# CHAPTER III
# RESEARCH METHODOLOGY

In order to accomplish the objectives as listed in Chapter 1, a study methodology was developed based on the simulated traffic environment. Basically, a variety of traffic environments were created, so that the travel times of vehicles represented various "actual" travel situations. However, this study did not attempt to replicate the real world, rather to study the accuracy of travel time generated by probe vehicles in various driving environments. Thus, the research was designed to have a variety of traveling scenarios, which then yielded understanding on the closeness of the travel times from probe vehicles to the "real" ones.

First, the traffic environment had to be created as a basis for travel time measurement. This study selected simulation as a test bed for generating various traffic scenarios. In principle, a traffic environment is the determinant of three main components: network configuration, traffic flow volume, and control condition. To vary the traffic situation, one or more components must be altered. In this study, the alteration of traffic flow volume was planned, while the network configuration was fixed. The control conditions were altered according to network and flow condition (to the optimal signal control condition). The change of traffic flow conditions created the varying traffic congestion, which directly affected amount of travel time. The analysis of travel time at various congestion levels could reveal different accuracies of probe vehicle travel time information under various congestion levels.

Moreover, in the simulated traffic environment the determination of "true" travel time could be done. The "true" travel time on each link was defined as the actual amount of time that a vehicle spends to traverse on the specified link. Therefore, the average of "true" travel time was basically the average of travel times of all vehicles passing the link. Data collected by probe vehicles could be considered as the sampling of travel times from the population (entire vehicles on streets). It was postulated that the accuracy was dependent on the random nature of the sampling. The important factor to the accuracy was not only the precision of the measurement (each travel time measurement on each probe vehicle can yield very precise and accurate figures) but also the number of samples to be captured. According to statistics theories, the greater number of samples, the greater accuracy gained. The number of samples implied the number of installation of probe vehicle equipment in the entire vehicle fleet, as expressed in percentage of probe vehicles (sometimes known as market penetration). Note that the average "true" travel time of all vehicles passing the link was considered the average of travel time since it was calculated from the "population" (entire number of vehicles).

The expected study results from travel time determination from probe vehicles on a hypothetical network could reveal understanding of travel time accuracy obtained by probe method. The accuracy could be examined under various traffic (congestion) conditions. Apart from the testing on the hypothetical network, the travel time determination was done on a case study, representing similar network, traffic, and control conditions to the real world. Although not attempting to replicate the real world, the study could reveal the actual gain of accuracy (of travel time from probes) if the data collection method is implemented in the real world.

The following sections describe the framework and method used in this study. This includes the general experiment procedures, equipment used, designed traffic environment, design of experiments, and analysis methods.

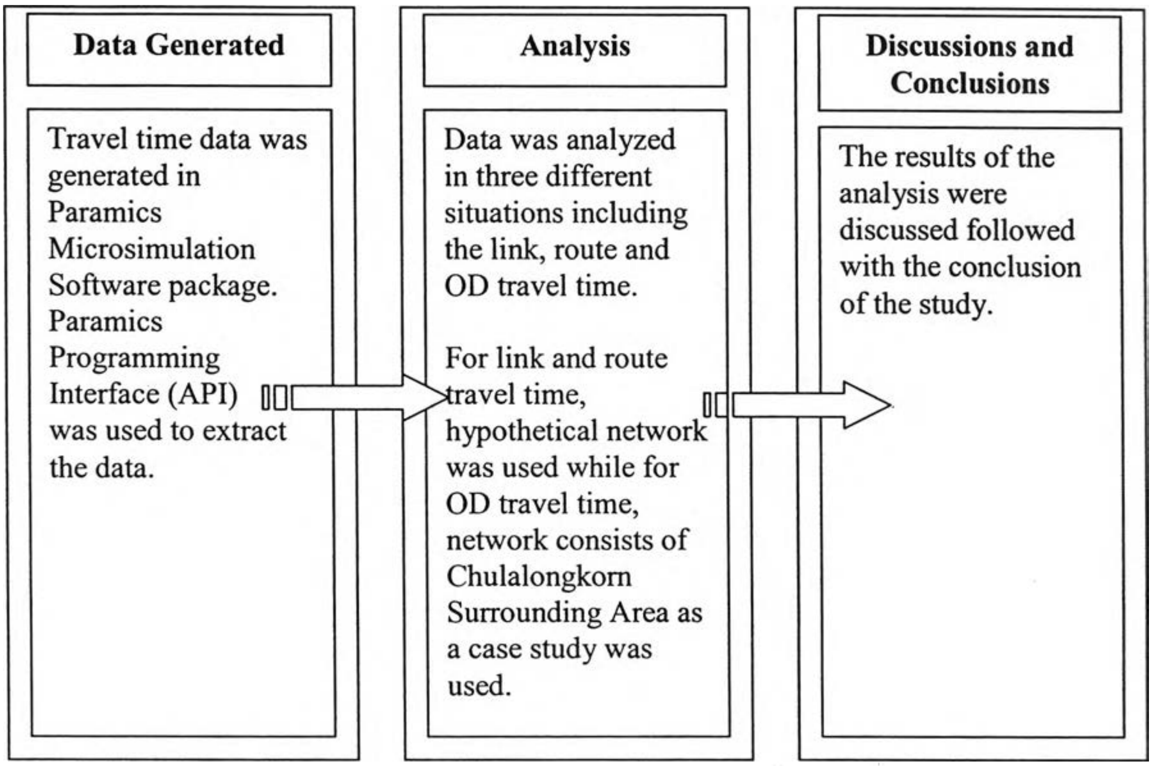



**Figure 3.1** General methodology employed in this study

As discussed in the previous sections, due to the difficulties collecting field data to fit the nature of the research reported herein, a simulation technique was used to generate the data. The general methodology used in this study is as illustrated in Figure 3.1. On the other hand, the full set of process used in the Paramics software package to generate travel time data is as illustrated in Figure 3.2 followed by detailed discussion of the process.

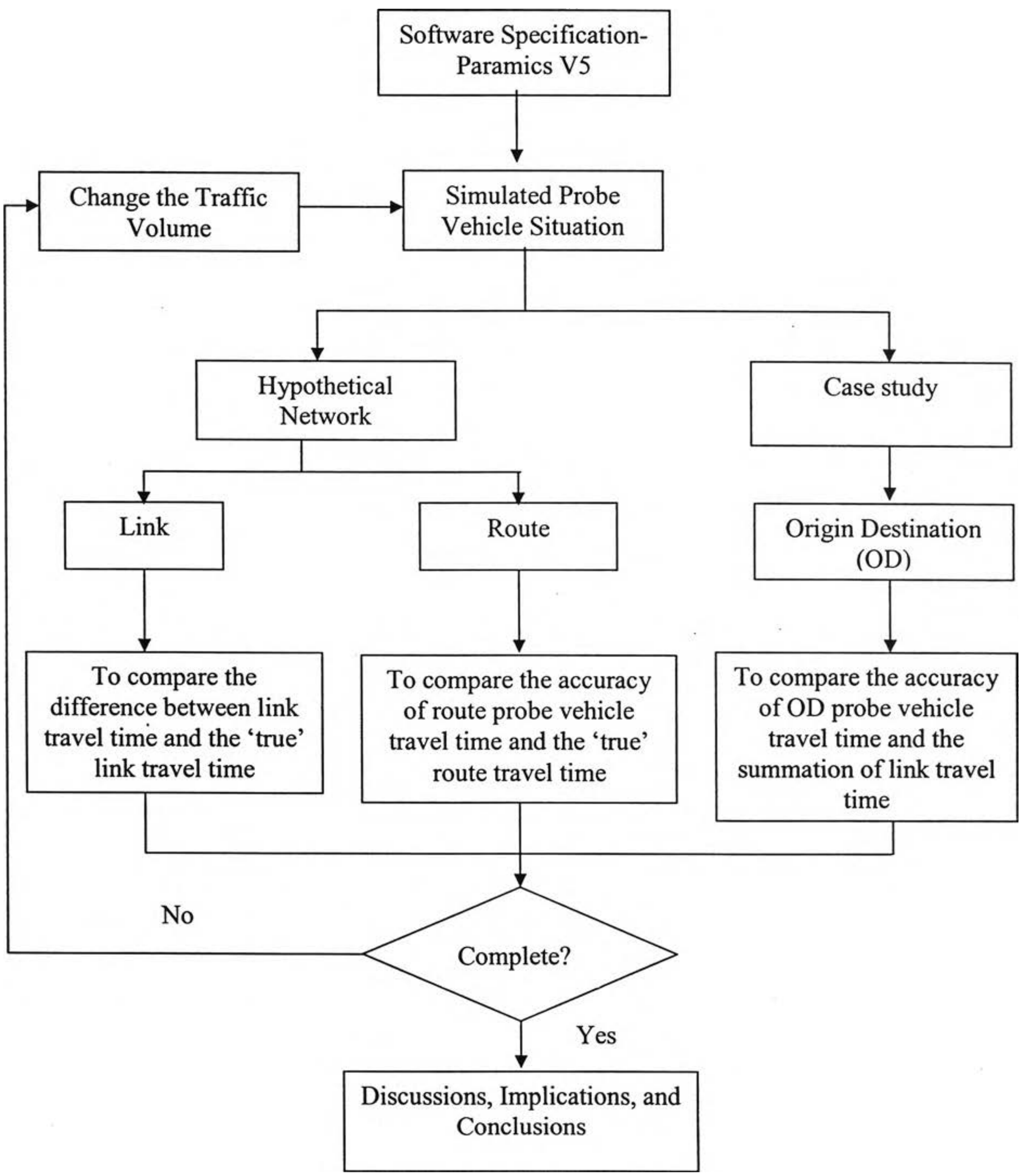



**Figure 3.2** Process to generate travel time data in Paramics V5

## 3.1 SOFTWARE SPECIFICATION - PARAMICS V5

The objectives of this study were to demonstrate the feasibility of using real-time traffic measurements and to provide accurate and reliable traffic information as well as to assess the effectiveness of probe vehicles in providing traffic information (travel time) under various traffic conditions. Due to the difficulties in collecting field data to fit the nature of the research reported herein, a simulation technique was used to generate the data. Recently, simulation techniques provide a new path to generate research data. The main benefit is to get data from various traffic conditions without disturbing the current transport environment. In terms of travel time study, it provides a potential source to generate traffic data in both good quality and enough quantity. A wide variety of models are available, both microscopic and macroscopic. However, a microscopic model is capable of modeling with great detail each individual vehicle in a network which is suitable to use in this research. Briefly, during each second of simulation, the program emits vehicles from entry links, moves vehicles in the network using embedded car-following, lane-changing, and gap-acceptance rules, and updates the status of various signals in the network. Even though simulation has its own problems (high level of detail and input data requirements in addition to the need for proper calibration and validation), it offers a viable alternative to field data collection. The major advantage of traffic simulation is that once a model has been developed and validated, it is possible to generate data for a wide range of situations.

A well known microscopic traffic simulation model, Paramics V5 was selected for application in this research. Paramics is a type of software that uses the microsimulation principle. It is a PC software system for road traffic flow analysis. It simulates the individual components of traffic flow and congestion, and presents its output as a real-time visual display for traffic management and road network design. Paramics can accurately simulate the traffic impact of signals, ramp meters and loop detectors (linked to variable speed signs) (McKay, 2000).

In this study, the purpose of using simulation was to simulate the traffic flow on the road as it might represent the real travel time condition. Besides, the conditions of the data, including the percentage of probe vehicles, inflow and outflow volumes can be control by using simulation. Simulation of the distribution of information would be accomplished by assuming that some percentages of the drivers would divert to alternative routes to avoid congestion. More precisely, in this research, simulation was used for the following purposes:

1. As a test bed to generate pseudo research data.
2. Illustrate the use of probe vehicle, probe percentage of fleet, movements, tracing as well as a display medium of all vehicles in the test network.
3. Illustrate dynamics queue build-up and dissipation.

Three different traffic scenarios were created for the purpose of examining link, route and OD travel time. A hypothetical network was used for link and route travel time. On the other hand, the Chulalongkorn University Surrounding Area was used as a case study for OD travel time. The next sections discuss these network designs.

## 3.2 HYPOTHETICAL NETWORK

The initial tasks of the network construction in Paramics Modeler are the physical input and the adjustment of the configuration and preference files because in Paramics, the road network representation is very specific in detail. In order to start the network construction, the basic parameters must be specified, for examples, preference units (US, UK and Metrics), right or left hand drive, roadway categories (arterial, freeway and ect.), number of lanes, lane width, speed limit and other display configurations. Second, the construction of nodes and then links throughout the study area, starting by putting all nodes positions and then connecting all nodes with proper links from set categories.

In this study, a five km hypothetical corridor was created to be modeled in Paramics V5 as a test bed for the generation of research data (link and route travel time consideration). The road section had two lanes in each direction with five intersections. Each lane had 3.6m width. Additionally, there were twelve different zones indicating that the vehicles were traveling from and to every zone in the test network. The following assumptions were made for the model development.

- The hypothetical network consisted of all passenger cars with the speed limit of 90 km/h.
- The driver behavior such as lane changing was not modeled.
- The vehicles maintained constant speed when they entered the system until they exited.
- The flow of traffic was free of road surface characteristics (e.g roughness) and weather conditions.

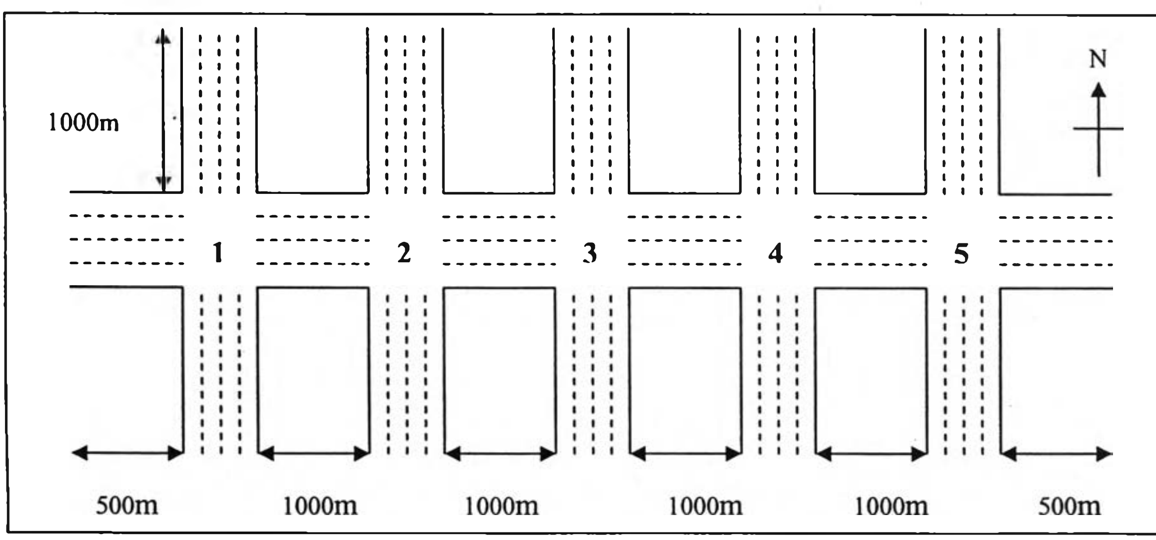



**Figure 3.3** Hypothetical network configuration indicating number of lanes

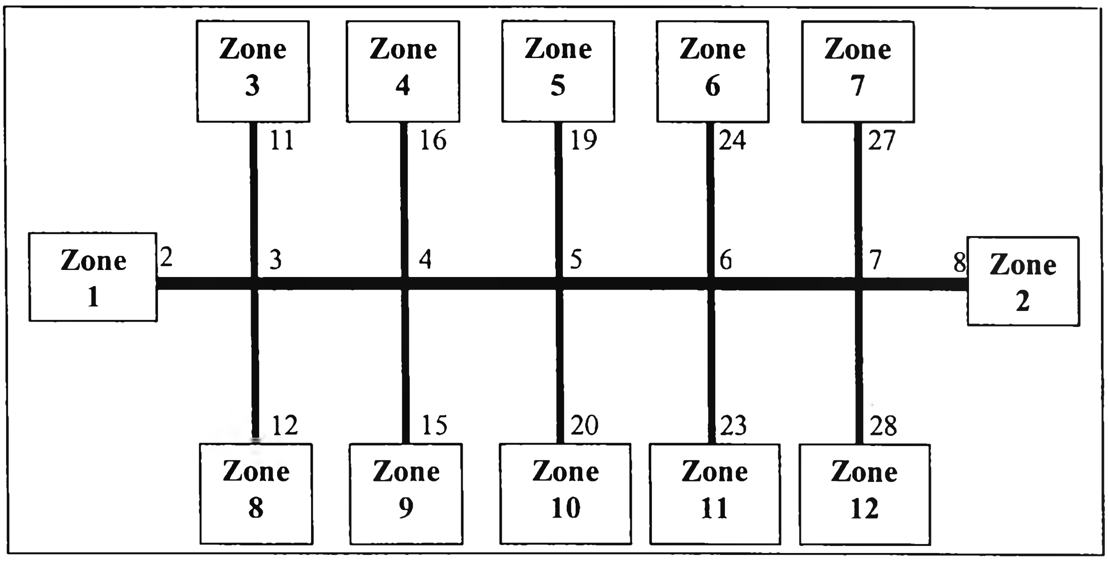



**Figure 3.4** Hypothetical network indicating zones and links number

Figure 3.3 illustrates the hypothetical network configuration indicating number of lanes. The numbers at the intersections represents the intersection number from Intersection 1 to Intersection 5. The entrance and exit link were specified for 500m from zone 1 to zone 2. The other entrance and exit link were specified to be 1000m while the middle link was specified to be 1000m each. Figure 3.4 depicts the hypothetical network indicating zones and link number in detail. The small numbers at the link signify the link number.

After the hypothetical network was built, the following task was the signal modification by a function "modify junction". In Paramics Modeler, the setting of phases and the priority directions for all movements according to recorded (actual or tested signal) data must be done before running the programme. Offsets should also be defined for signal coordination. It should be noted that in this study, no recorded field signal setting was used. Therefore, the optimum signal setting was specified in every network where Synchro 4, Traffic Signal Coordination Software was used for this purpose.

For link and route travel time, the traffic volume for the entire network needs to be set. Thus, the network with traffic volume of 4000 veh/h, 6000 veh/h, 8000 veh/h, 10000 veh/h and 12000 veh/h were fed in the hypothetical network. Unlike many of other simulation packages, in Paramics, traffic demand is described by an origin-destination matrix specified in the "demands" file whereas Synchro is a complete software package for modeling and optimizing traffic signal timings which basically use turning count as an input. Therefore, for the purpose of optimization, after the initial Paramics simulation run, the turning count from Paramics Modeler was identify using Paramics Analyzer. Since the purpose of the initial run was to get the turning count for every intersection, the default signal timings was used. The "demand" file in Paramics is shown in Appendix.

The design of the theoretical corridors was determined so that the network represented typical corridor in order to create a traffic situation which might give the various effects to the probe vehicle travel times. The theoretical corridors were investigated to cover a broader range of traffic volume. For link travel time, the purpose of this was to see the difference between the link travel time and the 'true' link travel time. In the case of route travel time, the purpose of this was to compare the accuracy of travel time data from the probe vehicle with the 'true' route travel time.

The 'true' average link travel time were measured by the summation of the travel time from all vehicles passing the link divided by the number of vehicles passing the link. On the other hand, since all vehicles in the network came with a unique ID (identity number), the probe vehicle travel time were measured by matching the ID of the vehicle in the link with the ID of the vehicle that specified the probe vehicle and the average travel time from the number of probe vehicles was calculated. It may not be feasible to include all links in the system coverage area. Selecting strategic links along the network to include in the system could ensure that travel time data were collected along critical links (e.g., most congested, greatest demand) in the network. Therefore, the main road consisted of 6 different links crossing 5 intersections for vehicle traveling from Zone 1 to

Zone 2 was chosen as the route travel time. The 'true' average route travel time is define as travel time from vehicles that traveled from Zone 1 to Zone 2 while the probe vehicle travel time is defined as the travel time from the vehicle specified as probe vehicle and matched with the ID of the one traveling along the route.

### 3.3. NETWORK OPTIMIZATION IN SYNCHRO 4 SOFTWARE

After the initial run to get the turning movement counting, all settings such as number of lanes and link length were transferred to Synchro 4, Traffic Signal Coordination Software in order to optimize the traffic signal settings for every intersection. The advantage of the signal optimization was to reduce overall intersection delay and to provide the optimal signal settings for the entire network. It should be noted that the optimization was done in order to create traffic scenarios with different congestion levels. The recommended signal timing was the result of an optimization strategy involving several performance measurements including the length of queue and delay. A Pre-timed traffic controller was specified in the network with split phases. Figure 3.5 illustrates the turning type specified and the numbers indicate the phasing priority. The phases were given to each approach in sequence. As illustrated, the first priority was given to the vehicles for east bound traffic, followed by west bound traffic, south and north bound traffic respectively. Once the level of service for every network was obtained, the optimum setting for the cycle length together with the offset setting were transferred back into Paramics V5 for further simulation.

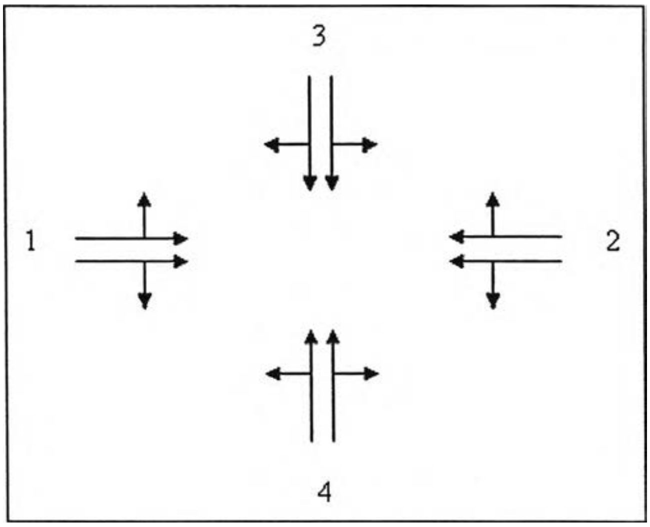



**Figure 3.5** Turning type specified in Paramics

**Table 3.1** Level of Service (LOS) for every traffic volume specified

| Traffic Volume (veh/h) | Intersection 1 | Intersection 2 | Intersection 3 | Intersection 4 | Intersection 5 |
|---|---|---|---|---|---|
| 4000 | B | B | C | C | B |
| 6000 | C | C | D | C | C |
| 8000 | C | D | D | D | C |
| 10000 | C | D | F | F | C |
| 12000 | E | F | F | F | F |

Table 3.1 shows the level of service for each intersection after network optimization in Synchro using the pre-timed intersection controller type. It shows that by loading extra vehicles in the network, the level of service of every intersection becomes F. Figure 3.5 shows the turning type specified in Paramics V5 where for the through movement shared lane with left and right turn. Table 3.2 enlightens the cycle length of each intersection together with the network offset which was then transferred to Paramics V5 for further simulation.

**Table 3.2** Cycle length and offset of intersections in test network

| | Intersection 1 | | Intersection 2 | | Intersection 3 | | Intersection 4 | | Intersection 5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Traffic Volume (veh/h) | Cycle Length (s) | Offset | Cycle Length (s) | Offset | Cycle Length (s) | Offset | Cycle Length (s) | Offset | Cycle Length (s) | Offset |
| 4000 | 80 | 0 | 80 | 40 | 80 | 0 | 80 | 40 | 80 | 0 |
| 6000 | 110 | 36 | 110 | 108 | 110 | 30 | 110 | 69 | 110 | 39 |
| 8000 | 100 | 63 | 100 | 4 | 100 | 64 | 100 | 26 | 100 | 85 |
| 10000 | 100 | 56 | 100 | 17 | 100 | 84 | 100 | 44 | 100 | 4 |
| 12000 | 130 | 4 | 130 | 104 | 130 | 77 | 130 | 68 | 130 | 68 |

## 3.4 SIMULATION WITH PARAMICS

### 3.4.1 Network Simulation

After the intersection optimization procedures, the networks were transferred back to Paramics V5 software for further analysis. It was important to make sure that the layout of the network in Paramics was the same as that in Synchro in order to make sure the optimum setting was achieved. For every network with different traffic volume settings, only one simulation run was conducted. The simulation started at 8 o'clock in Paramics V5 time for one hour using seed number 5. It should be noted that in this study, the selection of the seed number did not vary because the purpose of it was not to see the variation of data given by Paramics V5, but rather to see the effects of probe vehicle in different variations of traffic level. Hence, only one run with the same seed number but different traffic levels was set. With the help of Application Programming Interface (API), the information such as the time of entry into link, time of exit from link together with the each vehicle ID could be extracted from Paramics V5. Therefore, in this study the API was used to get the travel time for every network. Using the API created, each vehicle ID could be extracted which will help for further analysis. Figure 3.6 illustrates the development of extracting travel time data.

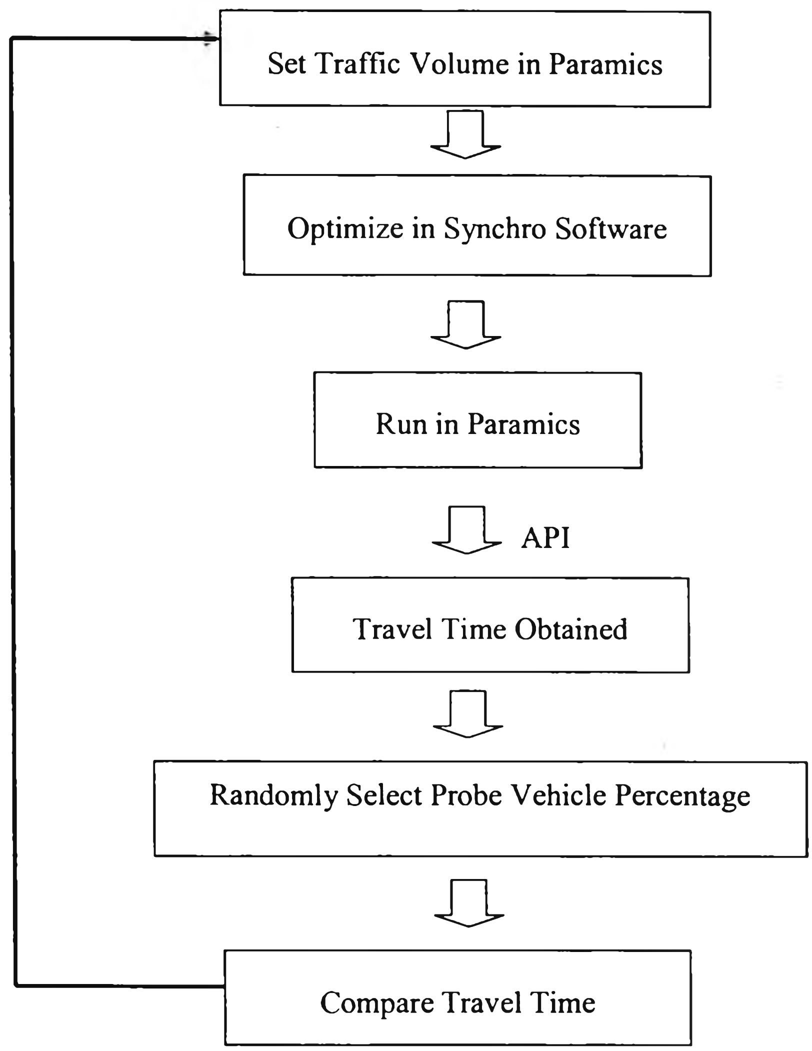



**Figure 3.6** Development of extracting travel time data

### 3.4.2 Paramics Programming (API Function)

One of the best functions that make Paramics different from the other software is the API function. API (Application Programmer Interface) can be considered as the key that allows users to overcome the indiscernible nature of the simulation program used. In Paramics, some data such as travel time cannot be extracted directly from the simulation. Therefore, the used of API for generating the data is very important. Paramics, one of the widely used microscopic simulation programs of recent years provides an API, but very little literature is available on the successful applications of the API. Lee, Chandrasekar and Cheu (2001) had described their experiences in exploiting the power of the API overcoming some of the challenges faced while developing a Paramics-based simulation test bed aimed for modeling ITS applications. According to them, the challenges include the non-availability of demand data defined in the form of OD matrices, the modeling the GLIDE (The Green Link Determining System) operation (a customized version of SCATS for Singapore), lack of readily available tools for traffic diversion control (for incident management studies), transit priority modeling and calibration and validation purposes. They came out with some problem solving in order to customize simulation modeling using Paramics application programmer interface experienced in Singapore.

In addition, Chu, Leu and Recker (2003) presented their practices on the development of the capability-enhanced PARAMICS simulation environment through API programming that included path-based routing, actuated signal control, ramp metering control, traffic information collection, database connection and performance measures. In order to classify certain function in Paramics API as well as to allow interface between Paramics programs or other data, C++ language is used. As Chu, Leu and Recker (2003) indicate, the simulation process in Paramics using the API comprise of updating some basic elements of the simulation such as vehicle positions or speed after the start of the simulation at every time step. When an API module is involved in the simulation, it may work at every time step, or will be activated at a specific simulation time or by a specific event. Generally, an API module gets necessary information from the simulation world through callback functions and then affects the simulation through control functions. Figure 3.7 shows the Paramics simulation process with API modules.

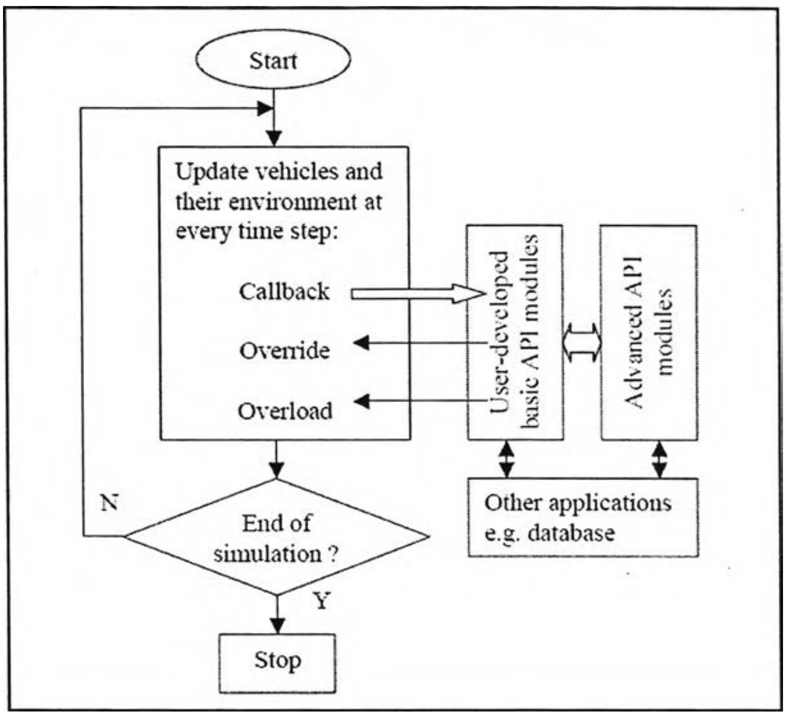



**Figure 3.7** Paramics simulation process with API modules as in Chu, Leu and Recker, 2003

For this study, an API was developed in order to get the vehicles time entering the link, time leaving the link as well as vehicle identification (ID) for each vehicle. The methodology displayed in Figure 3.7 was altered to match with the criteria needed for this study. C++ language was used in the Paramics API to classify certain function in a convenient way to allow interfacing with other programs or data. The name of the API plug was "base.dll", which should be placed in the network directory. The simulation network together with the plug in should be loaded together in Paramics Modeler. The process of using an API in order to gather travel time data in this study is described in Figure 3.8.

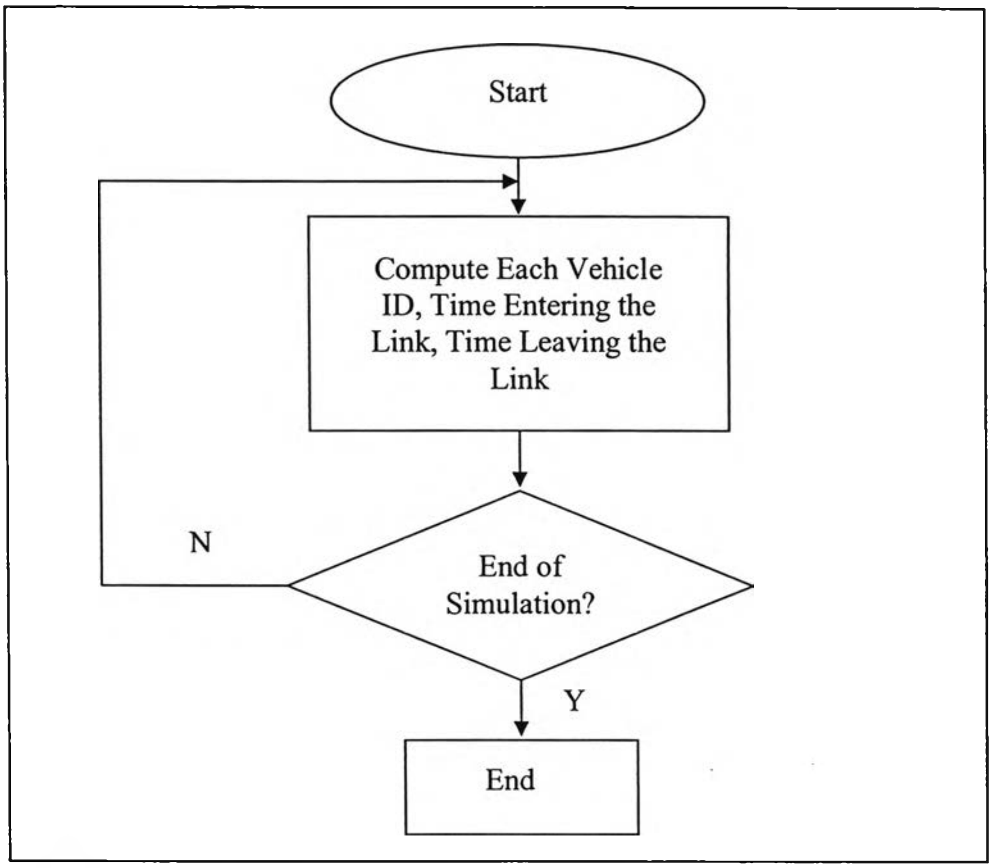



**Figure 3.8** Process of extracting travel time data using Paramics API

As mentioned earlier, the simulation ran for 1 hour. Therefore, once the simulation started, the API processed the information and this plug in generated the output files continuously. In every time step, each vehicle ID, time entering the link as well as the time that the vehicle leaves the link was computed. Once the simulation ended, the data available came in a DAT type file. For example, "VehIn_2_3" and "VehOut_2_3". The "VehIn_2_3" file consists of ID and time entering link number 2-3 and "VehOut_2_3" file consists of ID and time leaving the link number 2-3. The file was transferred to Excel sheet in the format of the output file is as shown in Table 3.3.

**Table 3.3** Format of the output files from Paramics

| 2-3 | | | |
|---|---|---|---|
| ID | Time in | ID | Time Out |
| 11 | 28821.5 | 29 | 28880.5 |
| 14 | 28829 | 11 | 28880.5 |
| 29 | 28838.5 | 14 | 28883 |
| 22 | 28841.5 | 22 | 28883.5 |
| 41 | 28860.5 | 41 | 28886 |
| 59 | 28872 | 59 | 28891.5 |
| 54 | 28875 | 61 | 28893 |
| 61 | 28875.5 | 54 | 28893.5 |
| 64 | 28877.5 | 64 | 28896 |
| 77 | 28888 | 77 | 28960.5 |
| 94 | 28902 | 94 | 28960.5 |
| 108 | 28914 | 108 | 28963.5 |

As shown in Table 3.3, "2-3" is the example of link number. "ID" is the identification number, "time in" is the time that the vehicle entered the link and "time out" is the time when the vehicle left the link. Since every link comes with pair data (ID with time in and ID with time out), travel time can be computed by subtracting the "time in" from the "time out". However, before doing this, the ID needs to match first before subtracting the time.

$$\text{Travel Time} = \text{Time in-Time out} \tag{3.1}$$

From the table, it can also be seen that the "time in" value starts from 28821.5. Since the simulation start at 8:00:00, the first vehicle that enters the link at 8:00:00 will generate "time in" of 28800 (8*3600). For the purpose of analyzing the data, only 45 minutes of simulation data was used. Therefore, only vehicles with "time in" of 29700 to 32400 which represent 8:15:00 to 9:00:00 were used for further analysis.

### 3.4.3 Data Analysis

For every network with traffic volume settings, the travel time for every vehicle together with vehicle unique ID was gathered. Some of the vehicles were specified to be probe vehicles. However, the specification was not done at the beginning of the simulation, but the iteration of producing and assuming some vehicles to be probe was set after the simulation was stopped and data were generated. For every data set (different traffic volume setting), 'bootstrapping' was made for 200 times. This meant that a set of vehicle ID was selected for 200 times randomly and the travel time of each ID was identified in order to get the variation of travel time. The 'bootstrapping' was conducted for 2.5%, 5%, 10% and 20% sample of probe vehicle in every network. Bootstrapping estimated the sampling distribution of a statistic by iteratively resampling cases, with replacement, from a set of observed data, and computing the sample statistic. Confidence intervals about the sample statistic can then be constructed, providing an empirical basis for inferential statements about the likely magnitude of the statistic. This approach allows for use of smaller samples for estimation of the underlying population parameter. Application of bootstrapping to estimation of probe vehicle travel time might allow us to user smaller samples in validation studies, thereby reducing the costs.

In this study, the percentages of probe vehicles are present and a set of vehicle IDs to be probes were selected from the entire traffic on the network. The selection of probes was not done as the percentage of number of vehicles on the selected links. This caused an inexact number of vehicles selected to be probes on each link and also the number of probe vehicles was not directly related to the number of vehicles on the corresponding links. However, the selection of probe vehicles herein for various percentages (2.5% 5% 10% 20%) was not random. To simplify the re-sampling process, the additional required number of probe vehicles (from the previous test) was selected from the list of ID of vehicles on the link, in addition to the already selected vehicles. For instance, the 5% probe vehicle case required 2.5% more vehicles from the number of vehicles chosen in the 2.5% probe vehicle case However, once the re-sampling was done for the second iteration, the sample was taken from the original sample. Therefore, there will be possibility of taking the same vehicle ID as in the first iteration. The whole process was repeated B times (where let B = 200 reps for this example). Thus, the generation of 200 resample data sets (b = 1, 2, 3, ..., 200) was conducted and from each of these, the computation of the average travel time and standard deviation was done and this values was stored into a file. It is important to understand this sampling process since the cases of greater percentage of the probe vehicles would not be created independently from the less percentage cases, in other words, the vehicles chosen in the low percentage of probe vehicles would appear the higher percentage case. This would affect the results of analysis and the interpretation, as it would appear later in the next Chapter (e.g. Table 4.3).

Based on these random probe samples, the analysis was conducted to determine how close the estimation of link and route average travel time matched the 'true' data. Again, in Paramics, warming up time is used to account for the discrepancy that occurs when the simulation starts and the system is empty, but in reality there are cars in the system needing to be classified. Hence, by skipping the first fifteen minutes, the link and route travel time estimation process were conducted for the remaining time period. For example in the case of 4000 veh/h in the network, the data generated for the remaining 45 minutes was 3200 vehicles. Therefore, the iteration of probe vehicle sample was done as 10% from 3200 vehicles. For further understanding regarding the bootstrapping iteration done in this study, the full process is illustrated in flow chart in Figure 3.9.

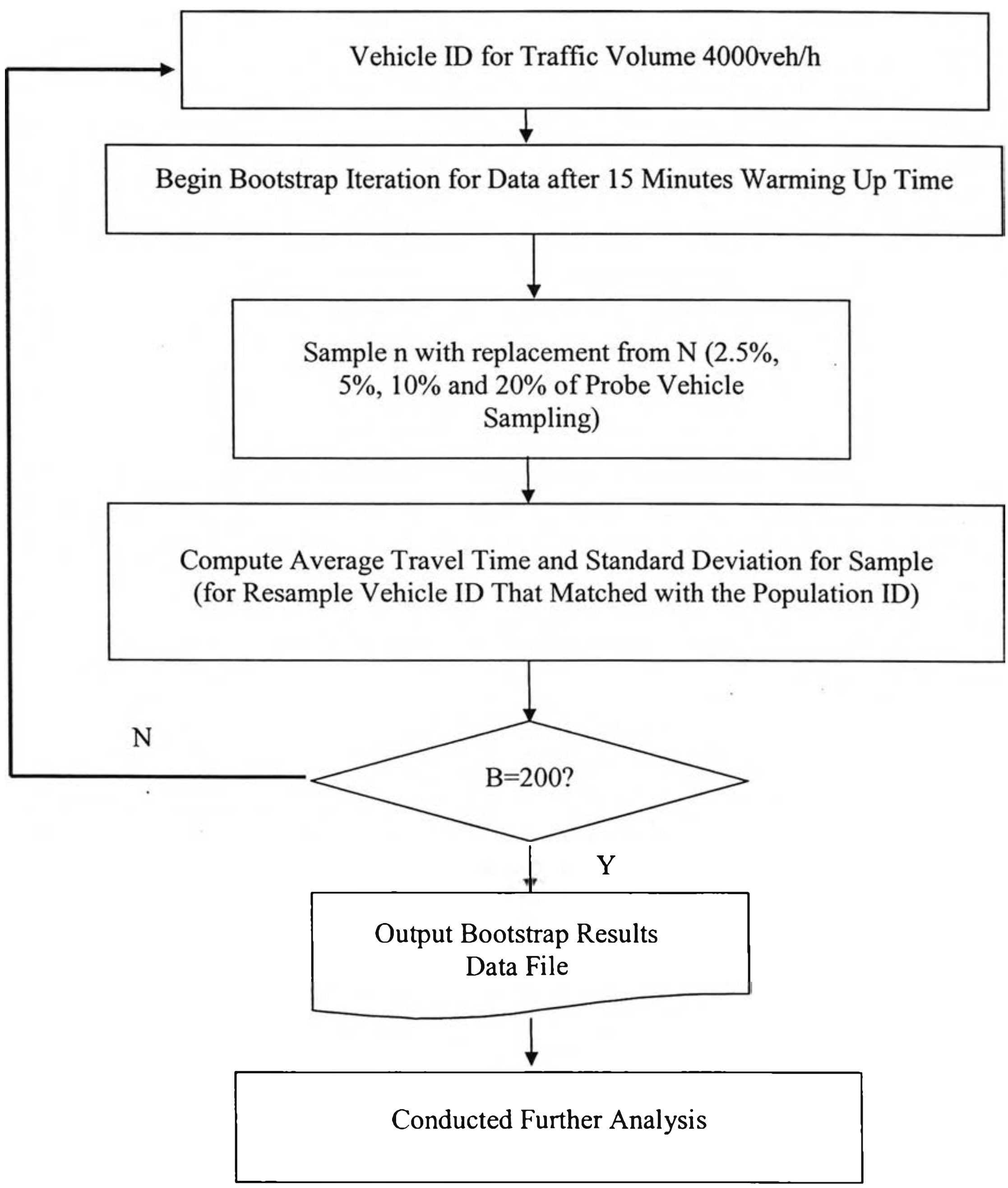



**Figure 3.9** Bootstrap iteration for probe vehicle resampling

## 3.5 CASE STUDY

In order to illustrate a simulation analysis of the potential of vehicle probes to provide OD information, an example network is required. To permit an analytical analysis, a simple network was defined. However, in order to provide meaningful results, the network characteristics were developed to be as realistic and objective as possible. Therefore, for this case study, a real network configuration was used. Chulalongkorn University surrounding area was selected for that purpose. The entire test bed network is shown in Figure 3.10.

The study area was known to be congested during week days periods, particularly in the morning and evening peak. The OD 7-5 connected the population in the east to the west through Rama 1 Road while OD 8-11 connected the population from east to west through Rama IV Road, crossing two intersections which were Intersection E (Sam yarn) and Intersection F (Saphan Leang). Si Phraya Road and Phaya Thai Road connect the OD 9-6, crossing four intersections which were the Samyarn, Chulalongkorn University, Chula 12 as well as the Pathumwan Intersection respectively. OD 8-5 was the longest route in the network, connected by Rama IV Road, joined the vehicles at five intersections which were Intersection E (Sam yarn), Intersection D (Chulalongkorn University), Intersection C (Chula 12), Intersection B (Pathumwan) and proceeded to Intersection A (Phong Phra Ram). Figure 3.11 illustrates the route taken by the vehicles for the selected OD.

The test network had almost 170 nodes and more than 200 links. There were six major signalized intersections in this network which represented by the alphabets (A-F). The traffic zones were shown by the numbers which were remarked in rectangular shapes. The traffic network was created using the network editing tools of Paramics to position the nodes and links so that the network matched the actual geometry indicated in the overlays. The screenshot of the signalized intersections are shown in Figure 3.12. The speed limit specified in this network was 80km/h. The vehicles specified in the network were according to real conditions with a mixture composition of vehicle characteristics. Using the real data taken from Bangkok Metropolitan Administration, the network demand level for 1 hour evening peak was calibrated to get the same level of congestion as similar to the real world. The level of congestions experienced by all vehicles at the intersection is represented by the level of delay at each intersection in Table 3.4.

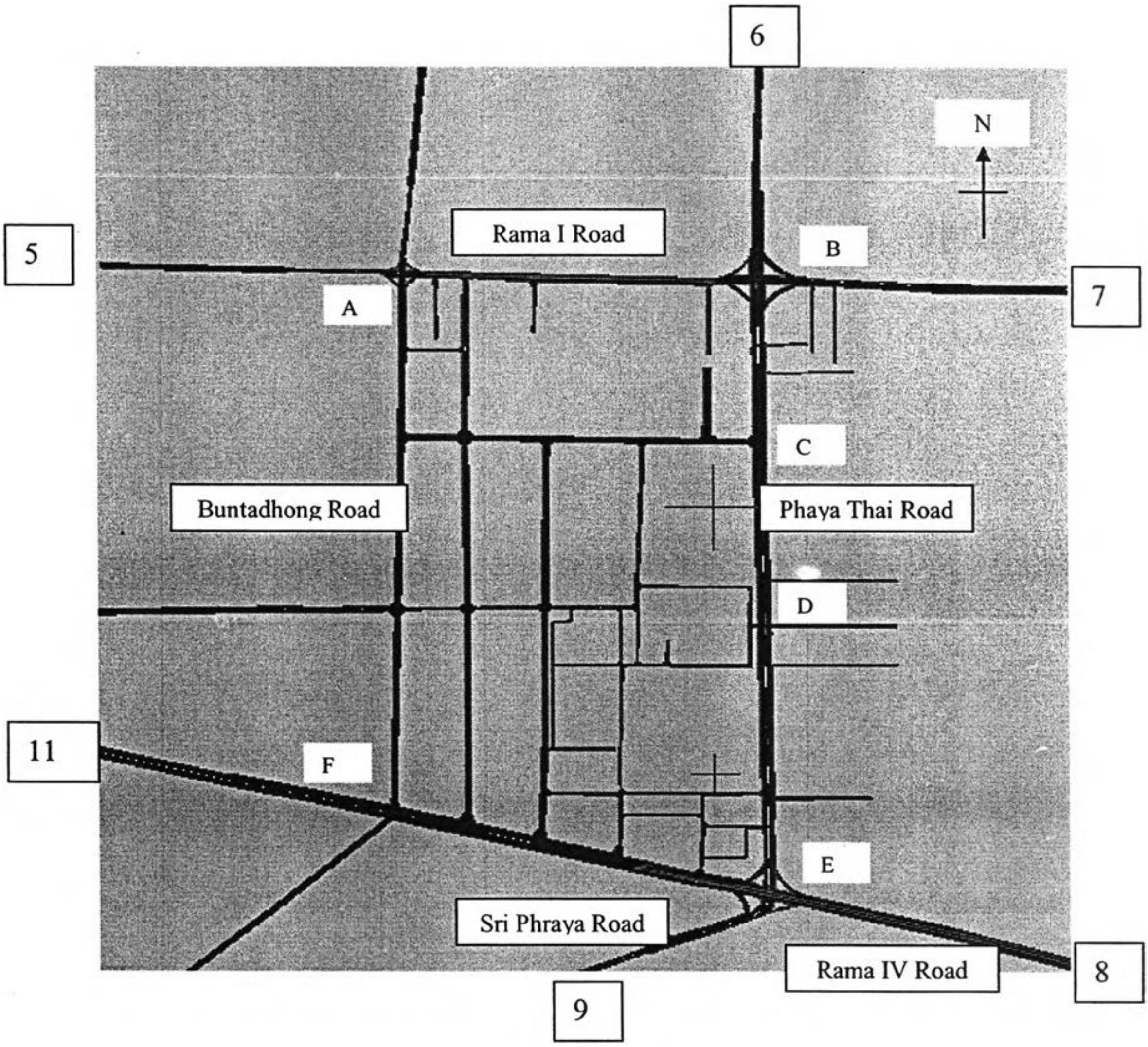



**Figure 3.10** Network built in Paramics for case study

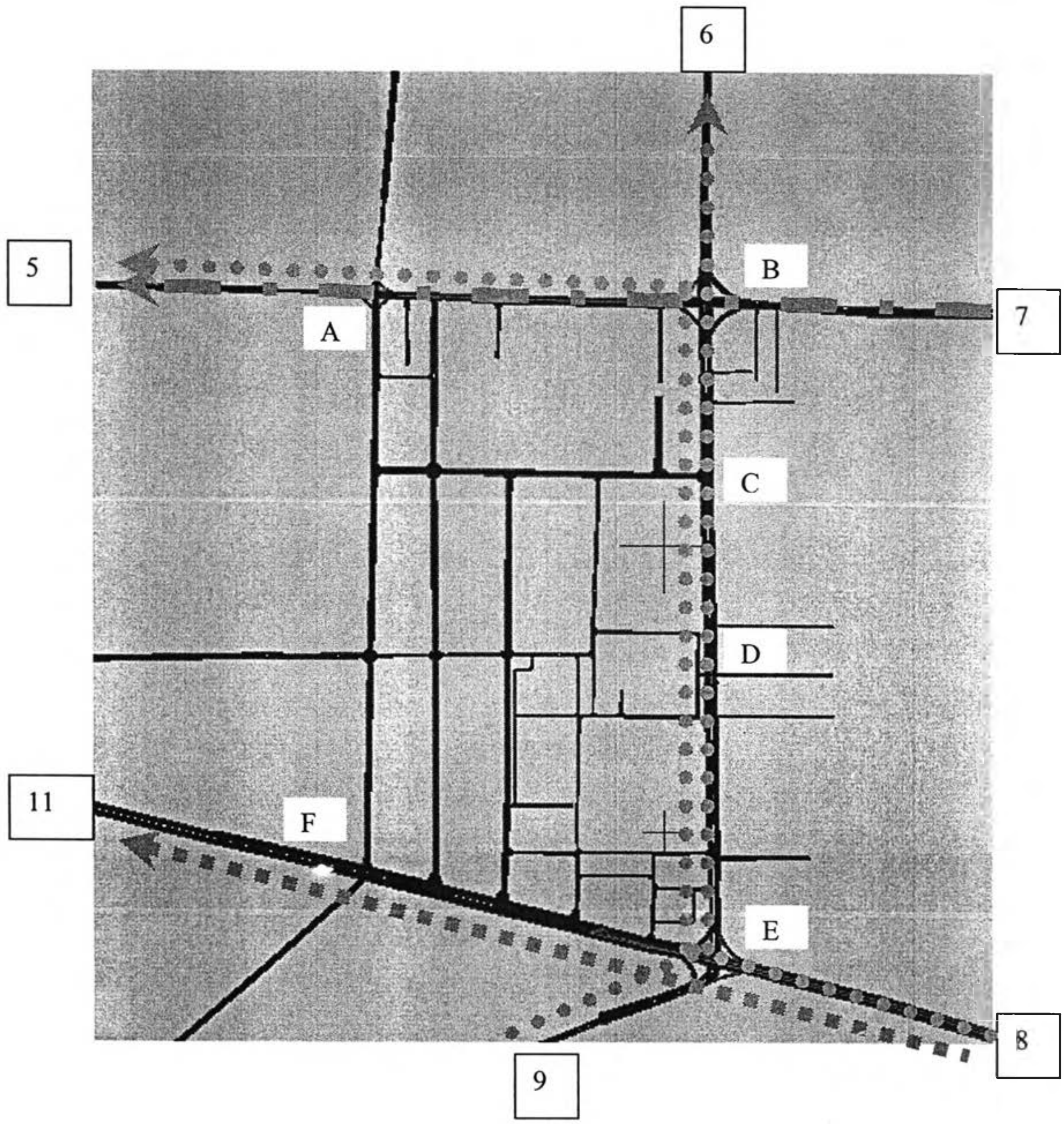
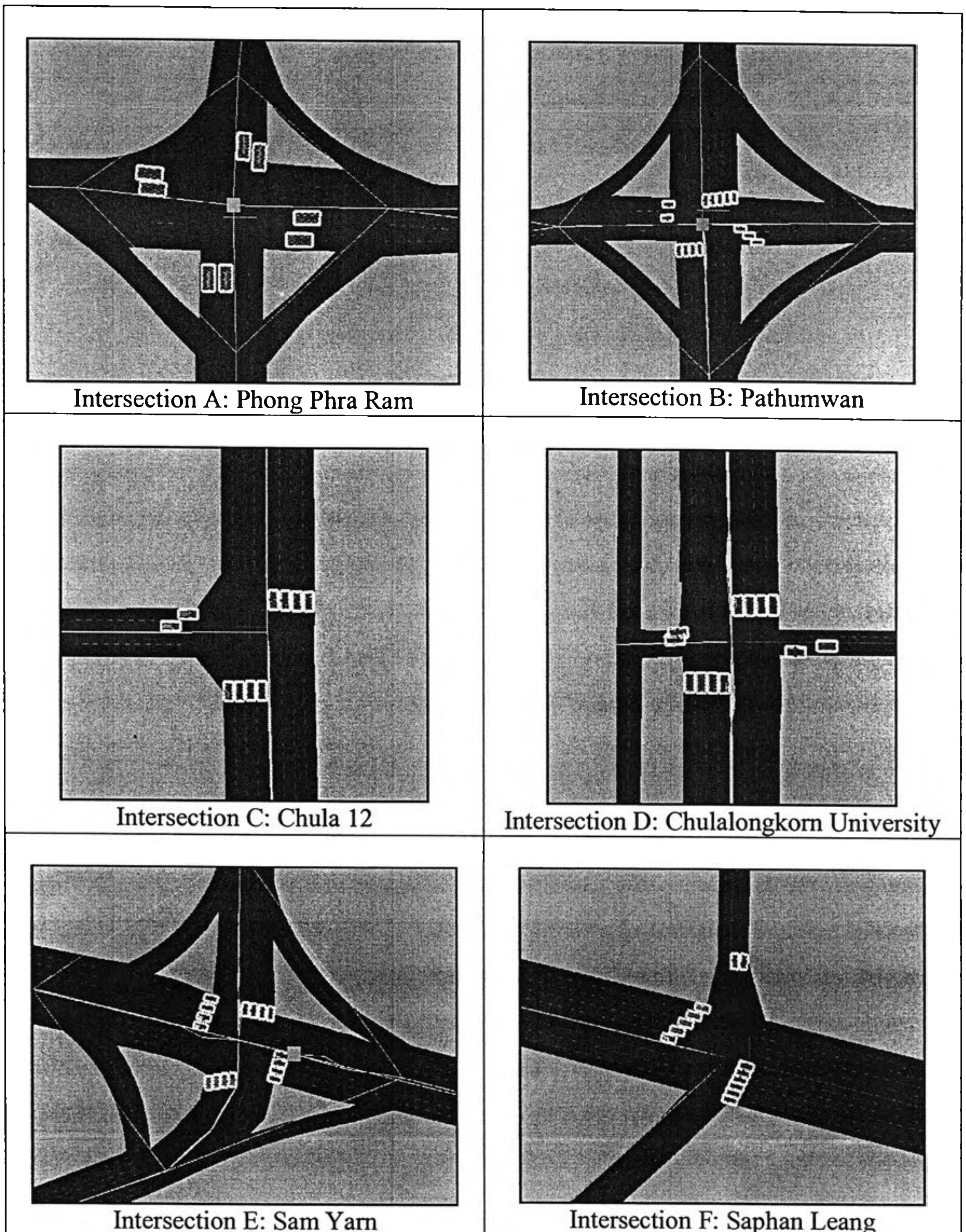



**Figure 3.11** Network with arrows showing the route taken by vehicles



Intersection A: Phong Phra Ram

Intersection B: Pathumwan

Intersection C: Chula 12

Intersection D: Chulalongkorn University

Intersection E: Sam Yarn

Intersection F: Saphan Leang

**Figure 3.12** Screenshot of intersections with traffic signals within the network

**Table 3.4** Delay and Level of Service (LOS) of each intersection

| Intersection | Delay (s/veh) | Level of Service (LOS) |
|---|---|---|
| Intersection A | 8.4 | A |
| Intersection B | 37.2 | D |
| Intersection C | 11.1 | D |
| Intersection D | 34.9 | C |
| Intersection E | 168.3 | F |
| Intersection F | 50.1 | D |

The level of congestion experienced by the vehicles at every signalized intersection is presented by the level of service and delay as in Table 3.4. As shown, Intersection E (Sam Yarn) has a highest delay (168.3s/veh) which represents the most congested intersection through out the network followed by Intersection F (Saphan Leang) with delay of 50.1s/veh. Besides, the Intersection B (Pathumwan) recorded the delay of 37.2s/veh with level of service of D followed by Intersection D( Chulalongkorn University) , Intersection C(Chula 12) and Intersection A (Phong Phra Ram) with delay of 34.9, 11.1 and 8.4s respectively.

The method used for the simulation and further analysis was the same as in the case of link and route travel time where the network was initially modeled in Paramics for 1 hour. Then, the turning movement of each intersection was transferred into Synchro Software to optimize the signal setting. After the optimization, the cycle length together with the offset for each intersection was transferred back into Paramics V5 for further simulation. And the network was run 1 hour with the API to gather the data. Again, for the purpose of data analysis, the warm-up time of 15 minutes was used to account for the discrepancy that occurs when the simulation starts and the system is empty, but in reality there were cars in the system. Hence, by skipping the first 15 minutes, the OD travel time estimation process was conducted for the remaining time period. Table 3.5 shows the 'demand' level specified in Paramics V5 for the selected OD.

**Table 3.5** Demand specified in Paramics for the selected OD

| OD | To 5 | To 6 | To 11 |
|---|---|---|---|
| From 7 | 3743 | - | - |
| From 8 | 400 | - | 5946 |
| From 9 | - | 236 | - |

The data analysis was conducted for the summation of link by link average travel time for four pairs of OD which was OD 7-5, 8-5, 9-6 and 8-11. Besides, there was also analysis for vehicles that completed the OD (from zone to zone) specified. Note that, the selection of these OD pairs was done because they are the most congested route on the simulation network, crossing intersections with high delay as shown in Table 3.4. The discussion regarding this section focus on the assumption that if no probes were available to collect the travel data, the only available data was from the summation of the link by link travel time. Full discussion regarding this section was carried out in Chapter 4.