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STUDY ON THE IMPACT OF SHORT-TERM WORK ZONE ALONG AN UN-INTERRUPTED FLOW HIGHWAY: A CASE STUDY IN THAILAND

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Abstract: This paper presents the evaluation of work zone capacity in Thailand and the development of closure scheduling tools in order to schedule work zone by minimizing all related traffic impacts. The results of the capacity analysis revealed that the work zone capacities deriving in this study are higher than the work zone capacities suggested by the highway capacity manual, HCM 1994. These capacities are used to develop the closure scheduling tool. The developed tool is computer-based which considers the excessive flows due to lane closure and determine the dissipation period affecting from the closure. The results show the summary of dissipation durations for different closure schedules. To demonstrate the real world application of this developed tool, a selected section of Highway No.1 (Phaholyothin highway) was selected as a case study. Results revealed that the unsuitable closure periods are 6:00 hr. to 8:00 hr. and 16:00 hr. to 18:00 hr.

Key Words: Work Zone Capacity, Scheduling Tool, Maintenance Activity, Lane Closure

1. INTRODUCTION

Highway repair and maintenance activities often resulted in traffic interruptions and congestions caused by reduction in its capacity, increased delay to road users, and increased accident rates and fuel consumption. Due to the ever increasing in traffic demands, even with a small repairing work, it can cause drastic effects on traffic conditions. Thus, the need to maintain an adequate traffic flow of short-term work zone is vital, especially on heavily traveled highways. Work zone traffic control strategies and methods must be carefully planned, selected, and applied to minimize these impacts. For these reasons, we need to predict various traffic-related characteristics such as traffic capacities, queue lengths, delays, speeds, etc.

The work zone capacity is one of the principal determinants of traffic impacts. Accurate estimation of the work zone capacity is critical to the success of traffic management and control plans at work zones. Therefore, it is essential to identify the appropriate estimation of the capacities for an un-interrupted flow highway work zone.

Thailand Department of Highways is experiencing growing congestion and traffic delays in work zones along the national highways. The congestion has resulted from decreasing roadway capacity along work zone section as illustrated in Figure 1. Nevertheless, this reduced capacity has never been studied for Thailand environment. This study observed a short-term work zone on Thailand highway with access controlled to measure the maximum volume of vehicles that can pass through a work zone lane closure prior to and during congested operations and to better understand related driver behaviors. The capacity deriving from this study is used as a part of closure scheduling tool which is also presented in this paper.

Figure 1. Traffic Congestion on Work Zone Segment

2. RATIONALE OF THE STUDY

Improper schedule of lane closure can lead to congestion. This congestion may still last for several hours after the closed lane has been opened to traffic. This improper schedule leads to ineffective use of the infrastructure. Therefore, it is important to properly schedule the work zone lane closure to avoid or minimize such situations. This study aims to mitigate such problems. Moreover, there are other motivations that urge the author to conduct the study which are;

1. Scheduling of short-term lane closure with a proper framework has never been undertaken in Thailand
2. Tool which is really applicable and suitable for actual practice does not exists (some tools in the market require data which is not collected in Department of Highways and the complexity of the tool does not persuade the practitioners to use them)
3. Work zone capacity which is the most important parameter in evaluating the proper schedule has never been studied for Thailand traffic environment
4. The existing capacity values recommended by several international agencies are believed that do not really reflect the driving situation in Thailand.

3. LITERATURE REVIEWS

Most of Highway agencies have conducted the study on work zone capacity values. Mainly, the capacity estimates in the *Highway Capacity Manual (HCM)* are based on the work done at the Texas Transportation Institute (TTI) by a variety of investigators over a number of years from the late 1970s and the mid –1980s.

Many studies have been conducted to estimate work zone capacity based on field data analysis. The determination of capacity studies was conducted at urban freeway maintenance and construction work zones in Houston and Dallas (Dudek and Richards, 1981). Studies were conducted on 5-, 4-, and 3- lane freeway sections. A new capacity values for short-term freeway work zone lane closures was suggested in the early 1990s (Krammes and Lopez, 1992). They showed that the new capacity values are higher than the older capacity values in the HCM.

The work zone capacity was defined as the flow rate at which traffic behavior changes from uncongested conditions to queued conditions (Dixon and Hummer, 1996). Another study defines capacity as the flow just before a sharp speed drop followed by a sustained period of low vehicle speeds and fluctuating traffic flow which defines a formation of a queue (Jiang, 1999).

TTI work zone capacity research published in 1982 was used as a basis for the methods for determining work zone capacity as described in the 1985 *Highway Capacity Manual* (as well as the 1994 manual). This work was based on hour-long data collected on urban Texas freeways with lane closures.

Another study (Ahmed et.al, 2000) was conducted to determine the mean capacity for different types of work zone lane closure configurations. It can be seen from the previous studies that the capacity values of work zone section are straightforwardly derived from the measurement of discharge rate under congested condition which is different from the capacity measurement of normal section where the speed-flow curve must be developed.

Although *Highway Capacity Manual (HCM)* has been used to determine work zone capacity in several countries, it is also widely accepted that HCM 's work zone capacity is difficult to duplicate to other countries particularly the developing countries due to the different driver behaviors and characteristics as well as different highway design standards and conditions. Therefore, it is important to conduct a study on work zone capacity for each specific condition. Unfortunately, this practice is not normally considered in developing countries. Often time, in Thailand repair and maintenance activities are treated as a normal routine activity resulted to several unforeseen impacts. Such impacts are not only causing traffic congestions but also create road safety problem at those work zone areas.
The work zone capacity for Thailand highway evaluated in this study considers the number of closed lanes as a factor affecting the capacity. The numbers of opened and closed lanes are important contributors to per-lane work zone capacity reduction. The per-lane work zone capacity might decrease as the number of closed lanes increases, and it might increase as the number of opened lanes increases.

4. DATA COLLECTION

In this study, the work zone capacity is considered as “the maximum number of vehicles that are discharged out of the work zone section in a period of time”. The video cameras are then acquired in this study to continuously capture the traffic discharging from the work zone as shown in Figure 2. The discharge rates are collected for at least 2 hours consecutively at each site. Traffic is classified into 4 major types which are 1) passenger car and pickup, 2) minibus and van, 3) bus, and 4) truck. The data are analyzed and only the discharge volumes under congested condition are considered. The congested condition is defined when queues are formed upstream of lane closure.

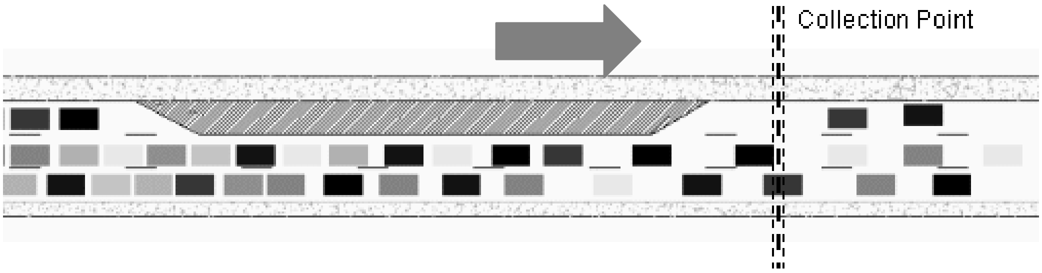
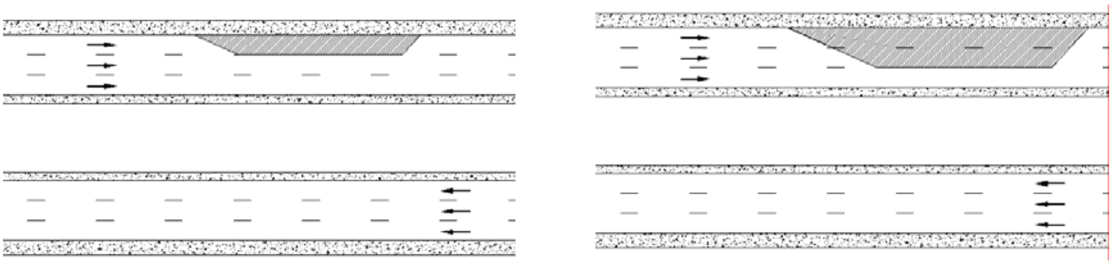


Figure 2. Location of Collection Point

4.1 Work Zone Site Characteristics

Twelve work zone sites located along Highway Number 1 (Phaholyothin road) are selected in this study. All of the work zone sites are 6 lanes highways with access control (entrance and exit) and 4 lanes frontage road. All of these work zone sites are short-term work zone lane closures covering about 2 – 6 hours period during daytime. The highway is partially closed for pavement resurfacing project. In this project, there are 2 major types of closure as illustrated in Figure 3.



Type 1: Two opened lanes and one closed 1anes

Type 2: One opened lanes and two closed lanes

Figure 3. Type of Closure Configuration

As mentioned earlier, the geometric impacts, the number of opened lane and closed lane, are considered in capacity evaluation. In reference to the geometric impacts, it is decided to confine the sampling effort to short-term work zone along the six-lane highway and no crossovers due to the following reasons:

1. Almost the entire highway system with access control in Thailand consists of 3 basic lanes in each direction. Therefore, six-lane highway is the predominant highway that has been access controlled.
2. Highway Number 1 is access control with 3.5 meters lane width, level terrain which is closely to the ideal condition for capacity determination.
3. Long term closures are generally considered in a macroscopic scale while short term closures are generally overlooked. However, the congestion due to short-term work zone must be treated as well through the proper schedule. In addition, the short-term work zones are often found in highways than long-term work zones.

4.2 Capacity Measurement

Traffic volumes counted at the termination area are conducted for 15 minutes interval. The 15-minute traffic volumes under congested condition are used to determine capacity.

The data of work zone sites 1 to 6 represent the traffic information of lane closure type 1 which is lane closure with 2 opened lanes and 1 closed lane and the data of work zone sites 7 to 12 represent work zone lane closure type 2 which is lane closure with 1 opened lane and 2 closed lanes. The traffic volumes under congested condition of each site are illustrated in Tables 1 and 2.

Table 1. Summary of Analyzed Work Zone Discharge Rate for Lane Closure Type 1

Traffic Volume Under Congested Condition				
Work zone Site 1	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	323	127	32	85
15-minute volume no.2	391	133	25	63
15-minute volume no.3	374	144	49	43
15-minute volume no.4	385	115	33	69
Work zone Site 2	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	389	136	23	62
15-minute volume no.2	384	117	29	71
15-minute volume no.3	321	129	29	87
15-minute volume no.4	373	142	50	44
Work zone Site 3	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	390	134	27	60
15-minute volume no.2	376	142	48	44
15-minute volume no.3	381	115	32	70
15-minute volume no.4	335	125	28	85
Work zone Site 4	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	360	140	46	53
15-minute volume no.2	342	124	27	84
15-minute volume no.3	395	133	25	61
15-minute volume no.4	386	112	29	73
Work zone Site 5	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	390	131	28	62
15-minute volume no.2	386	113	31	71
15-minute volume no.3	334	120	28	89
15-minute volume no.4	339	129	18	90
Work zone Site 6	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	368	118	26	79
15-minute volume no.2	352	129	21	83
15-minute volume no.3	374	112	20	85
15-minute volume no.4	369	122	40	65

Table 2. Summary of Analyzed Work Zone Discharge Rate for Lane Closure Type 2

Traffic Volume Under Congested Condition				
Work zone Site 7	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	200	60	4	8
15-minute volume no.2	194	64	12	2
15-minute volume no.3	214	50	2	10
15-minute volume no.4	234	30	4	12
Work zone Site 8	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	248	26	8	6
15-minute volume no.2	262	16	8	6
15-minute volume no.3	192	48	6	16
15-minute volume no.4	214	62	6	2
Work zone Site 9	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	232	44	6	4
15-minute volume no.2	242	14	14	10
15-minute volume no.3	218	40	10	8
15-minute volume no.4	186	54	10	12
Work zone Site 10	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	174	8	20	36
15-minute volume no.2	216	38	8	14
15-minute volume no.3	228	38	12	6
15-minute volume no.4	238	28	16	4
Work zone Site 11	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	212	14	24	14
15-minute volume no.2	194	32	10	22
15-minute volume no.3	236	48	2	4
15-minute volume no.4	250	18	4	14
Work zone Site 12	V_{PC}	V_{MB}	V_B	V_T
15-minute volume no.1	170	62	8	16
15-minute volume no.2	186	36	18	16
15-minute volume no.3	228	34	10	8
15-minute volume no.4	242	10	4	20

In order to determine the capacity, the relationship of the 15-minute volumes of each vehicle type is defined in equation (1). This multivariable equation is applied to each 15-minute data at each site which are the summation of number of vehicles in passenger car per hour per lane.

$$V_C = V_{PC} + a\,V_{MB} + b\,V_B + c\,V_T \qquad (1)$$

Where

V_C = Total 15-min volume passing the collection point under congested condition (pcphpl)
V_{PC} = Total 15-min volume of passenger car passing the collection point under congested condition (vph)
V_{MB} = Total 15-min volume of minibus and van passing the collection point under congested condition (vph)
V_B = Total 15-min volume of bus passing the collection point under congested condition (vph)
V_T = Total 15-min volume of truck passing the collection point under congested condition (vph)
a, b, c = Constants (Passenger car conversion factors)

Four multivariable equations are used to solve the 4 unknown parameters for each work zone site. The "V_C"s of all equations are assumed to be equaled in each site for the analysis. Therefore, the 15-minute traffic volumes in pcphpl and the passenger car conversion factors are calculated. The a, b, and c are considered as the Passenger Car Equivalents (PCEs) which are used to convert the number of vehicles into number of passengers car. The results are shown in Table 3 while a, b, and c are represented by PCE_{MB}, PCE_{B}, and PCE_{T} respectively.

The work zone capacities from the analysis for 2 opened lanes and 1 closed lane is 1,648 pcphpl while the work zone capacity for 1 opened lane and 2 closed lane is 1,290 pcphpl. It shows that capacities evaluated in this study are higher than the values recommended by HCM which are 1,480 and 1,170 pcphpl for 2 opened lanes and 1 opened lane respectively. In addition, the passenger car conversion factor calculated in this study revealed that passenger car conversion factors (PCEs) used in work zone analysis are higher than vales used in normal highway section analysis. The PCEs for bus and truck for work zone analysis are approximately 2.2 and 2.75 while the values used by DOH for normal highway section are 2.0 and 2.5 respectively. However, the PCEs for minibus/van are 1.5 which are equal for either work zone and normal highway section.

Table 3. Work Zone Capacity and Passenger Car Equivalents

Type of Closure	**Work zone capacity (pcphpl)**	**Passenger Car Equivalents (PCEs)**		
		Minibus and Van	**Bus**	**Truck**
2 opened lanes and 1 closed lane	1648	1.54	2.2	2.76
1 opened lane and 2 closed lanes	1290	1.45	2.21	2.86

5. CLOSURE SCHEDULING TOOL

According to the determination of work zone capacity in previous section, these values are useful for highway practitioners in developing a maintenance schedule. The capacity values are encoded into the developed tool as the default capacity values for work zone. The algorithm for closure scheduling analysis is illustrated in Figure 4.

The analysis of closure schedule is undertaken based on this algorithm. The concept of analysis is based on the “Volume Compensation” which is calculated on hourly basis. The hourly volumes are compared to the capacity while the capacity during closure is reduced to the obtained values found in this study. The differences of hourly volumes and capacity are “excessive flows”. These excessive flows can be either positive or negative values. The positive excessive flows are added to the traffic volumes in the next period. If the volumes of the next period are less than the capacity then the excessive flows are gradually dissipated. The negative differences of volume-capacity are considered as the amount of volumes that can be dissipated in that period. The logic is applied to the entire periods. The time duration between the starting period of lane closure and the period that excessive volumes are completely dissipated is considered as the “Dissipation Duration”.

The trials of starting periods ranging from 0:00 hr. to 23:00 hr. are performed to determine the “Dissipation Duration”. The dissipation durations of all 24 trials are compared together. The starting closure periods are ranked based on these dissipation durations. The shortest dissipation duration is considered the best schedule for closing traffic lane and performing the maintenance activities.

It is obvious that the analysis of closure schedule requires looping computation which is a time-consuming task for manual calculation. Therefore, the computerized tool is developed in this study to perform this task. The closure scheduling tool is developed based on the algorithm as shown in Figure 4. The tool analyzes the hourly volumes and computes the hourly excessive flows to obtain the period where excessive flows are completely dissipated. This process is repeatedly undertaken for 24 cycles of trial starting closure periods in the tool. The results show the summary of dissipation durations for all starting closure periods.

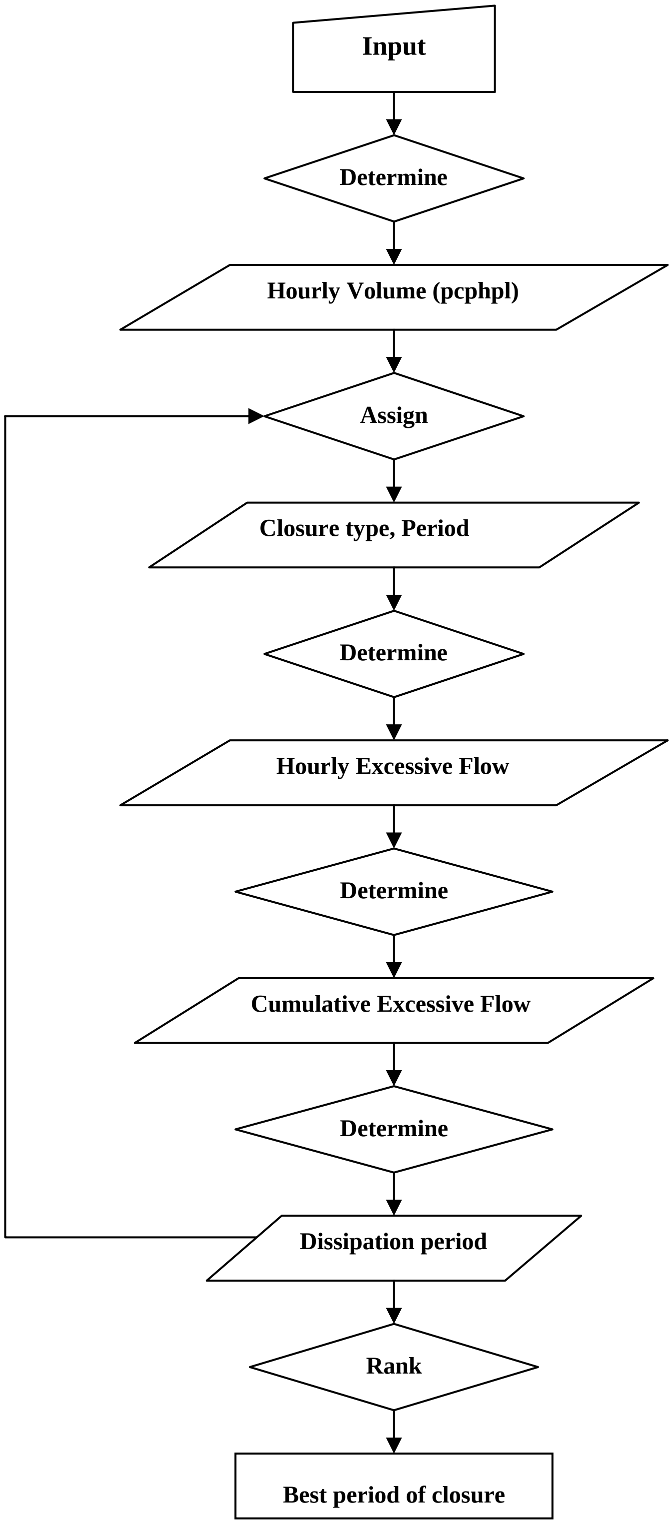


Figure 4. Algorithm for Scheduling Analysis

6. APPLICATION OF CLOSURE SCHEDULING TOOL

The computerized closure scheduling tool is developed based on the algorithm mentioned earlier. The computer-based is well suited for the looping computation as required in scheduling analysis. The tool is designed to provide user-friendly environment. The graphical User Interface (GUI) is then applied to the development. Similar to other analysis tools, the sets of information must be edited into the analysis tools. In this paper, the application of closure scheduling tool is presented by the example of real world case which is the closure of traffic lane on Highway Number 1. The closure of traffic lane is undertaken to repair the concrete pavement as shown in Figure 5.

Figure 5. Site Location of the Example Case for Closure Scheduling Tool Analysis

The outer lane is closed for 150 meters length. Closure duration is approximately 2 hours. The closure is undertaken at 10:00 hr. to 12:00 hr. during daytime.

The application of closure scheduling tool is demonstrated using this case. After the user logs in to the tool, user is required to provide the information for the analysis. Two groups of information can be classified which are the hourly traffic volume at the work site and the parameters related in the analysis. The input can be edited by clicking the “Hourly Volume” and “Parameters” buttons on Work zone Scheduling Main window as shown in Figure 6.

In this demonstration, the hourly traffic volumes on Highway Number 1 are used. The average daily traffic at this section is 24,545 vehicles per day. The 24-hour traffic volumes are edited in to the tools as shown in Figure 7. The volumes are divided into 4 major types which are passenger car and pick up, minibus and van, bus, and truck. These values must be saved prior to the analysis by clicking “save”. The total numbers of lanes are 3 lanes and the closure configuration is 2 opened lanes and with 1 closed lane. The duration of closure is 2 hours. These parameters must be edited in “Parameter Input” window as illustrated in Figure 8. The capacities used in this analysis are 1,800 pcphpl for normal period and 1,648 pcphpl during closure period. The PCEs are selected from the obtained results as shown in Table 3 for closure type 1.

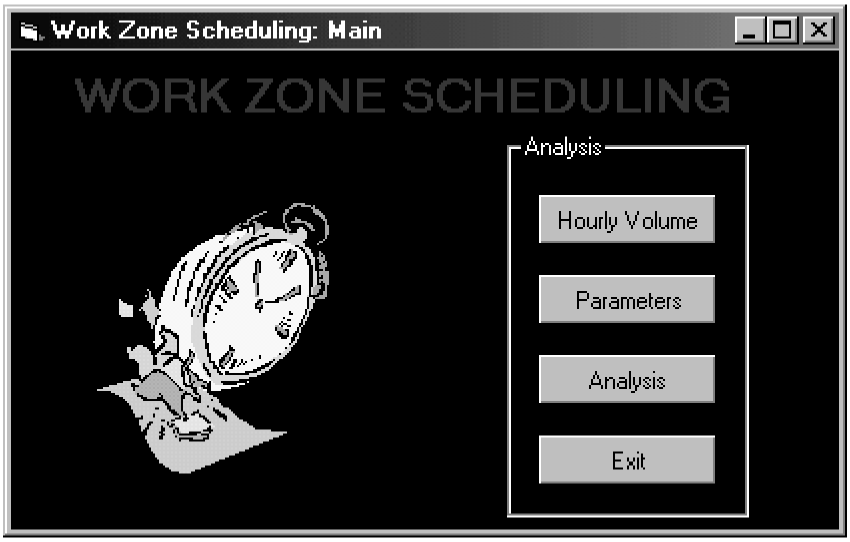


Figure 6. Closure Scheduling Tool Main Window.

Input: Volume

Volume_PC	Volume_MB	Volume_B	Volume_HV
491	163	63	77
245	80	33	68
252	91	32	9
261	76	30	18
240	82	29	9
736	245	99	27
1,718	572	222	63
2,209	735	284	81
2,086	694	269	8
1,841	613	237	5
982	327	127	36
730	241	91	25
1,227	408	155	45
488	163	63	15
491	166	61	18
729	244	97	26
1,472	490	190	54
1,963	649	253	27
1,966	653	251	18
1,720	577	222	9
1,231	410	158	44
730	243	95	72

Record: 1 of 24

Save <<Back

Figure 7. Table for Hourly Volume Data Input

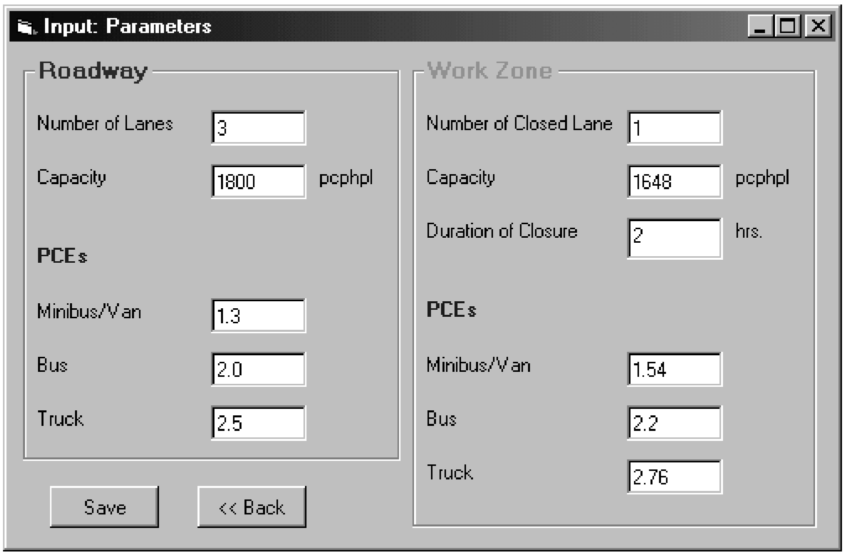


Figure 8. Parameter Input Window

Once all information is edited, the analysis can be performed by clicking “Analysis” button as shown in Figure 6. The tool then performs the analysis based on the algorithm showed in Figure 4. The results of the analysis are illustrated in tabular form as shown in Figure 9.

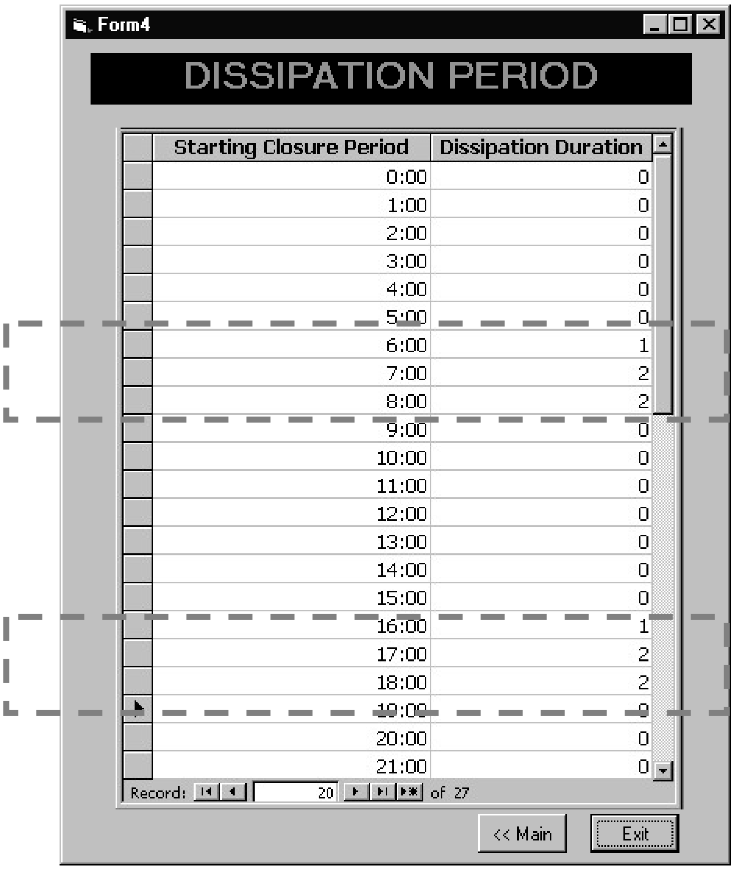


Figure 9. The Results of Scheduling Tools (List of Dissipation Period)

According to the findings, it can be seen that there are two time durations that closure should not be started which are 6:00 hr. to 8:00 hr. and 16:00 hr. to 18:00 hr. Closure during these periods resulted in the excessive flow which leads to congestion.

The results from the scheduling tools reveal that the one lane closure along Highway Number 1 can be performed during 10:00 hr. to 15:00 hr. and 19:00 hr. to 5:00 hr. based on the defined traffic volumes. These results provide the guidelines for the highway practitioners to assign their crews to conduct the maintenance activities along this highway. In addition, the tool is tested with another scenario which is 1 open lane and 2 closed lanes. The results reveal that closing of 2 lanes along Highway Number 1 should not be performed during 4:00 hr. to 8:00 hr. and 16:00 hr. to 18:00 hr. The practitioners can run different closure scenarios such as varying the closure duration or traffic volumes due to the unexpected error of maintenance duration or changes in traffic volumes as well. Accordingly, the practitioners can then eliminate the subjective decision-making in scheduling lane closure.

7. CONCLUSION

The results of the first part which are the determination of work zone capacities indicated the capacities calculated in this study are higher than the capacities recommended by HCM. These capacity values shall be adopted when the work zone traffic impact analysis is performed for Thailand highway. In addition, the results of the evaluation are used to develop the closure scheduling tool. This tool helps providing the highway practitioners a guideline of proper schedule based on the 24-hourly traffic volumes. The computer package was developed to provide user-friendly and looping computation. The result of the tool is the list of dissipation duration according to different starting period of closure. The best period is the period that has the least dissipation duration.

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