (2018), Wang et al. (2018), Ren et al. (2019), Gupta et al. (2020), Lou and Qiu et al. (2020), and Reddy and Selvajyoithi (2020) were observed to have a common point which was the application of Genetic Algorithm (GA) methods. The method focused on using natural evolution to randomly determine SPKLU location through selection, crossover, and population transfer processes for electric vehicle users or to ensure the reliability of power support. However, the differences between this research were identified in the criteria and objective functions. The research was considered beneficial due to the easy application of the results to different electric vehicle user populations. Meanwhile, it was limited by the long time required for the convergence process to optimize SPKLU.

The limitation led to the application of mathematical models in the form of Ant Colony Optimization (ACO) and ANP algorithms to determine the optimal locations for SPKLU along the Trans Java toll road. The mathematical optimization model was used to measure the initial development cost, total power capacity, active power reduction index, reactive power loss reduction index, voltage profile improvement index, and pheromone or probability of electric vehicle charging at potential SPKLU. Moreover, the objective function to make decisions related to the optimal location was determined by initially weighing the elements of the function using the ANP. The novelty of this research was associated with the addition of the probability of electric vehicle charging at SPKLU as a criterion.

The ACO algorithm reported to have been developed is more advantageous than other metaheuristic methods due to its ability to operate continuously and in real-time (Colorni et al., 199) , making it suitable for determining the optimal routes between vehicle and SPKLU locations. The intensity of vehicle on the toll road was compared to pheromones and represented by τ to form an n x n matrix, where n is the number of points that can be a solution and applied in this research to represent the coordinate index on the map.

ANP is one of the methods normally used to solve Multi-Attribute Decision Making (MADM) problems (Saaty et al., 2013). It makes optimal decisions from interrelated factors or dependence and systematic feedback. The advantage of

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ANP compared to other methods is associated with its ability to assist decision-makers by measuring and synthesizing several factors or hierarchies in the network.

2.2 Electric Vehicle Policy in Indonesia

Leard and McConnell (2020) reported that electric vehicles could effectively reduce carbon dioxide emissions by up to 28% in 2030. This led to the implementation of electric vehicle policy instruments outlined in Government Regulation Number 74 of 2021 to reduce energy consumption in the transportation sector and carbon dioxide emissions affecting climate change. These policies provided some incentives to electric vehicle consumers such as a 0% Luxury Goods Sales Tax (PPnBM) and a 0% down payment with low-interest rates, supported by Bank Indonesia Regulation Number 22/13/PBI/2020. Electric vehicle manufacturers are also granted incentives, including tax holidays, mini-tax holidays, tax allowances, and customs duties covered by the government.

Presidential Regulation number 55 of 2019 on the Acceleration of Battery-Based Programs for Road Transportation also shows the commitment of the government to the development of an energy transportation system that inclines towards electric vehicles. This commitment originates from the adoption of new technologies in transportation energy in anticipation of the increasing demand for oil. According to Farid (2017), the primary effect of a mass transition from conventional road transportation to electric vehicle was the significant increase in the demand for electrical energy. Therefore, the regulation was made to cover incentives to produce SPKLU units, financing of the exportation, fiscal bonuses for research and development, parking rates, and electricity charging cost relief at SPKLU. Some others also include the support for SPKLU development financing, competency certification for battery-based electric vehicle human resources, as well as product certification and technical standards for battery-based electric vehicle industry companies. Moreover, the non-fiscal incentives suggested including exemption from certain road use restrictions, delegation of production rights for electric vehicle-related technology, and operational safety guidance for the industry sector. It is important to state that additional fiscal and non-fiscal incentives are also provided for nationally branded electric vehicle industries.

Standards have also been established for electric vehicle charging stations in Indonesia in addition to the Presidential Regulation 55/2019 and Minister of Energy and Mineral Resources Regulation 13/2020. This is observed from the SNI for electric vehicle charging stations covering plugs, sockets, vehicle connectors, and vehicle inlets.

The government policies and support proposed are expected to ensure the rapid development of electric vehicle in Indonesia. This means the sales and use of electric vehicle technology are projected to increase in the future. The data from the Ministry of Transportation on the number of vehicle type test registration certificates, as of March 9, 2023, showed the existence of 53,091 units of electric motor-based vehicles in the country. These include 40,312 electric two-wheeled vehicles, 12,395 electric passenger cars, 297 electric three-wheeled vehicles, 77 electric buses, and 10 electric cargo vehicles.

Charging facilities are one of the major infrastructures required to support electric vehicle and this led to the division of those designed for the public in Indonesia into three types including SPLU, SPKLU, and SPBKLU. Public Electric Charging Stations (SPLU) are designed mainly for electric motorcycles while SPKLU is specifically for electric cars with the capacity to perform both normal and fast charging. There is also a Public Electric Vehicle Battery Swapping Stations (SPBKLU) developed based on Regulation 13/2020 issued by the Ministry of Energy and Mineral Resources in 2020. The regulation covers electric charging infrastructure, electricity tariff for electric vehicle charging, and safety standards for electric charging infrastructure. Moreover, SPKLU is defined in Presidential Regulation number 55 of 2019 as a public facility designed for battery-based electric motor vehicle to obtain electric energy.

3. Model Development

This research focused on optimizing a mathematical model through the measurement of the initial development cost of potential SPKLU, total power capacity at potential SPKLU, active power reduction index, reactive power loss reduction index at potential SPKLU, voltage profile improvement index, and pheromone or probability of electric vehicle charging at potential SPKLU using the ant colony algorithm. The objective function was determined by initially weighing the elements of the function using the ANP to make decisions related to the determination of the optimal location to site SPKLU. The model was later developed into a program to facilitate the decision-making process for the stakeholders.

The research limitations associated with this research are stated as follows:

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a) The data collection and processing process is limited to type A rest areas along the Trans Java toll road.
b) The voltage and power of electric vehicle follow the Indonesian National Standard (SNI).
c) Only Battery Electric Vehicle (BEV) types are discussed.
d) The model development is limited to normal transportation situations on the Trans Java toll road with an electric vehicle capacity of 60 kWh.
e) The toll road density data for 2022 used in the research assumes that 50% of vehicle passing through the Trans Java toll road are electric.
f) The research object is the Trans Java toll road.
g) Optimization is viewed in terms of setup costs and elements that are inversely proportional and affect optimization. These include the total power capacity, active power reduction index, reactive power loss reduction index, voltage profile improvement index, and the probability of electric vehicle charging.

The model developed was applied to a real case, specifically, the Trans Java toll road which is the longest and busiest on Java Island spanning from Jakarta to Surabaya, with a length of approximately 1200 km and a daily traffic density (LHR) of 688,000 vehicle. SPKLU researched were Level 3 (fast charging) with an output current of 100 AC/250 DC, output power ≤ 50 kW as well as Level 4 (ultra-fast charging) with 300 AC/500 DC and ≤ 150 kW respectively. This research was used to enhance the existing model by incorporating the element of the probability of electric vehicle charging at SPKLU and the element of total power capacity. The proposed model is developed based on Awasthi (2017) model with differences is shown in Table 1.

Table 1. Differences between the Awasthi et al. (2017) and proposed model

Difference	Awasthi et.al (2017)	Proposed Model
Criteria	Setup cost, power capacity, power quality, and power reliability	Setup cost, power capacity, power quality, power reliability, probability of electric vehicle charging
System	Non-toll land transportation route	Toll land transportation route
Method	Hybrid GA and particle swarm algorithm	Integration of ant colony algorithm and ANP

The number of SPKLU required along the Trans Java toll road was determined by considering two different objective functions. These included the setup cost function which was inversely related to the power capacity function, power reliability function, and power quality function. This led to the development of a model in a multi-objective optimization system to determine the number of SPKLU with due consideration for the setup cost, total power capacity, active power reduction index, reactive power loss reduction index, profile improvement index, and probability of electric vehicle charging as the decision variables. Moreover, the determination of the optimal number of SPKLU using minimum setup cost while ensuring power capacity, power reliability, and power quality was also explored. The notations used in developing the model are shown as follow (Table 2).

Table 2. The notations used in developing the model

Notation	Meaning
TBI_i	= Total setup cost of SPKLU-i
BP	= Connector power value
Bk	= Connector development cost
Bi	= Installation cost
BL	= Land leasing cost
N_i	= Number of connectors at SPKLU-i
T^i_{cap}	= Total power capacity at SPKLU-i
$PLRIi$	= Active power reduction index of SPKLU-i
$PL_{(base)}$	= Active power lost before SPKLU connection
$PL_{(Csi)}$	= Active power lost after SPKLU connection
$QLRIi$	= Reactive power loss reduction index at SPKLU-i
$QL_{(base)}$	= Reactive power lost before SPKLU connection
$QL_{(CSI)}$	= Reactive power lost after SPKLU connection
$VPII$	= Voltage profile improvement index

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Pk(r,s)	=	Probability of ant k choosing to move from r to s
$\tau(r,s)$	=	Number of pheromones on the edge from node *r* to *s*
$\eta(r,s)$	=	(Length of the edge from node r to s) $^{-1}$
t(r,u)	=	Number of pheromones on the edge from node r to u
h(r,u)	=	(Length of the edge from node r to u)) $^{-1}$
Jk	=	Set of nodes visited by ant *k*
Ur	=	Node in Jk
α	=	Scale value
NC	=	Potential SPKLU to be built
CI	=	Consistency index
λ	=	Eigenvalue or weighting
λ_{Max}	=	Largest eigenvalue
N	=	Number of elements compared

The steps required to determine the number based on the variables are presented in the following algorithm:

Step 1: This is the initialization step which focuses on identifying the transportation system density data, electrical power network data supplying the rest areas for potential SPKLU, and the cost data required to determine setup cost.

Step 2: Calculate setup cost using the following formula:

$$TBI_i = Bi + (BL \times Ni) + Bp \times Bk \times (Ni - 1) \quad (1)$$

Step 3: Calculate the total capacity of potential SPKLU rest area

$$T^i_{cap} = Bp \times Ni \quad (2)$$

Step 4: Calculate the active power reduction index from the transmitter to SPKLU.

$$PLRI_i = \frac{P_{L(base)} - P_{L(CS_i)}}{P_{L(base)}} \quad (3)$$

Calculate the active power lost index before reaching SPKLU.

$$QLRI_i = \frac{Q_{L(base)} - Q_{L(CS_i)}}{Q_{L(base)}} \quad (4)$$

Calculate the reactive power loss reduction index at SPKLU-i.

$$VPII_i = \frac{1}{\alpha + \max_{i=2}^{n}\left(\left|1 - V_{(CS_i)}\right|\right)} \quad (5)$$

Step 5: Calculate additional elements such as the probability of electric vehicle charging at potential SPKLU using the ant colony method.

$$P_k(r,s) = \begin{cases} \frac{[\tau(r,s)]^{\alpha}.[\eta(r,s)]^{\beta}}{\sum_{u \epsilon J_k(r)}[\tau(r,u)]^{\alpha}.[\eta(r,u)]^{\beta}} & Jika\ s \ \epsilon\ J_k(r) \\ 0 & \end{cases} \quad (6)$$

The algorithm parameters include ant trail intensity, ant cycle constant, ant trail intensity control constant, visibility control constant, inter-location visibility, the number of ants, ant trail reinforcement constant, maximum cycle count, and place coordinate filling.

Step 6: Calculate the weight of elements (W) using the ANP method through the four stages of element determination, paired comparison determination, eigenvalue determination, and consistency ratio calculation.

Step 7: Calculate the value of the criteria function including the power capacity, power quality, power reliability, and the probability of electric vehicle charging at SPKLU using the weighting of elements derived from the ANP calculation.

$$Fi = \frac{1}{\text{W1 VPIIi} + \text{W2 PLRI i} + \text{W3 QLRI i)} + \text{W4 Pk (r, s)}} \quad (7)$$

Step 8: Calculate the value of the objective function by adding the setup cost to the sum of the weighted criteria functions, including power capacity, power quality, power reliability, and the probability of electric vehicle charging at SPKLU.

$$Fmin = \text{ICi} + \text{Fi} \quad (8)$$

with restrictions or constraints

$$Vi_{min} \leq V \leq Vi_{max} \quad (9a)$$

$$P_{min} \leq P \leq Pi_{max} \quad (9b)$$

Step 9: Select the minimum objective function i as the location for SPKLU due to its low setup cost, sufficient power capacity for SPKLU operation, good power quality for extended productive time, good power reliability, and a high probability of electric vehicle charging at SPKLU.

4. Data Collection

The initial step for using the ant colony algorithm is to initialize the parameters value of the algorithm, namely distance among origin/transit/destination places (Table 3), distance path A between main gate and SPKLU (Table 4), and distance path B between main gate and SPKLU (Table 5).

Table 3. Data initial SPKLU Type A

Rest Area (N)	Latitude	Origin (r)	Transit (u)	Destination (s)
KM 6B	-6.259226, 106.928093	Cikampek	Bekasi	Jakarta
KM 19A	-6,268818, 107,036162	Jakarta	Bekasi	Cikampek
KM 39A	-6.341240, 107.217067	Jakarta	Bekasi	Cikampek
KM 42B	-6.355542, 107.230103	Cikampek	Karawang	Jakarta
KM 57A	-6.367548, 107.360255	Jakarta	Karawang	Cikampek
KM 62B	-6.389455, 107.395271	Cikampek	Karawang	Jakarta
KM 86A	-6.471792,107.586042	Cikampek	Purwakarta	Palimanan
KM 101B	-6.509744, 107.718712	Palimanan	Subang	Cikampek
KM 102A	-6.507644, 107.722084	Cikampek	Subang	Palimanan
KM 165B	-6.706485, 108.225342	Palimanan	Majalengka	Cikampek
KM 166A	-6.713475, 108.242157	Cikampek	Majalengka	Palimanan
KM 207A	-6.775294, 108.562653	Kanci	Cirebon	Palimanan
KM 208B	-6.775300, 108.562650	Palimanan	Cirebon	Kanci
KM 228A	-6.881215, 108.703453	Kanci	Kuningan	Pejagan
KM 229B	-6.885057, 108.706757	Pejagan	Kuningan	Kanci
KM 282B	-6.943148, 109.172065	Pemalang	Tegal	Pejagan
KM 429A	-7.021505, 110.406654	Semarang	Ungaran	Solo
KM 519A	-7.480155, 110.919471	Solo	Karanganyar	Ngawi
KM 519B	-7.480790, 110.920991	Ngawi	Karanganyar	Solo
KM 575A	-7.408005, 111.381497	Solo	Ngawi	Ngawi
KM 575B	-7.410218, 111.381133	Ngawi	Ngawi	Solo
KM 626A	-7.546953, 111.757660	Ngawi	Madiun	Jombang
KM 626B	-7.548570, 111.757114	Jombang	Madiun	Ngawi
KM 725A	-7.378954,112.542078	Jombang	Gresik	Surabaya
KM 725B	-7.376676,112.551465	Surabaya	Gresik	Jombang

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Table 4. Initialization of distance Line A between main gate (GT) and SPKLU

	GT CWG	KM 19A	KM 39A	KM 57A	KM 86A	KM 102A	KM 166A	KM 207A	KM 228A	KM 429A	KM 519A	KM 575A	KM 626A	KM 725A	GT SBY
GT CWG	0	19	39	57	86	102	166	207	228	429	519	575	626	725	782
KM 19 A	19	0	20	38	67	83	147	188	209	410	500	556	607	706	763
KM 39A	39	20	0	18	28	44	127	168	189	390	461	536	568	686	743
KM 57A	57	38	18	0	29	45	109	150	171	372	462	518	569	668	725
KM 86A	86	67	28	29	0	16	80	121	142	343	433	489	540	639	696
KM 102A	102	83	44	45	16	0	64	105	126	327	417	473	524	623	680
KM 166A	166	147	127	109	80	64	0	41	62	263	353	409	460	559	616
KM 207 A	207	188	168	150	121	105	41	0	21	222	312	368	419	518	575
KM 228A	228	209	189	171	142	126	62	21	0	201	291	347	398	497	554
KM 429A	429	410	390	372	343	327	263	222	201	0	90	146	197	296	353
KM 519A	519	500	461	462	433	417	353	312	291	90	0	56	107	206	263
KM 575A	575	556	536	518	489	473	409	368	347	146	56	0	51	150	207
KM 626A	626	607	568	569	540	524	460	419	398	197	107	51	0	99	156
KM 725A	725	706	686	668	639	623	559	518	497	296	206	150	99	0	57
GT BY	782	763	743	725	696	680	616	575	554	353	263	207	156	57	0

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Table 5. Initialization of distance Line B between main gate (GT) and SPKLU

	GT SBY782		KM 725B	KM 626B	KM 575B	KM 519 B	KM 282B	KM 229B	KM 208B	KM 165B	KM 101B	KM 62B	KM 42 B	KM 6B	GT CWG
GT SBY KM782	0		57	156	297	263	500	553	574	617	681	720	740	776	782
KM 725 B	57		0	99	150	206	443	496	517	560	624	663	683	719	725
KM 626b	156		99	0	51	107	344	397	418	461	525	564	584	620	626
KM 575B	207		150	51	0	56	293	346	367	410	474	513	533	569	575
KM 519B	263		206	107	56	0	237	290	311	354	418	457	477	513	519
KM 282B	500		443	344	293	237	0	53	74	117	181	220	240	276	282
KM 229B	553		496	397	346	290	53	0	21	165	128	167	187	223	229
KM 208B	574		517	418	367	311	74	21	0	43	107	146	166	202	208
KM 165B	617		560	461	410	354	117	165	43	0	64	103	123	159	165
KM 101B	681		624	525	474	418	181	128	107	64	0	39	59	95	101
KM 62B	720		663	564	513	457	220	167	146	103	39	0	20	56	62
KM 42 B	740		683	584	533	477	240	187	166	123	59	20	0	36	42
KM 6B	776		719	620	569	513	276	223	202	159	95	56	36	0	6
GT CWG KM0	782		725	626	575	519	282	229	208	165	101	62	42	6	0

Other initialization data that must be provided are intercity visibility and distance invers Line A and Line B, ant-cycle constant (Table 6), setting of ant trace intensity control Line A (Table 7) and Line B, cycle iteration for Line A and B (Table 8). Tabulation for number of pheromones is shown in Table 9.

Table 6. Initialization of ant-cycle constant

No	Pheromone Cycle	Q (Unit per day)	L^k (Km)	Rest Area
1A	Ruas Jkt-Palimanan A	477,584	189	Km 19A, Km 39A, Km57A, Km 86A, Km 102A, Km166A
1B	Ruas Jkt- Palimanan B	477,584	189	Km 164B, Km 101B , Km 62B, Km 42B, Km6B
2A	Ruas Palimanan-Ngawi A	340,13	412	Km207A, Km228A, Km429A, Km519A, Km 575A
2B	Ruas Ngawi-Palimanan B	340,213	412	Km 575B, Km519B, Km282B, Km229B, Km208B
3A	Ruas Ngawi-Surabaya A	282,203	183	Km 626A, Km725A
3B	Ruas Surabaya-Ngawi B	282,203	183	Km 725B, Km 626B

Table 7. Initialization of ant trace intensity control for Line A

Rest Area (N)	Empirical Data for 2023 (Month/Date)							Average of traffic density	Parameter α
	8/28	8/29	8/30	8/31	9/1	9/2	9/3	Kpj	
KM 19A	23.3	25.3	28.5	24.8	30.0	33.5	40.7	29.4	3
KM 39A	37.1	39.0	40.3	37.7	43.3	49.8	52.0	42.7	2
KM 57A	48.2	56.1	55.2	50.3	65.8	59.0	61.1	56.5	2
KM 86A	62.6	68.6	60.0	53.3	48.0	42.4	57.6	56.1	2
KM 102A	40.9	42.9	48.6	45.0	52.9	47.4	50.0	46.8	2
KM 166A	81.7	85.5	88.1	98.9	92.5	81.7	82.9	87.3	1
KM 207A	63.7	70.9	66.4	78.0	69.3	61.2	72.6	68.9	2
KM 228A	42.0	46.7	44.2	52.5	49.4	60.0	56.0	50.1	2
KM 429A	68.5	70.8	74.2	76.8	75.0	77.8	84	75.3	2
KM 519A	44.5	53.1	49.3	51.1	60.0	55.2	62.7	53.7	2
KM 575A	41.0	44.3	43.2	45.6	42.4	41.7	43.9	43,2	2
KM 626A	80.6	78.3	88.2	82.9	85.5	72.3	74.2	80.3	1
KM 725A	76.0	83.4	87.7	85.5	83.4	92.4	95.0	86.2	1

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Table 8. Initialization of cycle iteration for Line B

Iteration #	**Path**
14	EV (ant) toll user on cycles#3B, charge at SPKLU rest area 725B Parameter α=2, β=2, ρ= 0.1, Q= 282.203 Unit/day, L^k= 59Km
15	EV (ant) toll user on cycles#3B, charge at SPKLU rest area 626B Parameter α=2, β=2, ρ= 0.1, Q= 282.203 Unit/day, L^k= 158Km
16	EV (ant)) toll user on cycles#2B, charge at SPKLU rest area 575B Parameter α=3, β=2, ρ= 0.1, Q= 340.213 Unit/day, L^k= 26Km
17	EV (ant) toll user on cycles#2B,, charge at SPKLU rest area 519B Parameter α=1, β=2, ρ= 0.1, Q= 340.213 Unit/day, L^k= 82Km
18	EV (ant) toll user on cycles#2B, charge at SPKLU rest area 282B. Parameter α=1, β=2, ρ= 0.1, Q= 340.213 Unit/day, L^k= 319Km
19	EV (ant) toll user on cycles#2B, charge at SPKLU rest area 229B Parameter α=2, β=2, ρ= 0.1, Q= 340.213 Unit/day, L^k= 372Km
20	EV (ant) toll user on cycles#2B, charge at SPKLU rest area 208B Parameter α=2, β=2, ρ= 0.1, Q= 340.213 Unit/day, L^k= 393Km
21	EV (ant) toll user on cycles#1B charge at SPKLU rest area 164B Parameter α=2, β=2, ρ= 0.1, Q= 477.584 Unit/day, L^k= 25Km
22	EV (ant) toll user on cycles#1B, charge at SPKLU rest area 101B Parameter α=1, β=2, ρ= 0.1, Q= 477.584 Unit/day, L^k= 88Km
23	EV (ant) toll user on cycles#1B, charge at SPKLU rest area 62B Parameter α=3, β=2, ρ= 0.1, Q= 477.584 Unit/day, L^k= 127Km
24	EV (ant) toll user on cycles#1B, charge at SPKLU rest area 42B Parameter α=3, β=2, ρ= 0.1, Q= 477.584 Unit/day, L^k= 147Km
25	EV (ant) toll user on cycles#1B, charge at SPKLU rest area 6B Parameter α=2, β=2, ρ= 0.1, Q= 477.584 Unit/day, L^k= 183Km

Table 9. Number of pheromones

Iteration #	Pheromone Level $\Delta \tau_{ij}^{k}(t) = \frac{Q}{L^{k}(t)}$	Pheromone Update $\tau_{ij}(t)=\tau_{ij}(t-1)+(\Delta\tau_{ij}^{k}(t)*\rho)$	Pheromone Evaporation $\tau_{ij}(t)=\tau_{ij}(t)*(1-\rho)$
1	25,136	2,13.7	2,262.3
2	12,246	1,224.7	1,102.2
3	8,379	838.0	754.2
4	5,553	555.4	499.8
5	4,682	468.3	421.5
6	2,877	287.8	259.0
7	18,901	1,890.2	1,701.2
8	8,723	872.4	785.2
9	1,418	141.9	127.7
10	1,031	103.2	92.9
11	881	88.2	79.4
12	11,328	1,132.9	1,019.6
13	2,230	223.1	200.8
14	4,783	478.4	430.6
15	1,786	178.7	160.8
16	13,085	1,308.6	1,177.8
17	4,149	415	373.5
18	1,066	106.7	96.0
19	915	91.6	82.4
20	866	86.7	78.0
21	19,103	1,910.4	1,719.4
22	5,427	542.8	488.5
23	3,761	376.2	338.6
24	3,249	325	292.5
25	2,610	261.1	235.0

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Ant colonies that have been distributed to the first city will begin to travel from the first city (origin) and one of the other cities as the destination city. To determine the destination city is used the probability of the city will be visited as follows.

$$p_{ij}^{k}(t)=\frac{\left[\tau_{ij}(t)\right]^{\alpha}\cdot\left[\eta_{ij}\right]^{\beta}}{\sum_{k}\left[\tau_{ij}(t)\right]^{\alpha}\cdot\left[\eta_{ij}\right]^{\beta}}$$

5. Results and Discussion

Recently, the number of SPKLU is 21 units. Meanwhile, the optimal number of SPKLU proposed is 25 units. The criteria used for optimal location determination are total setup cost (connector power value, connector development cost, installation cost, and land leasing cost), and index of active power reduction, reactive power loss reduction, and voltage profile improvement at every SPKLU. Table 10 shows the suitability of potential SPKLU location.

Table 10. SPKLU location optimal

Order	Value of objection function (minimization)	Rest Area	Latitude
#1	1.6878	KM 575B	-7.410218, 111.381133
#2	1.6881	KM 19A	-6,268818, 107,036162
#3	1.6886	KM 626A	-7.546953, 111.757660
#4	1.6905	KM 725B	-7.376676, 112.551465
#5	1.7298	KM 102A	-6.507644, 107.722084
#6	1.7399	KM 207A	-6.775294, 108.562653
#7	1.7855	KM 164B	-6.706485, 108.225342
#8	1.8198	KM 62B	-6.389455, 107.395271
#9	1.8642	KM 42B	-6.355542, 107.230103
#10	1.8889	KM 282B	-6.943148, 109.172065
#11	1.8898	KM 208B	-6.775300, 108.562650
#12	1.8902	KM 228B	-6.881215, 108.703453
#13	1.9163	KM 6B	-6.259226, 106.928093
#14	1.9387	KM 626B	-7.548570, 111.757114
#15	1.9435	KM 725A	-7.378954,112.542078
#16	1.9466	KM 519B	-7.480790, 110.920991
#17	1.9466	KM 519A	-7.480155, 110.919471
#18	1.9470	KM 39A	-6.341240, 107.217067
#19	1.9478	KM 575A	-7.408005, 111.381497
#20	1.9491	KM 101B	-6.509744, 107.718712
#21	1.9512	KM 429A	-7.021505, 110.406654
#22	1.9815	KM 86A	-6.471792,107.586042
#23	1.9840	KM 166A	-6.713475, 108.242157
#24	2.2564	KM 57A	-6.367548, 107.360255
#25	2.2701	KM 228A	-6.881215, 108.703453

6. Conclusion

In this study, we proposed a model based on ant colony algorithm to determine the number of charging stations and locate them that minimize total setup cost. The research benefits are to create a decision support system to assist decision-makers in making informed decisions on the determination of the optimal number of SPKLU needed as well as to ensure electric vehicle drivers experience safety and comfort, specifically along the Trans Java toll road. it is necessary to add a social cost component to make it more accurate.

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Biographies
Sulistyo Prabowo AK is a head of Production Planning and Inventory Control Division at PT Keramika Indonesia Association (KIA). It was the main producer of ceramics in Indonesia, starting in 1968. Mr. Prabowo holds a Bachelor of Science degree in Industrial Engineering. Nowadays, he is a master's student in Industrial and Management Engineering at Universitas Pembangunan Nasional Veteran, Yogyakarta, Indonesia.

Apriani Soepardi is an Associate Professor in Industrial Engineering Department at the Universitas Pembangunan Nasional Veteran, Yogyakarta, Indonesia. She earned a Doctoral Program in Mechanical Engineering. In 2017, Mrs. Soepardi was a Sandwich-Doctoral Program student in the Department of Management and Engineering, Division of Energy Systems, Linköping University, Sweden. She has published journals and conference papers. Her research areas include industrial energy efficiency, agile and sustainable manufacturing, and system modelling.

Agus Ristono is a senior lecturer in Industrial Engineering Department at Universitas Pembangunan Nasional Veteran, Yogyakarta, Indonesia. He earned a Doctoral Program in Mechanical Engineering from Universitas Brawijaya, Indonesia. He has published many books, journals, and conference papers. His research areas include supply chain modeling, optimization, and decision-making analysis.

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