FINAL PROJECT – TI 184833

PROPORTION OPTIMIZATION OF DIGITAL AND CONVENTIONAL PARKING WITH MULTIMODAL CONSIDERATION (CASE STUDY: KABUPATEN SIDOARJO)

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APPROVAL SHEET

PROPORTION OPTIMIZATION OF DIGITAL AND CONVENTIONAL PARKING WITH MULTIMODAL CONSIDERATION (CASE STUDY: KABUPATEN SIDOARJO)

FINAL PROJECT

Submitted to Acquire the Requirement of Bachelor Degree at Undergraduate Program Industrial and System Engineering
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PROPORTION OPTIMIZATION OF DIGITAL AND CONVENTIONAL PARKING WITH MULTIMODAL CONSIDERATION (CASE STUDY: KABUPATEN SIDOARJO)

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ABSTRACT

The government of Sidoarjo introduced a subscription parking policy to improve the service level of parking, but the execution did not run as expected. Community feedback found that illegal levy still existed. This action resulting in the actual revenue from parking in 2018, is only 27.5% of the total potential revenue. To overcome this problem, the government of Sidoarjo collaborates with third parties in developing a digital parking application. A study by ITS Tekno Sains (2019) analyzed that the program is financially feasible. However, the study used an assumption of 100% digital parking that is unrealistic considering the customer's preference and the theory of adopting an innovation. This research will determine the optimal proportion of digital and conventional parking. It considers the factors that influence the parking demand to achieve maximum profit and optimized using an integer programming model. This research uses parameters based on the demand forecasting model, and the sensitivity analysis found that service level has the most significant impact on parking demand, resulting in more profit. The parameters are grouped into two coefficients to simplify the modeling. These coefficients are combined with the decision variables (parking lot) and other parameters to obtain revenue. The objective function subtracts total cost from revenue to obtain profit maximization. The best solution found for Gajah Mada street is an annual profit of Rp670,225,200, with average offline proportion for car and motorcycle is 25.06% and 22.68% respectively.

Keywords: on-street parking, digital parking, parking demand forecasting, integer programming.

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The author realizes that there still many possibilities to explore this research further. The author hopes that this research may provide new insight, recommendations, and benefits regarding the topic discussed.

Surabaya, August 2020

Betalia Febianita

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CHAPTER 1
INTRODUCTION

This chapter will explain the background of research, problem formulation, research objectives, benefits, scopes, and research outline.

1.1 Background

Increasing transportation needs are unbearable when the number of populations grows. As more people need to mobilize to places, they will require a transportation mode. This phenomenon also happens in one of the regencies in East Java, which is Sidoarjo. According to recent data from Badan Pusat Statistik Kabupaten Sidoarjo (2019), among other regencies in East Java, Sidoarjo is the most densely populated region with 3,104 people for every square kilometer. The number of populations in Sidoarjo reaches 2.2 million in 2018, increasing by 1.17% compared to the previous year.

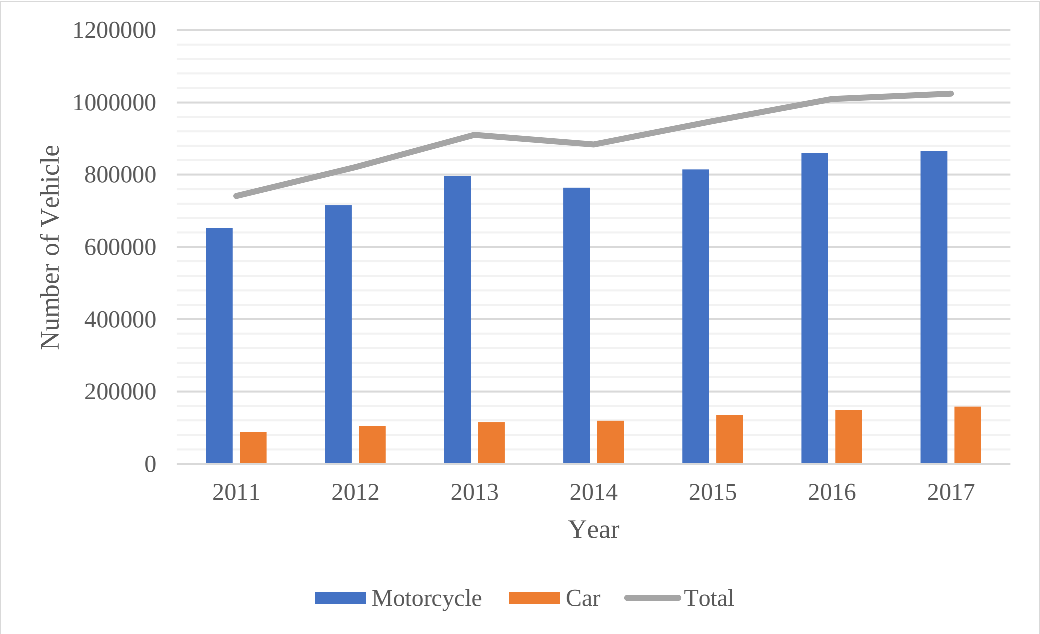

Figure 1.1: Number of Motorcycle and Car in Sidoarjo

Along with the population, the number of motorcycle and car in Sidoarjo also shows an increasing trend. The data from Dinas Perhubungan Kabupaten Sidoarjo, as cited in PT. Wukir Mahendra Sakti (2018) rearranged and shown in figure 1.1. As seen in figure 1.1, the total amount in 2017 surpasses 1 million units. This fact makes Sidoarjo become the third region in East Java in terms of the highest vehicle quantity after Surabaya and Malang.

According to Yulong He *et al.* (2015), in any urban transportation system, the parking service has an essential role in the system. The statement also applies in Sidoarjo as it had numerous amounts of vehicles in the city that needs to be organized in such a way. The Government of Sidoarjo Regency develops parking service as a meant to support the community to ease transportation and smoothen businesses. The payment process of parking service is regulated in *Peraturan Daerah Kabupaten Sidoarjo Nomor 2 Tahun 2012* about parking management in Sidoarjo. The regulation mentions 'subscription parking' as a payment method implemented in Sidoarjo, where drivers or vehicle users paid parking retribution as a subscription with a designated parking place. The subscription system is a promising policy since the number of vehicles in Sidoarjo keeps increasing by the year, as shown previously in figure 1.1. Although the concept seems convincing, the execution evokes public complaints. Emir Firdaus, as the Vice-Chairman of DPRD Sidoarjo, in Mam, Atep, and Lim (2019), stated that the program receives many complaints from the public, mainly when parking officers still collect parking fees in a subscription parking area, that later be considered as an illegal levy.

If seen individually, the illegal levy might only look like a small amount of money, but the real data implies another way. Sidoarjo has a high potential of Pendapatan Asli Daerah (PAD) through the parking retribution in several crowded areas, including GOR Delta, Gajahmada Street, and large markets. According to PT. Wukir Mahendra Sakti (2018), in 2018, the actual income from parking retribution is Rp28,176,793,500, only 27.5% from the potential that reaches Rp102,147,595,652. Nur Ahmad Syaifuddin, Vice-Regent of Sidoarjo, in Manna (2020) stated that up to this point, the government receives no income from parking and will give strict prosecution to parties that take advantages from this situation. According to Bahrul Amiq, Head of Dinas Perhubungan Sidoarjo, in Manna (2020), starting from June 2019, the subscription parking has been stopped. Since then, the government instructed not to take any parking fee, but thoughtless parties take this as an opportunity to obtain illegal collection. To overcome this problem, the local government collaborates with a third-party provider to implement an online parking system in Sidoarjo.

The local government of Sidoarjo believes that the public characters have developed as the internet reaches many people. Based on a survey conducted by APJII (2019), 64.8% of the total population in Indonesia and, more specifically, 58.9% of people in East Java have access to the internet. This fact becomes the underlying reason behind the choice of an online system as the new parking service platform. The digital parking is a pilot project, and according to Saiful Ilah, Regent of Sidoarjo, in Sigit (2019), the *E-Parkir* is expected to run in 2020. Saiful Ilah also stated that the project is an improvement from the subscription parking that previously implemented in Sidoarjo. By implementing the system, the government expected that citizens of Sidoarjo could have easier access to the parking facility provided, without having to worry about the illegal collection. Besides improving parking service level to the community, the online parking system has three other goals, which are to reduce the risk of parking retribution leakage, as the main issue mentioned previously, reduce the congestion level in Sidoarjo. The project also becomes a manifestation of regional innovation.

The main benefit of implementing online parking for the government is to improve income from parking retribution. At the same time, the community also benefited from this, as they can have better parking service experience. In Indonesia, e-parking has been implemented in several regions. According to Astuti, Dewi, and Julianto (2019), in Tabanan, Bali, the information system in e-parking has run smoothly. E-parking system in the research uses *Terminal Parkir Elektronik* (TPE) to record payment of parking transactions. The successful execution made the parking income can be deposited directly to regional cash. The e-parking system that ran since July 2018 surpasses the targeted income made by *Dinas Perhubungan Kabupaten Tabanan*, an average of 116% from July to December 2018. However, different outcome happened in Bandung. Based on Suherman (2020), the execution of electronic parking in the city is still not optimal, from usage of parking machine, manual payment system, to the income realization that far below the target of Bandung regional revenue. Other regions, such as DKI Jakarta and Surakarta, are currently developing their e-parking system. According to Henry Satya, as the Head of Parking in *Dinas Perhubungan Kota Surakarta* in Perdana (2019), the e-parking implementation will be expanded to seven new spots with the more sophisticated e-parking device. Meanwhile, DKI Jakarta planned to shift from parking meter to e-parking technology. Aji Kusambarto from *Dinas Perhubungan DKI Jakarta*, as cited in Pambudhy (2020), stated that they would replace 214 parking meter machines with e-parking because it is not functioning correctly. Implementation of e-parking in different regions resulted in a different outcome. However, this implies that e-parking is a potential solution to solve problem in parking, especially the unclear revenue flow and leakage. The previous research in Tabanan by Astuti, Dewi and Julianto (2019) proved that if executed properly, e-parking can solve the revenue problem. Therefore, it is recommended to conduct a study to analyze if the program is suitable or not to be applied in Sidoarjo, also research on how to execute the program correctly.

Table 1.1 Results of Financial Feasibility Study

Financial Feasibility Aspect	Value
Break-Even Point (BEP)	2% from maximum capacity
Return on Investment (ROI)*	9228%
Internal Rate of Return (IRR)*	9248%

**investment for parking lots not included as the local government owns it*

Source: ITS Tekno Sains (2019)

To determine whether the project is suitable or not to be applied in Sidoarjo, a feasibility study has been conducted. The study done by ITS Tekno Sains (2019) analyzes the human factor feasibility, system & technology feasibility, and economic feasibility of the online parking system. Through careful calculation using economics analysis instruments, the result of the study shows that the e-parking application in Sidoarjo is financially feasible and will increase the regional income from parking retribution. The complete result for the financial feasibility can be seen in table 1.1.

In the previous study of ITS Tekno Sains (2019), it assumes that the project is implemented in an ideal condition where all the parking areas use an online parking system or 100% is online parking. Using this assumption, the government can maximize the contribution to local income because all the transactions are cashless, reducing the chance of illegal collection that usually happens in offline or conventional parking. However, on the other side, not all customers are convenient in using the e-parking application. The study shows that the proportion of parking users that agree to use online parking is 59.3%, 28.5% disagree to use online parking, and the remaining 12.2% are hesitant. It infers that there is a probability of potential parking users that change their decision and cancel their intention to park in the area because of the system implemented (offline or online), thus also canceling the potential income from parking retribution.

Implementing innovation, such as the digital parking, simultaneously is not preferable. Based on LaMorte (2016), adoption of a new idea, behavior, or product (innovation) does not happen simultaneously; it is a process where some people can adapt faster to the innovation than others. Therefore, the conventional (offline) parking will still be retained. The government of Solo also implemented a similar thing. According to Perdana (2019), the cash payment is still accepted as the community is still adapting to the new system. Thus, it is recommended that the conventional way with cash payment will still be accepted until the community has fully adapted to the new method of parking.

The parking retribution can increase when the demand for parking is high, and if it is appropriately managed. As a simple illustration, when more vehicles can park in the designated parking lot, the income from parking will also become high. Demand is a need for something to be sold or supplied (Cambridge Dictionary, 2020a), or in the parking context, is a need for parking lot or space. Researchers have been studying factors or parameters that affect parking demand for parking demand forecasting purposes. The majority of the researches considers parking facility characteristics as studied by Ajeng and Gim (2018). In this research, the proper model of parking demand forecasting that best fits the condition in the object, and the goals that want to be achieved will be determined.

After knowing the parameters that affect parking demand, it will be considered for determining the proportion of online and offline parking. The proportion is required as it determines the limit of the maximum number of allowable parking slots for both car and motorcycle that still use the offline system. Limiting the offline slots is necessary as the goal of the project is to eliminate or at least minimize the illegal collection that expected to increase the contribution to local income.

A branch from operations research will be used to come up with an optimal number of the proportion that satisfies the conditions. Linear programming is a widely used mathematical technique used to help planning and decision making relative to resource allocations. According to Mahto (2012), linear programming is a mathematical method to determine a way to obtain the best outcome using mathematical models under some linear requirements. In conditions when one or more of the variables required to be an integer, such as in this research, integer programming should be used. Integer programming problem is linear programming in which some or all of the variables must be a non-negative integer (Winston, 2004). The demand forecasting model mentioned previously will link the decision variable with the expected output or objective function, which is demand maximization. In this research, the demand forecasting model will refer to the modified parking generation rate model developed by Cheng, Tai, and Ma (2012) that can provide a relation between parking lot proportion and parking demand. The decision variable is the number of the parking lot for both car and motorcycle, allocated either for online or offline parking. After constructing the mathematical model, the model will be solved using LINGO. LINGO is chosen as it can merely solve linear programming problems, including the integer programming problems.

1.2 Problem Formulation

Based on the existing condition described in the background, this research will solve the problem in determining the limit of offline (conventional) parking lots proportion. The scope includes both parking lots for motorcycles and cars in the most utilized on-street parking facility in Sidoarjo. This research will consider the parameters affecting the demand for online and offline parking system, with known parking fee. To obtain optimal proportion that satisfies the objective of obtaining maximum profit, a branch of linear programming – integer programming

– will be used. Along with that, a demand forecasting model links the decision variable and objective function.

1.3 Objectives

This research wants to achieve these objectives:

1. To calculate the parameters (parking generation rate, utilization rate, growth factor of vehicle, and operational cost) and analyze the assumed parameters that affect the demand for online and offline parking.
2. To convert the result of parameters into coefficients that could define the relationship with local income.
3. To construct the mathematical model for determining the proportion of online and offline parking lots.
4. To solve the optimization model and obtain the optimal proportion of online and offline parking lots.

1.4 Benefits

By doing this research, several benefits expected are:

1. The government of Sidoarjo can minimize the illegal levy and increase contribution to local income from parking retribution.
2. Citizens of Sidoarjo can experience better parking service.
3. Better on-street parking management can reduce the congestion level in Sidoarjo.

1.5 Scope

To ensure the research is focused on clear scope, there are several limitations and assumptions implemented and will be described below.

1.5.1 Limitations

The limitation used in this research are as follows:

1. The research only observes the on-street parking facility in Gajah Mada street.
2. The research uses secondary data from surveys conducted between 2018 to 2019.

1.5.2 Assumptions

The assumptions used in this research are as follows:

1. There is no change in the pricing of the parking system.
2. There is no change in parking management in Sidoarjo within the research time horizon.
3. The demand and parking duration are assumed to be deterministic.
4. The value of *Koefisien Lantai Bangunan* (KLB) is 1.2, based on *Peraturan Daerah Kabupaten Sidoarjo no. 1 tahun 2019* (Bupati Sidoarjo, 2019a).

1.6 Research Outline

This research report will be written in six chapters. The outline of the report is explained below.

CHAPTER 1 INTRODUCTION

This chapter explains the background of doing research, problem formulations based on the background, research objectives that want to be achieved, expected benefits from the research, scope of research consisting of limitations and assumptions, also the report outline that explains the overview of each chapter in this research.

CHAPTER 2 LITERATURE REVIEW

This chapter will explain the literature review done by the author as a basis for conducting the research. The literature may include books, journal articles, or other reliable resources used as a reference during the research. The topics discussed in this chapter include the parking system, deterministic and stochastic system, demand forecasting model, linear programming, and previous related research summarized in the research position.

CHAPTER 3 RESEARCH METHODOLOGY

This chapter will describe the systematic steps done to conduct the research. The steps covered in this chapter are those processes conducted after the research problem has been clearly defined. The methodology consists of three main stages, which are the stage of data preparation, model building and running, and analysis and conclusion. The chapter will also provide a brief explanation of each step.

CHAPTER 4 MODEL BUILDING AND DATA COLLECTION

This chapter is divided into two main sections, which are optimization model building and data collection. The optimization model building is divided into a demand forecasting model and an integer programming model. While in the data collection, the data collected from various sources will be shown.

CHAPTER 5 DATA PROCESSING AND MODEL RUNNING

In this chapter, the data collected will be processed using several approaches. The first stage is processing the survey data to obtain the parameter's value. Then, the LINGO model is generated and ran to determine the optimal offline parking slots. The LINGO model will also be verified in this chapter.

CHAPTER 6 ANALYSIS AND INTERPRETATION

This chapter will elaborate on the results of optimal online and offline parking slots and provide analysis regarding the results. This chapter will also explain the sensitivity analysis for assumed parameters.

CHAPTER 7 CONCLUSION AND RECOMMENDATION

In this chapter, the conclusions for each objective will be explained, and recommendations will be given for future research.

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CHAPTER 2
LITERATURE REVIEW

This chapter will explain the literature review used in this research, including a brief explanation of the parking system, data pre-processing, and integer linear programming.

2.1 Parking System

Based on DPR RI (2009), parking is a condition when vehicles stop or not moving for a particular moment and left by the driver. Parking is an essential component of the transportation system (Litman, 2006). As a regency that has a growing number of vehicles annually, Sidoarjo also considers parking as a critical component of its transportation system. Parking retribution also contributes a

According to Ajeng and Gim (2018), several parking characteristics can be used to evaluate on-street parking service; one of them is parking demand that will be discussed further. Besides parking demand, there are also other topics to be discussed in this subchapter, including on-street and off-street parking, also conventional and digital parking in Sidoarjo.

2.1.1 Parking Demand

Cambridge Dictionary (2020a) defines demand as a need for goods or services that customers want to buy or use. In this research context, the demand is associated with the need for a parking lot. Another perspective comes from the study by Ajeng and Gim (2018), parking demand is the maximum number of vehicles that parked at the same time on the segment. According to Hui (2012), the inability to match the supply of parking stalls with parking demand can lead to parking problems or static traffic problems. To solve the parking problem, an accurate parking demand forecast, construction of parking facilities, reasonable, controlled parking demand, and a balance between supply and demand is required. This research will focus on the parking demand forecast.

2.1.2 Off-street and on-street Parking

As in other regional, Sidoarjo also implements two types of parking, which are off-street and on-street parking. Off-street parking is when spaces of cars located on private property rather than on a public street (Collins Dictionary, no date a). Off-street parking is usually independently organized by the property owner. According to Ajeng and Gim (2018), as demand for parking spaces increases and lack of off-street parking lots, most vehicles were parked on the street. This situation makes on-street parking becomes overloaded; it also reduced traffic safety (traffic congestion), air quality, and could harm the economic potential of the city. They are making it essential to have proper management of on-street parking.

On-street parking is parking (of a car, vehicle, et cetera.) that is or is allowed to be done on the street (Collins Dictionary, no date b). On-street parking is commonly organized directly by the government and becomes one form of retribution to the local income.

2.1.3 Conventional Parking in Sidoarjo

Conventional or offline parking is the condition where users can access the parking facility without using the mobile application. The detailed mechanism for offline procedures is still under discussion, to consider the threshold of ‘offline’ activities. According to *Perda 17 Tahun 2009* about the parking system by Bupati Sidoarjo (2019), the regular parking fee applied for on-street parking in Sidoarjo is shown in Table 2.1. All parking fees are in a flat system, meaning that the duration of parking does not affect the fee incurred to the users.

Table 2.1 Normal Parking Fee for On-street Parking in Sidoarjo

No.	Type of Vehicle	Parking Fee
1	Motorcycle	Rp 2,000 (flat)
2	Car (sedan, minibus, and it is kind)	Rp 4,000 (flat)

Source: Bupati Sidoarjo (2019)

2.1.4 Digital Parking in Sidoarjo

Digital parking is proposed by Dinas Perhubungan, as a representative of the local government, to reduce the likelihood of illegal levies, thus maximizing the local income potential from parking. The main idea is to make all transactions cashless through a mobile application. Currently, the program is still a pilot project, and according to Sigit (2019), it is planned to launch in 2020. The mobile application is a collaboration work between Dinas Perhubungan, PT. ITS Tekno Sains (to give more insight from academic's point of view), and PT. SPON Tech Indonesia (as the application developer).

Figure 2.1: Process Flow of Digital Parking

Ideally, all transactions should be done through the application. However, based on the study conducted by ITS Tekno Sains (2019), an estimation of 60 to 70 percent of the population in Sidoarjo agreed to use digital parking, leaving the rest requires specific allowance for the conventional method. The digital parking system in which all parking-related activities, including check-in, payment, and check-out is conducted through the app is the online system. The process illustration of digital parking is shown in Figure 2.1. The process begins with users look for nearby parking spaces that still have remaining parking spaces. After choosing the destination, the application will guide the user to take a specific route. Then, before the entrance, the user will scan the QR code provided by the parking officer. The process enables the user to enter the parking facility and create a timestamp for the entrance time. Then, the user parks their vehicle in a specific place directed by the application. The system will automatically mark the place as occupied. Therefore, no other user can occupy the same parking lot, and it will decrease the number of available parking spaces on the database. If a user has finished parking, they will pay the parking fee using an in-app digital wallet, then leaving the system. On the contrary, if one of the processes mentioned previously done outside the application, is named as the conventional or offline system.

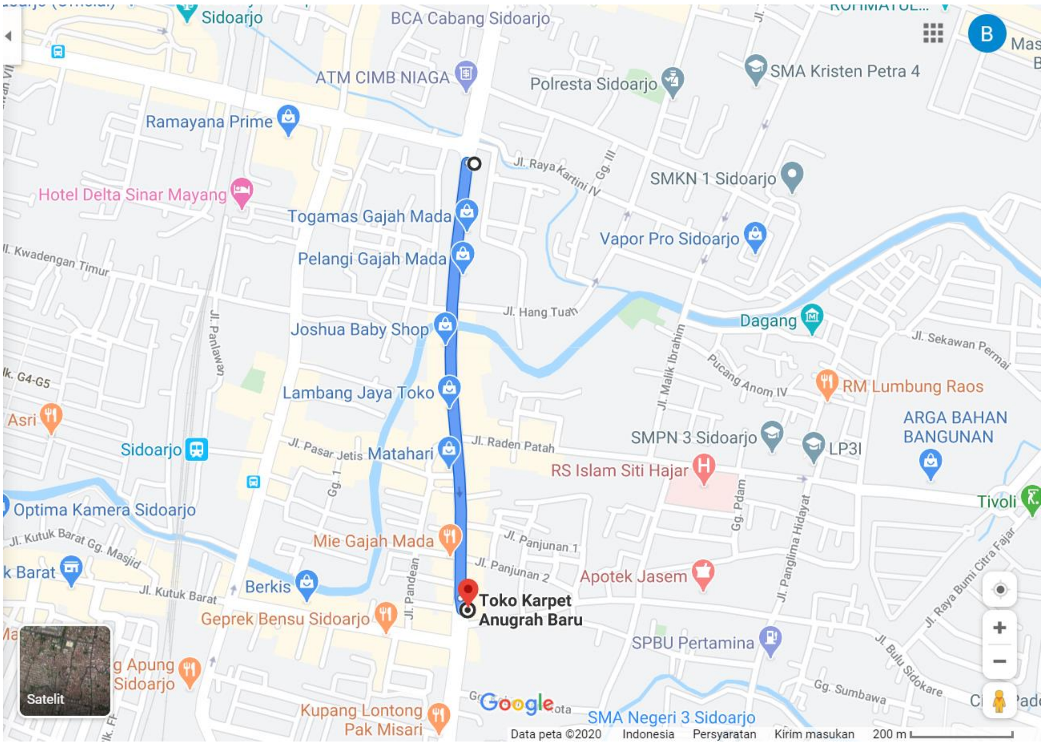

Figure 2.2: Gajah Mada Street viewed on Maps

Source: Google Maps, 2020

According to PT. Wukir Mahendra Sakti (2018), there are several potential parking spots in Sidoarjo regency divided into three categories: crowded, moderate to quiet, and market zone. The crowded zone category consists of several parking spots, and one of them is in Gajah Mada street, as shown in Figure 2.2. Besides the crowd factor, there are several other reasons why Gajah Mada street is chosen. First, the street is one of the major arterial roads in Sidoarjo, meaning that it is one of the critical roads in the region. The road is also a center for business activities as it has many stores along the street, leading to the next reason where it has the most considerable amount of parking space unit (*satuan ruang parkir*) in Sidoarjo. All the three factors mentioned substantiating the reasons for choosing Gajah Mada street as the research object.

2.2 Deterministic and Stochastic System

A deterministic system is a system whose behavior can be predicted precisely for any given initial state of the system and control inputs (Daellenbach and McNickle, 2005). In this system, there are no random inputs, or random behavior occurs. By nature, there only a few genuinely deterministic activity systems. Based on Daellenbach and McNickle (2005), if the randomness is small or the variations and behavior are minor, the deterministic system can be used as an approximation to stochastic systems. In contrast with the deterministic system, the stochastic system is a system that is subject to random, uncontrollable inputs (Daellenbach and McNickle, 2005).

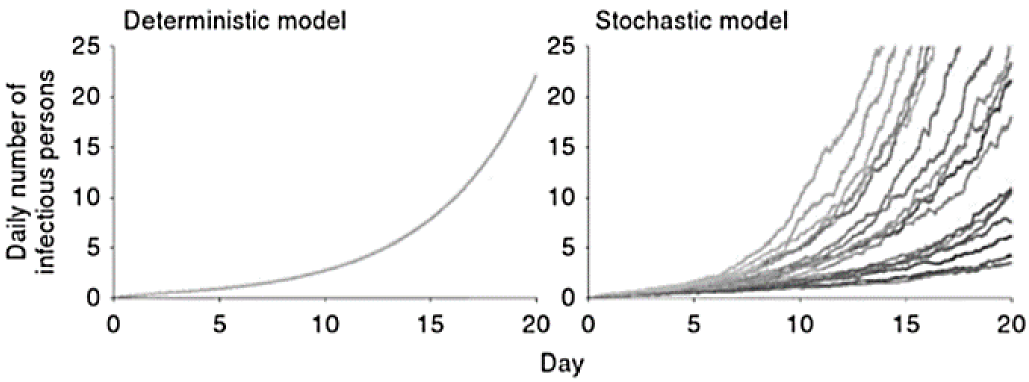

Figure 2.3: Illustration of Difference Between Deterministic and Stochastic Model

Source: Theodorakos, 2016

A model can be used to depict a system. Cambridge Dictionary (2020) defines a model as something that represents another thing, either as a physical object that is usually smaller than the real object or as a simple description that can be used in calculations. Specifically, according to Daellenbach and McNickle (2005), a system model represents all essential parts of a system. System modeling can also be implemented in a deterministic and stochastic system.

Table 2.2 Difference between Deterministic and Stochastic Model

Author	Deterministic Model	Stochastic Model
Gross (2013)	The output of the model is entirely determined by the parameter values and the initial conditions	Possess some inherent randomness. The same set of parameter values and initial conditions will lead to an ensemble of different outputs
Anderson (2014)	A process is deterministic if its present and past ultimately determine its future	A stochastic process is a random process evolving in time
Winston (2004)	All value of decision variables, objective function, and the constraints are known with certainty	Some or all value of decision variables, objective function, or the constraints are not known with certainty

Several definitions of the deterministic and stochastic model from different authors compiled in Table 2.2. The highlight is that the stochastic model covers randomness that not covered in the deterministic model. However, referring to Daellenbach and McNickle (2005), a deterministic approximation can be used if the randomness is small.

2.3 Demand Forecasting Model

Forecasting is an approach to estimate something that have uncertainty and related to time in the future. According to Chopra and Meindl (2007), forecasting is the key driver to every decision in design and planning in an enterprise. This research will use a parking generation rate model with a linear regression approach developed by Cheng, Tai, and Ma (2012). The model is considered as linear regression because it fulfills the criteria of linear regression, as stated in Groebner *et al.* (2011), which is examining the relationship between one independent variable with the dependent variable.

2.3.1 Parking Demand Forecasting Model

According to Cheng, Tai, and Ma (2012), the increasing number of automobiles, city parking demand, making the parking of automobiles becomes a severe traffic problem for Central Commercial District (CCD) in cities. Thus, making parking demand forecast is the key to public parking planning and provides the primary data for the size of the parking lot (Cheng, Tai, and Ma, 2012). The research uses this model because it fits to become the moderation variable between parking lot and demand.

For years, experts have been researching the topic of parking demand forecast and analysis in CCD. One of the models is Parking Generation Rate Model established by Professor Yan Kefei (1994) as cited in Cheng, Tai, and Ma (2012).

$$y = \sum_{i=1}^{n} a_i \times R_i \ (i = 1, 2, \dots, n) \qquad (2.1)$$

Index:

i : unit area

$i = 1, 2, \dots, n$ (n: number of the unit area)

Variable:

y : parking demand in certain CCD in rush hour (unit: parking lot)

a_i : parking generation rates

R_i : the individual area (m^2)

In this research, the author will implement an improved version of the Parking Generation Rate Model based on Cheng, Tai, and Ma (2012), which considers several factors that not considered in the previous one.

$$y = \left(\sum_{i=1}^{n} \frac{a_i \times R_i}{\mu_i \times \gamma_i} \right) \times \delta \times L \times \beta \ (i = 1, 2, \dots, n) \qquad (2.2)$$

Variable:

y : parking demand in certain CCD in rush hour (unit: parking lot)

R_i : the individual area (m^2)

μ_i : average turnover rates, which is defined using the formula:

$$\mu_i = \frac{A_i}{D_i} \tag{2.3}$$

A_i : the total amount of parking

D_i : the total number of lots

γ_i : lot occupancy, which is parking time of each lot divided by the total time in a certain period, calculated using the formula:

$$\gamma_i = \frac{\sum t_{ij}}{D_i T} \; (j = 1, 2, \dots, D) \tag{2.4}$$

t_{ij} : the parking time in each lot

D_i : the total number of parking lots

T : the working time of the parking lot

L : parking price impact coefficients

δ : parking service level

β : growth coefficients of motor vehicles, calculated using the formula:

$$\beta = \frac{Z_1}{Z_2} \tag{2.5}$$

Z_1 : the number of the motor vehicle in the future year

Z_2 : the number of motor vehicles in the base year

2.4 Linear Programming

Linear programming (LP) is the most common type of mathematical programming. According to Balakrishnan *et al.* (2006), as cited in Ureten (2009), all relevant input data and parameters are assumed to know with certainty in models or often called as deterministic models. In developing an LP model, based on Ureten (2009), there is a three-step process that must be taken, as shown in Figure 2.4.

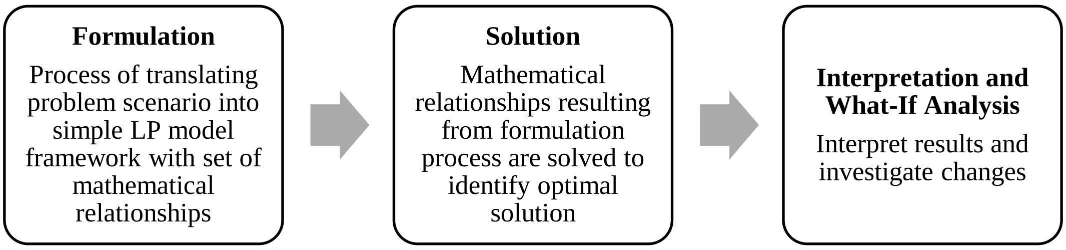

Figure 2.4: Steps of Developing an LP Model

In implementing an LP model, several assumptions are required. According to Winston (2004), there are four underlying assumptions of an LP model. The assumptions include proportionality, additivity, divisibility, and certainty assumption. Proportionality is when the contribution of the objective function from each decision variable is proportional to the value of the decision variable. Also, the contribution of each variable to the left-hand side of each constraint is proportional to the value variable value. In additivity assumption, the total of all activities equals the sum of individual activities. For divisibility, it requires that each decision variable be allowed to assume fractional values. The case where all the variables must be nonnegative integers is called an integer programming problem. Lastly, the certainty assumption requires that all parameter in LP is known with certainty or in the exact amount.

According to Stein (2009), there are some essential definitions in LP to notes. A solution to a linear program is a setting of the variables. A feasible solution is a solution that satisfies all constraints. The feasible region is the set of all possible feasible solutions. When LP has no feasible solutions, it is called infeasible LP. An optimal solution is a feasible solution with the largest objective function value (for a maximization problem). In exceptional cases, based on Winston (2004), some LPs can be unbounded where points in the feasible region have arbitrarily large (in a max problem) z-values or objective function or, in other words, infinite objective function.

As mentioned previously, some cases require the variables to be an integer, and it needs the integer programming approach. The following sections will explain the brief description of integer linear programming, branch-and-bound method, and solving integer programming in LINGO software.

2.4.1 Integer Linear Programming

Standard linear programming models are categorized as continuous, where the decision variables can be fractional, for example, in the divisible goods such as oil or rice. According to Orlin (2010), at some times, the fractional solutions are not realistic. With such conditions, other optimization problems where the decision variables are integer should be considered. Integer programming problem (IP) is linear programming (LP) in which some or all of the variables must be a non-negative integer (Winston, 2004). According to Orlin (2010), the general integer programming problem can be written as:

$$Maximize \sum_{j=1}^{n} c_j x_j \ , \tag{2.6}$$

$$\sum_{j=1}^{n} a_{ij} x_j = b_i \ \ (i = 1, 2, \dots, m), \tag{2.7}$$

$$x_j \geq 0 \ \ (j = 1, 2, \dots, n), \tag{2.8}$$

$$x_j \ integer \ (for\ some\ or\ all\ j = 1, 2, \dots, n). \tag{2.9}$$

Where:

c_j : the contribution of decision j to the objective function

x_j : decision variable

a_{ij} : the amount of resource used for decision j

b_i : the amount of available resource

Based on Winston (2004), IP is categorized into several types based on the amount of integer required in the variables:

1) Pure IP : all variables must be in integers.
2) Mixed IP : only some of the variables are required to be integers.
3) Binary IP : all variables must equal 0 or 1.

In solving IP problems, the commonly used method is the branch and bound.

2.4.2 Branch-and-Bound

According to Orlin (2010), branch-and-bound is a strategy of ‘divide and conquer’. The idea is to divide the feasible region into more manageable subdivisions. Based on Taylor (2015), the branch-and-bound method is not a solution specific to IP problems. It is a solution approach that can be used for different problems. It is an example of the exact algorithm, as shown in Figure 2.5. The principle used in the branch-and-bound approach is partitioning a set of feasible solutions into a smaller subset of solutions then evaluated until the best solution is found. When the branch and bound method is applied to an IP problem, it is used in conjunction with the typical non-integer solution approach (Taylor, 2015).

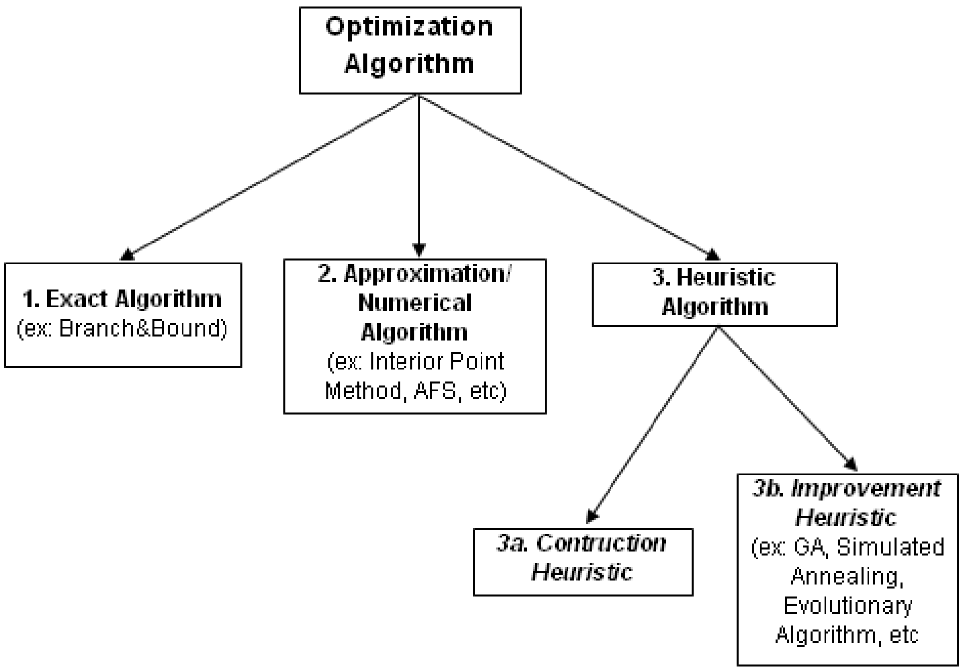

Figure 2.5: Type of Solutions for Optimization Problem

Source: Bouras and Syam (2013)

The branch and bound method can be used for pure, mixed, or binary integer problems. According to Taylor (2015), the steps of the branch and bound method for determining an optimal integer solution for a maximization model (with ≤ constraints) are as follows.

1) Find the optimal solution to the linear programming model using the integer restrictions relaxed (LP relaxation of IP is when the LP obtained by omitting all integer or 0-1 constraints on the variable).
2) At node one, let the relaxed solution be the upper bound, and the rounded-down integer solution is the lower bound.
3) Select the variable with the highest fractional part for branching. Create two new constraints for this variable, reflecting the partitioned integer values. The result will be a new ≤ constraint and a new ≥ constraint.
4) Create two new nodes, one for the ≥ constraint and one for the ≤ constraint.
5) Solve the relaxed linear programming model with the new constraint added at each of these nodes.
6) The relaxed solution is the upper bound at each node, and the existing maximum integer solution (at any node) is the lower bound.
7) If the process produces a feasible integer solution with the highest upper bound value of any ending node, the optimal integer solution is reached. If a feasible integer solution does not emerge, a branch from the node with the highest upper bound.
8) Return to step 3.

Figure 2.6 shows an example of the enumeration tree used in branch-and-bound. In the minimization model, relaxed solutions rounded up, and upper and lower bounds are reversed.

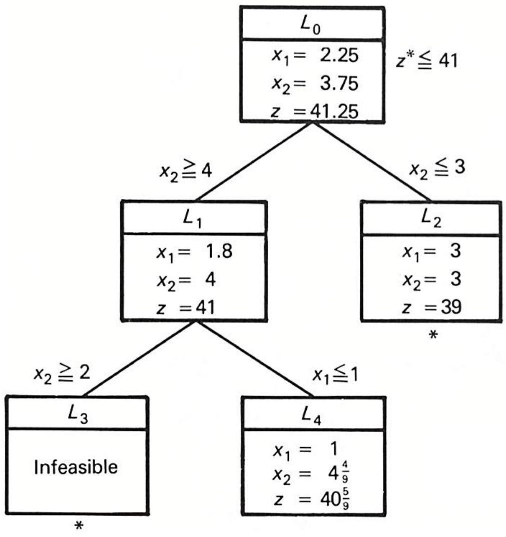

Figure 2.6: Example of Enumeration Tree in Branch-and-Bound

Source: Orlin (2010)

2.4.3 Solving Integer Programming using LINGO

One software that can help in solving IP problems is LINGO. In LINGO, users can use built-in operators to ease calculation. According to Winston (2004), several notable operators are useful for solving IP problems. The @BIN operator indicates that a variable must equal 0 or 1. The @GIN operator indicates that a variable must equal a non-negative integer. The operators will be used depending on the requirement in each model and combined with other LINGO operators and functions.

2.5 Research Position

This subchapter will compare the previous research similar to this research in several aspects, including the research object (on-street or off-street parking), methods, and parameters or factors considered. Table 2.3 shows the comparison of seven previous research and this research.

The comparison shows that 5 out of 7 of the research applies a linear regression approach to do demand forecast. For the parameter, 3 of the research considers the parking generation rate. By also considering the requirement in the actual system, this research will use linear regression and parking generation rate model as the approach to solving the research problem.

Table 2.3 Research Position

No.	Author	Year	Title	Object		Method				Parameter / Factors Considered
				On-street Parking	Off-street parking	Correlation Analysis	Linear Regression	Multiple Regression	Linear Programming	
1	Cheng, Tai and Ma	2012	The Model of Parking Demand Forecast for the Urban CCD	√			√			Parking generation rate, individual area, average turnover rates, utilization rate, parking price impact coefficient, parking service level, growth coefficients of motor vehicles
2	Xu, Zhang and Rong	2012	The Forecasting Model of Bicycle Parking Demand on Campus Teaching and Office District		√		√			Parking generation rate, trip distance, parking distance, facility cycling rate, and the use factor
3	Chen, Wang and Han	2012	The Research of Parking Demand Forecast Model Based on Regional Development		√			√		Regional development factors (economy, society, transportation, and other levels of development affecting parking demand in different regions)

Table 2.3 Research Position (extension)

No.	Author	Year	Title	Object		Method				Parameter / Factors Considered
				On-street Parking	Off-street Parking	Correlation Analysis	Linear Regression	Multiple Regression	Linear Programming	
4	Ottosson *et al.*	2013	The sensitivity of on-street parking demand in response to price changes: A case study in Seattle, WA	√				√		Pricing, neighborhood characteristics Dependent variable: parking occupancy at a block
5	Tembhurkar and Khobragade	2015	Parking Demand Forecast Model for Institutional Campus		√		√			Parking generation rate, attraction rate, number of trips during peak hours to attract, parking facility cycling rate, service facility factor, influence rate of travel distance, utilization rate
6	Ramli, Hassan and Hainin	2017	Parking Demand Analysis of Rest and Service Area along Expressway in Southern Region, Johor Malaysia		√	√	√			Total vehicular volume on main-line expressway (sum of vehicular volume passing and entering the RSA), and the size of the facilities

Table 2.3 Research Position (extension)

No.	Author	Year	Title	Object		Method				Parameter / Factors Considered
				On-street Parking	Off-street Parking	Correlation Analysis	Linear Regression	Multiple Regression	Linear Programming	
7	Ajeng and Gim	2018	Analyzing on-Street Parking Duration and Demand in a Metropolitan City of a Developing Country: A Case Study of Yogyakarta City, Indonesia	√			√			Street and land use characteristics
This Research				√			√		√	**Parking generation rate, individual area, total number of parking (potential), utilization rate, parking service level, price impact coefficient, growth factor of vehicle, customer preference coefficient**

CHAPTER 3
RESEARCH METHODOLOGY

This chapter will show the research methodology both in the flowchart form and a brief description of each process.

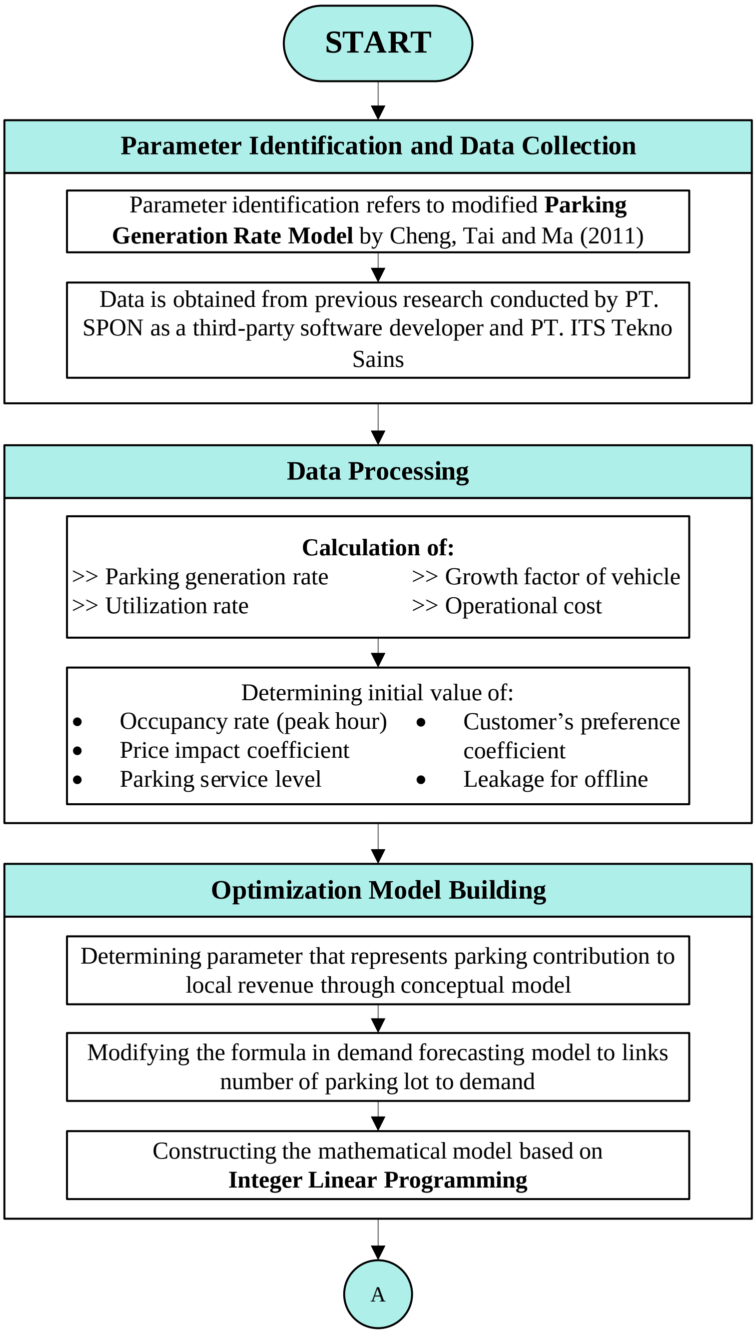

Figure 3.1: Research Methodology

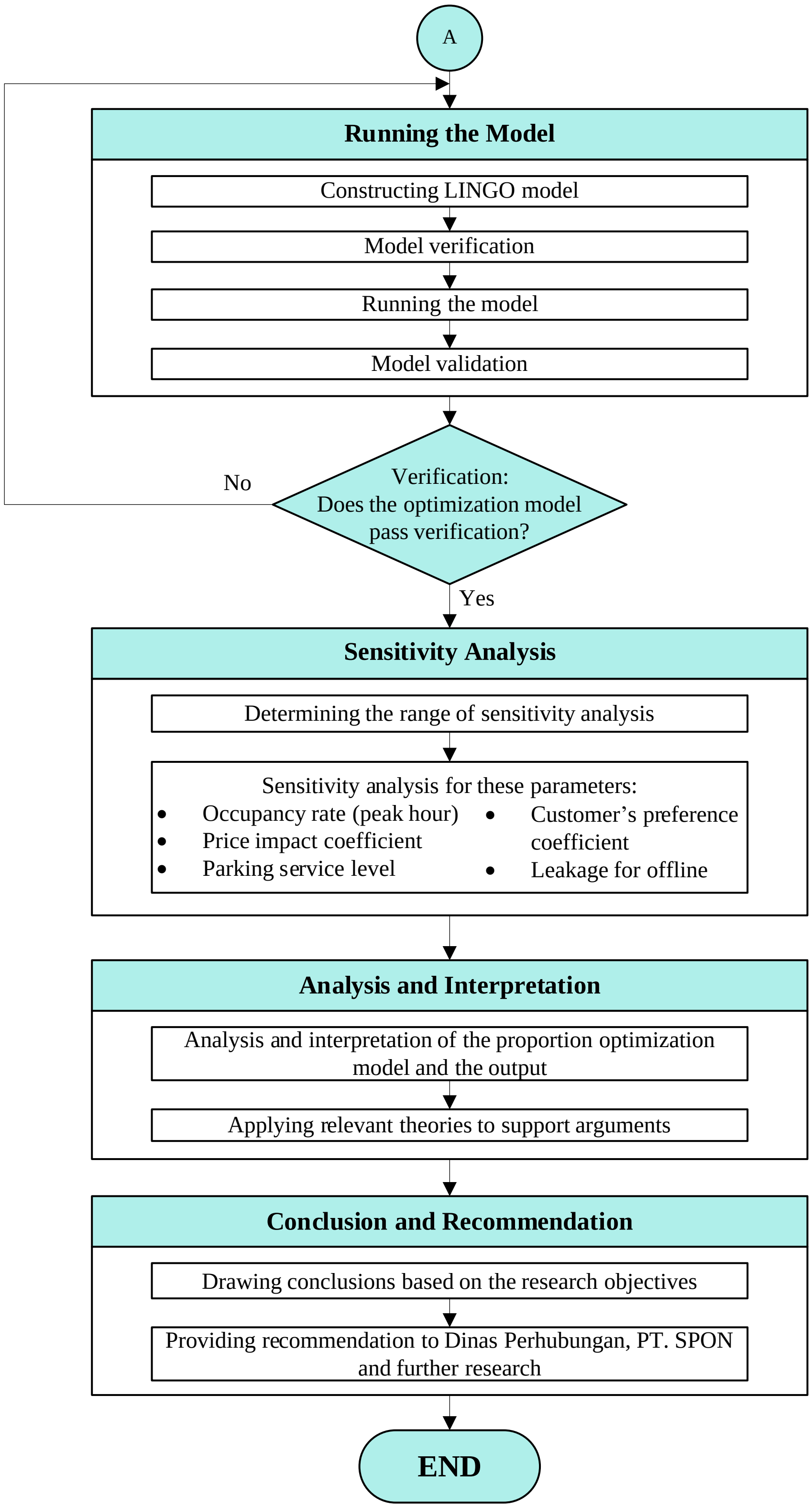

Figure 3.1: Research Methodology (extension)

3.1 Stage of Data Preparation

In this stage, the input for the optimization model is collected and processed further. The processes include parameter identification and data collection and data processing.

3.1.1 Parameter Identification and Data Collection

In identifying the parameter used in this research, the author refers to the modified parking generation rate model by Cheng, Tai, and Ma (2012). This model considers several parameters to do parking demand forecasting, including parking generation rate, individual area, the total amount of parking, utilization rate, parking service level, price impact coefficient, and vehicle growth factor. For this research purpose in considering online and offline parking selection, new coefficients are introduced. The coefficients are the customer preference coefficient and leakage for offline parking.

The topic of this research relates to a previous feasibility study conducted by ITS Tekno Sains (2019). Therefore, some required data are already available. However, the author still needs to collect additional data. Table 3.1 shows the detail about the data collection process.

Table 3.1 Data Collection Method for Each Parameter

No.	Parameter	Required Data	Data Collection Method
1	Parking Generation Rate	The largest number of vehicle in one day	Assumption
		Building's floor area	Google Maps
2	Individual area	Building's floor area	Google Maps
		Plot ratio (*Koefisien Lantai Bangunan*)	*Perda* Sidoarjo
3	The total amount of parking	The total amount of parking in one day	Existing data
4	The utilization rate of parking	Number of the occupied lot	Existing data
		The total amount of lot	Existing data
5	Parking service level	Service level	Assumption
6	Price impact coefficient	-	Assumption

Table 3.1 Data Collection Method for Each Parameter (extension)

No.	Parameter	Required Data	Data Collection Method
7	The growth factor of vehicle or vehicle growth coefficient	Number of the vehicle in the future and base year	Existing data
8	Customer preference coefficient	The proportion of customer agrees to use an online parking	Existing data
9	Leakage for offline parking	Leakage coefficient	Assumption
10	Operational cost per transaction	The variable cost of parking operational	Existing data
11	Fixed cost per day	Cost component of fixed cost	Existing data

Based on Table 3.1, most of the parameter value is obtained from existing data, except the building's floor area, service level, price impact coefficient, and leakage for offline parking. For the building's floor area, data can be obtained using a feature in google maps, as shown in Figure 3.2. The value of the service level and price impact coefficient cannot be obtained due to several reasons. For parking service level, the value can only be obtained after the online parking system is executed directly in the community, which has not been done during the research time horizon. Meanwhile, for the price impact coefficient, a study by Ottosson *et al.* (2013) found that price elasticity of the parking occupancy is inelastic. Other data from the previous research by ITS Tekno Sains (2019), shows that only 13% of respondents that chooses parking fee as a reason for choosing parking facility. A similar result is also shown in the study by PT. Wukir Mahendra Sakti (2018), in which only 6.43% of the respondents that consider parking fee as a reason to select a parking facility. The assumption for leakage is based on the existing condition of leakage on the same study, and it is expected that the number would reduce after the implementation of the online parking.

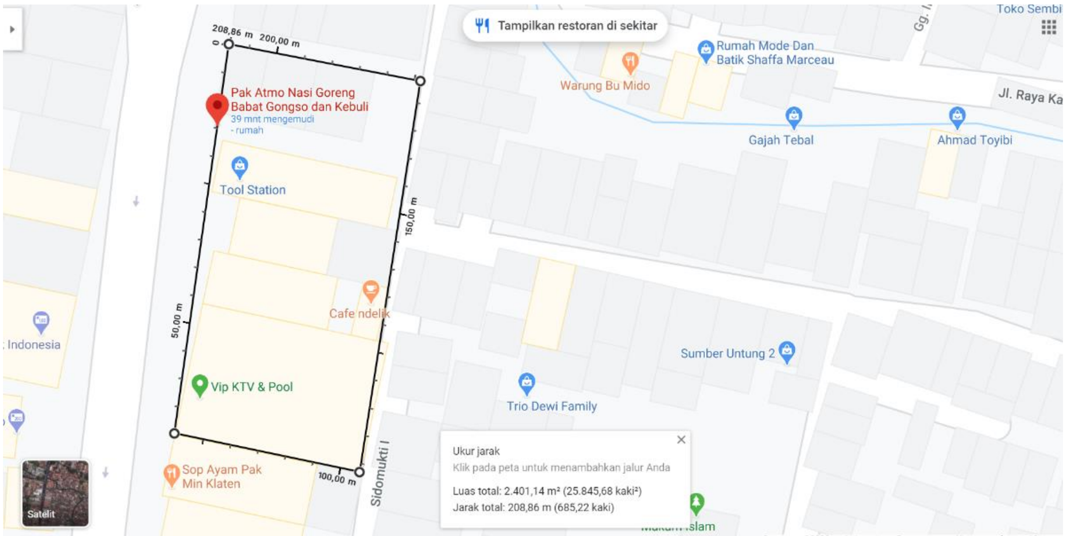

Figure 3.2: Google Maps Area Measurement

Source: Google Maps, 2020

3.1.2 Data Processing

The data obtained from the previous step will be processed to obtain values that will be used in the next process. The process uses simple mathematical operation as required by the modified demand forecasting model. This process includes the calculation of the parking generation rate (3.1), utilization rate (3.2), the growth factor of the vehicle (3.3) also, the cost for operating one unit of the parking lot, both for cars and motorcycles (3.4). Then, determining the initial value of the parking service level and price impact coefficient that later be adjusted in the sensitivity analysis step.

$$a_i = \frac{Largest\ number\ of\ vehicle\ in\ one\ day\ (unit)}{Building's\ floor\ area\ (m^2)} \tag{3.1}$$

$$\gamma_i = \frac{Arrival\ rate\ of\ vehicle\ (unit\ per\ slot\ per\ day)}{Average\ slot\ usage\ (per\ day)} \tag{3.2}$$

$$\beta = \frac{Number\ of\ vehicle\ in\ future\ year\ (unit)}{Number\ of\ vehicle\ in\ base\ year\ (unit)} \tag{3.3}$$

$$OC = \frac{\left(\frac{Total\ operational\ cost\ (annual)}{Number\ of\ days\ in\ one\ year}\right)}{Total\ number\ of\ Parking\ Space\ Unit} \tag{3.4}$$

Index:

i : unit area

$i = 1, 2, \ldots, n$ (n: number of the unit area)

Variable:

a_i : parking generation rate (lots/100 m^2)

γ_i : utilization rate

β : growth factor of vehicle (vehicle growth coefficient)

OC : operational cost per parking lot per day (Rupiah)

3.2 Stage of Model Building and Running

This subchapter will describe the processes conducted in model building and running stage, which includes optimization model building, verification, and running the model.

3.2.1 Optimization Model Building

The optimization model constructed from two main steps, which are demand forecasting model and integer linear programming (ILP). In this research, the demand forecasting model uses a modified version of the parking generation rate model developed by Cheng, Tai, and Ma (2011). The demand forecasting model is used as a function that converts the decision variable (parking lot) into demand. Then it becomes the coefficient in the ILP. After obtaining a function for the coefficient, the mathematical model is constructed based on the basic model of integer programming that already mentioned in subchapter 2.4. The process of optimization model building is shown using the conceptual model in Figure 3.3.

Daellenbach and McNickle (2005) define a conceptual model as a corresponding system definition. For this research, the conceptual model is related to the mathematical and optimization model. Figure 3.3 shows the conceptual model that connects input, variables, and output for the problem in this research.

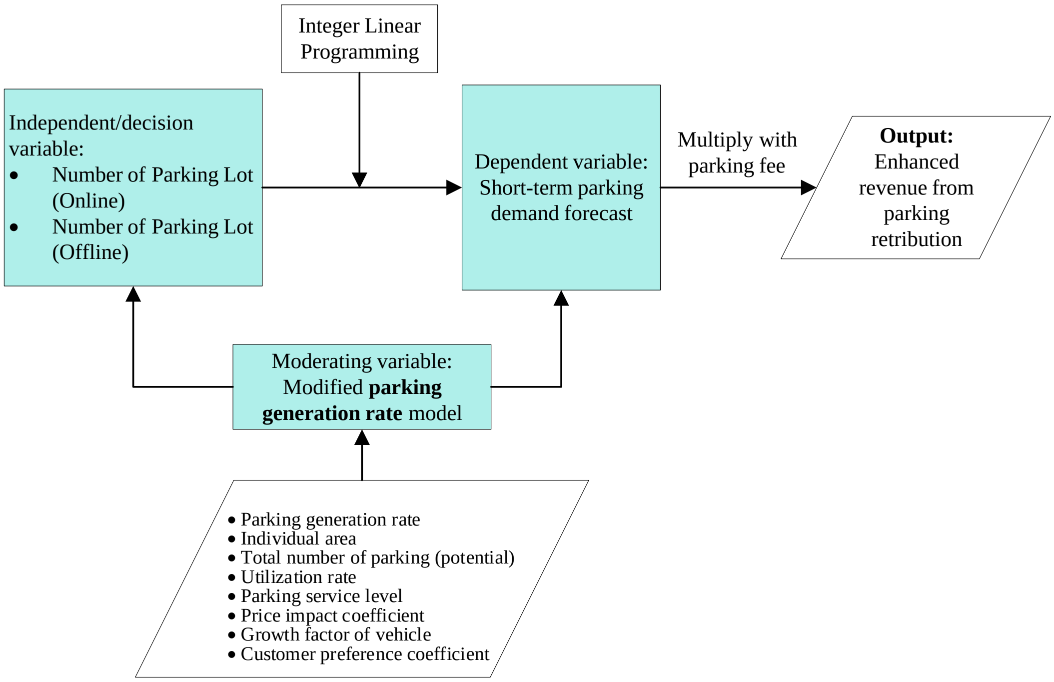

Figure 3.3: Conceptual Model

In the model, the independent or decision variable is the number of the parking lot for online and offline parking, both car and motorcycle. The dependent variable is the short-term parking demand forecast. A modified parking generation rate model is used to moderate the two variables. According to Judd (2015), a moderator variable is a variable that defines the magnitude of the effect of an independent variable on a dependent one. The inputs required for this moderating variable are the results of the data processing step. Then, integer linear programming obtain the optimal proportion. Finally, the result is multiplied with the parking fee to determine the enhanced revenue from parking retribution.

3.2.2 Constructing LINGO Model

After generating a mathematical model, the modeler can construct the model in LINGO. According to LINDO Systems Inc. (2016), LINGO is a comprehensive tool designed to make building and solving mathematical optimization models easier and more efficient. Some things to note in making the LINGO model are that ‘comment’ in the model defined with (!) and presented in the green letter. ‘Function’ and specific operators are blue colored. The remaining words are in black. Every statement in LINGO is closed with a semi-colon (;). Also, the variable name is not case-sensitive. Figure 3.4 shows an example of the LINGO model.

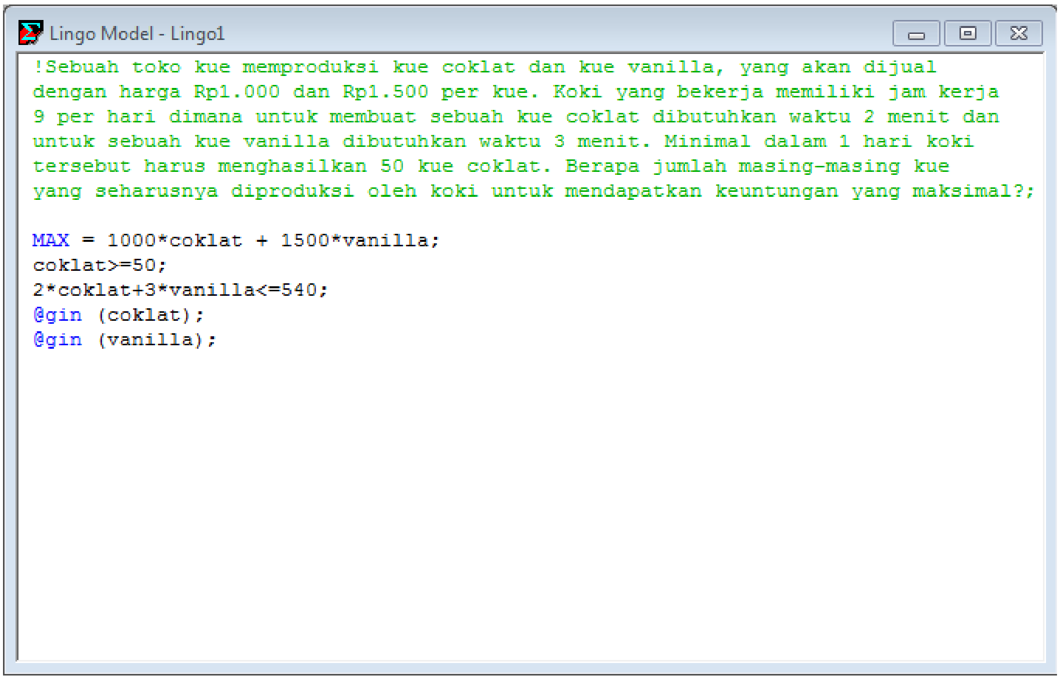

Figure 3.4: Example of LINGO Model

3.2.3 Verification

Based on Daellenbach and McNickle (2005), verification is a process in determining whether a model is correct and consistent in a logical and mathematical perspective, also to see if the data inputs are correct. A command in LINGO (Solver | Generate) checks if there is any syntax error in the model. According to LINDO Systems Inc. (2016), it is also useful to do model verification, as it can expand all of the model's compact set-based expressions and writes out the full model. Then, the modeler can check if the generated model is already developed as intended by the modeler. An example of verification in LINGO can be seen in Figure 3.5.

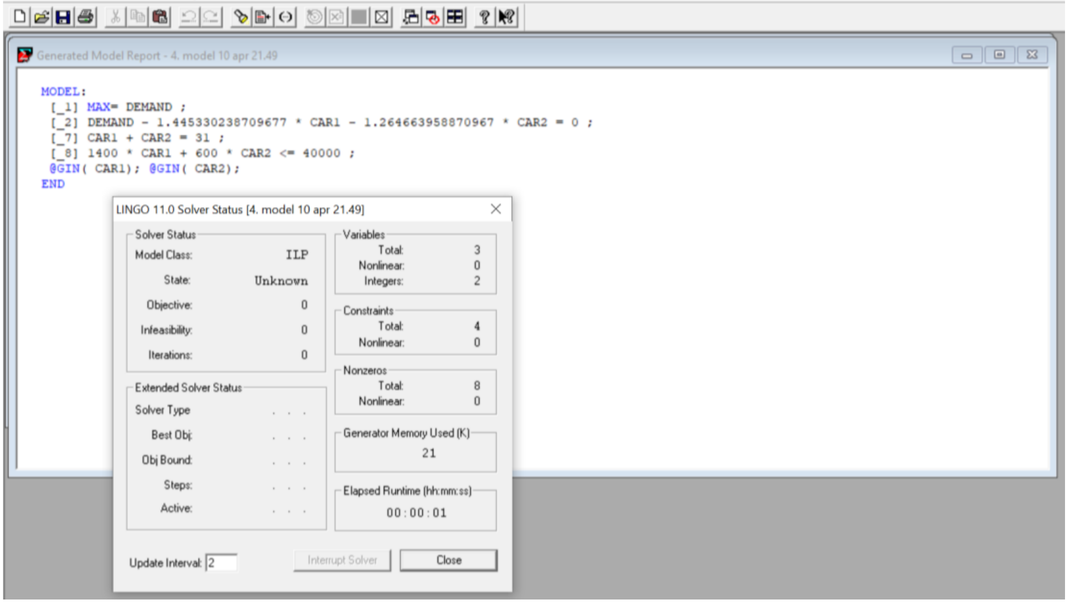

Figure 3.5: Verification in LINGO

3.2.4 Running the Model

To run the integer linear programming model, the author chooses LINGO software. One of the primary features in the software that will be useful to help solve the model is the 'Powerful Solvers and Tools' feature, where it has built-in solvers for linear, nonlinear, quadratic, and integer optimization. Furthermore, LINGO also provides complete running information such as the method, result, also a sensitivity analysis. To run the model, the user only needs to click the 'Solver' button on the upper ribbon. Then, after running at a time, the results will be generated, as shown in Figure 3.6.

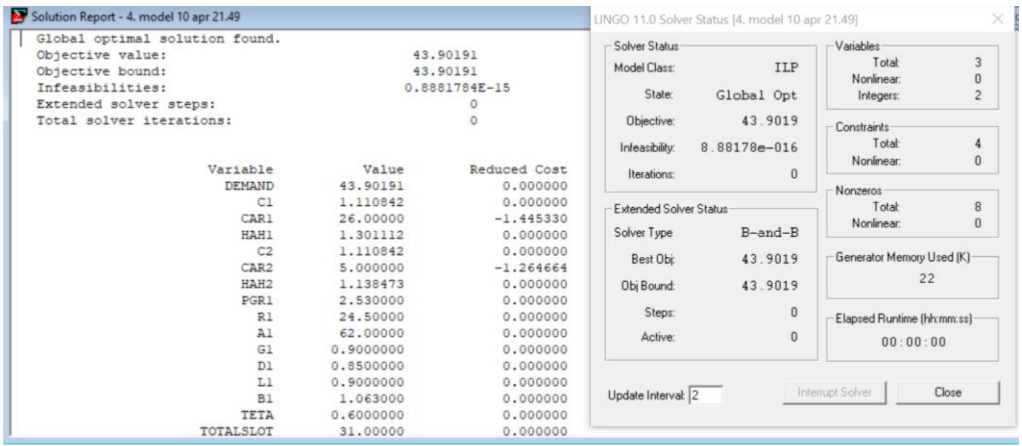

Figure 3.6: Example of Solution Report in LINGO

3.3 Stage of Analysis and Conclusion

This stage will elaborate on the results obtained from the previous stage by doing sensitivity analysis, analysis, and interpretation to obtain the desired conclusion, also providing suggestions.

3.3.1 Sensitivity Analysis

According to Daellenbach and McNickle (2005), sensitivity analysis is used to determine how the optimal value of the performance measure is affected by the change done in uncontrollable inputs. Based on Salciccioli, Crutain, and Komorowski (2016), sensitivity analysis and model validation are related since they attempt to check the model specification and strength of conclusions. In the ideal condition, validation is done by checking if the model fits within a specific dataset. However, since the digital parking project is still a pilot project, a real dataset is not available to conduct external validation.

In this research, the process begins with determining the range of sensitivity analysis. Then, the sensitivity analysis is applied to the parameters, including occupancy rate at peak hour, price impact coefficient, parking service level, customer preference coefficient, and leakage for offline. Each of the changes is done separately for each input and keeping all other inputs unchanged.

The process of sensitivity analysis is done by changing the data in LINGO, rerun the model, and observe the change occurred in the objective function. Output in LINGO provides ‘shadow price’ and ‘reduced cost’ for sensitivity analysis. However, according to Winston (2004), it refers to the subproblems generated during branch-and-bound solution and not the integer programming. Therefore, it is necessary to rerun the optimization model.

3.3.2 Analysis and Interpretation

To analyze the results obtained from the previous stage, the author will do analysis and interpretation. The solution obtained using the initial assumption will be analyzed to interpret the result. Also, the results from the sensitivity analysis will be interpreted and analyzed further in this step. The analysis will include the impact of changing the value of occupancy rate at peak hour, price impact coefficient, parking service level, customer preference coefficient, and leakage for offline to the performance measure, which is profit. Thus, the parameter that has the most significant impact on the performance measure would be identified. Furthermore, relevant theories will be included to support the arguments.

3.3.3 Conclusion and Recommendation

After getting the results, a conclusion can be taken to answer the objectives of the research. Also, the recommendations about the improvements for future research will also be given. The recommendations are expected to help execute the project better.

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CHAPTER 4
MODEL BUILDING AND DATA COLLECTION

This chapter will explain the model building and the process of generating an optimization model, which includes the parking demand forecasting model and the integer programming model. Also, the chapter will show the data collection used in this research.

4.1 Parking Demand Forecasting Model

The modification of the parking generation rate model is shown in the following equation.

$$y = \left(\sum_{i=1}^{n} \frac{a_i \times R_i}{\mu_i \times \gamma_i}\right) \times \delta \times L \times \beta \times \theta \ (i = 1, 2, \ldots, n) \tag{4.1}$$

$$y = \left(\sum_{i=1}^{n} \frac{a_i \times R_i}{\frac{A_i}{D_i} \times \gamma_i}\right) \times \delta \times L \times \beta \times \theta \ (i = 1, 2, \ldots, n) \tag{4.2}$$

$$y_{online} = \left(\sum_{i=1}^{n} \frac{a_i \times R_i \times \boldsymbol{Di}}{A_i \times \gamma_i}\right) \times \delta \times L \times \beta \times (1 + \theta) \ (i = 1, 2, \ldots, n) \tag{4.3}$$

$$y_{offline} = \left(\sum_{i=1}^{n} \frac{a_i \times R_i \times \boldsymbol{Di}}{A_i \times \gamma_i}\right) \times \delta \times L \times \beta \times \big(1 + (1 - \theta)\big) \ (i = 1, 2, \ldots, n) \tag{4.4}$$

Index:

i : unit area

$i = 1, 2, \ldots, n$ (n: number of the unit area)

Where:

y : parking demand in a certain area in rush hour (unit: lot)

a_i : parking generation rates

R_i : the individual area m^2

D_i : number of lots → decision variable

A_i : total number of parking

γ_i : utilization rate

L : parking price impact coefficients

δ : parking service level

β : growth coefficients of motor vehicles, calculated using the formula:

$$\beta = \frac{Z_1}{Z_2} \tag{4.5}$$

Z_1 : number of motor vehicle in the future year

Z_2 : number of motor vehicles in the base year

$(1+\theta)$: customer preference coefficient for online parking

$\big(1+(1-\theta)\big)$: customer preference coefficient for offline parking

The modification process begins with adding coefficient in the equation (4.1). The additional coefficient represents customer preference in choosing either online or offline parking. Then the variable of number of lots (D_i) is moved to the numerator side to simplify the calculation. Finally, an additional number (1) is added to the equation to prevent the customers' preference coefficient from reducing the demand (y). Equation (4.3) and (4.4) applies both for car and motorcycle.

4.2 Integer Programming Model

This subchapter will show the integer programming model for the proportion optimization problem. Using the formula from subchapter 4.1, the parameters from the demand forecasting model is combined with the other parameter. The mathematical model is as follows.

Objective function:

$$max\ \sum_{k=1}^{2}\sum_{j=1}^{2}\sum_{i=1}^{n}\left(\left[\left(\frac{x_{ijk}}{A_{ij}}\right)\times coef_{ij}\right]\times cm_{jk}\right)\times pf_j - \sum_{i=1}^{n} TC_{ij} \tag{4.6}$$

Constraints:

$$\sum_{k=1}^{2} x_{ijk} = p_{ij} \quad \forall j = 1..J \;\; \forall i = 1..I \tag{4.7}$$

$$\sum_{k=1}^{2} c_{jk} \times \left(\left\lceil \left(\frac{x_{ijk}}{A_{ij}}\right) \times coef_{ij} \right\rceil \times cm_{jk}\right) \le b_{ij} \quad \forall j = 1..J \;\; \forall i = 1..I \tag{4.8}$$

$$x_{ijk} \ge 0 \tag{4.9}$$

$$x_{ijk} \in \{integer\} \tag{4.10}$$

Index:

i : unit area / block

$i = 1, 2, \ldots, n$ (n: number of the unit area)

j : type of vehicle

$j = 1$ for car

$j = 2$ for motorcycle

k : method of parking

$k = 1$ for online/digital parking

$k = 2$ for offline/conventional parking

Parameter:

A_{ij} : total number of parking for block i and vehicle j

$coef_{ij}$: coefficient for block i and vehicle j

$$coef_{ij} = \frac{a_{ij} \times R_i}{\gamma_i} \tag{4.11}$$

cm_{jk} : coefficient for vehicle j and method k

$$cm_{jk} = \delta \times L \times \beta \times (1 - leakage_k) \times (1 + \theta_k) \tag{4.12}$$

pf_j : parking fee for vehicle j

TC_{ij} : total cost (operational and fixed cost) for block i and vehicle j

p_{ij} : total available parking lot for block i and vehicle j

c_{jk} : cost per transaction per lot for vehicle j and method k

b_{ij} : total cost limit allocated for block i and vehicle j

Decision variable:

x_{ijk} : number of parking lots allocated for block i, vehicle j and method k

The objective function (4.6) represents profit maximization, which is obtained by multiplying the decision variable (number of lots) with parameters related to the parking generation rate model, and subtracted with total operational cost. The first constraint (4.7) shows that the total number of lots must equal to the actual number of parking lots in the real system. The second constraint (4.8) defines that the cost spent on each parking method must not exceed the cost limit allocated. The third constraint (4.9) is a nonnegative constraint for the decision variable x_{ijk}. The last constraint (4.10) makes the decision variable to be integer.

4.3 LINGO Model

To solve the optimization model, the author uses LINGO optimization software. The model consists of four parts, which are SETS, DATA, OBJECTIVE FUNCTION, and CONSTRAINTS. Figure 4.1 shows the model overview. The complete coding is included in the attachment.

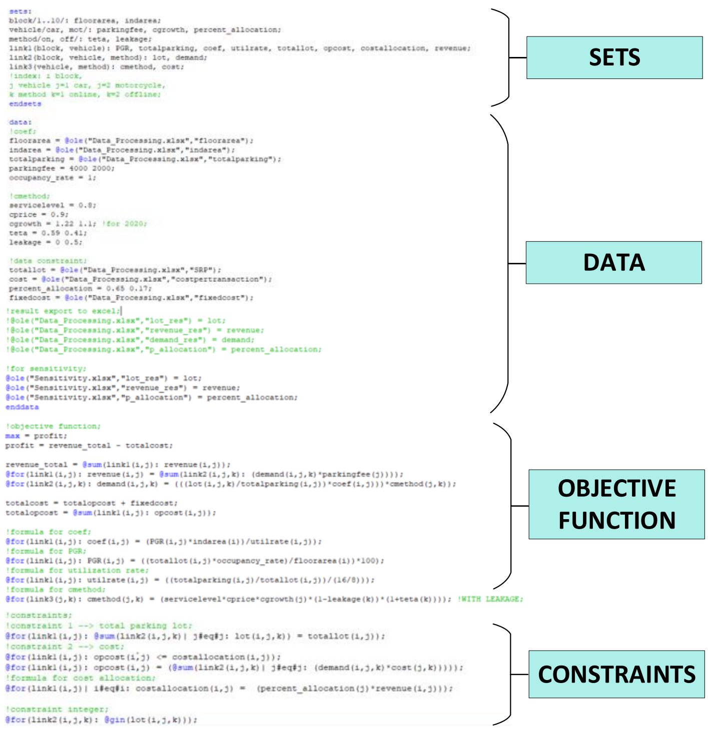


Figure 4.1: LINGO Model

4.4 Data Collection

This subchapter will show the required data as mentioned previously in subchapter 3.1.1, that includes existing parking data, building's floor area, number of the vehicle in different years, the proportion of customer agree to use online parking and component for the operational and fixed cost.

4.4.1 Existing Parking Data

This section will show the existing parking data in Gajah Mada street. The data includes parking duration, block division, number of workers, working shift, parking space unit (SRP), and parking potential. Figure 4.2 shows the duration of the parking of the respondents. The most significant percentage is occupied by less than 2 hours of duration, followed by 2-4 hours, 4-6 hours, and more than 6 hours.

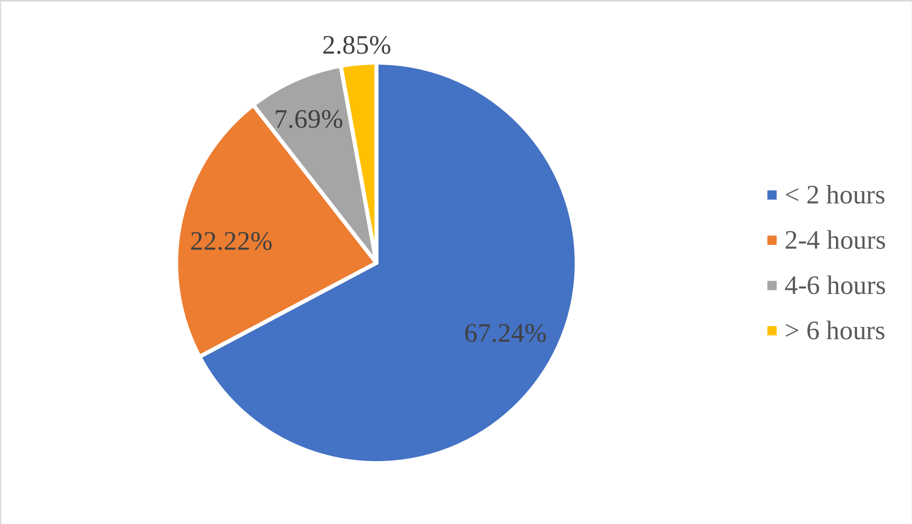


Figure 4.2: Duration of Parking

Source: PT. Wukir Mahendra Sakti (2018)

Table 4.1 shows the existing parking data for the number of parking officers, parking space units, and parking potential. The worker indicates the existing number of parking officers in each block. The parking space unit (SRP) indicates the quantity of parking lot available for each block. For example, block 1 has 31 car parking lots and 105 lots for motorcycles. Potential is the number of vehicles expected to park in one day or the expected total parking in one day. For example, in block 1, the expected number of cars and motorcycles to park in one day is 62 and 110 vehicles, respectively.

Table 4.1 Existing Parking Data

Block	Point	Worker	Shift	SRP (unit of vehicle)		Potential (unit of vehicle)	
				Car	Motorcycle	Car	Motorcycle
Block 1	Counter Oppo to KTV & Pool	3	2	31	105	62	110
Block 2	Sop Ayam Klaten to RJ Steel	4	2	76	255	87	300
Block 3	Jamu Iboe to Seb. Utara Buk Wedi	1	2	12	33	26	66
Block 4	Toko Sinar Mas to Apotik Pangestu	3	2	34	112	69	132
Block 5	Indomaret Gama to Apotek 7	4	2	43	144	84	200
Block 6	Tk Gunung Mas to Cwiemie Malang	3	2	27	91	54	167
Block 7	Bata to Homemart	2	2	25	83	50	161
Block 8	Toko Benang to BNI Syariah	3	2	32	107	63	110
Block 9	Toko Nazir to Pusat Kuliner Baru	2	2	15	51	30	102
Block 10	Tk Nusantara to Anugrah Baru Karpet	2	2	18	60	36	120
TOTAL		**27**		**313**	**1,041**	**561**	**1468**

Source: PT. SPON Technology (2018)

4.4.2 Parking Regulation

Parking guidelines published by Direktorat Bina Sistem Lalu Lintas Angkutan Kota (1998) is used to obtain the standard in the parking facility. Classification of vehicles in Table 4.2 acts as the basis for determining the type of vehicle. As shown in Table 4.3, a different type of vehicle requires a different size of the parking space unit.

This research will refer to passenger car for class I as the standard size for the car and the motorcycle as itself. Passenger car for class I is chosen because, as seen in Table 4.2, this class is used for visitors of the central business district or trading area, which matches with the majority of building in Gajah Mada street. Therefore, in this research, the standard size of the parking space unit will be set to 2.30 x 5.00 meter for car and 0.75 x 2.00 meter for motorcycle.

Table 4.2 Class of Vehicles

Type of Door Openings	User and/or Allocation of Parking Facility	Class
Front/back door opened for 55 cm (early opening)	• Employee/office worker • Guest/visitor of central business district, trading, government, or university area	I
Front/back door opened for 75 cm (full opening)	Visitor of gym, entertainment/recreational place, hotel, supermarket, hospital, or cinema	II
Front door is fully opened and additional space for wheelchair movement	Disabled people	III

Source: Direktorat Bina Sistem Lalu Lintas Angkutan Kota (1998)

Table 4.3 Standard Size of Parking Space Unit for Each Type of Vehicle

No.	Type of Vehicle	Parking Space Unit (m^2)
1	Passenger car for class I	2.30 x 5.00
	Passenger car for class II	2.50 x 5.00
	Passenger car for class III	3.00 x 5.00
2	Bus/truck	3.40 x 12.50
3	Motorcycle	0.75 x 2.00

Source: Direktorat Bina Sistem Lalu Lintas Angkutan Kota (1998)

4.4.3 Building's Floor Area

Building's floor area is one of the required inputs to calculate the parking generation rate. The area in Gajah Mada street is divided to 10 blocks. Figure 4.3 and Figure 4.4 shows the big picture for the block division. Each of these blocks have their own on-street parking slots. To obtain the data for the building's floor area, the author uses google maps area measurement.

Figure 4.3: Area Division for Block 1 – 5

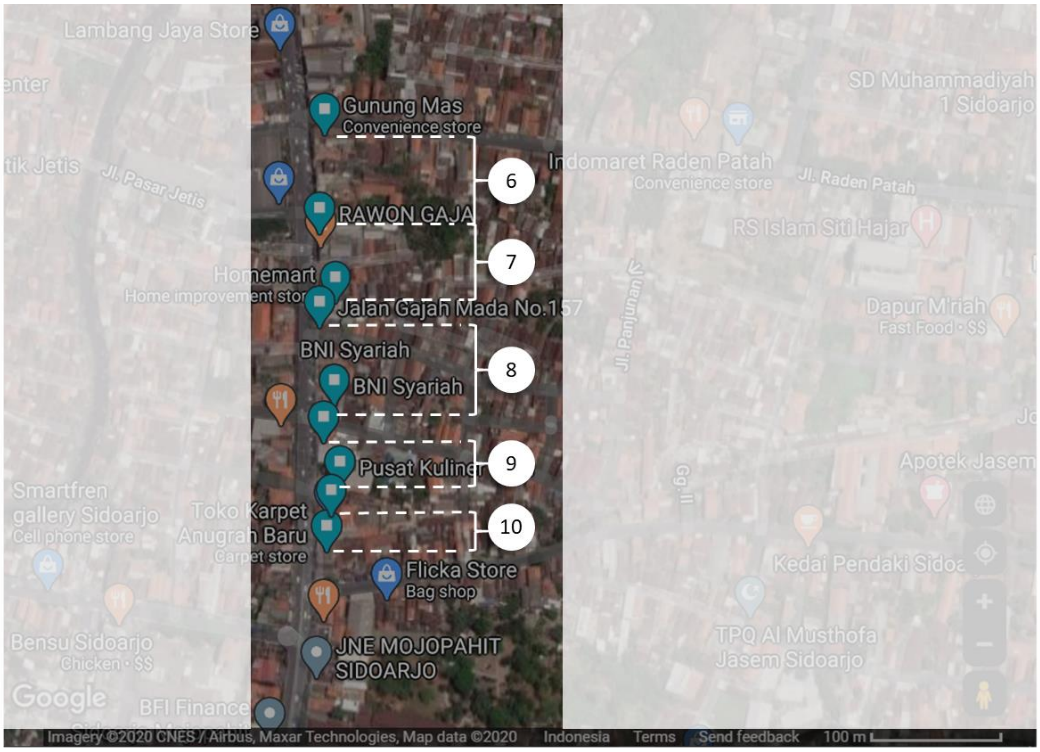


Figure 4.4: Area Division for Block 6 – 10

Figure 4.5 shows the illustration of using area measurement for block 1. The total area will be measured automatically for the selected area. This step is repeated for all the remaining blocks. The compiled result of the building's floor area can be seen in Table 4.4.

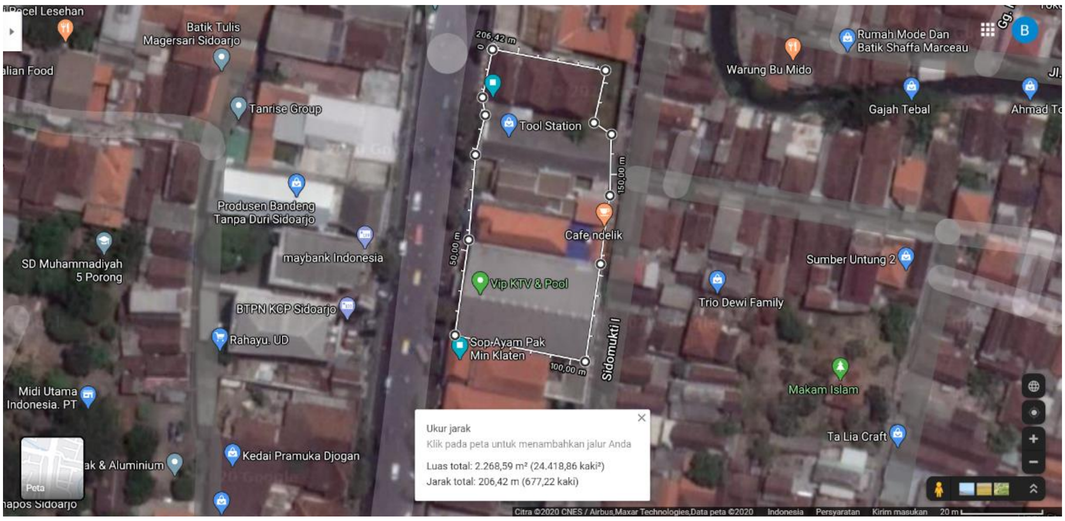


Figure 4.5: Example of Google Maps Area Measurement for Block 1

Source: Google Maps (2020)

Table 4.4 Building's Floor Area for Each Block

Block	Point	Building's Floor Area (m^2)
Block 1	Counter Oppo to KTV & Pool	2268.59
Block 2	Sop Ayam Klaten to RJ Steel	7878.83
Block 3	Jamu Iboe to Seb. Utara Buk Wedi	712.8
Block 4	Toko Sinar Mas to Apotik Pangestu	6842.49
Block 5	Indomaret Gama to Apotek 7	4163.48
Block 6	Tk Gunung Mas to Cwiemie Malang	4251.91
Block 7	Bata to Homemart	1623.33
Block 8	Toko Benang to BNI Syariah	1780.43
Block 9	Toko Nazir to Pusat Kuliner Baru	1322.64
Block 10	Tk Nusantara to Anugrah Baru Karpet	1918.92

Source: Google Maps (2020)

The planning region (SBWP) is defined to obtain the value of the plot ratio required for the individual area. The individual area is the building's floor area multiplied with plot ratio or in Indonesian named as *Koefisien Lantai Bangunan* (KLB). According to Bupati Sidoarjo (2019a), KLB is the percentage of the ratio between the whole area of the building's floor and the owned land area. The entire Gajah Mada street is in three different subdistricts. Table 4.5 shows the subdistrict for each block and the SBWP block. The block is divided into five divisions in Table 4.6, where it also shows the maximum KLB for trade and services area. Thus, the value of 1.2 will be used as the KLB parameter for the optimization model.

Table 4.5 Subdistrict in Gajah Mada Street

Block	Subdistrict	SBWP
1 – 3	Sidokumpul	
4 – 7	Pekauman	C
8 – 10	Bulusidokare	

Source: Bupati Sidoarjo (2019a)

Table 4.6 Maximum KLB Value for Region C

SBWP C Division	Maximum KLB for Trade and Services Area
C1	1.2
C2	1.2
C3	1.2
C4	1.2
C5	1.2

Source: Bupati Sidoarjo (2019a)

4.4.4 Number of Vehicles

The number of vehicles will be used later to obtain the vehicle growth coefficient. Table 4.7 shows the prediction of the number of vehicles from 2018 to 2027. The prediction from PT. Wukir Mahendra Sakti (2018) is based on the available data from 2011 to 2017.

Table 4.7 Prediction of Number of Vehicles

Year	Car	Motorcycle
2018	175,184	908,175
2019	193,263	953,124
2020	213,215	1,000,296
2021	235,226	1,049,804
2022	259,510	1,101,761
2023	286,301	1,156,291
2024	315,858	1,213,519
2025	348,465	1,273,579
2026	384,440	1,336,612
2027	424,128	1,402,765

Source: PT. Wukir Mahendra Sakti (2018)

4.4.5 Proportion of Customer Agree to Use Online Parking

Figure 4.6 shows the result of the study conducted by ITS Tekno Sains (2019). From total of 344 respondents, 59.3% agree to use online parking, 28.5% disagree, and the rest 12.2% are hesitant.

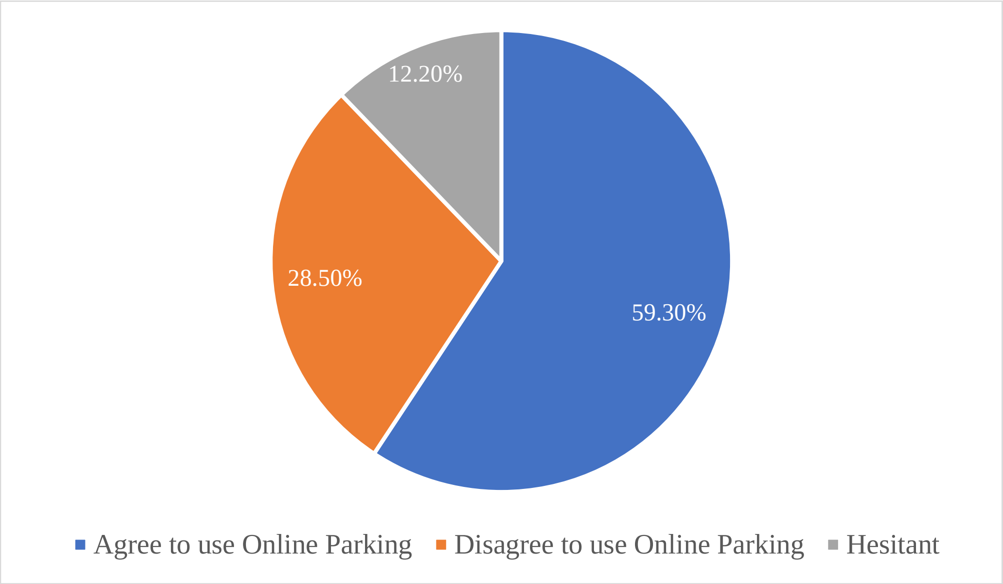


Figure 4.6: Customer Preference for Parking Method

Source: ITS Tekno Sains (2019)

4.4.6 Component for Cost

In this research, the cost is divided into two types, which are the operational and fixed cost. Operational cost is defined as the cost required to run parking on a daily basis and differentiated based on their method (online or offline). There are three cost components included in the operational cost, which are salary for parking officer, supervision cost, and QR scanner cost. The complete value can be seen in Table 4.8.

Table 4.8 Value for Operational Cost Component

Cost Component	Value	Source
Monthly salary for parking officer (based on minimum wage)	Rp 4,200,000	Keputusan Gubernur Jawa Timur Nomor 188/ 568 /KPTS/013/2019 Tentang UMK Jawa Timur Tahun 2020 (Gubernur Jawa Timur, 2019)
Supervision cost	10% of total parking officer salary	ITS Tekno Sains (2019)
QR scanner (only for online parking)	Rp 1,000,000	ITS Tekno Sains (2019)

The value for fixed cost does not depend on the amount of parking lot allocated for each method. The fixed cost consists of three cost components, which are payroll overhead, system development, and administration. Table 4.9 shows the value for each component.

Table 4.9 Value for Fixed Cost Component

Cost Component	Value	Source
Payroll overhead	15% of labor cost	ITS Tekno Sains (2019)
System development	10% of labor cost	ITS Tekno Sains (2019)
Administration	2% of total cost	ITS Tekno Sains (2019)

CHAPTER 5

DATA PROCESSING AND MODEL RUNNING

This chapter will explain the data processing required for each parameter. Those include parking generation rate, utilization rate, growth factor of vehicle, operational cost, initial value determination, also the model running phase that is divided into model verification and model running result.

5.1 Data Processing

This subchapter will describe the calculation done for obtaining parking generation rate, utilization rate, growth factor of vehicle, and operational cost. Also, including the initial value determination for service level and price impact coefficient.

5.1.1 Parking Generation Rate

According to Cheng, Tai, and Ma (2012), Parking Generation Rate (PGR) is the quantity of parking demand generated from land use in each unit area. In this research, land use is mainly for commercial purposes, from the small convenience store to a large department store. The PGR can be calculated by collecting the largest number of vehicles in one day and divided by the building's floor area, as seen in equation (5.1). However, due to the inability to collect primary data, the formula is modified into equation (5.2). The formula assumes that during peak hours, a certain proportion (occupancy rate) of the parking space unit will be occupied. The assumed value is discussed further in subchapter 5.1.5.

$$a_i = \frac{Largest\ number\ of\ vehicle\ in\ one\ day\ (unit)}{Building's\ floor\ area\ (m^2)} \quad (5.1)$$

$$a_i = \frac{Parking\ Space\ Unit\ (SRP) \times Occupancy\ Rate\ (\%)}{Building's\ floor\ area\ (m^2)} \quad (5.2)$$

Index:

i : unit area

$i = 1, 2, \dots, n$ (n: number of the unit area)

Where:

a_i : parking generation rates

Table 5.1 and Table 5.2 shows the PGR calculation for car and motorcycle, respectively. The calculation uses initial condition where during peak hour, all the parking space unit is fully occupied. Other occupancy rate values will be discussed in the sensitivity analysis. The calculation is conducted using equation (5.2). The parking space unit (SRP) is multiplied by occupancy rate, then divided by the building's floor area (per 100 m^2).

Table 5.1 PGR Calculation for Car

Block	**SRP**	**Floor Area**	**Plot Ratio (*Koefisien Lantai Bangunan*)**	**Ri (Individual Area)**	**Ai (Total Number of Parking)**	**PGR (every 100 m^2)**
Block 1	31	2268.59	1.2	27.22308	62	1.366488
Block 2	76	7878.83	1.2	94.54596	87	0.96461
Block 3	12	712.8	1.2	8.5536	26	1.683502
Block 4	34	6842.49	1.2	82.10988	69	0.496895
Block 5	43	4163.48	1.2	49.96176	84	1.03279
Block 6	27	4251.91	1.2	51.02292	54	0.635009
Block 7	25	1623.33	1.2	19.47996	50	1.540044
Block 8	32	1780.43	1.2	21.36516	63	1.797319
Block 9	15	1322.64	1.2	15.87168	30	1.134095
Block 10	18	1918.92	1.2	23.02704	36	0.938028

Table 5.2 PGR Calculation for Motorcycle

Block	**SRP**	**Floor Area**	**Plot Ratio (*Koefisien Lantai Bangunan*)**	**Ri (Individual Area)**	**Ai (Total Number of Parking)**	**PGR (every 100 m^2)**
Block 1	105	2268.59	1.2	27.22308	110	4.628426
Block 2	255	7878.83	1.2	94.54596	300	3.236521
Block 3	33	712.8	1.2	8.5536	66	4.62963
Block 4	112	6842.49	1.2	82.10988	132	1.636831
Block 5	144	4163.48	1.2	49.96176	200	3.458645
Block 6	91	4251.91	1.2	51.02292	167	2.140215
Block 7	83	1623.33	1.2	19.47996	161	5.112947
Block 8	107	1780.43	1.2	21.36516	110	6.009784
Block 9	51	1322.64	1.2	15.87168	102	3.855925
Block 10	60	1918.92	1.2	23.02704	120	3.126759

5.1.2 Utilization Rate

The utilization rate indicates the usage of each parking lot during the whole operating hour. The utilization rate is considered as a parameter in this early period of project implementation. The number of parking lot is assumed to follow the existing condition with no dynamic change. This adjustment ensures that during the trial period, the project is not too complex. According to Sahin (2006), too complicated innovation will not be quickly adopted by the community. It is possible that in the future, the number of parking lot allocated is adjustable. The utilization rate is calculated by dividing the arrival rate of the vehicle with the average slot usage. Equation (5.3) and (5.4) shows the formula for calculating the utilization rate. First, the total number of parking in one day is divided by the parking space unit to obtain the arrival rate of the vehicle. Then, the total operating hour (16 hours) is divided into the maximum duration of parking (8 hours). The arrival rate of the vehicle is divided with average slot usage to obtain utilization rate.

$$\gamma_i = \frac{Arrival\ rate\ of\ vehicle\ (unit\ per\ slot\ per\ day)}{Average\ slot\ usage\ (per\ day)} \tag{5.3}$$

$$\gamma_i = \frac{\frac{Total\ num\ of\ parking\ (one\ day)}{SRP}}{\frac{Total\ operating\ duration\ (hour)}{Maximum\ duration\ of\ parking\ (hour)}} \tag{5.4}$$

Where:

γ_i : utilization rate

Table 5.3 Calculation of Utilization Rate

Block	SRP		Total Number of Parking		Utilization Rate	
	CAR	MOT	CAR	MOT	CAR	MOT
1	31	105	62	110	1.000	0.524
2	76	255	87	300	0.572	0.588
3	12	33	26	66	1.083	1.000
4	34	112	69	132	1.015	0.589
5	43	144	84	200	0.977	0.694
6	27	91	54	167	1.000	0.918
7	25	83	50	161	1.000	0.970
8	32	107	63	110	0.984	0.514
9	15	51	30	102	1.000	1.000
10	18	60	36	120	1.000	1.000

5.1.3 Growth Factor of Vehicle

The prediction number of vehicles is used to calculate the growth factor of the vehicle. This coefficient is used to move the forecast from the parking generation rate to be applicable in a different year. In this research, the parking data used originated from 2018. Using this coefficient, the parking demand forecast for the upcoming year can still be calculated. Each year will have a different value of beta, as it compares the number of vehicles in the future year and the number of vehicles in the base year, as shown in equation (5.5).

$$\beta = \frac{Number\ of\ vehicle\ in\ future\ year\ (unit)}{Number\ of\ vehicle\ in\ base\ year\ (unit)} \tag{5.5}$$

Where:

β : growth coefficients of motor vehicles

The calculation result for car and motorcycle can be seen in Table 5.4 and Table 5.5, respectively.

Table 5.4 Growth Factor of Vehicle for Car

Year	**Number of Vehicle**	β
2018	175,184	1.00
2019	193,263	1.10
2020	213,215	1.22
2021	235,226	1.34
2022	259,510	1.48
2023	286,301	1.63
2024	315,858	1.80
2025	348,465	1.99
2026	384,440	2.19
2027	424,128	2.42

Table 5.5 Growth Factor of Vehicle for Motorcycle

Year	Number of Vehicle	β
2018	908,175	1.00
2019	953,124	1.05
2020	1,000,296	1.10
2021	1,049,804	1.16
2022	1,101,761	1.21
2023	1,156,291	1.27
2024	1,213,519	1.34
2025	1,273,579	1.40
2026	1,336,612	1.47
2027	1,402,765	1.54

5.1.4 Operational Cost

In this research, operational cost is the amount of money required for one parking transaction. Therefore, it is divided into the operational cost for online and offline, that later be divided further into car and motorcycle. For this calculation, the number of working days in a year is set to be 300 days.

The calculation for operational cost begins by determining the number of workers in each block. As can be seen in Table 5.6, the new worker is proportional to the area of parking in each block. Thus, the total operational cost for online and offline parking can be calculated. Each worker has a salary based on regional minimum wage, along with the supervision cost, for both online and offline parking. However, for the QR scanner, the cost is only assigned for online parking, as they need it to execute the digital parking procedures. Then, the cost per day can be obtained. Table 5.9 shows the calculation for cost per transaction for online and offline parking. The cost per day is divided into the total area to obtain the cost per meter square. The cost per meter square is multiplied with the standard parking area for one unit of car and motorcycle, which are 11.5 m^2 and 1.5 m^2. Then, it is divided with the average usage (based on the average usage in utilization rate). Finally, the cost per transaction is obtained.

Table 5.6 Number of Worker Assigned for Each Block

Block	Car	Motorcycle	Total Area	Worker Initial (Survey Result)	Area Covered by One Worker	Worker New (Proportional to Area)	Online	Offline
1	31	105	514.00	3	250 m^2	2	1	1
2	76	255	1256.50	4		5	3	2
3	12	33	187.50	1		1	1	0
4	34	112	559.00	3		2	1	1
5	43	144	710.50	4		3	2	1
6	27	91	447.00	3		2	1	1
7	25	83	412.00	2		2	1	1
8	32	107	528.50	3		2	1	1
9	15	51	249.00	2		1	1	0
10	18	60	297.00	2		1	1	0
	313.00	1041.00	5161.00	27		21	13	8

Table 5.7 Operational Cost for Online Parking

No.	Component	Unit Cost	Quantity	Period	Total
1	Parking officer salary (monthly)	Rp 4,200,000	13	12	Rp 655,200,000
2	Supervision (10% of salary)	Rp 65,520,000	1	1	Rp 65,520,000
3	QR Scanner	Rp 1,000,000	13	1	Rp 13,000,000
				TOTAL	Rp 733,720,000
				Cost per Day	**Rp 2,445,733**

Table 5.8 Operational Cost for Offline Parking

No.	Component	Unit Cost	Quantity	Period	Total
1	Parking officer salary (monthly)	Rp 4,200,000	8	12	Rp 403,200,000
2	Supervision (10% of salary)	Rp 40,320,000	1	1	Rp 40,320,000
				TOTAL	Rp 443,520,000
				Cost per Day	**Rp 1,478,400**

Table 5.9 Cost per Transaction for Online and Offline Parking

Component		Online	Offline
Cost per day		Rp 2,445,733	Rp 1,478,400
Parking space unit - car	313		
Parking space unit - motorcycle	1041		
Area - car	11.50		
Area - motorcycle	1.50		
Total Area (m2)		5161	5161
Cost / m2		Rp 473.89	Rp 286.46
Cost - Car		Rp 5,449.71	Rp 3,294.25
Cost - Motorcycle		Rp 710.83	Rp 429.68
Average usage	2		
Cost - Car per transaction		Rp 2,724.85	Rp 1,647.12
Cost - Motorcycle per transaction		Rp 355.42	Rp 214.84

5.1.5 Initial Value Determination for Assumed Parameters

In this research, some parameters set using assumptions. The parameters include the occupancy rate, service level, price impact coefficient, and leakage for offline parking. Each of the parameters has different value as shown in

Table 5.10 followed with different reasoning.

Table 5.10 Initial Value for Assumed Parameters

Parameter	Value
Occupancy Rate (at peak hour)	1
Service Level	0.8
Price Impact Coefficient	0.9
Leakage for Offline Parking	0.5

The occupancy rate is used as one of the inputs in determining parking generation rate. Initially, the required data is the number of parking units filled during peak hours, but since the data is not available and it is not possible to do a direct observation, this parameter is assumed. The value assumes that during peak hours, the parking lot will be fully occupied. For service level, the value is assumed because this project is currently listed as a pilot project. Therefore it is not possible to obtain the data from the community. The value of 0.8 is obtained as an expert judgment from Mr. Erwin Widodo, who is involved directly in the project. For the price impact coefficient, the value is obtained from Cheng, Tai, and Ma (2012) as it has similar conditions with the observed object, where the parking fee does not really impact the parking demand. Previously, it is known that offline parking is prone to income leakage. Based on the data from PT. Wukir Mahendra Sakti (2018), in 2018, the actual income received by the local government is only 27.5% of the total potential. Alternatively, in other words, there is a possibility that 72.5% of the income is gone or considered as leakage. Thus, it is expected that during the early period of this project, the leakage for offline parking can be reduced to 50%. All these assumed parameters will be analyzed using sensitivity analysis.

5.2 Model Running

The optimization model in LINGO is made based on the integer programming model. The model is ran using LINGO 11 version.

5.2.1 *Model Verification*

Model verification is done using a built-in feature in LINGO. It is done to check whether the expanded model is run as expected. Also, it can be useful to check if there is an error in the model. Figure 5.1 shows an example of an error that can occur while running the model in LINGO. When such error occurred, the modeler must check the code, especially near the line of indicated error. Then, check again if there still an error in the model.

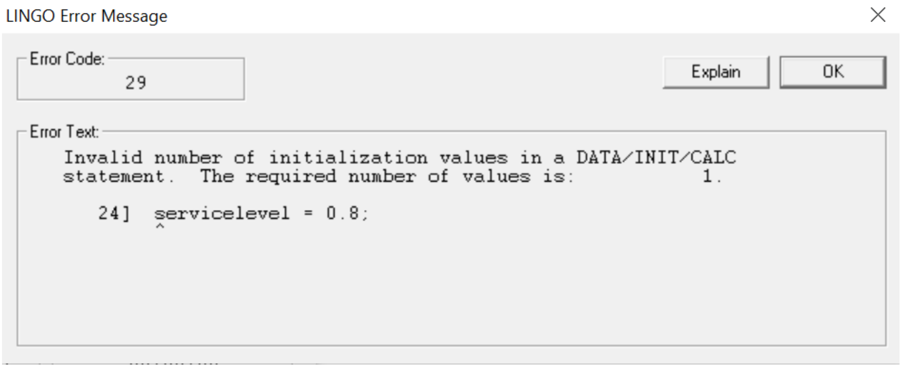


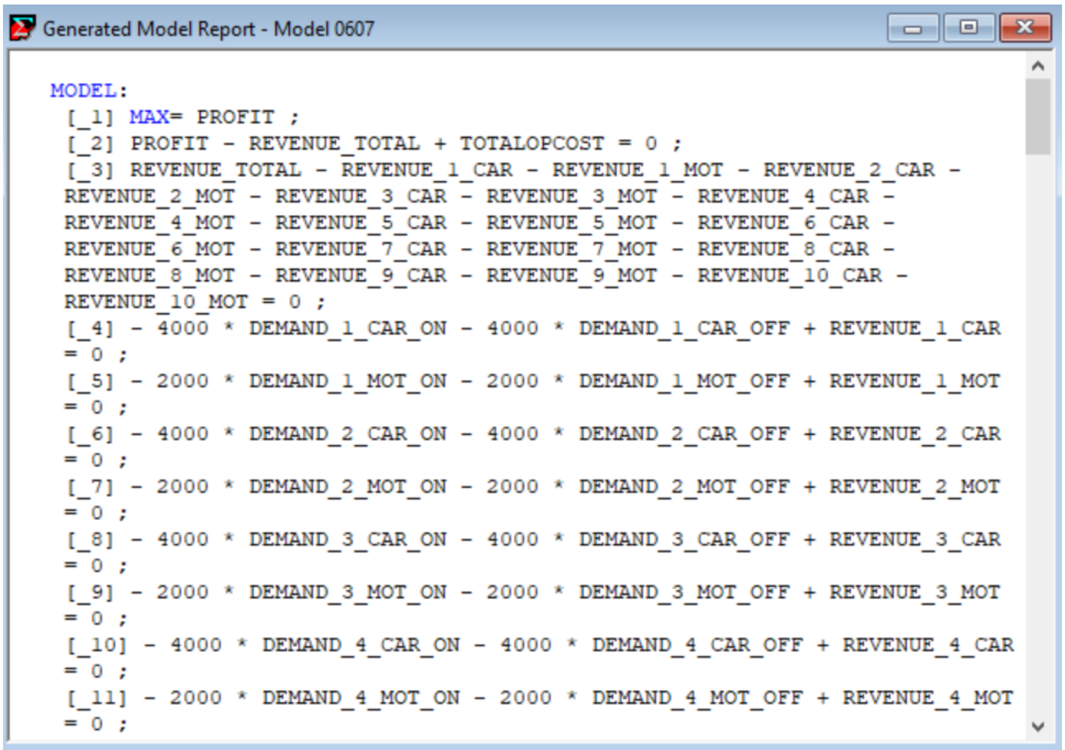
Figure 5.1: Example of Error in Lingo

If there is no error in the model, then it can be proceeded to check the expanded model. The expanded model is used to check if the 'sets' created, as in Figure 5.2, correspond with the mathematical model intended by the modeler. Figure 5.3 shows the partially generated model report. If the generated model report already appears, it indicates that there is no syntax error in the model.

```
sets:
block/1..10/: floorarea, indarea;
vehicle/car, mot/: parkingfee, cgrowth, percent_allocation;
method/on, off/: teta, leakage;
link1(block, vehicle): PGR, totalparking, coef, utilrate, totallot, opcost, costallocation, revenue;
link2(block, vehicle, method): lot, demand;
link3(vehicle, method): cmethod, cost;
!index: i block,
j vehicle j=1 car, j=2 motorcycle,
k method k=1 online, k=2 offline;
endsets
```

Figure 5.2: Sets for Lingo Model

According to LINDO Systems Inc. (2016), there are two types of sets in LINGO, which are primitive and derived sets. As in Figure 5.2, this research applied three primitive sets, which are block, vehicle, and method, and three derived sets, which are link1 to link3. For illustration, the variable ‘revenue’ in link1 connects the set of ‘block’ and ‘vehicle’. Then after generating the expanded model, there are 20 variables for revenue. Figure 5.3 shows that ‘revenue_total’ is a sum of ‘revenue_1_car’ to ‘revenue_10_mot’. The number refers to the block (1 – 10), while the term ‘car’ and ‘mot’ indicates the type of vehicle (car and motorcycle). This step is repeated for other variables. After the model passes verification, the modeler can proceed to run the model.


Generated Model Report - Model 0607

```
MODEL:
 [_1] MAX= PROFIT ;
 [_2] PROFIT - REVENUE_TOTAL + TOTALOPCOST = 0 ;
 [_3] REVENUE_TOTAL - REVENUE_1_CAR - REVENUE_1_MOT - REVENUE_2_CAR -
 REVENUE_2_MOT - REVENUE_3_CAR - REVENUE_3_MOT - REVENUE_4_CAR -
 REVENUE_4_MOT - REVENUE_5_CAR - REVENUE_5_MOT - REVENUE_6_CAR -
 REVENUE_6_MOT - REVENUE_7_CAR - REVENUE_7_MOT - REVENUE_8_CAR -
 REVENUE_8_MOT - REVENUE_9_CAR - REVENUE_9_MOT - REVENUE_10_CAR -
 REVENUE_10_MOT = 0 ;
 [_4] - 4000 * DEMAND_1_CAR_ON - 4000 * DEMAND_1_CAR_OFF + REVENUE_1_CAR
 = 0 ;
 [_5] - 2000 * DEMAND_1_MOT_ON - 2000 * DEMAND_1_MOT_OFF + REVENUE_1_MOT
 = 0 ;
 [_6] - 4000 * DEMAND_2_CAR_ON - 4000 * DEMAND_2_CAR_OFF + REVENUE_2_CAR
 = 0 ;
 [_7] - 2000 * DEMAND_2_MOT_ON - 2000 * DEMAND_2_MOT_OFF + REVENUE_2_MOT
 = 0 ;
 [_8] - 4000 * DEMAND_3_CAR_ON - 4000 * DEMAND_3_CAR_OFF + REVENUE_3_CAR
 = 0 ;
 [_9] - 2000 * DEMAND_3_MOT_ON - 2000 * DEMAND_3_MOT_OFF + REVENUE_3_MOT
 = 0 ;
 [_10] - 4000 * DEMAND_4_CAR_ON - 4000 * DEMAND_4_CAR_OFF + REVENUE_4_CAR
 = 0 ;
 [_11] - 2000 * DEMAND_4_MOT_ON - 2000 * DEMAND_4_MOT_OFF + REVENUE_4_MOT
 = 0 ;
```

Figure 5.3: Generated Model Report

5.2.2 *Model Running Result*

Model running can be conducted after the model passes the verification. Figure 5.4 shows the solver status when running is done in LINGO. The model class shows ILP as an abbreviation for Integer Linear Programming. The state indicates that the solution found is global optimal. According to LINDO Systems Inc. (2016), a global optimal solution is a feasible solution with the objective value that is as good or better than all other feasible solutions. The objective presents the best solution found for the objective function. In this case, the objective function is to maximize profit. Therefore, the value shown is the profit. The solver type indicates the method used to solve the optimization problem. This problem is solved using B-and-B, which are the abbreviation for Branch-and-Bound. The B-and-B method has been discussed previously in subchapter 2.4.2, as it is a common method to solve integer programming problems. From Figure 5.5, the profit obtained from the model can be seen, which is Rp2,234,084 per day.

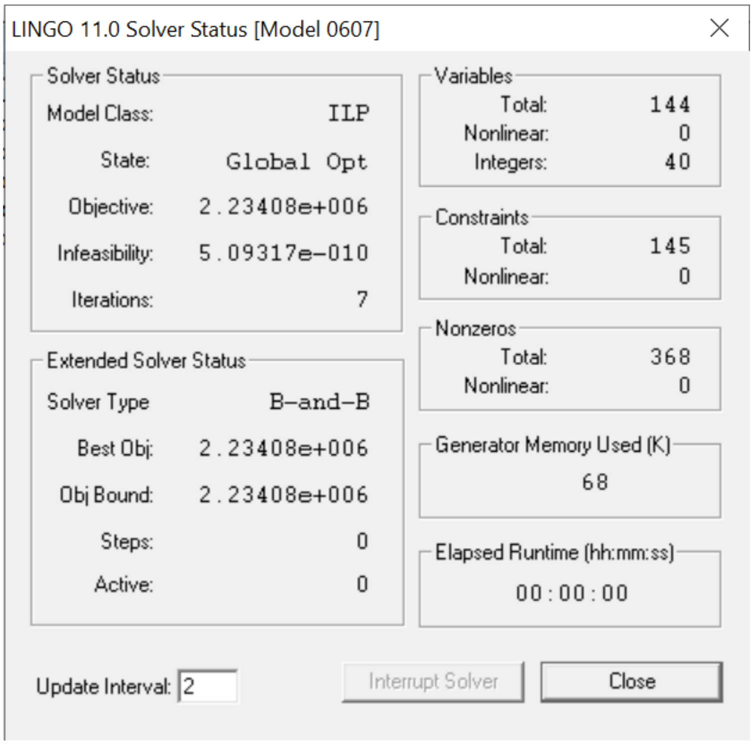


Figure 5.4: Solver Status in LINGO

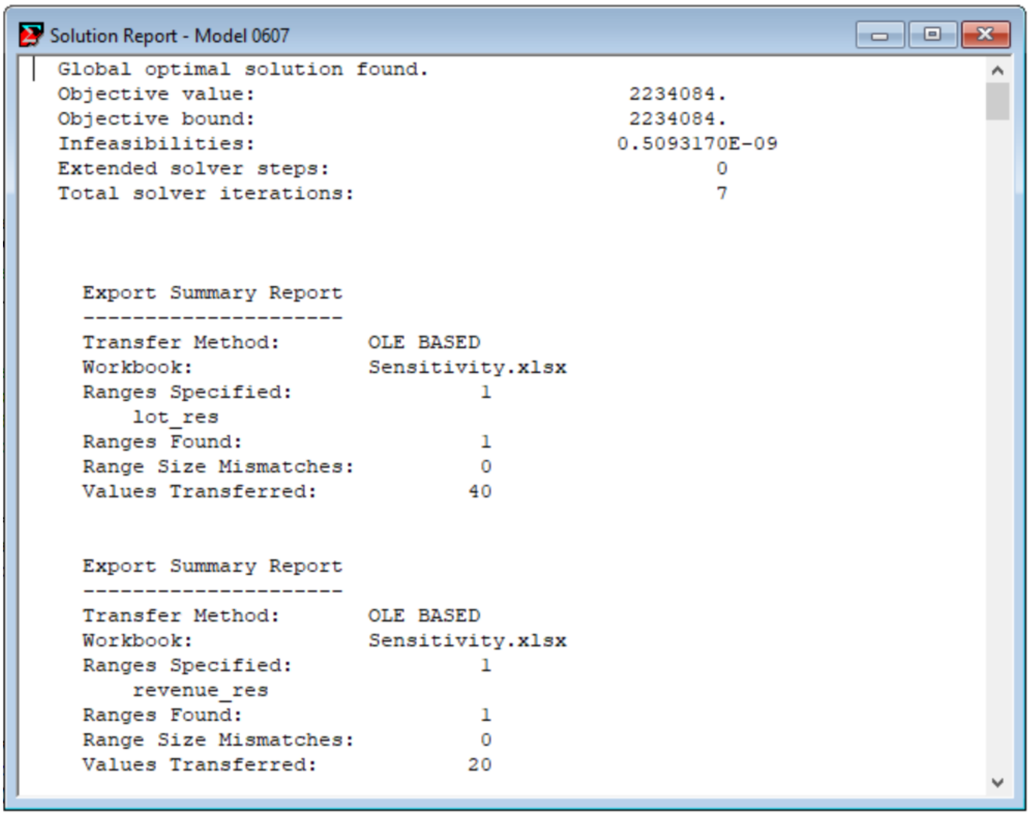


Figure 5.5: Partial Solution Report in LINGO

Table 5.11 Compiled Result of Model Running

Block	Car		Motorcycle		Offline %	
	Online	Offline	Online	Offline	Car	Motorcycle
1	23	8	82	23	25.81%	21.90%
2	58	18	199	56	23.68%	21.96%
3	9	3	25	8	25.00%	24.24%
4	26	8	87	25	23.53%	22.32%
5	33	10	112	32	23.26%	22.22%
6	20	7	71	20	25.93%	21.98%
7	19	6	64	19	24.00%	22.89%
8	24	8	83	24	25.00%	22.43%
9	11	4	39	12	26.67%	23.53%
10	13	5	46	14	27.78%	23.33%
	236	77	808	233	25.06%	22.68%

Table 5.11 shows the exported result of the model running for all blocks. In block 1, there are 8 car parking lot and 23 motorcycle parking lot allocated for offline parking. For the proportion, it is obtained by dividing the number of offline parking lot, with the total parking lot. In average, car has 25.06% parking lot

allocated for offline, and motorcycle has 22.68% for offline. Figure 5.6 and Figure 5.7 present the offline proportion for car and motorcycle in pie chart.

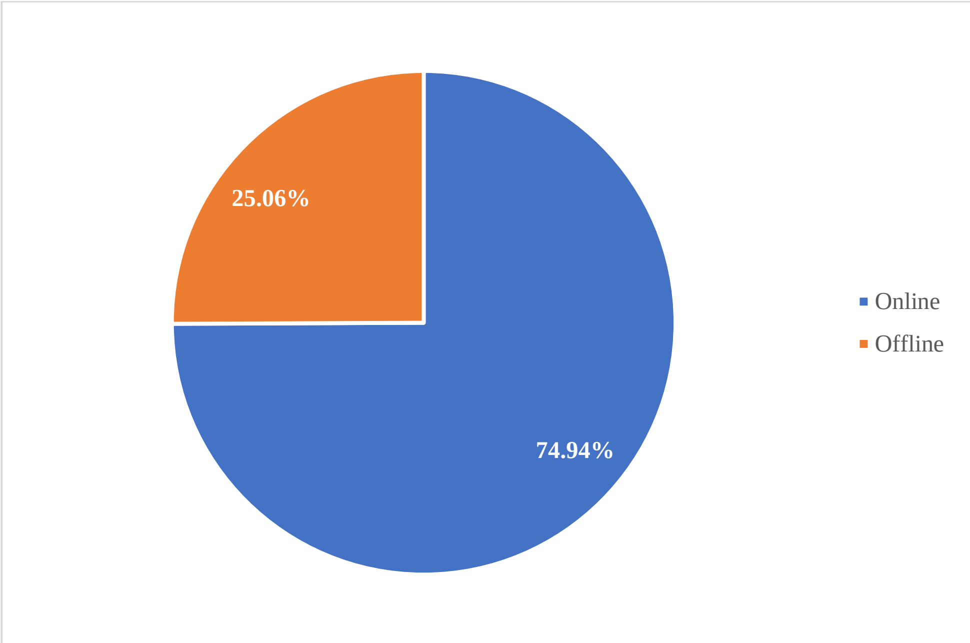


Figure 5.6: Proportion for Car

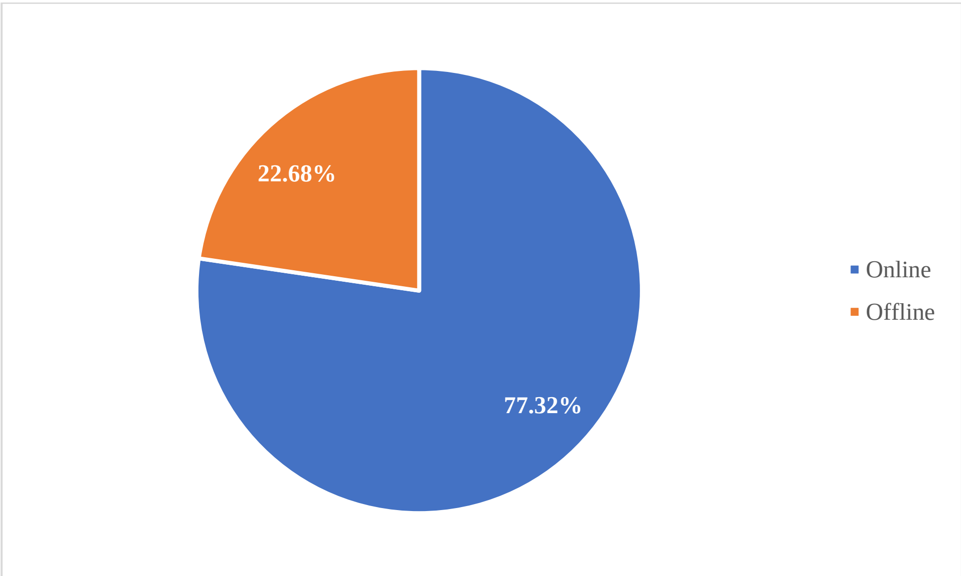


Figure 5.7: Proportion for Motorcycle

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CHAPTER 6
ANALYSIS AND INTERPRETATION

This chapter will explain the analysis and interpretation of the result of the research, including the analysis of optimization model running results, and the sensitivity analysis. The sensitivity analysis is applied to occupancy rate, parking service level, price impact coefficient, customer's preference coefficient, and leakage.

6.1 Analysis of Optimization Model Running Result

The purpose of the optimization model is to obtain the optimal proportion of online and offline parking lot for both cars and motorcycles. The optimality is represented using profit as a performance measure. According to Manser (2010), to create higher value for consumers, firms continually searching for strategies and tactics that will maximize profit. To achieve that, one approach that can be implemented is using process innovation. In this research, the form of process innovation is changing the way parking is given to the customer by using a mobile application. Sadati *et al.* (2017) and Anand, Narang, and Dhillon (2018) also used profit maximization as the goal in their optimization study. Therefore, it can be said that profit maximization is an appropriate performance measure to be implemented. In this research, profit is obtained from subtracting the total cost from total revenue. From the model, the profit obtained is Rp2,234,084 for each day. Assuming 300 working days in a year, from Gajah Mada street only, the profit that will be received by the government of Sidoarjo is Rp670,225,200. As a comparison, according to the data from PT. Spon Technology (2018), Gajah Mada street covers approximately 16% of parking space unit for Sidoarjo sub-district and 5% for all Sidoarjo regency.

After running the model, known that the average offline proportion for car and motorcycle is 25.06% and 22.68%. The proportion for car ranged from 23.26% to 27.78%, and motorcycle ranged from 21.90% to 24.24%. Giving allowance for the conventional or old way is a good step for implementing a pilot project. This applies when people are required to shift to a new method, in this context, shifting from conventional to digital parking. According to LaMorte (2016), adoption of a new idea, behavior, or product (innovation) does not happen simultaneously. It is a process where some people can adapt faster to innovation than others. In this research, the 59.3% of respondents who agreed to use online parking might be those who can adapt faster to changes than the rest 40.7% who either still hesitant or disagree with the new system.

From the result, the offline proportion for the car is slightly larger compared to the offline proportion for a motorcycle. Based on ITS Tekno Sains (2019), motorcycle dominates the result for the most frequent type of vehicle used by 85%, followed by car in 14%, and other vehicles by 1%. However, the result of the study by ITS Tekno Sains (2019) also shows that statistically, there is no link between the type of vehicle and the decision to agree or disagree with online parking implementation. Therefore, there is no proof that the type of vehicles determines the preference of using online or offline parking.

Table 6.1 Scenario for Cost Allocation

Scenario	Allocation (CAR)	Allocation (MOT)	Average Offline % (CAR)	Average Offline % (MOT)	Profit (Annual)
1	0.45	0.13	95.03%	83.43%	Rp 358,708,900
2	0.45	0.15	95.03%	60.10%	Rp 470,301,100
3	0.45	0.17	95.03%	22.68%	Rp 651,106,600
4	0.5	0.13	83.97%	83.43%	Rp 361,644,100
5	0.5	0.15	83.97%	60.10%	Rp 473,236,300
6	0.5	0.17	83.97%	22.68%	Rp 654,041,800
7	0.55	0.13	71.14%	83.43%	Rp 365,419,600
8	0.55	0.15	71.14%	60.10%	Rp 477,011,800
9	0.55	0.17	71.14%	22.68%	Rp 657,817,000
10	0.6	0.13	51.00%	83.43%	Rp 370,646,800
11	0.6	0.15	51.00%	60.10%	Rp 482,238,700
12	0.6	0.17	51.00%	22.68%	Rp 663,044,500
13	0.65	0.13	25.06%	83.43%	Rp 377,827,600
14	0.65	0.15	25.06%	60.10%	Rp 489,419,800
15	0.65	0.17	25.06%	22.68%	Rp 670,225,300
16	0.7	0.13	0.00%	83.43%	Rp 384,473,800
17	0.7	0.15	0.00%	60.10%	Rp 496,066,000
18	0.7	0.17	0.00%	22.68%	Rp 676,871,500

The number for proportion is a result of taking account of the parameters into the model. One of the parameters used is cost, that consists of operational and fixed cost. For the operational cost, each block has a different amount of cost allocated based on the number parking space unit. Cost allocation is obtained by multiplying the coefficient of cost allocation with the revenue. Table 6.1 shows the different value of cost allocation for car and motorcycle and the resulted outcome for offline proportion and annual profit. The number under the cost allocation column comes from the ratio between operational cost and parking fee. The range value will be shown in the attachment. The green blocks show the top 20% profit, and it is obtained by using scenario 12, 15, and 18. Scenario 18 generates the largest profit compared to another scenario. However, it resulted in 0% for offline car parking. This means that there is no parking lot allocated for offline parking. As mentioned previously, according to LaMorte (2016), the process of adapting to innovation is not simultaneous but a process. Therefore, applying an extreme change as totally removing conventional parking is not recommended.

According to Rogers (2003), as cited in Sahin (2006), the process of seeking and processing information, where an individual is learning the advantages and disadvantages of innovation, is called the innovation-decision process. The process consists of five steps: knowledge, persuasion, decision, implementation, and confirmation. Therefore, it requires time to make the community to accept the innovation fully. Rogers (2003) also classifies adopter categories into five categories, based on the speed of adapting to new ideas. The categories are divided to innovators, early adopters, early majority, late majority, and laggards. Innovators are the fastest to adopt since they were willing to experience new ideas, while laggards are those who are more skeptical about innovations. These categories are most likely also applicable for people in Sidoarjo. Based on these theories, it is recommended for the government to acknowledge the community first to ensure they understand the advantages of digital parking, and finally make them adapt to the innovation.

For the early period of implementation, the government may still give allowance for conventional parking. Therefore, for this time, scenario 15 is the best as it still provides an allowance for offline parking, yet still gives a large profit in return. In the long run, the government might consider reducing the offline proportion to obtain more profit, as well as enhancing the parking experience for the community. This can be done by increasing the cost allocation, as illustrated in Table 6.1.

6.2 Sensitivity Analysis

An essential step after finishing the primary analysis of the model is to test the assumptions used in the study. According to Salciccioli, Crutain, and Komorowski (2016), sensitivity analysis and model validation are related as they both attempt to determine whether a particular model specification is appropriate, and also to know the strength of conclusions drawn from the model. Ideally, model validation is done by checking if the model fits within a specific research dataset. However, since the object of the research is still a pilot project, a real dataset is not available to do external validation. Therefore, sensitivity analysis is used to check all possibilities that can occur in the real system. Furthermore, sensitivity analysis is done to check parameters that are subjectively assumed in the study. Figure 6.1 and Table 6.2 shows the profit sensitivity analysis accumulated for one year, in graphical and tabular form. The explanation will be discussed further in this subchapter.

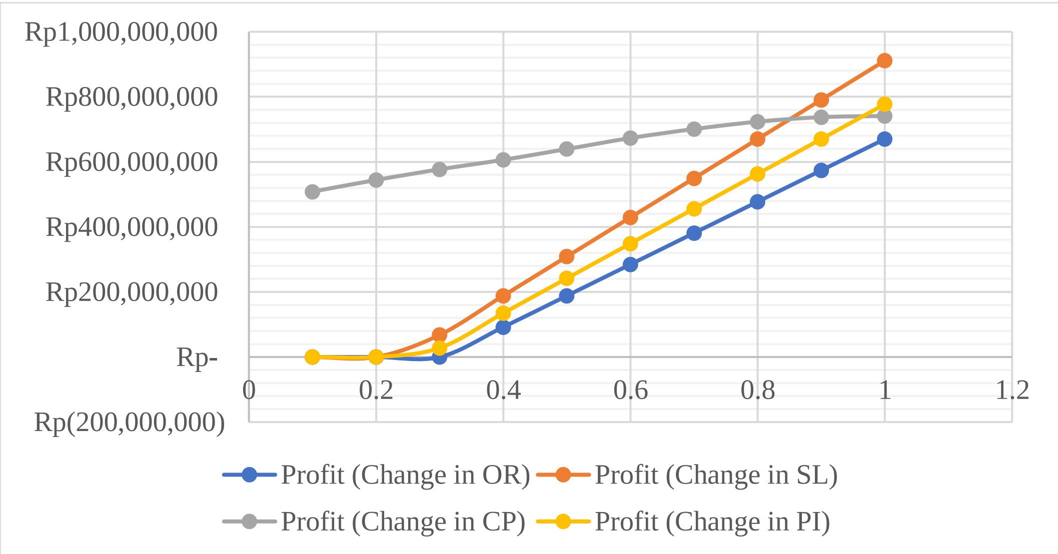

Figure 6.1: Profit Sensitivity Analysis for One Year

Table 6.2 Heatmap for Profit Sensitivity Analysis

Coefficient Value	Profit (Change in OR)	Profit (Change in SL)	Profit (Change in CP)	Profit (Change in PI)
0.1	No feasible solution	No feasible solution	Rp 508,414,800	No feasible solution
0.2	No feasible solution	No feasible solution	Rp 544,353,600	No feasible solution
0.3	No feasible solution	Rp 67,936,500	Rp 577,069,500	Rp 27,783,900
0.4	Rp 92,028,000	Rp 188,394,000	Rp 606,299,100	Rp 134,857,200
0.5	Rp 188,394,000	Rp 308,852,100	Rp 639,492,900	Rp 241,930,800
0.6	Rp 284,760,300	Rp 429,309,900	Rp 673,271,700	Rp 349,004,700
0.7	Rp 381,126,600	Rp 549,767,700	Rp 700,895,100	Rp 456,078,300
0.8	Rp 477,492,900	Rp 670,225,200	Rp 723,538,500	Rp 563,151,900
0.9	Rp 573,859,200	Rp 790,683,000	Rp 737,475,300	Rp 670,225,200
1	Rp 670,225,200	Rp 911,140,800	Rp 741,103,800	Rp 777,298,800

6.2.1 Sensitivity Analysis for Occupancy Rate

In this research context, the occupancy rate differs from the utilization rate. The occupancy rate is the rate of parking lot usage limited to only during peak hours. Initially, based on Cheng, Tai, and Ma (2012), the parking generation rate requires the largest number of vehicles in one day. Nevertheless, due to the situation, it is not possible to obtain secondary or primary data. Therefore the assumption is used. Occupancy rate value equals to 1 means that during peak hour, all parking space is occupied. Value less than one means that not all parking space is occupied.

For this research, the initial assumption used is 1. The determination considers the fact that according to Kominfo (2019), Gajah Mada street is one of Major Arterial Roads in Sidoarjo regency. Sometimes, the road has congestion. Figure 6.2 shows an example of the traffic condition in Gajah Mada street at two different times. The first picture shows the condition on Saturday, at 08.00 AM, with no traffic congestion. Meanwhile, the second picture shows the condition on the same day, 08.00 PM, with moderate congestion that caused more extended trip estimation. Therefore, it is assumed that during peak hours, where congestion most likely to occur, the parking lot is fully occupied.

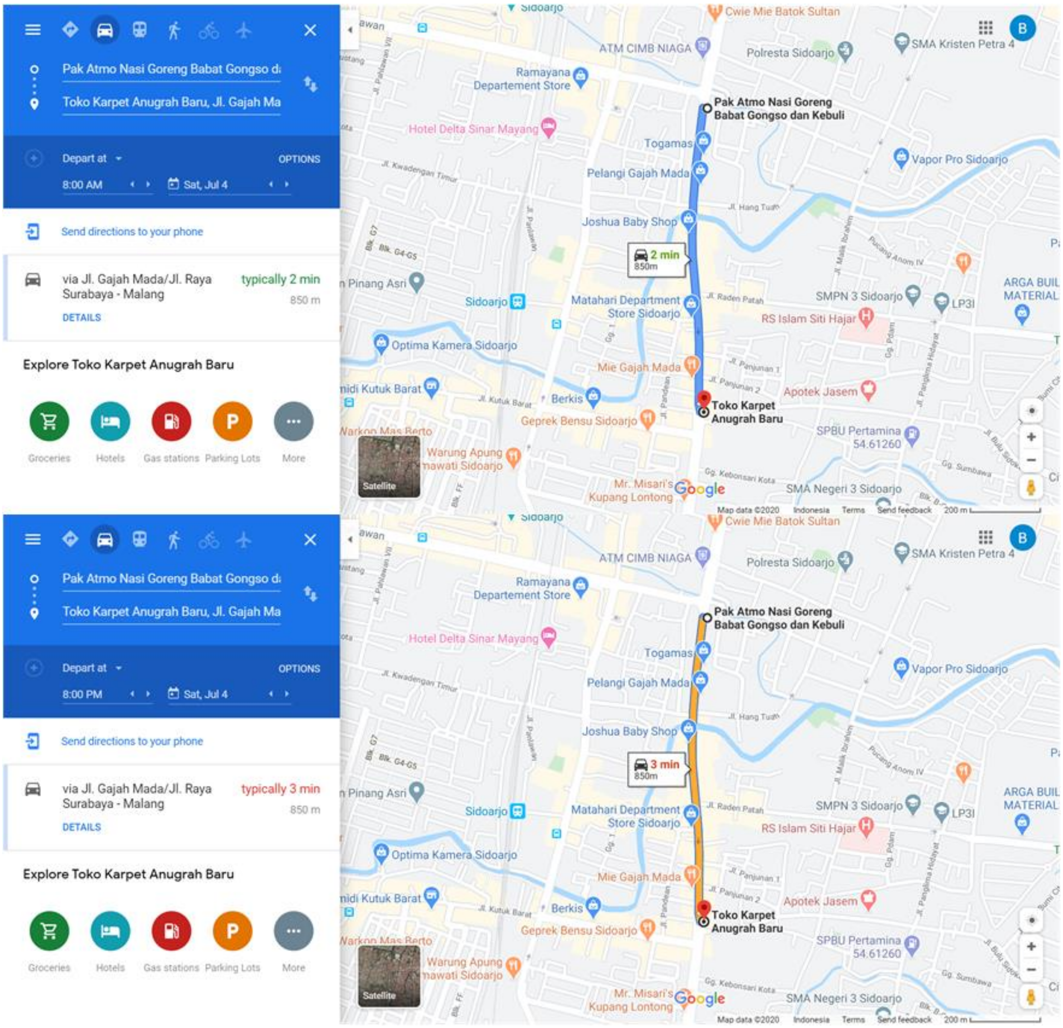

Figure 6.2: Comparison of Traffic Condition in Gajah Mada Street

As shown in Figure 6.1, changes in occupancy rate give the lowest profit value compared to other parameters. Other parameters in lower value achieve the same amount of profit. For example, when the occupancy rate value equals 1, the profit is similar to the service level value of 0.8 and the price impact coefficient value of 0.9. Also, other parameters in the same coefficient value can reach a higher profit if compared to the occupancy rate. In addition, the occupancy rate in peak hours is an uncontrollable variable. Therefore, the government shall put more consideration into the other parameters. Das and Ahmed (2018) state that understanding the level of service in on-street parking is essential to modify an existing parking system.

6.2.2 Sensitivity Analysis for Parking Service Level

Past researches have been studying the service level or level of service in a parking facility. Yulong He *et al.* (2015) states that parking facility service evaluations have an essential role in the planning and operation of urban transportation. In the paper, LOS (level of service) is introduced, where the model reflects the user's perception of the quality of the service. It uses four service variables and put it into one single index to quantitatively evaluate the parking facility. Das and Ahmed (2018) discuss the estimation of LOS, specifically for on-street parking. They calculate the LOS by considering parking characteristics, safety characteristic, and design characteristic. Both studies imply that service level is an important component to achieve an efficient parking service.

Figure 6.1 shows that the service level has the largest impact to profit. Compared to other parameters, changes in the value of service level caused the steepest line, resulting in a larger profit. When all parameters are set to 1, the service level has the highest profit. As shown in Table 6.2, the annual profit value due to change in service level is Rp911,140,800, while the change in occupancy rate only gives Rp670,225,200. The difference between the two reaches Rp240,915,600. This indicates that the service level is an important thing to be considered while developing a parking system. According to Das and Ahmed (2018), understanding the service quality of on-street parking is essential before modifying an existing parking system. Also, to refer to one of the main objectives of the government of Sidoarjo in implementing digital parking is to improve the parking service level to the community.

Implementation of smart parking to improve parking service has been discussed in previous researches. Doulamis, Protopapadakis and Lambrinos (2013) proposed an intelligent parking reservation using interval scheduling algorithms and aim to improve service quality for the drivers while increasing parking lot utilization. Paidi *et al.* (2018) review smart parking sensors, technologies, and application suitability at open parking lots. They found that a combination of smart parking technologies and sensors can be used to improve parking behavior efficiency. The studies suggest that smart parking, as the government of Sidoarjo planned to implement, requires thorough planning for the execution. As seen in

Table 6.2, if the government desires a profit of at least Rp670,225,200, the service level should be maintained at a minimum of 0.8. Das and Ahmed (2018) categorize 1 – 0.75 as an excellent level of service for on-street parking. A proper execution should be done by the government to achieve the desired service level, which can maximize the profit from parking and increase the community's satisfaction.

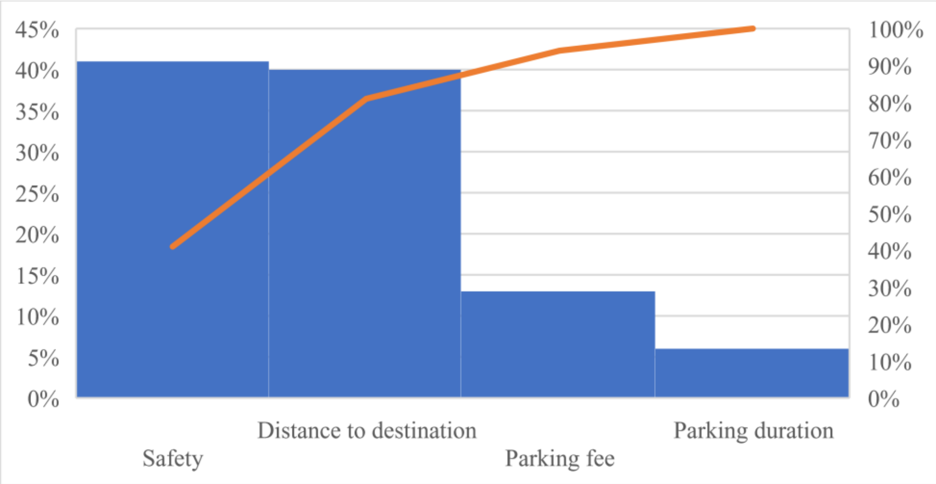

Figure 6.3: Reasons for Choosing Parking Place

Source: ITS Tekno Sains (2019)

To improve the service level as wanted by the community, the government can refer to the reasons for choosing a parking place. Figure 6.3 shows a Pareto chart of the reasons for choosing the parking place. The two most important reasons considered by parkers are safety and distance to the destination aspect. Therefore, the government should focus on these two aspects. In the long-term, the government might consider investing in smart parking technology. Paidi *et al.* (2018) recommend that open parking lots use machine vision using a visual camera to obtain real-time parking occupancy information as it is one of the feasible smart parking technologies. With real-time information, users can know the available parking lot nearest to their destination and, at the same time, know if their vehicles still in the exact parking lot.

6.2.3 Sensitivity Analysis for Price Impact Coefficient

Bouchaud *et al.* (2018) define price impact as the correlation between an incoming order (to buy or to sell) and the following price change. The impact of the price change on parking demand has been discussed in several past research. According to Hongzhi, Yang and Huanmei (2006) as cited in Cheng, Tai and Ma (2012), an increase in parking price will reduce the number of car travel, but increase the number of buses and taxis, as there are alternative travel modes. A similar result also discussed by Milosavljević and Simićević (2014), where the rise in prices resulting in the decrease in parking volume and garage occupancy and also causing a reduction in parking duration.

As shown in Figure 6.1, changes in profit due to price impact is the second steepest line after the service level. When the coefficient value is 1, the profit value Rp777,298,800, is still higher than profit due to changes in customer's preference and occupancy rate. Based on Table 6.2, if the government wants to achieve an annual profit of at least Rp670,225,200, they should retain the price impact in a minimum of 0.9. According to Cheng, Tai and Ma (2012), a higher price impact coefficient means that price change gives relatively small changes in parking demand, or the elasticity to parking demand is low. This is also supported by the data from ITS Tekno Sains (2019), that only 13% of the respondents choose parking place based on the parking fee.

Studies have found several aspects that might affect the elasticity of parking demand or factors that cause changes in parking demand. Milosavljević and Simićević (2014) state that parking charge is considered as a powerful policy for transportation demand management. The parking fee policy not only affects parking demand but can even cause users to shift to other transportation modes. Alavi (2016) found that parking costs and parking availability statistically correlated with driver's willingness to change their transportation mode. In Sidoarjo Regency, there are different types of public transportation provided. According to Kominfo Kabupaten Sidoarjo (2018), the facilities for intercity transportation include Juanda Airport, Purabaya Bus Station, Sidoarjo Railway Station, Trans Sidoarjo, and the highway connecting to Surabaya and Pasuruan/Malang. The local transportation available is *Angkutan Kota* (Angkot) and Elf Car. These local transportations can be utilized by the government as a part of the pricing policy for parking. Although the main goal of the government is to maximize income from parking, it is also important to consider the flow of traffic. The objective of the pricing policy is to reduce congestion in the major arterial road. For example, during peak hours when usually parking is fully-occupied, the parking fee can be set higher to induce the citizen to use public transport instead, rather than driving their vehicle. According to Litman (2006), the parking pricing strategy can reduce 10-30% of parking demand, while improving user information can reduce parking demand by 5-15%. Also, a comprehensive parking management program that combines cost-effective strategies can reduce parking demand by 20-40% while at the same time providing additional social and economic benefits. If the pricing strategy is combined with the digital parking, it can create a more significant reduction in traffic flow. To not confuse between demand reduction and profit maximization, the idea requires more in-depth analysis.

6.2.4 Sensitivity Analysis for Customer's Preference Coefficient

For this research, the customer's preference is defined as whether the customer agrees or disagrees with the implementation of online parking. Data from ITS Tekno Sains (2019) shows that 59.3% of the respondents agree to use online parking, 28.5% disagree, and 12.2% still hesitant. In the model, the value of the customer's preference for online and offline are complementary. For example, when the customer's preference for online parking is 0.59, the offline preference will be 0.41, thus making a sum of 1.

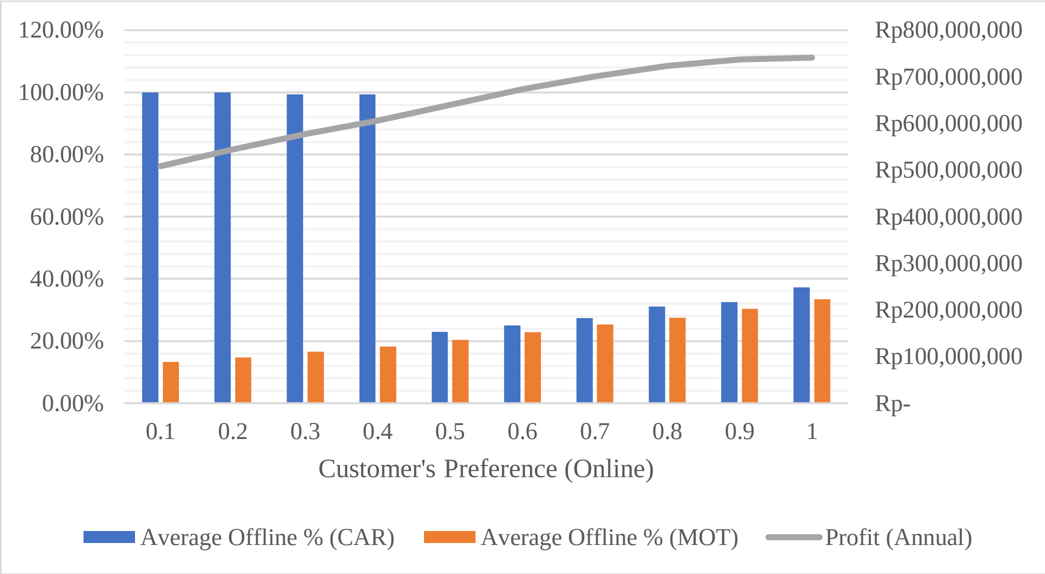

Figure 6.4: Sensitivity Analysis for Customer's Preference Coefficient

As in Figure 6.1, changes in customer's preference generates the least steep line if compared to other parameters. From a technical perspective, it might be caused by the *(1+ teta %)* used in the model. However, Figure 6.4 shows the detailed impact of the changes in customer's preference to the average offline proportion. The operational cost for a car is larger than a motorcycle, thus causing it to require more customers that prefer online that leads to higher demand. For the offline proportion, it still increases, although the preference for online is larger. This phenomenon is probably caused as the cost allocation remains the same. Thus there are not enough funds to facilitate more online parking lot.

There are some ways to convince people who either hesitant or disagree with the implementation of online parking. Based on Rogers (2003) as cited in Sahin (2006), there are some attributes of innovations that can reduce the uncertainty of innovation or convince people regarding innovation. The attributes are relative advantage, compatibility, complexity, trialability, and observability. People will adapt faster if they see the innovation offers more advantages, consistent, less complex (simple), can be experimented, and the result is visible. Therefore, the government should consider these attributes to make the community can adopt the innovation of digital parking faster. For example, the government can provide free parking fees for the first month for people who willing to try the mobile app. More analysis should be conducted to determine the best method to approach people in Sidoarjo, as different regions might have different characteristics of citizens. Also, it is recommended for the mobile application developer to consider receiving real-time feedback from the user. For example, when all parking lot for a specific method, either online or offline, is fully occupied, and a user cannot get their desired parking lot. Thus, the developer can get actual insight on the user demand for the parking lot that can become a consideration for future improvement.

6.2.5 Sensitivity Analysis for Leakage

Leakage is a parameter that applied only to offline parking. Previously, data from PT. Wukir Mahendra Sakti (2018) shows that there is approximately 72% of potential income from parking that was not received by the government. The 72% is considered as a 'leakage'. Therefore, for the early period of digital parking implementation, it is expected that the leakage will reduce to 50%.

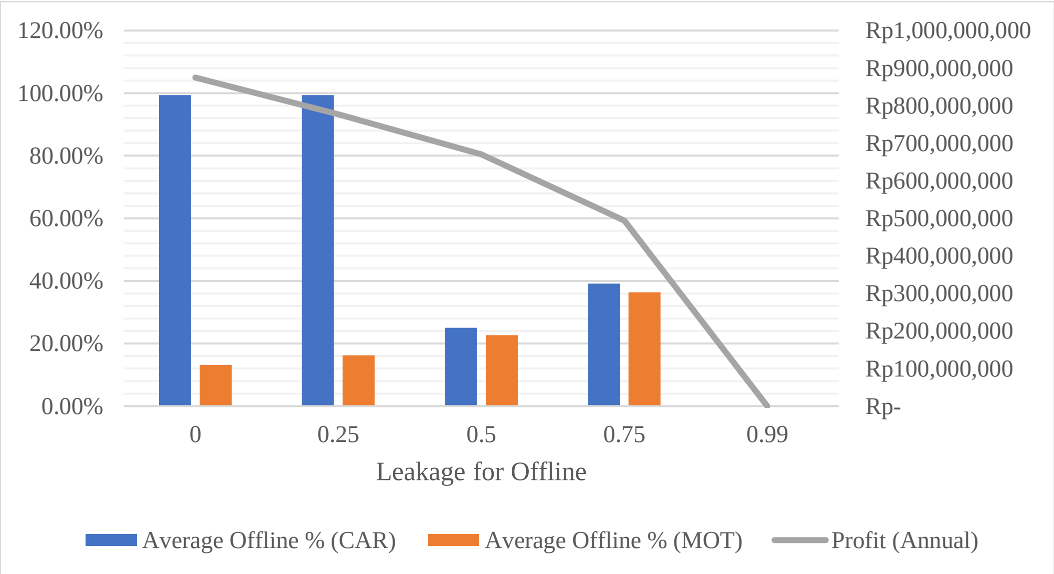

Figure 6.5: Sensitivity Analysis for Leakage

The impact of leakage change to offline proportion and profit can be seen in Figure 6.5. Figure 6.5 shows that leakage has a drastic impact on the average offline proportion for the car when it reaches 0.5 or 50% of leakage. This is probably caused by the online, operational cost of a car that is very large if compared to the offline operational cost. Since the objective function is profit maximization, the model will generate a decision variable that creates the largest profit margin. If the leakage value is still small, the difference between online and offline is not so distinctive to make the model allocates more online parking lot that requires a higher cost. As an illustration, the parking fee for cars is Rp4,000, and the operational cost per transaction for the car is Rp2,724.85 for online and Rp1,647.12 for offline. If both generate a similar amount of revenue, the model will allocate more lot for offline because it will create more profit.

As can be seen in Figure 6.5, larger leakage generates less profit, but at the same time, the model allocates more offline parking proportion. A similar pattern also occurred for the sensitivity analysis for the customer’s preference coefficient. Ideally, when the leakage is larger, the offline proportion should be smaller. Unfortunately, there are not enough fund to operate more online parking lot. In a longer period, it is expected that the leakage can be minimized by shifting towards digital parking. The leakage for offline is an uncontrollable parameter since it is relatively hard to keep directly monitoring the execution all the time. However, there are some alternatives that can reduce the probability of illegal collection in offline parking. According to Aji (2019), in Kudus Regency, Central Java, the parking officer is given an official uniform and ID card. This ensures there is no illegal parking and, at the same time, maintaining the standard for parking service delivered by the parking officer. In Bandung, Ade Komarudin, as the Head of Department of Transportation, as cited in Sari (2017), instructed the citizen to ask for parking tickets. By asking for a ticket, it helps the government to monitor the actual amount received compared to the actual tickets sold.

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CHAPTER 7
CONCLUSION AND RECOMMENDATION

This chapter will explain the conclusion and recommendations taken from the entire research process. The conclusion summarizes the result of research as the solution for determining objectives. Recommendations consist of a room for improvement that can become the basis for future research.

7.1 Conclusion

Below are the conclusions that are drawn from this research.

1. Based on the demand forecasting model, there are some parameters used in this research. The calculated parameters are parking generation rate, utilization rate, growth factor of vehicle, and operational cost per transaction. The assumed parameters are service level, price impact coefficient, and leakage for offline parking. From the sensitivity analysis, it is found that the service level has the most significant impact on demand, resulting in more profit.
2. Some parameters are grouped into two coefficients to simplify the modeling. The first coefficient ($coef_{ij}$) differs for each combination of block and vehicle, and the second coefficient (cm_{jk}) for each combination of vehicle and method. These coefficients are multiplied with the decision variable (parking lot) and other parameters to obtain revenue. Profit is obtained by subtracting the total cost (operational and fixed cost) from the revenue.
3. The mathematical model consists of two main parts, which are objective function and constraints. The objective of the model is to maximize profit, which is the difference between total revenue and total cost. The decision variable is the number of lots for each block, vehicle type, and method (online or offline). The decision variable is multiplied with parameters for parking demand forecasting model and parking fee to obtain revenue. Since the decision variable must be in integer, the model applies integer linear programming.

4. The optimization model is solved using LINGO, and the global optimal solution found is the profit value of Rp2,234,084 for each day or Rp670,225,200 each year. The average offline proportion for cars is 25.06%, and the motorcycle is 22.68%. This result is obtained after trying 18 scenarios of cost allocation and considering that adopting innovation takes time and effort. In the short-term, the government can acknowledge the community about the advantages of online parking, enable free online parking fees during the trial period, and release official attributes for parking officers. In the long run, the government may gradually increase the cost allocation and reduce the offline proportion to obtain more profit and enhancing the parking experience. Also, it is recommended to consider investing in smart parking technology and implement a dynamic parking fee policy.

7.2 Recommendation

Below are the recommendations that can be used as an improvement for future research.

1. For data collection, it is advisable to do direct observation to get more accurate and timely data. It can also be used to have a better understanding of the behavior of people and traffic situations.
2. Consider dynamic conditions at different times, such as the different number of vehicles, parking duration, street condition, and people's behavior.
3. Research more about how to induce people in adopting new technology and do a more in-depth analysis of strategies to ensure the execution of digital parking runs smoothly.

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ATTACHMENT

Attachment 1. Gantt Chart for Thesis

Task Name	Week																										
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	25	26	Aug
Pre-thesis																											
Consultation for thesis proposal																											
Proposal seminar																											
Data collection and consultation for thesis																											
Thesis defense																											
Guest lecture participation																											
Yudisium																											

Attachment 2. LINGO Coding

```
sets:
block/1..10/: floorarea, indarea;
vehicle/car, mot/: parkingfee, cgrowth, percent_allocation;
method/on, off/: teta, leakage;
link1(block, vehicle): PGR, totalparking, coef, utilrate,
totallot, opcost, costallocation, revenue;
link2(block, vehicle, method): lot, demand;
link3(vehicle, method): cmethod, cost;
!index: i block,
j vehicle j=1 car, j=2 motorcycle,
k method k=1 online, k=2 offline;
endsets

data:
!coef;
floorarea = @ole("Data_Processing.xlsx","floorarea");
indarea = @ole("Data_Processing.xlsx","indarea");
totalparking = @ole("Data_Processing.xlsx","totalparking");
parkingfee = 4000 2000;
occupancy_rate = 1;

!cmethod;
servicelevel = 0.8;
cprice = 0.9;
cgrowth = 1.22 1.1; !for 2020;
teta = 0.59 0.41;
leakage = 0 0.5;

!data constraint;
totallot = @ole("Data_Processing.xlsx","SRP");
cost = @ole("Data_Processing.xlsx","costpertransaction");
percent_allocation = 0.65 0.17; !ideal = 0.65 0.17;
fixedcost = @ole("Data_Processing.xlsx","fixedcost");

!result export to excel;
!@ole("Data_Processing.xlsx","lot_res") = lot;
!@ole("Data_Processing.xlsx","revenue_res") = revenue;
!@ole("Data_Processing.xlsx","demand_res") = demand;
!@ole("Data_Processing.xlsx","p_allocation") = percent_allocation;

!for sensitivity;
@ole("Sensitivity.xlsx","lot_res") = lot;
@ole("Sensitivity.xlsx","revenue_res") = revenue;
@ole("Sensitivity.xlsx","p_allocation") = percent_allocation;
enddata

!objective function;
max = profit;
profit = revenue_total - totalcost;

revenue_total = @sum(link1(i,j): revenue(i,j));
@for(link1(i,j): revenue(i,j) = @sum(link2(i,j,k):
(demand(i,j,k)*parkingfee(j))));
@for(link2(i,j,k): demand(i,j,k) =
(((lot(i,j,k)/totalparking(i,j))*coef(i,j)))*cmethod(j,k));
```

```
totalcost = totalopcost + fixedcost;
totalopcost = @sum(link1(i,j): opcost(i,j));

!formula for coef;
@for(link1(i,j): coef(i,j) = (PGR(i,j)*indarea(i))/utilrate(i,j));
!formula for PGR;
@for(link1(i,j): PGR(i,j) =
((totallot(i,j)*occupancy_rate)/floorarea(i))*100);
!formula for utilization rate;
@for(link1(i,j): utilrate(i,j) =
((totalparking(i,j)/totallot(i,j))/(16/8)));
!formula for cmethod;
@for(link3(j,k): cmethod(j,k) =
(servicelevel*cprice*cgrowth(j)*(1-leakage(k))*(1+teta(k))));
!WITH LEAKAGE;

!constraints;
!constraint 1 --> total parking lot;
@for(link1(i,j): @sum(link2(i,j,k)| j#eq#j: lot(i,j,k)) =
totallot(i,j));
!constraint 2 --> cost;
@for(link1(i,j): opcost(i,j) <= costallocation(i,j));
@for(link1(i,j): opcost(i,j) = (@sum(link2(i,j,k)| j#eq#j:
(demand(i,j,k)*cost(j,k)))));
!formula for cost allocation;
@for(link1(i,j)| i#eq#i: costallocation(i,j) =
(percent_allocation(j)*revenue(i,j)));

!constraint integer;
@for(link2(i,j,k): @gin(lot(i,j,k)));
```

Attachment 3. Determination for Cost Allocation

Table 1. Operational Cost Per Transaction

	Online		Offline	
Cost - Car per transaction	Rp	2,724.85	Rp	1,647.12
Cost - Motorcycle per transaction	Rp	355.42	Rp	214.84

The cost allocation is determined through the ratio between operational cost and parking fee, as shown in the following table.

Table 2. The ratio of Operational Cost and Parking Fee

	Online	Offline
Car	0.68	0.41
Motorcycle	0.18	0.11

Table 3. The Complete Table for Cost Allocation Scenario

Scenario	Allocation (CAR)	Allocation (MOT)	Average Offline % (CAR)	Average Offline % (MOT)	Revenue	Total Op. Cost	Fixed Cost	Profit	Profit (Annual)
1	0.45	0.13	95.03%	83.43%	Rp 2,768,493	Rp 594,674	Rp 978,123	Rp 1,195,696	Rp 358,708,900
2	0.45	0.15	95.03%	60.10%	Rp 3,253,908	Rp 708,115	Rp 978,123	Rp 1,567,670	Rp 470,301,100
3	0.45	0.17	95.03%	22.68%	Rp 4,040,394	Rp 891,916	Rp 978,123	Rp 2,170,355	Rp 651,106,600
4	0.5	0.13	83.97%	83.43%	Rp 2,862,424	Rp 678,821	Rp 978,123	Rp 1,205,480	Rp 361,644,100
5	0.5	0.15	83.97%	60.10%	Rp 3,347,839	Rp 792,262	Rp 978,123	Rp 1,577,454	Rp 473,236,300
6	0.5	0.17	83.97%	22.68%	Rp 4,134,325	Rp 976,063	Rp 978,123	Rp 2,180,139	Rp 654,041,800
7	0.55	0.13	71.14%	83.43%	Rp 2,983,254	Rp 787,066	Rp 978,123	Rp 1,218,065	Rp 365,419,600
8	0.55	0.15	71.14%	60.10%	Rp 3,468,669	Rp 900,507	Rp 978,123	Rp 1,590,039	Rp 477,011,800
9	0.55	0.17	71.14%	22.68%	Rp 4,255,155	Rp 1,084,309	Rp 978,123	Rp 2,192,723	Rp 657,817,000
10	0.6	0.13	51.00%	83.43%	Rp 3,150,547	Rp 936,935	Rp 978,123	Rp 1,235,489	Rp 370,646,800
11	0.6	0.15	51.00%	60.10%	Rp 3,635,961	Rp 1,050,376	Rp 978,123	Rp 1,607,462	Rp 482,238,700
12	0.6	0.17	51.00%	22.68%	Rp 4,422,448	Rp 1,234,177	Rp 978,123	Rp 2,210,148	Rp 663,044,500
13	0.65	0.13	25.06%	83.43%	Rp 3,380,367	Rp 1,142,819	Rp 978,123	Rp 1,259,425	Rp 377,827,600
14	0.65	0.15	25.06%	60.10%	Rp 3,865,782	Rp 1,256,260	Rp 978,123	Rp 1,631,399	Rp 489,419,800
15	0.65	0.17	25.06%	22.68%	Rp 4,652,268	Rp 1,440,061	Rp 978,123	Rp 2,234,084	Rp 670,225,300
16	0.7	0.13	0.00%	83.43%	Rp 3,593,074	Rp 1,333,372	Rp 978,123	Rp 1,281,579	Rp 384,473,800
17	0.7	0.15	0.00%	60.10%	Rp 4,078,489	Rp 1,446,813	Rp 978,123	Rp 1,653,553	Rp 496,066,000
18	0.7	0.17	0.00%	22.68%	Rp 4,864,975	Rp 1,630,614	Rp 978,123	Rp 2,256,238	Rp 676,871,500

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