STUDY ON THE TRAFFIC IMPACT OF LOGISTIC-RELATED LAND USE

LOUIS TAN PAO CHIANG

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STUDY ON THE TRAFFIC IMPACT OF LOGISTIC-RELATED LAND USE

By

LOUIS TAN PAO CHIANG

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Name of Student: Louis Tan Pao Chiang

I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

Signature: Approved by:

______________________ ______________________

(Signature of Supervisor)

Date : Name of Supervisor :

Date :

Approved by:

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(Signature of Examiner)

Name of Examiner :

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ABSTRAK

North Butterworth Container Terminal (NBCT) dan empat persimpangan telah dipilih dalam kajian ini untuk menunjukkan kesan trafik dalam penggunaan tanah berkaitan logistik. Empat persimpangan tersebut ialah Persimpangan Pintu Masuk NBCT (Persimpangan A), Persimpangan Jalan Heng Choon Thian/Jalan Bagan Luar/Jalan Kampung Gajah (Persimpangan B), Persimpangan Lebuhraya Butterworth Kulim/Jalan Siram/Jalan Sungai Nyior (Persimpangan C) dan Persimpangan Lebuhraya Lingkaran Luar Butterworth/Jalan Chain Ferry/Jalan Syarikat (Persimpangan D). Data trafik telah dikumpul di pintu masuk NBCT dan empat persimpangan berhampiran dengan terminal kontena tersebut. Operasi NBCT disiasat melalui pemerhatian dan temubual yang telah dijalankan dengan pihak pengurusan Penang Port Sdn. Bhd. Hasil analisis memberikan penjanaan perjalanan dan waktu puncak NBCT, dan menunjukkan variasi dalam permintaan lalu lintas oleh jenis kenderaan ke terminal kontena dan dari terminal kontena tersebut. Daripada data yang dikumpul, purata masa proses lori berat di kaunter pendaftaran NBCT adalah 104.8s. Semasa waktu puncak, terdapat 50 lori berat yang beratur dan menunggu di jalan pendekatan NBCT. Perjalanan tertinggi yang dijanakan oleh NBCT adalah dari 1615 jam hingga 1715 jam dengan jumlah 1697 pcu/jam. Dari NBCT, 73% lori berat bergerak ke Persimpangan B dengan melalui Persimpangan A. Apabila lori berat tiba di Persimpangan B, 90% daripada lori berat bergerak ke Persimpangan C. 51% lori berat yang tiba di Persimpangan C bergerak ke Persimpangan D. Daripada analisis, ia menunjukkan bahawa peratusan tinggi lori berat bergerak sepanjang laluan dari NBCT ke kawasan perindustrian Mak Mandin dan Prai dan sebaliknya. Dari analisis kapasiti, jalan pendekatan di setiap persimpangan dengan jumlah lori berat yang tinggi menunjukkan LOS E dan F.

ABSTRACT

The North Butterworth Container Terminal (NBCT) and four intersections were selected in this study to address the traffic impact of logistic-related land use. The four intersections are NBCT Entrance Intersection (Intersection A), Jalan Heng Choon Thian/Jalan Bagan Luar/Jalan Kampung Gajah Intersection (Intersection B), Lebuhraya Butterworth Kulim/Jalan Siram/Jalan Sungai Nyior Intersection (Intersection C), and Lebuhraya Lingkaran Luar Butterworth/Jalan Chain Ferry/Jalan Perusahaan Intersection (Intersection D). Traffic data was collected at the entry of NBCT and four intersections near to the container terminal. The operation of NBCT is investigated by observation and interview conducted with the management team of Penang Port Sdn. Bhd. The results of analysis provide trip generation and peak hour of NBCT, and the variation in the traffic demand by vehicle types to and from the container terminal. From the data collected, the average process time of heavy lorries at the registration counter of NBCT is 104.8s. During the peak hour, there are 50 heavy lorries queued and waited on the NBCT approach road. The highest trip generated by NBCT is from 1615 hrs to 1715 hrs with the volume of 1697 pcu/hr. From NBCT, 73% of heavy lorries travelled to Intersection B by passing through Intersection A. As the heavy lorries reached Intersection B, 90% of the heavy lorries travelled to Intersection C. 51% of heavy lorries arrived at Intersection C travelled to Intersection D. From the analysis, it shows that high percentage of heavy lorries travelled along route from NBCT to Mak Mandin and Prai industrial area and vice versa. From the capacity analysis, the approach roads at each intersection with high volume of heavy lorries show LOS E and F.

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LIST OF ABBREVIATIONS

LOS	**L**evel **O**f **S**ervice
PCU	**P**assenger **C**ar **U**nit
TEU	**T**wenty-foot **E**quivalent **U**nit

CHAPTER 1

INTRODUCTION

1.1 Background

Logistics is defined as ‘part of the supply chain process that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers’ requirements’ by Council of Logistics Management (1991). Logistics is critical success factor affecting the productivity, profitability, and competitive advantage. The key element in a logistics chain is the transportation system, which joints the separated activities. Therefore, transportation of goods in logistic system is of increasing interest and concern. The development of logistic facilities is important in contributing to efficient flow of goods and services. One of the major logistic facility is the maritime container terminal where transshipment of shipping containers that arrive via ocean vessels are carry out between different transport vehicles. The containers are transferred to inland carriers, such as canal barges, trucks, or trains based on Caserta et al. (2011).

Despite the relevant role of logistic activity, goods distribution also generates negative impacts on the surrounding land use. The cargo traffic reduces the accessibility of passenger transport in surrounding area and may cause congestion, in this way also affecting mobility in the area. Trucks are used for the transportation of containers into and out of the container terminal. The effect of trucks on the surrounding traffic are greater compared to passenger cars. These heavy vehicles have a substantial impact on macroscopic and microscopic traffic flow characteristics due to the interference effect they have on surrounding vehicles especially during heavy traffic conditions. The heavy vehicle drivers and passenger car drivers show different driving behavior. Moreover, the impact of trucks on traffic flow is prominent due to their physical and operational characteristics. The physical characteristics of trucks that impose physical and psychological effects on surrounding traffic are length and size while the operational characteristics are acceleration, deceleration and maneuverability.

Trucks have significant influence in the travel times especially under heavy traffic condition or when the trucks comprise a large proportion of traffic. In addition, the increase of trucks also results in the increase of number of passenger car lane changing maneuvers. Passenger car tend to avoid being near to trucks and thus, change to other lanes. The high numbers of lane changing maneuvers will increase the potential for vehicular conflicts and therefore increase the occurrence of traffic accidents.

1.2 Problem Statement

With the on-going flourish growth of global trade, the container movements is expected to keep growing substantially followed by increasing use of transhipment transport. The distribution of goods and services has become challenging due to the rapid growth of population and economy. The larger community promote the delivery of goods and services which generated negative impact to city area. Trucks transporting goods can be restricted from desire performance due to insufficient infrastructure along with access restrictions which in return may cause traffic and safety issue. On the other hand, goods distribution caused congestion followed by negatively affected people and trucks accessibility which in return imposes extra costs for both passengers and freight companies.

The number and frequency of trucks movement is growing and is expected to continue to grow at a steady rate due to the current production and distribution practices based on low inventories and fast arrival deliveries. In contrast to the high transportation demand, the growth in in-land goods distribution has not been given due concern. The overall socio-economic development causes the abundant growth in goods distribution which in turn affects the surrounding area's overall traffic functionality by aggravating congestion, mobility, accessibility and safety issues.

1.3 Objectives

The objectives in this study are:

1. To investigate the operation of a container terminal and its logistic system with respect to queue length.
2. To assess the trips generated by the container terminal.
3. To determine the trip distribution pattern of heavy lorries at surrounding intersections.
4. To examine the impact of the freight traffic at surrounding intersections.

1.4 Scope of Work

This study focuses on a container terminal at Butterworth, Penang. Four intersections in the vicinity of the container terminal were investigated and traffic count was conducted during weekday for 12 hours to account the variation in heavy lorries traffic flows on a weekly basis. The selected intersections are the intersections that are most vulnerable to the impact of the logistic activities.

1.5 Significance of Study

This study is important to understand the operation of the container terminal with respect to the queue length because the queue of heavy lorries will extend to the intersection and it will create blockage to other nearby intersections as well. In addition, the distribution pattern of heavy lorries nearby the container terminal was determined in order to access the intersections performance due to the heavy lorries.

The research is important because the outcome can create a better understanding of freight traffic behaviour generated by a container terminal for better transport planning and a more sustainable development. Moreover, the traffic impact of a container terminal to the surrounding land use is examined so that the traffic impact to surrounding land use will have to be taken into consideration during logistic-related development.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Logistics is the entire process of materials and products moving into, through and out of a company. Logistics covers activities such as information exchange, transport service, warehousing, inventory management, cargo handling and packaging. It includes any activity involved in the management of inventory at rest or in motion. Kondratjev (2015) stated that transportation is one of the key logistics functions associated with moving goods vehicle on a particular technology in the supply chain. However, it is important to understand the negative impacts that may arise from the logistic activities.

Through the review of the literature and knowledge of traffic impact analysis, it is clear that the trucks have significant effect on the traffic condition of surrounding area. The amount of literature available on freight transportation has been found to be very large, but studies on traffic impact of logistic-related land use to surrounding land use is very limited.

2.2 City Logistic

According to Taniguchi et al. (2001), "*City Logistics is the process of totally optimizing the logistics and transport activities by private companies while considering the social, environmental, economic, financial and energy impacts of urban freight movement*". Michael (2005) defines city logistics as the study of the dynamic management and operations of urban freight transport and distribution systems. However, city logistics is a relatively new field of investigation brought by the challenges of moving growing quantities of freight within metropolitan areas (Dablanc and

Rodrigue, 2009). Based on Taniguchi et al. (2001), city logistics initiatives are required to solve urban freight transport problems including high levels of traffic congestion, negative environmental impacts, high energy consumption and a shortage of labour. Urban freight represents 10 to 15% of vehicle equivalent miles travelled on city streets and 2 to 5% of the employed urban. 3 to 5% of urban land is devoted to freight transport and logistics (Dablanc and Rodrigue, 2009).

2.3 Logistic Facilities

A logistics facility can be understood as a terminal, a distribution or a production site based on Pfohl and Hans-Christian (2009) as cited by Miodrag et al. (2012).

According to Desalegn (2013), goods distribution involves several functions relating to nodes and links on a network. The functions of links are transportation and pickup delivery; node functions including storage, deposit, handling, processing, assembling, packaging, wrapping and loading unloading. Logistics terminals are required to fulfil these node functions and to make both functions interact with each other.

The selection of freight facilities location require balance between land price and distance to the final distribution points (Hesse and Rodrigue, 2004 cited in Moazami and Noroozi, 2011). Ogden (1992) as cited by Moazami and Noroozi (2011) states there are four main factors which influence the location of freight facilities:

- Closeness to the main roads, freeways and services
- Closeness to customers (reduced vehicle-kilometre)
- Labour availability
- Site availability

2.4 Intermodal Transport Systems

Multimodal transport infrastructure is defined as an optimal integration of different transport modes enabling an efficient and cost-effective use of the transport system through seamless and customer-oriented door-to-door services (Reggiani ,2000). Kanafani and Wang (2010) state that transport infrastructure provides the means for goods carriage by at least two different modes of transportation.

Intermodal transport infrastructure is the crucial component in dry port operations and normally, this type of terminal is referred to as an integrator of various modes of transportation (Kapros, 2003). Moreover, based on UNESCAP (2009), dry ports are specific terminals under the umbrella of intermodal terminals which encourage the application of modal shift through intermodal transportation activities. Based on this criterion, it is evidently indicated that intermodal transportation and dry ports are well connected through interoperability to provide significant advantages to their stakeholders including seaports, freight forwarders, shippers, shipping lines, rail operators, hauliers and manufacturers (Jeevan et al., 2015).

2.5 Maritime Transport in Malaysia

Robinson (2002) clarifies that seaports are key elements in value driven system which contribute to supply chains by creating value added services to increase the competitive advantages in the transport chain. The ministry of transportation governs federal seaports and some examples of federal seaports are Port Klang Authority (PKA), Penang Port Commission (PPC), Johor Port Authority (JPA), Kuantan Port Authority (KPA) and Bintulu Port Authority (BPA). State seaports are normally administered by the state governments with Lumut Port, Sabah Port Authority (SPA), Rajang Port

Authority (RPA) and Miri Port Authority (MPA) being some of the examples of state seaports from MIMA (2014) as cited in Othman et al. (2016).

Penang Port is the third largest seaport in Malaysia and the landlord for this seaport is the Penang Port Commission (PPC, 2014). According to Lee et al. (2015), the Penang Port is located at the northern tip of the Straits of Malacca which is one of the busiest shipping lanes in the world. In addition, this seaport is located at the northern region of peninsular Malaysia and is adjacent to an economic hub including the Indonesia-Malaysia-Thailand Growth Triangle (IMT-GT) which encourages trade development between these countries (PPC, 2014). This seaport is well connected to PBCT and ICT and the main intermodal terminal connecting this seaport with domestic and international stakeholders.

2.6 Operation of Container Terminal

In a port, a container terminal, is where container vessels are often berthed alongside, and each vessel is served by multiple quay cranes which are supported by large number of yard cranes in the yard. When a vessel arrives at the terminal, containers are normally discharged from the vessel, mounted onto trucks by quay crane and then unloaded by yard cranes at various locations in the yard for storage. In the loading operation, export containers loaded onto trucks by yard cranes at the yard are off loaded at the quay and loaded onto a vessel by quay cranes (Ng and Mak, 2005).

Based on Koh et al. (1994), container terminal operations are activities for transferring containers between modes of transport and provide a package of activities or services to handle and control container flows from vessel to landside and vice versa. The seaport operations are dominated by container and trailer movements. Thus, operational and infrastructure changes are required to maintain the growth of international cargo operations (Al-Deek et al., 2000).

2.7 Trip Generation

According to Guan and Liu (2009), marine container terminals generated high truck trips. In the trip generation study (Pilot Study) of Malaysia by Highway Planning Division (2010), trip generation can be defined as the total number of inbound and outbound vehicle trip-ends from a site over a given period of time. Trip is a journey of a person or vehicle that begins at one location and ends at another one. Land use created the demand for travel, and these trips indicate the need for transportation facilities in order to serve the trip-making demands. Trip generation can be determined by conducting traffic count and therefore, the impacts can be analysed. Trip generation analysis examine the relationship between number of trips made and certain quantifiable parameters such as socio-economic, locational, and land use characteristics which can be used to predict subsequent changes in transport demand (Paquette and Ashford, 1982 cited in Dodeen, 2014).

2.8 Impact of Freight Transportation

Road transportation creates the most pollution per unit of distance travelled, but there are limited alternatives than the road to provide for urban deliveries (Dablanc and Rodrigue, 2009).

Freight distribution is more polluting than other transportation activities in cities. The main reasons according to Dablanc and Rodrigue, (2009) are:

- Freight delivery vehicles are older on average. It is common that trucks end their life cycle in drayage operations between port terminals and urban distribution centres.
- Operating speeds are slower due to congestion and traffic restrictions, implying that the engine is running consistently lower than optimal speed (75 km per hour on average).
- Constant acceleration and deceleration, due to traffic lights and congestion.
- Vehicle idling is frequent either for deliveries or at stops.

According to Urbanyi-Popiolek and Klopott (2016), container terminals have an impact on the roads adjacent to the port area due to the traffic that uses the terminal. It is important and necessary to calculate and document trip rates of these types of land uses to forecast traffic flows generated by the land use.

2.8.1 Traffic Impact of Trucks

Based on Moridpour et al. (2015), an increase of 5% in the likelihood of accidents, when proportion of heavy trucks increased to 30% of total traffic. Increase in proportion of heavy trucks intensified the likelihood of accidents and therefore reduced traffic safety. Therefore, heavy trucks have pronounced effect on traffic characteristics, particularly average travel time and average speed. The existence of larger percentage of heavy trucks can increase the likelihood of accidents and reduce traffic safety. According to Morrison et al. (2014), underpowered longer heavy vehicles have potential to cause congestion and affect the performance of the intersection. Based on Roh et al. (2017), the average speed decreased when the flow rate and heavy vehicle ratio increased for the six-lane and the eight-lane highways. The average speed also decreased as the flow rate increased for the four-lane highway. From the examination effort, it was found that heavy vehicles are responsible for affecting the traffic characteristic of smaller dimensions' vehicles and other complication on urban roads. The impact of heavy vehicle on the passenger car and other small dimension vehicle is a critical issue in urban roads (Pokulwar et al., 2016). Moreover, based on Lake et al. (2002), there are two main traffic related issues associated with multi-combination freight vehicles in urban areas which are delays that they may cause to other vehicles and safety related impacts. Other considerations of multi-combination freight vehicles in urban regions include: efficiency; contribution to the national and local economy; and environmental effects. In addition, the tremendous truck trips generated at marine container terminals have a direct bearing on the local highways and arterial roads (Guan and Liu, 2009).

2.9 Intersection Performance Measures

Each facility type has defined method for assessing the performance. In this study, the performance of signalized intersections was examined. The capacity and level of service (LOS) of the intersections are determined.

Based on Arnold and McGhee (1995) as cited by Abidin (2007), capacity analysis is a set of procedures used to estimate the traffic carrying capacity of transportation facilities over a range of defined operational conditions.

Chandra et al. (1994) described the capacity analysis for a signalized intersection as more complex than carrying out capacity analysis for a road. This is because the capacity of a road is only influenced by the parameters for the road itself, whereas the capacity for a signalized intersection differs according to the parameters of all the roads that make up the intersection. This includes the geometric parameters of the individual lanes, the area type, the turning movements and other related parameters.

According to Highway Capacity Manual 2000, Level of service (LOS) is a qualitative measure describing operational conditions within a traffic stream, generally in terms of such service measures as speed and travel time, freedom to manoeuvre, traffic interruptions, and comfort and convenience. There are six levels, with LOS A representing the best operating conditions and LOS F representing the worst condition. Based on Roess and McShane (1987), delays are used to determine the level of service (LOS) of a signalized intersection. Delay is the parameter perceived by the vehicles drivers at the point of location as it describes the total time drivers spend at the intersection while being unable to move their vehicles due to certain conditions such as the traffic signalization and queues. Table 2.1 shows the description of LOS.

Table 2.1: Description of LOS

Level of Service	General Description
A	Free flow
B	Stable flow (slight delays)
C	Stable flow (acceptable delays)
D	Approaching unstable flow (tolerable delay, occasionally wait through more than one signal cycle before proceeding)
E	Unstable flow (intolerable delay)
F	Forced flow (congested and queues fail to clear)

According to Highway Capacity Manual 2000, there are 4 factors affecting the capacity and level of service, which are roadway conditions, traffic conditions and control conditions.

The standard conditions are the base conditions. Assumption made in base conditions are good weather, good pavement conditions, users familiar with the facility, and no impediments to traffic flow.

Roadway condition can influence the capacity of a road and in some cases, they can affect a performance measure such as speed, but not the capacity or maximum flow rate of the facility. The roadway factors are associated with the geometric characteristics and design elements of the facility such as number of lanes, lane widths, type of facility and its development environment, shoulder widths and lateral clearances, design speed, horizontal and vertical alignments, and availability of exclusive turn lanes at intersections. Semeida's (2013) study shows that the most influential variables on capacity of desert sections are lane width, followed by median width. The increase in lane width from 3.6 m to 3.7 m leads to an increase in capacity from 1940 to 2115 veh/h/ln. In addition, the increase in median width from 8 m to 10 m leads to an increase in capacity from 1900 to 1990 veh/h/ln. For agricultural sections, the most influential variables on density are side access followed by heavy vehicle. The existence of side access leads to a considerable decrease in capacity. The increase in heavy vehicle by 10% leads to a decrease in capacity by 60 veh/h/ln.

Highway Capacity Manual 2000 states that traffic conditions that influence capacities and service levels include vehicle type and lane or directional distribution. The traffic conditions are associated with the characteristics of the traffic stream on the segment of the highway. Heavy vehicles are vehicles that have more than four tires touching the pavement. Example of heavy vehicles are trucks, buses and recreational vehicles. Heavy vehicles adversely affect the traffic due to the larger size than passenger cars and occupy more roadway space. Moreover, heavy vehicles have lower operating capabilities than passenger cars. The inability of heavy vehicles to keep pace with passenger cars create large gaps in the traffic stream, which are difficult to fill by passing manoeuvres. Heavy vehicles also can affect downgrade operations. Heavy vehicles must operate at speeds slower than passenger cars, forming gaps in the traffic stream.

Heavy vehicle’s operational characteristics vary based in the weight of its load and its engine performance. Example of trucks are lightly loaded vans, panel trucks, heavily loaded coal, timber, and gravel haulers.

Apart from heavy vehicles, buses and recreational vehicles are the other two types of vehicles that cause impact on capacity and level-of-service. Intercity buses are relatively uniform in performance. Urban transit buses adversely affect the traffic stream due to the discharge and pickup of passengers on the roadway. Recreational vehicles cover a wide range of vehicles such as campers, motor homes, and passenger cars or small trucks towing a variety of recreational equipment. These vehicles might operate better than trucks. However, the drivers are not professionals, thus, accentuating the negative impact of recreational vehicles on the traffic stream.

In addition, directional distribution has a dramatic impact on two-lane rural highway operation, which achieves optimal conditions when the amount of traffic is about the same in each direction. Nevertheless, each direction of the facility usually is designed to accommodate the peak flow rate in the peak direction. Lane distribution also is a factor on multilane facilities. Typically, the shoulder lane carries less traffic than other lanes.

Moreover, the capacity and LOS also affected by the types of traffic control devices in operation, signal phasing, allocation of green time, cycle length, and the relationship with adjacent control measures. Kravchenko (2013) as cited by Chubukov (2017) clarifies that optimization of traffic control implies challenging of forecasting, recognition and elimination of pre-congestion situations, preventing road blocks, which requires exclusion of causes of traffic overloading by means of redistributing of traffic flows onto alternative routes. The traffic control system should promptly inform the drivers on possible traffic congestions and recommend bypass routes.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter presents the research methodologies to study the traffic impact of the container terminal to surrounding land use. In this study, both qualitative and quantitative research methods were used to draw the hypothesis based on the available theories in the study area. Qualitative data collected through interviews was analysed. Moreover, quantitative data was collected through field measurements and analysis of the data were carried out. The general research process is presented in Figure 3.1.

3.2 Study Area Description

Seberang Perai is a hinterland on the Peninsular Malaysia. The strip of land is also known as Province Wellesley. It is bounded by Kedah to its south and east, and Perak to the south. It covers an area of 760 sq. km and has an estimated population of 815,767 as of 2010. The main town is Butterworth. Seberang Perai is divided into three administrative districts - North, Central and South.

The main industrial area within Seberang Perai are located at Mak Mandin, Perai, Bukit Mertajam and Nibong Tebal. There is high concentration of manufacturing activities within the Central District, which encompasses Perai and Bukit Mertajam, making it the most industrialised district within Seberang Perai.

Figure 3.2 shows the location of NBCT. The North Butterworth Container Terminal (NBCT) which provide container services is located at Butterworth, Penang, Malaysia.

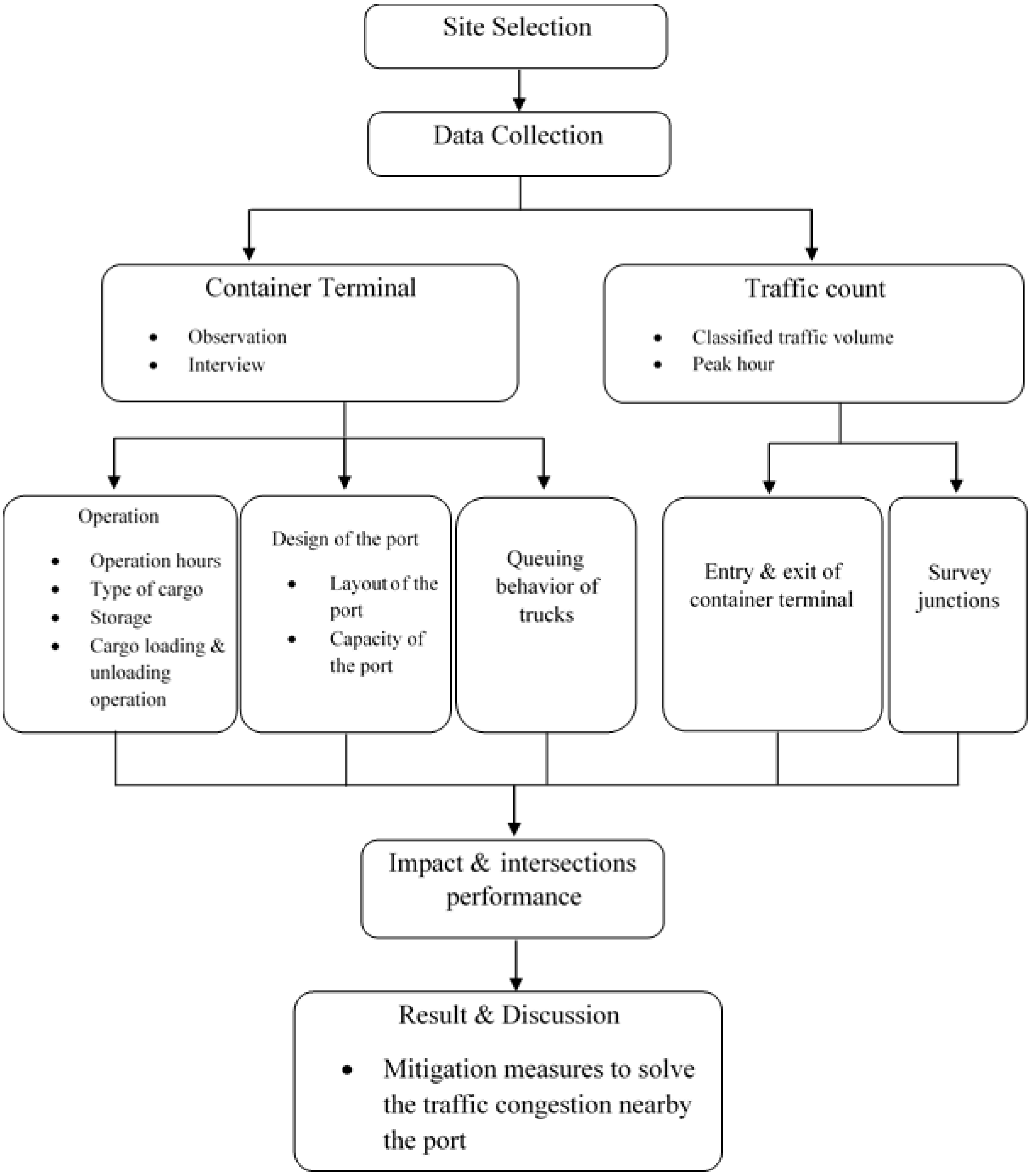

Figure 3.1: Research methodology

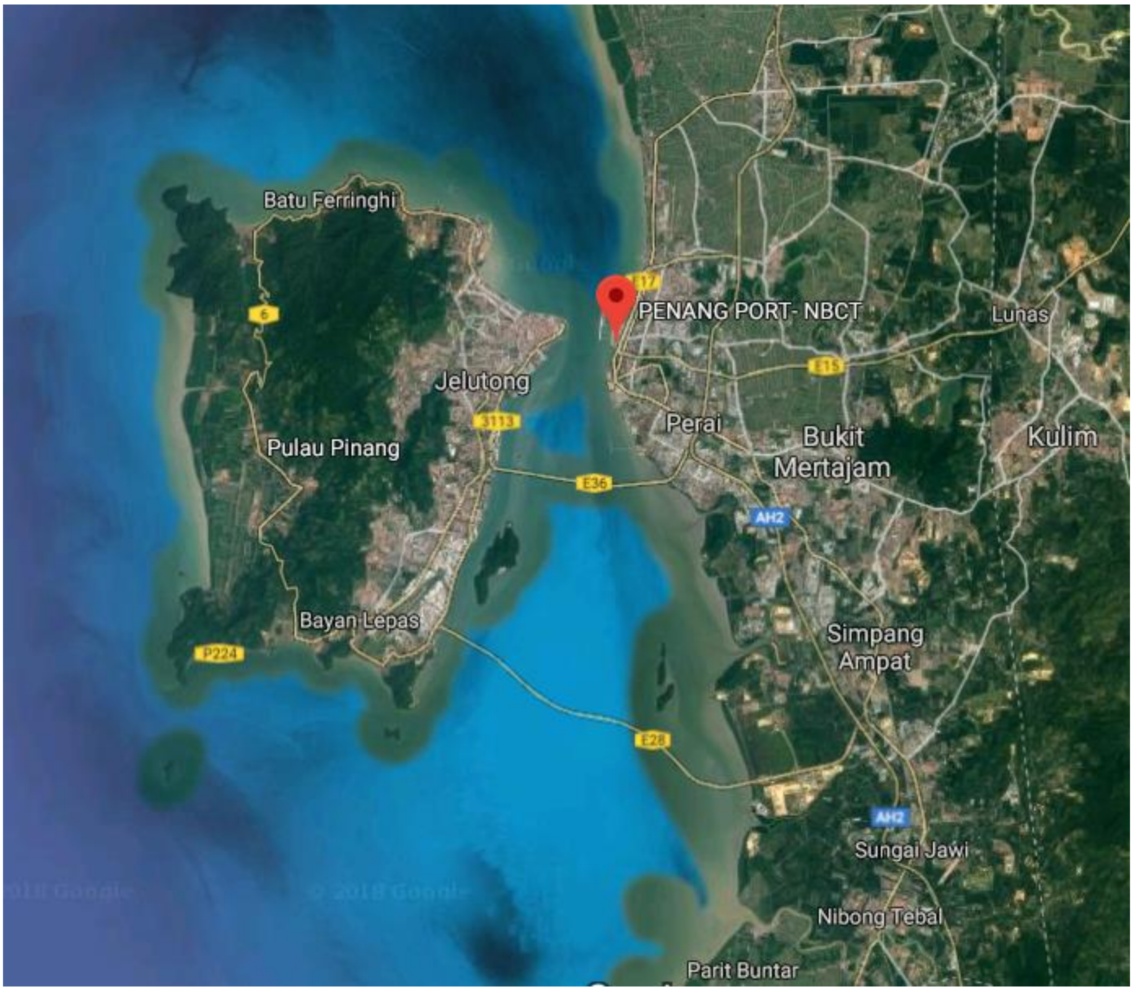

Figure 3.2: Location of NBCT

3.2.1 Site Selection

The selection of suitable intersections for this study was within Seberang Perai, Pulau Pinang. The route travelled by heavy vehicles generated by NBCT was identified initially through observation to determine the intersections prone to the impact by logistic activities. Several intersections were observed during the preliminary site selection process to identify the intersections most vulnerable to the impact of the logistic activities. Four intersections that which have high trucks movement were selected. All selected intersections were signalized intersection. The intersections were located within Seberang Perai. Table 3.1 and Figure 3.3 shows the location of the selected intersections.

Table 3.1: Selected intersections

Label	Intersection
A	NBCT Entrance Intersection
B	Jalan Heng Choon Thian/Jalan Bagan Luar/Jalan Kampung Gajah Intersection
C	Lebuhraya Butterworth Kulim/Jalan Siram/Jalan Sungai Nyior Intersection
D	Lebuhraya Lingkaran Luar Butterworth/Jalan Chain Ferry/Jalan Perusahaan Intersection

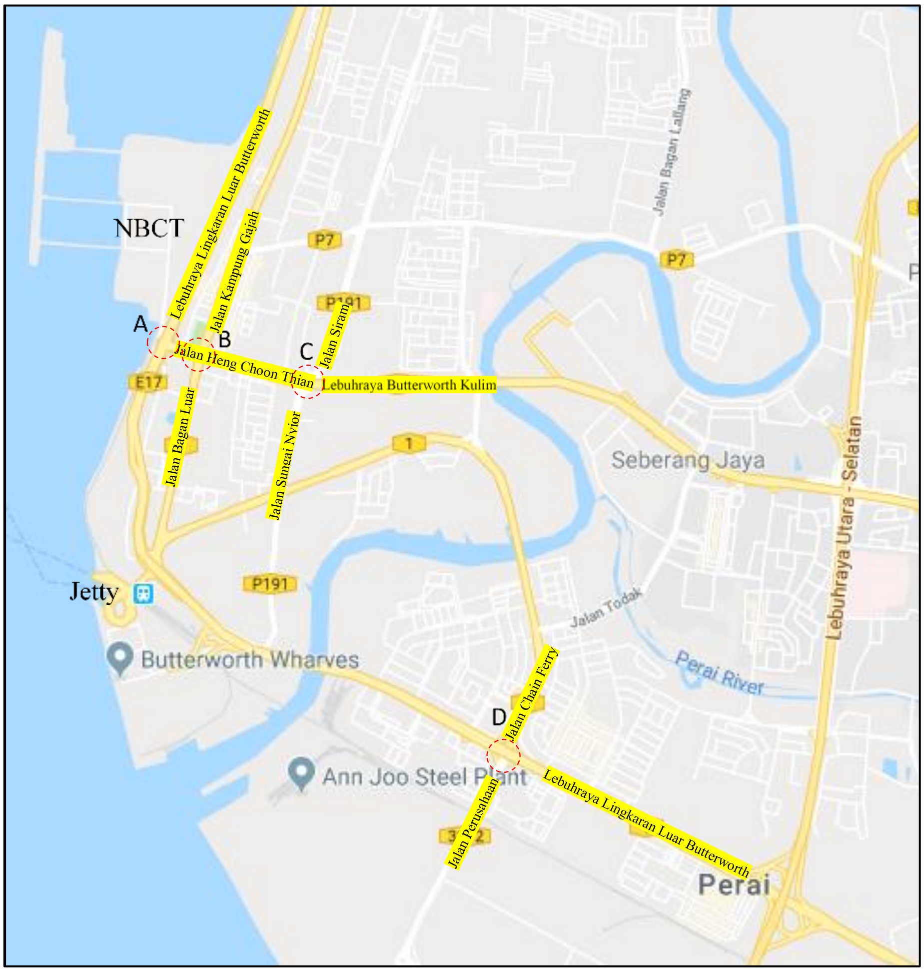

Figure 3.3: Location of selected intersections

3.3 Data Collection

In this study, survey through direct interviews, site observations and field measurements were carried out to collect necessary data for the research.

3.3.1 Survey

- Direct Interview

Direct interview based on streams of question on a guided conversation approach was carried out with the management team of Penang Port Sdn. Bhd. that have direct or indirect involvement with the research question or theme of the study.

- Observation

Field observation method was used to identify the arrival pattern of heavy lorries, the queuing behaviour of the heavy lorries and the operation of the registration counter at the container terminal.

3.3.2 Field Measurements

Quantitative field measurements were carried out at the selection site. The process time of the heavy lorries at the registration counter of NBCT was taken during the peak hour by using a stopwatch. Manual classified traffic count and geometric measurements were carried out on selected intersections. The signal phasing of each intersection was recorded by using a stopwatch. The signal phasing recorded were the green time, amber time and all red time. The phasing sequence was also recorded.

3.3.2.1 Manual Classified Counts

Two video cameras were used to record the traffic flow at the intersection connected to the entrance and exit of North Butterworth Container Terminal for 12 hours from 0700 hrs to 1900 hrs to determine the trip generated by the NBCT. The video cameras were located at such position to record the movements from all approach roads at the intersection. The setting of the video cameras at the intersection as shown in Figure 3.4. The data acquired was then extracted manually from the video camera recording.

The data extracted from the recording were analysed to obtain the traffic volume for each movement at the intersection and trip generated by NBCT.

Figure 3.4: Setting of video cameras

After the peak hour of the trip generation was identified, traffic counts were conducted at another three selected intersections to determine the traffic volume by type of various categories of vehicle in the traffic stream. The traffic volume was determined by a group of people, where each person was assigned to determine the traffic volume of two movements. The vehicles were categorized by a visual assessment of the vehicle size and configuration of axles. Manual classified counts were conducted for two hours with 15 minutes intervals. It started from 30 minutes before to 30 minutes after the peak hour of trip generation by the NBCT, that is 1545 hrs to 1745 hrs.

Besides vehicle categories, another important factor in traffic count is the selection of appropriate days of a week and hours of a day. A week day, namely Tuesday, was selected after preliminary observation to account the variation in heavy lorries traffic flows on a weekly basis. The traffic volume was counted by identifying the three movement patterns of the intersection.

3.3.2.2 Intersection Geometry Measurement

Some intersection geometric elements measurement was carried out. The measured geometric elements of the intersection are; lane configuration, length of lane, and number and widths of approach and exit lanes. The lanes width was measured by using a measuring wheel. The distance between each intersection is measured by using Google Earth Pro.

3.4 Data Analysis

3.4.1 General

The data collected from different sources were analysed to achieve the general and specific objectives of this study. Different analysis techniques were adapted based on the type of data and relevance of techniques to be used. The first approach used was problem analysis based on detailed literature studies in the subject area and understanding of existing conditions in the area of study. The second was application of software such as SIDRA INTERSECTION 7, SPSS Statistics 1.7 and Microsoft Excel 2016 to ultimately meet the intended objectives of the study.

3.4.2 Operation of NBCT

The average time spent by heavy lorries at the registration counter of NBCT was obtained by using SPSS Statistics. The queue length at the approach road to the registration counter during peak hour was calculated by using the Equation 3.1:-

$$\text{Queue length (veh)} = \text{A} - \frac{3600 * \text{N}}{\text{B}} \tag{3.1}$$

Where:

A = Number of heavy lorries enter to NBCT (veh/hr)

B = Average process time at a registration counter (s)

N = Number of registration counter

3.4.3 Traffic volume analysis along the entry and exit of NBCT

The traffic volume was first extracted from the video recording. After that, Microsoft Excel 2016 is used to obtain the average vehicle per hour data and the composition of the trip generated by NBCT.

3.4.4 Heavy lorries' trip distribution

The percentage of heavy lorries from each approach was calculated to show the inbound and outbound heavy lorries from the NBCT to industrial area. The trip distribution of heavy lorries was calculated in percentage to identify the approaches that contributed most number of heavy lorries to the selected intersections and the route travelled by most of the heavy lorries.

3.4.5 Capacity analysis of selected intersections

The capacity of the selected intersections was analysed using SIDRA INTERSECTION 7 software. First, the classified traffic volume data collected on each intersection was analysed using Microsoft Excel 2016 to obtain the average vehicle per hour data on each approach of the intersection with their distinct movement directions. Traffic volume considered for this analysis was a 60 minutes or hourly value of total traffic. The peak hour volume of the intersections was determined and entered into SIDRA INTERSECTION 7.

For intersection analysis, SIDRA INTERSECTION 7 defined a heavy vehicle as any vehicle with more than two axles or with dual tires on the rear axle. Thus, buses, trucks, semitrailers, cars towing trailers or caravans, tractors and other slow-moving vehicles were classified as Heavy Vehicles. All other vehicles such as cars, vans and small trucks were defined as Light Vehicles. The volume of motorcycle was categorized separately due to its smaller dimension.

In this research, heavy vehicles were defined as lorries with more than 2 axles and their percentage shares calculated from the total traffic volume. The volume of heavy vehicles, volume of light vehicles, and volume of motorcycles has been specified and used during the analysis.

The parameters entered into SIDRA INTERSECTION 7 were traffic volume, directional distribution, number of lanes, lane configuration, lane length, lane width and signal phasing. Calibrations were carried out in the software to ensure that the analysis represented the actual situation. The calibrations of vehicle parameters made are shown in Table 3.2. Figure 3.5 shows the queue space of heavy vehicle.

Table 3.2: Calibration of vehicle parameters

Category	PCU values	Queue space (m)
Heavy Vehicle (HV)	2.25	14.0
Light Vehicle (LV) • Car • Van • Small lorry	1.0	5.5
Motorcycle	0.33	2.7