The changes of group behavior in mixed traffic flow

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Abstract: Mixed traffic flow is the popular problem now, not only in Vietnam but also in almost developing countries. With the mix traffic flow, we have to consider many problems in traffic control and traffic safety, especially in the cases of some countries that private vehicle ownership increase very quickly. This study was conducted to analyze the change in motorcycle driver behaviors with the progress of urbanization and motorization, the observations is inside intersections between left-turn groups and straight-go groups. From the analysis in this study, the results show the changes of driver behavior in case of one popular city in developing countries - Hanoi. This study also conducted the analysis about the relations between group behaviors and conflict situation inside intersection, from that propose some suggestion in traffic control measures and policies for mixed traffic flow.

Key Words: Mixed Traffic Flow, Driver Behavior Changes, Conflict Analysis, Intersection

1. INTRODUCTION

Nowadays, motorcycles play an important role in traffic in many cities in Asia and Africa. Private cars are still extremely expensive not only in buying but also in using them (parking fee, fuel prices, etc. For almost all citizens who usually have much lower income than those in developed countries, the proper choice for mobility is the motorcycle traffic mode. This choice is reasonable because on the one hand, motorcycle is inexpensive, flexible, and has relatively high speed compared with car traffic. In general, these cities show the following picture of traffic: low car usage, no good public transport systems, high ownership and usage motorcycles, and relatively low bicycle usage.

However, besides the advantages above, there are also some problems caused by using too many motorcycles in the city, such as traffic safety, traffic congestion, and critical impacts on the environment. So that, we need to take more researches in deeply to understand more about traffic situation in mixed traffic flow, from that we can have the suitable measures to control and improve the traffic quality in motorcycle city.

Hanoi is one of the motorcycle cities with the high rate in traffic flow is motorcycle. Therefore, the traffic behavior in here also has many special features that we need to understand more. With the expansion of the city, there are many changes in the traffic flow from suburb to the center; therefore, the changes are not only in the traffic volume but also in the traffic components, from that, the behavior and interactions between vehicles in the flow also changes.
If we don’t have any information or we cannot show the main factors which effect to these changes and phenomena, it may be very difficult and inefficient in traffic control designing.

Figure 1 shows the Ratio between the number of Motorcycle Registration and Car Registration from 1996 to 2009 in Hanoi, from this figure; we can have the deeper understanding about the real situation from 1996 to 2009 in traffic components.

![Figure 1: The Ratio between Motorcycle and Car Registration in Hanoi (Hanoi Transportation Department – 2009 Report)](image)

We can see the changes in traffic flow component from 2000 to 2008, with the increasing of automobiles, the more automobile inside traffic flow, and the more inflexible situation.

Interestingly, Vu.A.Tuan(2005) found that at both signalized and non-signalized intersections, motorcycles usually move in groups while crossing intersection. This phenomenon is very unique and very interesting because it cannot be observed in car-dominated traffic. Hereafter, it is called as “Group-riding”. Why the drivers prefer to move or cross intersection in groups? It can be a matter of psychology that the motorcyclists would feel safer to cross and, perhaps, more confident to fight against other groups and automobiles during the conflicts. Remarkably, if the number of cars and/or speed of main stream flow increase, intentions to make groups by motorcycle drivers would become extremely obvious. Therefore, it is of very importance to investigate the group-riding phenomenon and to realize how it will affect performance of mixed traffic as well as traffic management measures to be introduced at present and in the future.

As the results, many conflicts between individual vehicles have become conflicts between groups of vehicles at intersections. Because most of the intersections in Hanoi are provided with two-phased signalized control systems, conflicts between groups of left-turn vehicles and groups of straight-go vehicles have been seen as the most dangerous and critical ones since there are many accidents and congestions caused by conflicts of this kind. In the research, an inter-group interaction is defined as a conflict between left-turn group and a straight-go group.
Figure 2: Group behavior and type of groups inside intersection

Figure 2 shows one popular intersection in Hanoi with normal traffic volume. We can see some types of behavior and types of group in this figure. It is focused on the conflicts and situation between left-turn groups and straight-go groups.

Name of groups show the main behaviors of those groups: Cut-front group; Stop-wait group; Drive-on group; Cut-tail group. We can see many segments and conflict areas; therefore, we will have many problems. This figure was taken in 2010, but the situations are changes from 2000 to 2010 and there are many changes in traffic volume and driver behaviors.

To understand more about these changes, in this study, the main objectives are conducted on the group behavior and the changes of group behavior inside intersection in mixed traffic flow. The case study is Hanoi, Vietnam.

The main objectives of this study are:
- The differences in driver behaviors when conflict happen between turn-left groups and straight-go groups from 2000 to 2010.
- The main factors effect to the changes in driver behavior in case of Hanoi, mixed traffic flow.
- The relations between conflict situation and group separation behaviors inside intersections from time to time.

2. BACKGROUND AND PHENOMENON

2.1 Literature Review

Though interactions between groups of mixed vehicles at intersections have not been studied yet, it would be meaningful conducting comprehensive reviews on previous related researches in order to construct a methodology for the present research. There are some researches about mixed traffic flow. C.C.Minh (2004) and Ng.C.Y (2009) researched about the factors in mixed traffic flow with the main relation factors of motorcycle. Do.Q.Cuong (2009) and Tzu-Chang Lee (2007) took the analysis about intersection operation and model for mixed traffic flow. Ng.H.Minh (2006) proposed the Personal Space Concepts. The research of Vu.A.Tuan (2005) shows the statistical analysis about some behaviors with group phenomenon. The unique and most interesting phenomenon in mixed traffic is group-riding.
phenomenon at intersections because crossing in group would make drivers, especially motorcyclists, feel safer and more confident in making decision. As the result, there have been many interactions between groups of mixed vehicles in intersection areas. More importantly, these interactions have been strongly influencing efficiency and safety of the mixed traffic. Deep understandings of the interactive mechanisms as well as “local” rules are very essential in order to recommend policies for strategically and periodically managing the mixed traffic under the effects of car share increase.

Therefore, the current research was conducted to analyze the interactions between groups of mixed vehicles at both signalized and non-signalized intersection.

There are many limits of these researches, one of limits is just concentrated on the simple group interaction and in the statistical analyses; the author assumed that the groups are not separated.

But actually, now, when the traffic volume are increasing very quickly, in mixed traffic flow, the separations of groups occur very frequently, so that, we need to take other deeper researches about the group behavior and interaction of the groups in the intersection.

In this study, some criteria factors will be used as the results of other studies about mixed traffic flow. Some new concepts will be introduced later.

2.2 Group behaviors

It is very important to determine the vehicle groups and number of vehicle group in this research. The key point in this research is the interaction between groups in the intersection, so that, the more accurate we determine groups, the more efficient results we will have.

To determine groups and the moment when one vehicle is the element of one group, the important criterion we have to define are:

Criterion 1: Relative distance ($d_i$): Distance from the vehicle $i$ to the member of the existing group that nearest to it, $d_i$ must be smaller than a critical value, $d_o$. In this research, critical value is selected equal to 1.0m, because the cases we are considering are the conflict cases, so that, the speed and the distance between vehicles are small.

Criterion 2: Relative moving direction ($\theta_i$): The difference between moving direction of vehicle and the existing group is smaller than 0.20. The value of 0.20 is chosen because the maximum lateral deviations from the currently moving lines of the vehicles are observed to be 0.20-0.25m per 1.0 traveled longitudinally. If a vehicle is moving with the direction difference greater than 0.2, it means the vehicles does not want to join the group because of several reasons, such as, different direction target and utilities.

Criterion 3: Speed deviation ($v_i$): The difference between speed of vehicles and the existing groups is smaller than 0.25m/s². The value of 0.25 is chosen base on the observations from real condition with the speed deviation in mixed traffic flow.
In this research, the main objects which we focus on are the interactions between groups in the intersections. The interaction will occur between motorcycles and automobiles. Some types of group behaviors will be considered in this study are: Driver-on; Cut-tail; Cut-front; Stop-wait. And after the driver reactions, we can see some modes of vehicle groups and the separation from one big group to smaller segments. With this phenomenon, we can say that it is separation phenomenon.

2.3 Vehicle modes inside intersection and phenomenon

Hanoi is motorcycle dominated city, but the percentage of motorcycle and automobile in the city change through the time. With the development of economic, the car-share in the traffic flow increased, the infrastructure also changed, therefore, traffic flow and driver behavior changed a lot. In the intersection, we can see and have some ideas about the changes through some type of vehicle interactions from 2000 to 2010.

*In 2000:* Low traffic volume, motorcycle ratio high, traffic awareness low
- Individual control was popular
- None group -> Individual phenomena

*In 2005:* Traffic volume higher, automobile ratio increase, the implementation of new traffic control measures, traffic awareness increased
- Group behavior was popular
- Single group phenomena

*In 2010:* Traffic volume is very high, auto/motor ratio changed, queue length is too big.
- Drivers cannot wait longer.
- Conflict between individual aspiration and common benefit

From this phenomenon, in this research, we classified three types of vehicle patterns inside intersection base on the group forms and interaction:

**Interaction 1: Individual interaction (a)**
- The characteristics are: Chaotic situation, High rate of motorcycle and None group.

**Interaction 2: Fixed group interaction (b)**
- The characteristics are: Interaction of two main groups: Turn-left Vs. Straight-go, Mixed Vehicle Group, Gap acceptance & Max number of groups after conflict ≤ 3

**Interaction 3: Separated group interaction (c)**
- The characteristics are: From big group divided to smaller groups, we can see the separation of groups in case of high traffic volume and drivers cannot accept wait. Therefore, the longer waiting time, the more groups appear → more conflicts appear.
- Max number of group after conflict > 3

Figure 4 show the form and the differences between three patterns

![Figure 4: Forms and differences between three patterns](image-url)
We surveyed in Hanoi in 2010 in 6 intersections and we also collected video data from 2002. From these data, we analyzed and have some results with the high rate of vehicle interactions in 2002 are similar with pattern 1.

With our data, in 2002, 90% of vehicle interactions in 2002 are Interaction 1. The situation changed to Interaction 2 in 2005; with 88% of vehicle interactions in our data are similar with Interaction 2. And now, in 2010, high rate of vehicle patterns are multiple group interactions with 94.6%.

Therefore, we can see the vehicle interactions are the changes between groups inside intersection. And we had very interesting phenomenon.

From this phenomenon, we considered some questions:
- What are the main factors influencing these vehicle patterns?
- How are the differences and the changes from 2000 to 2010?

To answer these questions, we analyzed video data of intersections in Hanoi from 2000 to 2010. The methodology and results will be introduced in next parts

### 3. METHODOLOGY

#### 3.1 General framework

The research is mainly aimed to deeply understand and to empirically analyze interaction between vehicles and groups at intersection.

The research was conducted based on a framework as shown in Figure 5

![Figure 5: Research framework](image)

The framework of this research is divided to two big parts:

**Part 1: Video survey and Data collection**

In this part, we will take the video data of traffic situation at the chosen intersection, and we also get the video data from other sources in the past, such as video data from 2002, and 2005. The data about the changes of infrastructure, social and policy also are considered to have the overview of the situation, from that we can have the ideas why the changes occurred.
**Part 2: Analysis**

In this part, we will take the deeply analysis with the data we get in part 1: At first, the video data will be extracted to frames, and from the analysis with each frame, we can get the input data in this list:

**About vehicles and traffic flow data:**
- One vehicles data will be stored in one record include:
  - Vehicle coordinate (x,y)
  - Vehicle type (Motorcycle, Automobile, Bus…)
  - Vehicle main target direction
  - Vehicle speed and acceleration vector

**About infrastructure data**
- Intersection type;
- Traffic signal period
- Intersection layout and dimensions
- Number of cells
- Cell coordinate

After have the input data, we will take some analysis functions and procedure. We can use the statistical analysis to have the relations results between influence factors to the separation phenomenon. We also discuss something about behavioral mechanism and key factors with each vehicle pattern inside intersection.

There are two main analysis procedures in the research.
- **Group determination procedure.**
  To determine the group inside intersection, we used the loopback procedures to check group criteria condition and store the results with the number of group segments time by time.
- **Conflict analysis procedure.**
  We used cell conflict analysis. In this procedure, we can calculate the accumulation conflict level. After one frame, in conflict cell, the conflict level will be accumulated if conflict situation happened. With this type of procedure, we can observe conflict situation not only in space, but also in time, intensity and power of conflict.

**3.2 Survey and video analysis steps**

The traffic situation in Hanoi changed a lot after ten years with large pressure to infrastructure. And the traffic components also changed. Therefore, Hanoi is chosen as case study in this research. The objectives of the survey are:
- Survey motorcycle behavior patterns in the intersection
- Collect the video data of mixed traffic to show the behaviors and the change of behaviors when the volume of flow increase
- Find out the changes when traffic volume increases

The survey will be taken in the same locations in 2004,2006,2008,2010. We choose 10 intersections in Hanoi and recorded the video data of traffic flow in these intersections. We also collected the video data from Hanoi Transportation Department and other researchers from 2002 to 2010.

After that, we had the video database of traffic flow in Hanoi.
In our video database, we had:
- 2004: Traffic flow video files in intersections: 1;5;6;7
- 2006: Traffic flow video files in intersections: 1;2;6;7;8
- 2008: Traffic flow video files in intersections: 1;2;5;6;7;8
- 2010: Traffic flow video files in intersections: 1;2;3;4;5;6;7;8;9;10

The video analysis steps can be summarized in steps:
- Define the events from video files
- Extract the frames for each event and analyze the data from each frame.
- Track vehicle movement and analysis each event
  - Define the first time conflict appear in each event
  - Define the first conflict cell
  - Use the loopback procedure to define the group segments with the criteria values. Define the time of group separation appears.
  - Record the value of conflict situation in all cells.
  - Record the change of segment quantity.
  - Finish one event analysis – Have the data.

4. GROUP INTERACTION AND CONFLICT ANALYSIS

4.1 Influences factors and number of group segment

From the data we got after we took video analyses, we can do some statistical analyses and we got some results which show the relations between the separation phenomenon and two factors: Traffic volume and Car-rate.

The Traffic volume is determined by the Total Motorcycle Equivalent per hour (MCU). Both main directions: Turn-left group and Straight-go group.

Total Motorcycle Equivalent per hour (MCU) is calculated by total number of motorcycles and number of converted automobiles. The ratios of converting function between automobiles and motorcycle are determined by type of automobiles. Converted ratio is in range: 1- 3.

Car-rate is determined by the percentages of motorcycle and Total motorcycle equivalent.
Size of group before separation depends on the number of cells which have vehicle before conflict.

Figure 7 shows the comparison between two years 2005 and 2010 with the relations of Number of Groups, Car-rate and Traffic Volume.

Figure 7: The relations of Car-rate, Traffic Volume and Maximum number of group

In 2005:

Figure 8 shows the relation between Car-rate (Mixed-ratio) and Traffic Volume and the effects of both Car-Rate and Traffic Volume on the separation group phenomenon. Number of groups is the maximum value which happened in each surveyed event.

If the number of group is 3, the color of the spots is blue.

In 2010:

Figure 8 shows the relation between Car-rate, Traffic volume and the maximum number of group in each event in 2010. With this figure, we can see that with the increasing of traffic volume, the separation phenomenon occurred more frequently. And with the higher of mixed ratio, the larger number of segments will appear. We can see that if the traffic volume in range from 60 MCU (Motorcycle Unit) to 80 MCU and the Car-rate in range from 80% to 90%, the value of maximum number of group are largest. This range may be the worse condition.

Figure 8: The relations between Car-rate, Traffic Volume and Maximum number of group from 2005 to 2010 in the same situation.
From the analyses of group separation and main influence factors, we can see in figures 7 and figures 8 the relations between Car-rate, Traffic Volume and the increasing of number of Group Segments in the intersection.

We also can see the differences between two years, 2005 and 2010 in the effects of Car-rate and Traffic Volume to the vehicles patterns.

We see that, in the same situation
- Car rate from 5% to 20% and Traffic volume from 50MCU/m to 80MCU/m
- In 2005: Separation phenomenon frequency: 12.5%
- In 2010: Separation phenomenon frequency: 94.6%

From figure 7, we can see that
- In 2005: The small effect of Traffic Volume & Car Rate to the number of group segment
- In 2010: The large effect of Traffic Volume & Car Rate to the number of group segment

4.2 Conflict patterns inside intersection analysis

In this part, we will show the conflict analyses and the relations between conflict situation and the separation phenomenon.

The concepts for this part are:
- **Conflict cell**
  One cell is defined as one conflict cell if we see that, at the same time, at least, there is one vehicle in the turn-left group and there is one vehicle in the straight-go group inside cell, or the acceleration of vehicles inside cell smaller than $1m/s^2$.

- **Conflict level**
  Conflict level is the value which determine by the accumulation conflict value after each frame. In the first state, if conflict occurred in one cell, so that the conflict value at that cell at that time will equal to 1. If conflict didn’t occur, the conflict value will equal to 0.

In next state, the conflict value will be calculated by the accumulation value, if one cell continue in conflict situation, the conflict value will be increase 1 more, if it is not, the conflict value will be kept.

We also propose some conflict indicators to describe the conflict situation and the change inside intersection. With our indicators, the conflict situation not only shows the changes in the space but also shows the changes time by time.

Some conflict indicators are introduced:
- **Maximum Conflict Level in each frame - MCL**
  This indicator show the fluctuation in the intensity of conflict situation
- **The Ratio of Maximum total number of Conflict cells with total number of cell in each frame (%) - RMC**
  This indicator show the fluctuation in the distribution of conflict
- **The Ratio between number of Highest Conflict level cells with total conflict cells in each frame (%) - RHC**
  This indicator show the correlation in the intensity and distribution of conflict
- **Average value of Total Conflict Time in all cells in one event - ATCT**
  This indicator show the fluctuation in the power of conflict

After calculation of all indicators, the results can show the differences and the changes from 2000 to 2010 in conflict situation.

Figure 9 show the comparison between 2005 and 2010 in the same situation of conflict inside intersection. We can see that:

With same situation
- In 2005: 85% events had maximum conflict level higher than 9
  With high conflict level, number of group is low (2-3) (Interaction 2)
In 2010: 96% events had maximum conflict level lower than 9
With low conflict level, number of group is high (4-6) (Interaction 3)

Figure 9: The relations Max Conflict Level of Cells, Traffic Volume and Number of Group segments from 2005 to 2010.

When we compare the conflict indicators from 2000 to 2010 we can see the differences in the charts below – Figure 10

Figure 10: Differences in conflict indicators from 2000 to 2010.

From the conflict analyses, conflict indicators, we can see the differences from 2000 to 2010 in the conflict patterns in Figure 11
5. CONCLUSION AND PERSPECTIVES

The main findings of this study are:
Whether a single (big) group will be separated into multiple smaller groups might depend on following key factors:
- The ratio between motorcycles and autos (Car-rate)
- Traffic flow rate. (Traffic volume)
The changes in vehicle patterns in group behavior from 2005 to 2010 don’t have strong relation with the changes of Traffic Volume and Car-rate

The conflict situation inside intersection changed its patterns, from 2000 to 2010
Practically, the most important question to the transport planners is how to manage the mixed-traffic in transitional periods prior to car-dominated traffic in the future. At present, the mixed-traffic is being dominated by motorcycles, sharing more than 70% of the total vehicular traffics. Even though the economy is increasing fast, it would take about 20 years for cars to dominate the traffic with the share of more than 70%. Fortunately, management of car traffic is not difficult since it is possible to apply the knowledge and technologies imported from developed countries.

Therefore, the contributions of this research are:
Show the changes of vehicle pattern inside intersection through the time and the effect factors to the vehicle patterns.
Take the conflict analyses for the mix traffic flow in consideration with the change of traffic volume, traffic components.
Show the relations between conflict situation and the separation phenomenon.
Through the research works which have been done so far could bring us some findings on the mixed traffic operation; however, there are many aspects remained to be investigated. Thus, we need to take deeper analysis with this phenomenon in the near future with more data.
And we need to analysis the effect of more factors to the change of behavior in mixed traffic flow, not only traffic factors but also social factors.

From the changes of traffic phenomena, understand the changes in driver behavior and the main effect factors.

Understand about the phenomenon and the behavior and conflict pattern inside intersection, from that we can have better intersection design.

Example: Waiting area for left-turn group for mixed traffic flow.
Traffic signal design – Green time for each phase

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