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Multiple Road User Interactions

A Methodological Approach Towards Autonomous Driving

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Abstract

The focus of this study is to accentuate the need to add socially interactive layers to Autonomous Vehicle Algorithm Design, and create a scope from which those social interactions between road users can be used in algorithm development. Firstly, presented is the current progress in AV algorithm development and the need for adding social layers in it. In order to achieve that, a basic method of identifying interaction patterns between road users was established. After gathering and analyzing video footage from an intersection in central Athens, that method is presented in the study. Data collection for this method focuses on incidents that involve multiple road user interactions, which follow a defined set of rules. The concept of these interactions is defined for the purpose of this study, while data collection involves screenshot gathering, noting the amount and type of road users, and assigning order numbers on road users, according to this study's set of rules. The aim of collecting data in that specific way is the creation of Interaction Patterns, meaning interactions between road users in the specific intersection that are repetitive throughout the gathered footage. Subsequently, the conceptual correlation of the Interaction Patterns is discussed, through categorizing and organizing the interaction patterns in several levels. Also discussed are further ways of using the collected data to extract useful information and gain deeper understanding of the driving environment and road user behavior. Furthermore, interaction patterns are presented that were observed but don't at this moment follow the conceptual framework that is proposed. Discussion is also being made on ways of expanding the current study through gathering more video footage from different environmental settings and parameters of data processing, and through the use of technology. Finally, the case is being made of how this method can be integrated in current Autonomous Vehicle Systems in order to improve the way vehicles perceive their environment through algorithms.

Περίληψη

Στόχος της παρούσας έρευνας είναι να τονίσει την ανάγκη να προστεθεί ένα επίπεδο κοινωνικής αλληλεπίδρασης στο σχεδιασμό αλγορίθμων για αυτόνομα οχήματα, και να δημιουργηθεί ένα πεδίο εφαρμογής στο πλαίσιο του σχεδιασμού αλγορίθμων για τις κοινωνικές αλληλεπιδράσεις μεταξύ χρηστών του δρόμου. Κατ'αρχάς παρουσιάζεται η τρέχουσα πρόοδος στην ανάπτυξη αλγορίθμων για αυτόνομα οχήματα, καθώς και η ανάγκη για προσθήκη κοινωνικών κριτηρίων σε αυτήν. Για να επιτευχθεί αυτό, αναπτύχθηκε μέθοδος για την αναγνώριση πρότυπων αλληλεπιδράσεων μεταξύ χρηστών του δρόμου. Αφού συλλέχθηκαν και αναλύθηκαν βίντεο από διασταύρωση στο κέντρο της Αθήνας, δημιουργήθηκε η μέθοδος που παρουσιάζεται σε αυτή τη μελέτη. Αρχικά η μέθοδος περιλαμβάνει συλλογή δεδομένων για τα περιστατικά πολλαπλών αλληλεπιδράσεων, τα οποία ακολουθούν ένα ορισμένο σύνολο κανόνων. Η έννοια των πολλαπλών αλληλεπιδράσεων ορίζεται στα πλαίσια της έρευνας, ενώ η συλλογή δεδομένων περιλαμβάνει συλλογή στιγμιότυπων από τα βίντεο, σημείωση του αριθμού και του τύπου των οχημάτων - χρηστών, και την ανάθεση αριθμού προτεραιότητας σύμφωνα με τους κανόνες που έχουν οριστεί στα πλαίσια της έρευνας. Σκοπός της συλλογής δεδομένων καθ' αυτόν τον τρόπο είναι η δημιουργία Πρότυπων Αλληλεπιδράσεων, δηλαδή αλληλεπιδράσεων μεταξύ χρηστών του δρόμου στη συγκεκριμένη διασταύρωση που επαναλαμβάνονται σε όλη τη διάρκεια των βίντεο. Στη συνέχεια, συζητείται η εννοιολογική συσχέτιση των Πρότυπων Αλληλεπιδράσεων, κατηγοριοποιώντας και οργανώνοντάς τις σε διάφορα επίπεδα. Στη συνέχεια συζητούνται περαιτέρω τρόποι για χρήση των συλλεχθέντων δεδομένων, εξαγωγή χρήσιμων πληροφοριών και βαθύτερη κατανόηση του περιβάλλοντος οδήγησης και της συμπεριφοράς των χρηστών. Παρουσιάζονται επίσης πρότυπες αλληλεπιδράσεις που παρατηρήθηκαν αλλά δεν είναι εννοιολογικά συνεπείς με το προτεινόμενο μοντέλο. Επιπρόσθετα, γίνεται συζήτηση για τρόπους επέκτασης της παρούσας έρευνας μέσω επιπλέον παρατήρησης σε διαφορετικά περιβάλλοντα ή με διαφορετικές παραμέτρους επεξεργασίας δεδομένων, και με τη χρήση τεχνολογίας. Τέλος, τίθεται το ερώτημα πώς η παρούσα μέθοδος μπορεί να αξιοποιηθεί από Συστήματα Αυτόνομης Οδήγησης, ώστε να βελτιωθεί ο τρόπος που τα αυτόνομα οχήματα μέσω αλγορίθμων αντιλαμβάνονται το περιβάλλον τους.

1. Introduction

Human error accounts for an estimated 94% of total accidents [1]. In Autonomous Vehicle Design, the biggest challenge is integrating the human factor into autonomous driving. Whether on the driver's seat of a self-driving car, or crossing the road in front of one, the way in which people process information, make decisions and take action has been the most challenging parameter to measure and utilize.

The Society of Automotive Engineers (SAE) defines 6 levels of driving automation ranging from 0 (fully manual) to 5 (fully autonomous). These levels have been adopted by the U.S. Department of Transportation [2]. ABI Research Forecasts 8 million Vehicles to Ship with SAE Level 3, 4 and 5 Autonomous Technology in 2025, with LiDAR Sensors being the key for Transition from Current ADAS Packages to Higher Level Autonomy [3].

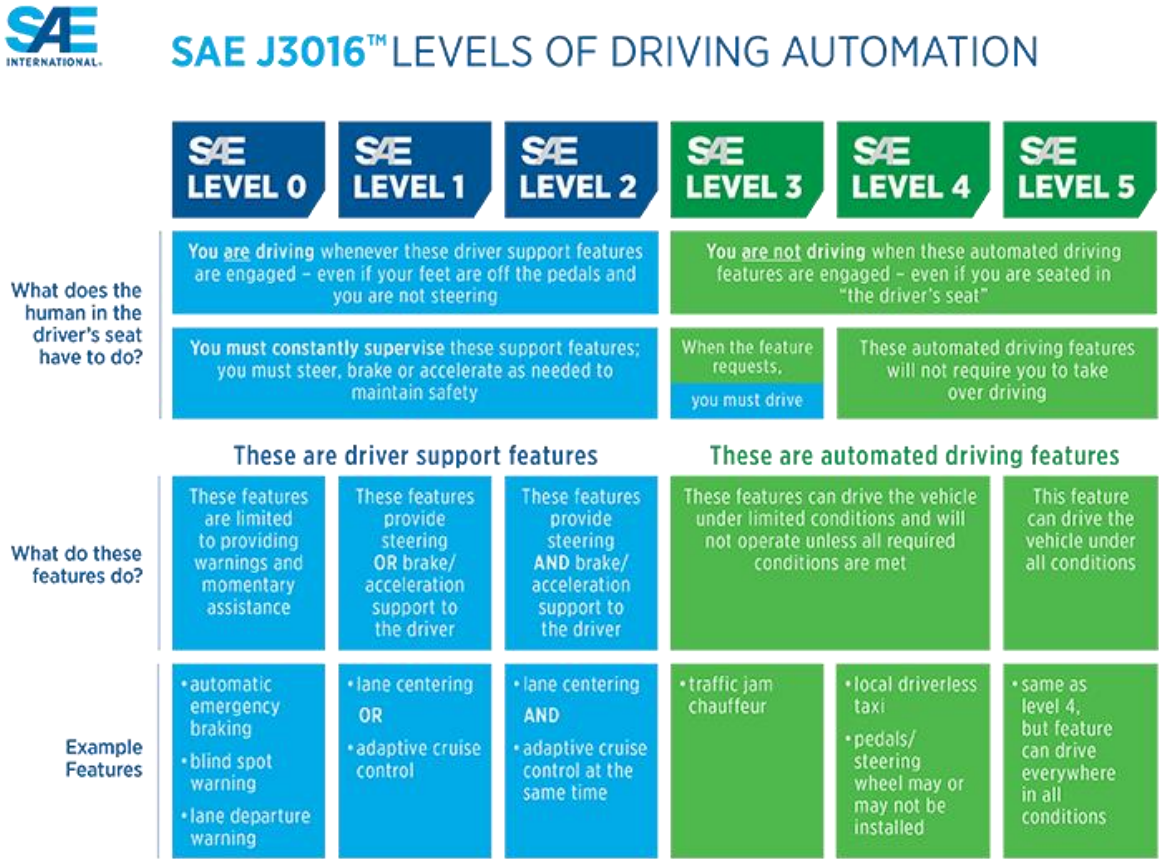


Figure 1: SAE levels of Vehicle Autonomy

While sensor technology is integral for the progress of autonomous driving, the importance of algorithm development is equally important. Integration of machine learning algorithms in the design of AVs is deemed a priority by researchers, as it enables the use and processing of multiple sensor data.

Machine learning algorithms can be divided in categories through various criteria, e.g., how the algorithms learn. In autonomous driving development, it is useful to categorize algorithms depending on what they

can offer in terms of identifying the driving environment. Required tasks that need to be performed from self-driving cars are the detection, recognition, classification and localization of surrounding objects and the prediction of movement. The machine learning algorithms can be divided in categories, according to which tasks they are able to perform [4].

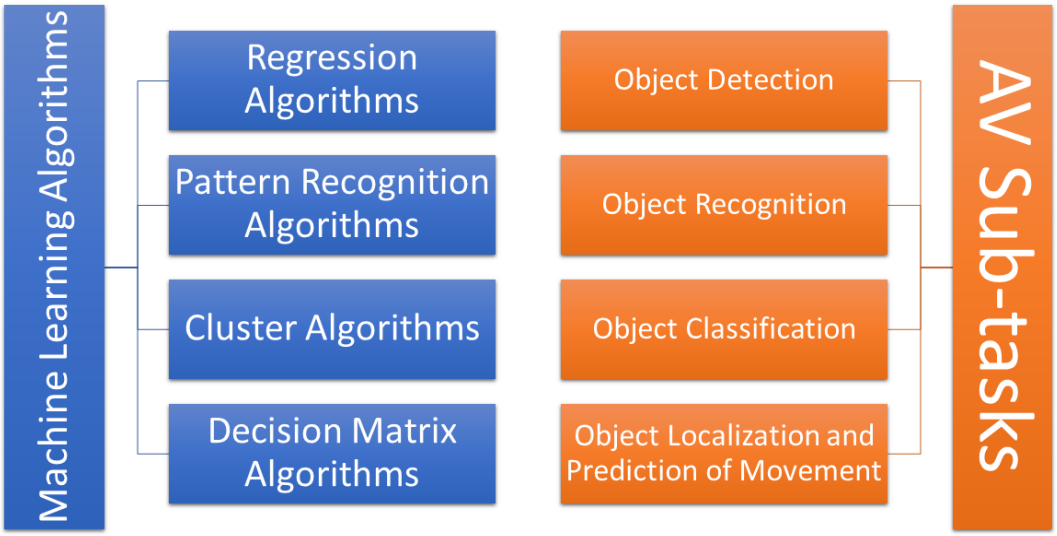


Figure 2: Machine Learning Algorithm Categories and Sub-tasks they perform

Autonomous vehicle systems are complex and consist of three major subsystems: (1) algorithms for localization, perception, and planning and control; (2) client systems, such as the robotics operating system and hardware platform; and (3) the cloud platform, which includes data storage, simulation, high-definition (HD) mapping, and deep learning model training. The algorithm subsystem extracts meaningful information from sensor raw data to understand its environment and make decisions about its actions. The client subsystem integrates these algorithms to meet real-time and reliability requirements. The cloud platform provides offline computing and storage capabilities for autonomous vehicles. Using the cloud platform, we are able to test new algorithms and update the HD map—plus, train better recognition, tracking, and decision models. [5]

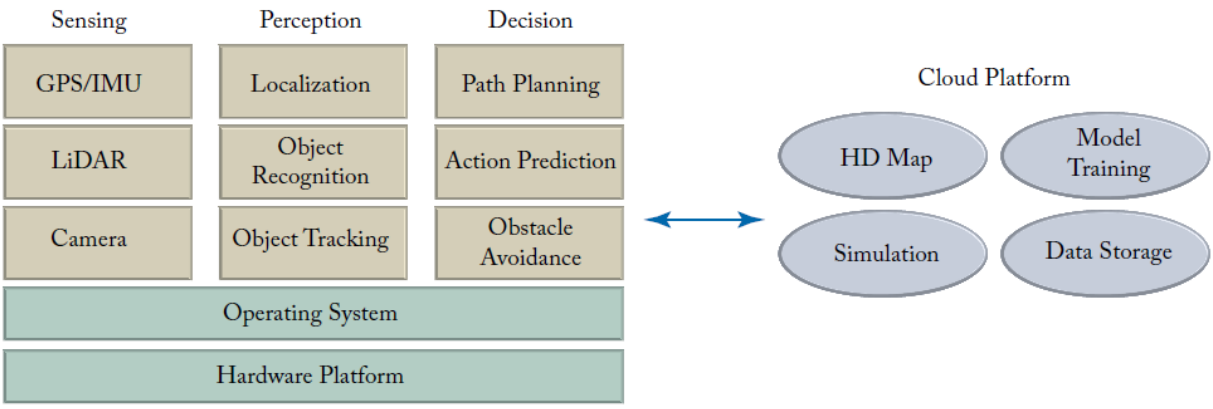


Figure 3: Autonomous Driving Systems - Algorithm Architecture Overview

Data that fall into the categories shown above are used to navigate a self-driving car. To predict actions of other vehicles, one can generate stochastic models of the reachable position sets of the other traffic participants, and associate these reachable sets with probability distributions [5].

In AV studies so far, proposed prediction models have mostly focused on kinematic and positional criteria, while the social background according to which human road users are making decisions has yet to be fully studied. In some studies, the focus has been given on the behavioral aspect of road users. As shown in the picture below, in an experiment where several road users were instructed to drive through an intersection, the interactions of the road user with every element of his surroundings are noted [6]. This is an instance of studying the social aspect of driving, where several types of road users were asked to perform tasks and were evaluated on their performance, so that their situational awareness can be measured.

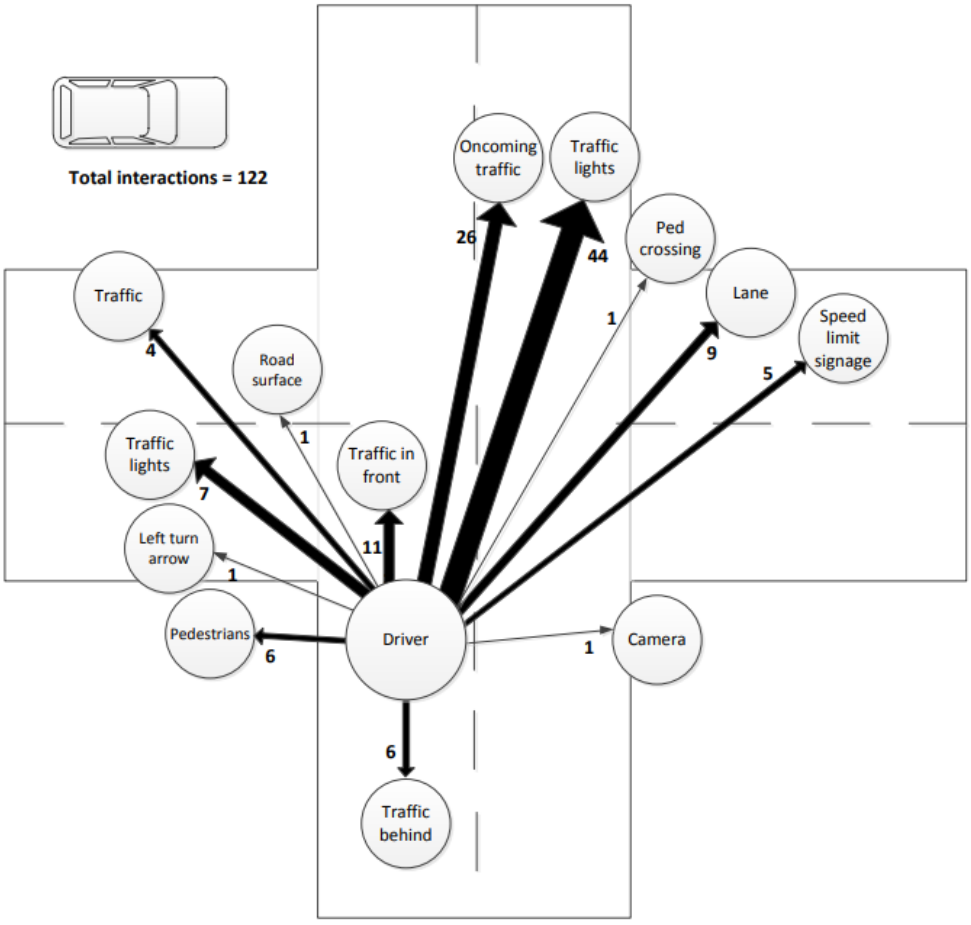


Figure 4: Interactions of Road User with surroundings

General studying on road user behavior to improve road safety can also be beneficial towards collecting data on human behavior and adding a social layer on AV algorithm design. In the following chart we can see the areas of focus in intersections in terms of road user behavior and road safety. [7]

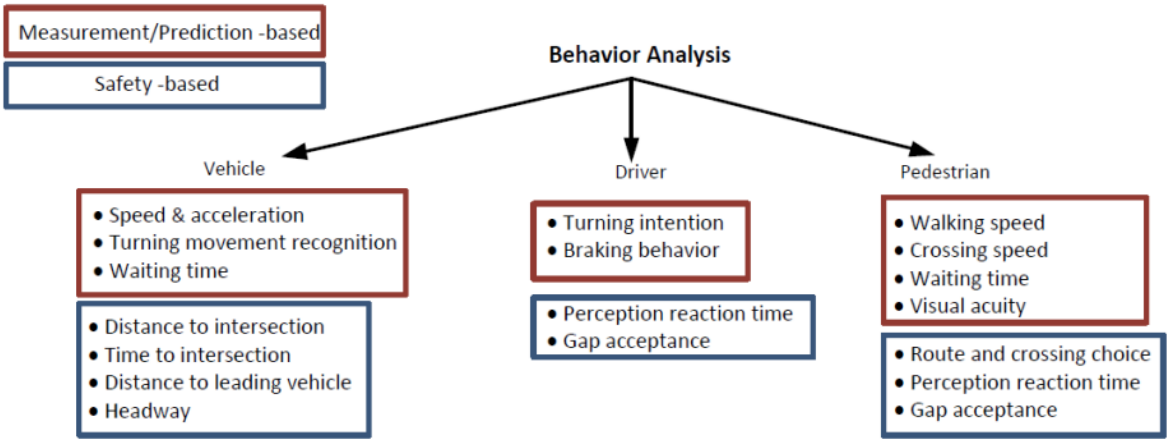


Figure 5: A typical structure of behavior analysis at intersection

Finally, road user behavior and psychological background can be studied through the use of simulations. In a recent study, with the use of intelligent agent-based simulations, in combination with experimental designs, the behavioral interaction of motorists and motorcyclists in urban traffic was modelled, when motorcyclists ride in between the lanes of slow-moving or stopped vehicles. The results of the computer model can be validated through a measure that estimates its agreement with the results of real-life traffic videos analyses. The implications of adopting intelligent agent-based simulations in experimental psychology were also discussed. [8]

Other studies have also discussed the prospect of designing AVs through social experiences and ethnographic studies, in order to integrate them into the road network [9] [10]. In this study, the proposed model introduces a methodological approach to identifying interaction patterns, which occur in an urban environment. The road users involved engage in interactions while trying to solve the conflicts between them in “irrational” ways, forming patterns which one can identify and study. The interactions of focus involve three or more road users. The aim for this proposed model is to add a socially interactive layer to the movement prediction aspect of algorithm structure.

2. Methods

2.1. Defining Multiple Road User Interaction

Defining what an interaction between two road users is has been an object of study by many. A definition composed by reviewing main themes and findings in previous theoretical and empirical interaction research [11] places the two-road user interaction as *"a situation where the behavior of at least two road users can be interpreted as being influenced by the possibility that they are both intending to occupy the same region of space at the same time in the near future"*.

Although there is a long tradition of research into road user interactions, defining a multiple road user interaction has not been methodologically studied before. To serve the purpose of this study, first it is needed to present a definition for multiple road user interactions. The definition of Multiple Road User Interaction is conceived in this study as followed:

The Multiple Road User Interaction is defined as a situation involving three or more RUs, who are moving or have intent to move, of whom at least one is performing a maneuver, to which everyone else is directly or indirectly reacting. This situation is taking place in specific space and time, in a way that allows all participants to react to each other.

In a three-way interaction we need two-way interactions from at least two road users. Every Road User has to at least once be aware of another road user, while maneuvering. For example, shown in the picture below, are the interactions that are taking place between road users in a specific interaction pattern that will be discussed in the following chapters.

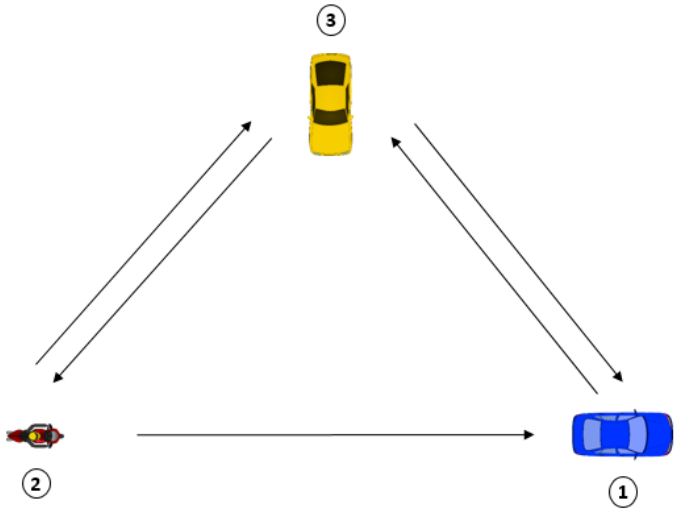


Figure 6: Road User Interaction Correlation

2.2. Establishing Method through Video Observation

For the purposes of this study footage of 1,110 minutes was gathered for a specific intersection in the center of Athens. The intersection is located in Metaksourgio, a region of central Athens, and is consisted by two one-way streets, Kolonou Street, which is the main street, and Leonidou Street which is the secondary street. There is a stop sign on the secondary street that regulates traffic and no crosswalks.

The footage was gathered on morning hours throughout several days. The purpose of gathering the footage was to study passing through traffic in order to identify behavioral patterns that occur in confined spaces, in regard to multiple road user interactions.

The recorded footage of the intersection expands through 4 days, and 1,110 minutes:

- 11/20/2017, 11 files of 12 minutes length and 1 file of 4 minutes length
- 11/21/2017, 19 files of 12:00 minute length and 2 files of 9 minutes length
- 11/24/2017, 19 files of 12:00 minute length, 1 file of 10 minutes length and 1 file of 11 minutes length
- 11/28/2017, 28 files of 12:00 minute length, 1 file of 8 minutes length, 1 file of 10 minutes length and 1 file of 1 minute length

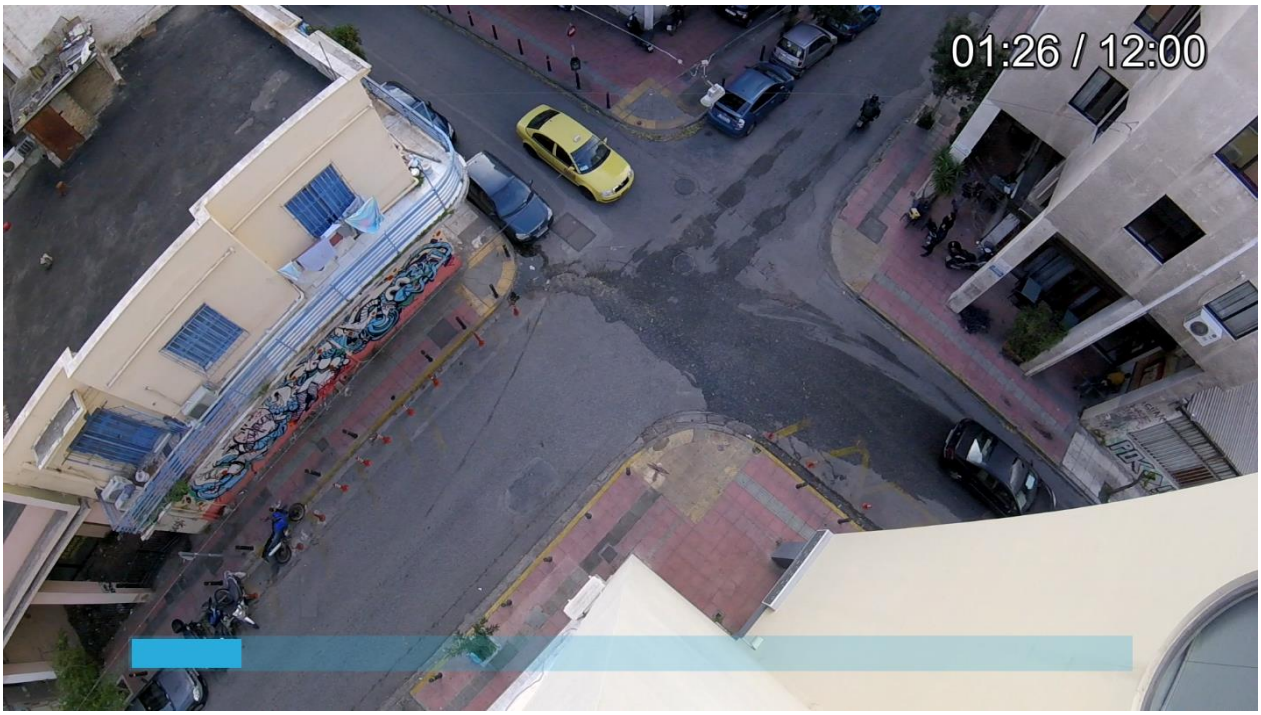


Figure 7: Screenshot from the recorded clips of the intersection

2.2.1. Gathering Data for Incidents of Interest

The readability of the incidents depends on the validity of gathered data. Multiple Road User interactions are a complex phenomenon, and so it is vital that the depiction of the data to be accurate and easily accessible by researchers. For that reason, a way of writing down information about those interactions is proposed.

After the footage was reviewed, interactions with three or more RUs were noted. Each interaction involving multiple RUs is referred to as an incident. For each of these incidents, a set of characteristics were recorded:

- Serial number of incident
- Video file title
- Time in video
- Screenshots of the incident
- Number of RUs involved
- Type of each RU
- Written description of the incident

It is important to collect and create all of the above information, so that the researcher can easily identify reoccurring behavioral patterns later.

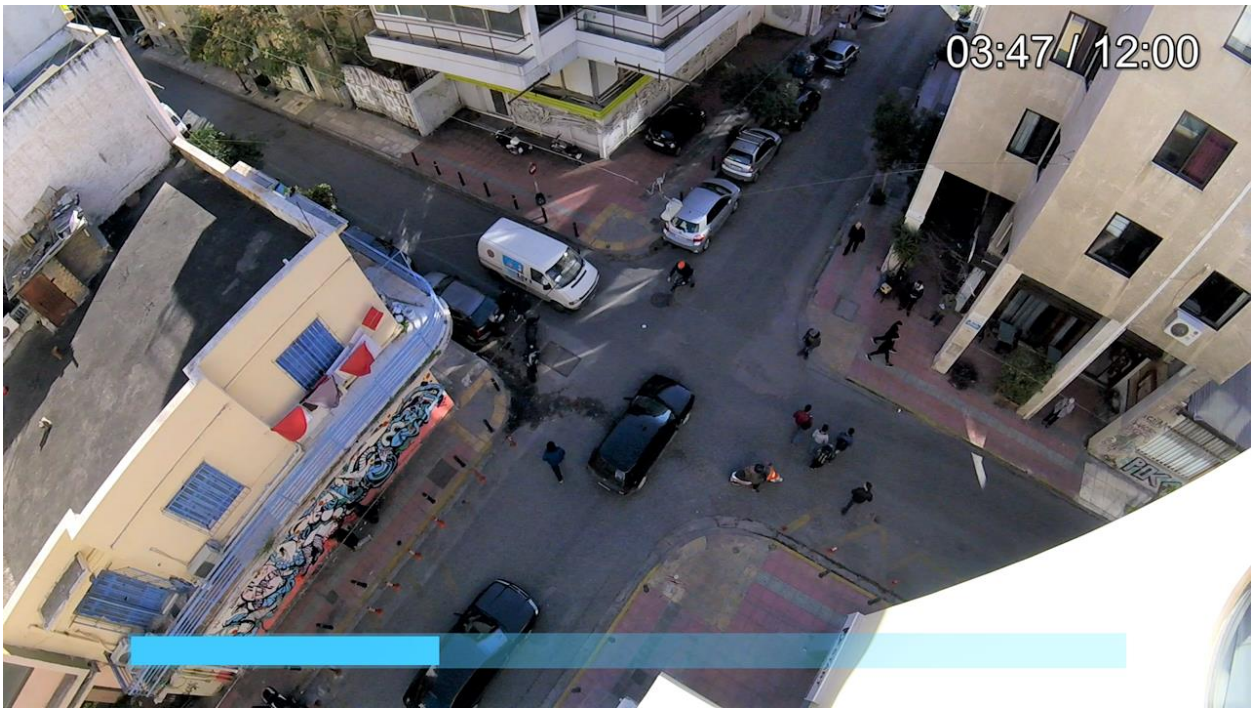


Figure 8: Incident with multiple interacting Road Users

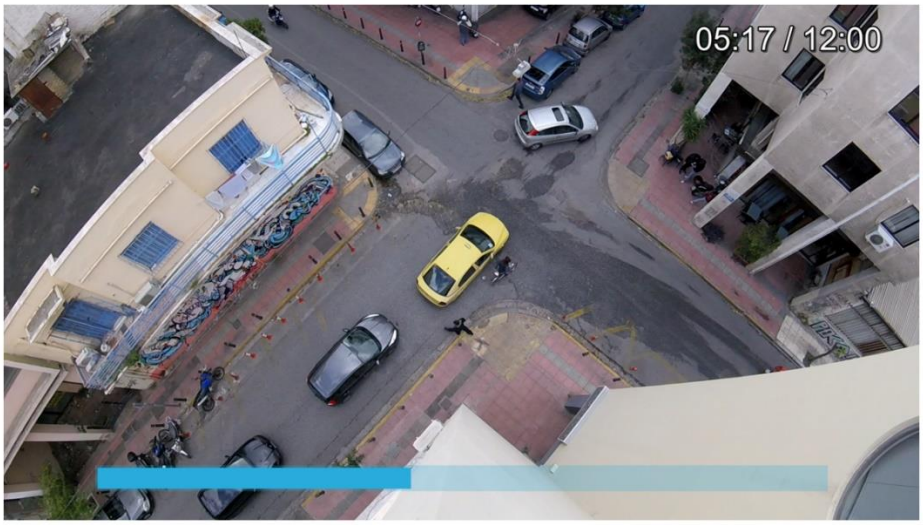
Firstly, several **screenshots** that can easily describe the flow of the Incident are taken. RUs that are involved in the Incident are noted as **types of vehicles in numerical order**., and a written **description** of the Incident is produced.

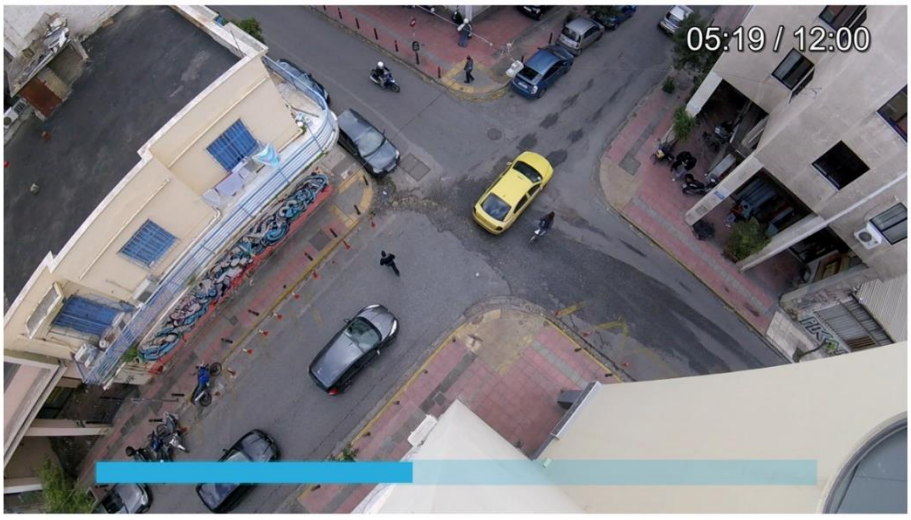
2.2.1.1. Screenshots

Although a video clip of an incident is the best way to get an understanding of how the interactions take place, it is important to depict an incident through images. That way it can be studied and analyzed deeper and gain a better understanding of road user interactions.

In most incidents of this study the first screenshot is taken when every RU involved is visible. If that is not possible, then the first screenshot is taken the moment the second involved RU is visible. After that, a screenshot is taken every time there is a maneuver initiation or change. The final screenshot is taken when there are the involved RUs are separated and there are no new maneuvers contributing to the multiple interaction. The time mark where this specific incident takes place among the footage is noted so it can be easily revisited. The time where the incident occurs in the video file is stamped on the upper right.

Below are presented two incidents, involving three and four interacting road users respectively. The steps followed in order to describe each incident will be thoroughly discussed in the following paragraphs.





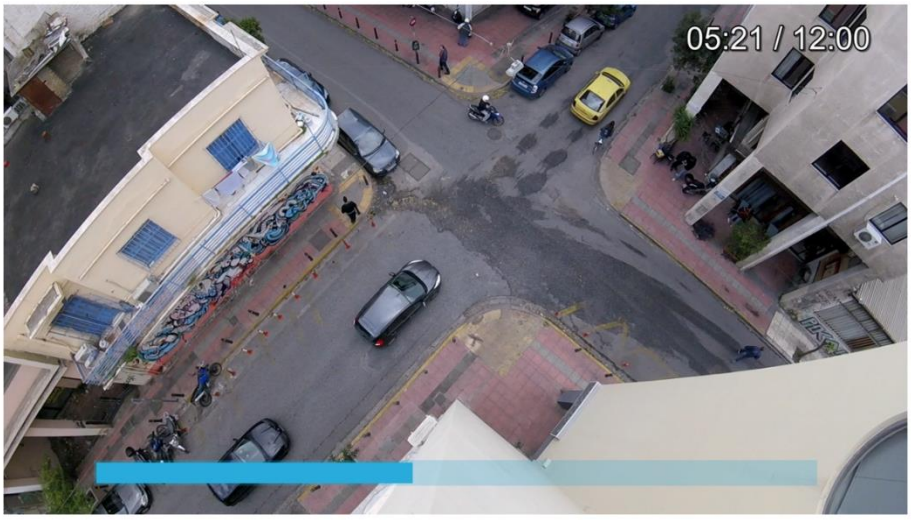


Figure 9: Incident 5 screenshot layout

Figure 10: Incident 20 screenshot layout

2.2.1.2. Types of Road Users

While there are many different types of road users that can be met throughout different types of traffic environments, this study focuses on the vehicles that are met in the specific incidents.

It is considered in this study that there is a need to communicate a general idea of what the vehicle type and size is. For that reason, there is no need to differentiate between different types of passenger cars (Sedan, SUV, Minivan, etc.), but there is a need to show that a certain road user is significantly different in size, speed and behavior than another (pedestrian, car).

In the intersection that was studied, the types of RUs that were met were:

- Car (C)
- Motorcycle (M)

- Pedestrian (P)
- Bicycle (BC)
- Truck (TR)
- Bus (BS)

In the second frame of incident 20, which is mentioned above, different kind of road users. In this study pedestrians that are walking together are considered as a single Road User. So, the two pedestrians (P) crossing the street represent RU 1. RU 2 is a motor tricycle, which falls into the category of motorcycles (M). RU 3 is a van, which in this study falls into the category of cars (C) and so is labeled as such. Finally, RU 4 is a car (C).

Figure 11: Incident 20 - Different types of Road Users

2.2.1.3. Road User Numbering

After road users with are designated with their respective type comes the matter of numbering them. It is deemed important that each RU is numbered in a consistent way, so that while describing the incident it can be easily indicated in which way and order the RUs are interacting with each other. Each RU is assigned a number in ascending order, according to the following criteria. If there is a tie in each criterion, then numbering moves to the next criterion and so on. So, numbers are assigned to RUs:

1) In the order in which each RU initiates their maneuver.
2) If RUs begin to maneuver at the same time, then in the order in which they end their maneuvers.
3) If they begin and end their maneuvers at the same time, then the RU that is already moving is numbered first.

4) If RUs are tied in all of the above, then whoever has the right of way gets numbered first.

In incident 20, we can clearly follow the RUs' movements, and can put them in order according to the above rules. The pedestrians (P) are the first to make a move, so are road user 1 in this incident and labeled as P1. The tricycle (M) doesn't initiate a maneuver until P1 do, so they it is labeled as M2. We're left with the van (C) and the car (C). The van crosses the intersection interrupting the car's advance, finishing its maneuver first and labeled as C3. The car is the final RU left in the intersection to complete its original maneuver, which is to cross the intersection, and so is labeled as C4.

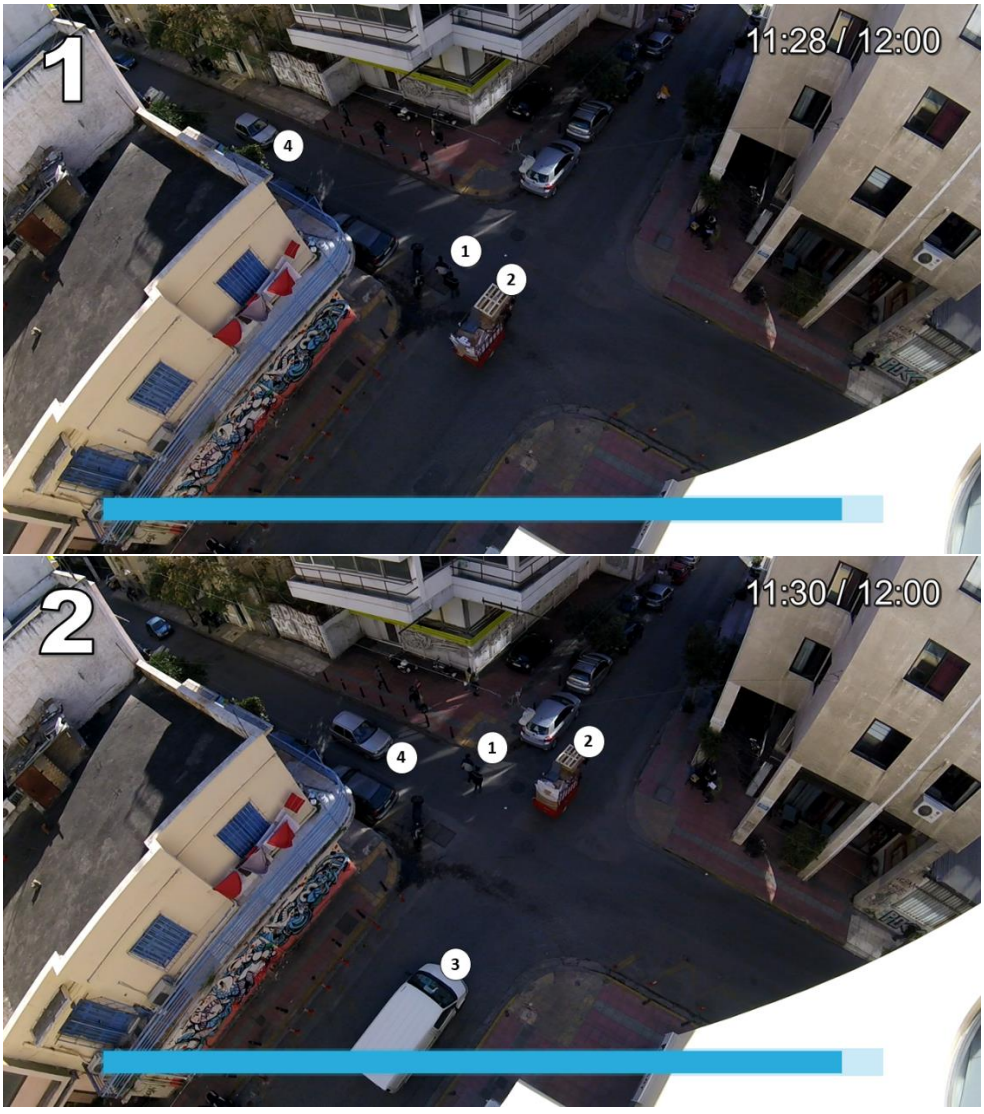


Figure 12: Incident 20 - Assigning Numbers to Multiple Road Users

In the beginning of incident 21, which is shown below, there are five RUs on the edge of the intersection intending to cross it from different positions. The group of pedestrians are the first to initiate a maneuver, so they are assigned with number 1. The cyclist is the first to react to P1 so he's assigned with number 2. The lone pedestrian notices BC2 and steps on the road, so he's assigned with number 3. At this point the first 3 RUs are on the intersection so the black car also moves ahead. Since he moves ahead of the white van, he's assigned with number 4 while the van is assigned with number 5.

Figure 13: Incident 21: Assigning Numbers to Multiple Road Users

In incident 47, we can see a cartwheel moving slowly and blocking the white van's advance. A motorist, who is right behind them, is maneuvering to overtake both and so is assigned with 1. Before he reaches the intersection, two vehicles take advantage of the slow-moving line, but because their maneuvers are initiated after M1 starts to overtake, they get assigned with numbers 2 and 3. After M1 crosses another vehicle (C4) moves ahead of the cartwheel (P5) and the van (C6).

Figure 14: Incident 47 - Assigning Numbers to Multiple Road Users

2.2.1.4. Incident Description

The written description of each incident has to include every RU involved and describe each one's actions quickly and accurately. It is important that the objective evolvement of the interactions is described. In that way, actions that RUs are taking are included, but assumptions regarding their intentions, awareness and criticality through the incident have to be avoided or carefully couched.

For example, in figure 12 shown in chapter 2.2.1.3, Road User 1 (pedestrians) intends to cross the road, while Road User 4 (silver car) approaches the intersection. Road User 2 (tricycle), who has stopped before entering the intersection, also intends to cross the road. As soon as RU 1 crosses, cutting RU4 off, RU 2 follows RU 1's lead, using him as cover to cross safely. RU 4 is forced to stop, giving RU 3 (white van) time and space to cross the intersection ahead of RU 4.

It is important that this interaction can be described in a more compact way. In that merit, a useful and efficient way to describe the above interaction is the following:

P1 cross the intersection with C4 being in a safe distance. M2 uses them as a mask, and C3 tails M2 to cross.

2.2.2. Rules and Assumptions

In order for the proposed methodology to be replicated a set of rules was needed so that recorded incidents can be described consistently.

First of all, the surrounding environment has to be noted and taken into consideration while reviewing the incidents. Here the studied location is an urban intersection. The intersected streets are one-way and paved, with a stop sign on one street regulating traffic. Since the streets are one-way, overtaking from either side is allowed per road code. There are no crosswalks, which means that pedestrians have to wait for traffic to clear before crossing. Parking is strictly regulated, as this intersection is part of a bus route.

As an urban intersection in the center of Athens, there are spans of increased traffic. Multiple RUs in the intersection does not necessarily result in multiple interactions. When identifying Multiple Road User Interactions, it is vital that RUs that are present but not involved in a multiple road user interaction are not taken into consideration.

Furthermore, the common theme that is applied throughout the gathered incidents is that RUs are interacting with each other while not strictly following Greek Traffic Code. For example, in the studied interactions vehicles may pass the stop sign and enter the intersection with other vehicles in sight. Similarly, pedestrians may cross the road with oncoming vehicles in close proximity. In these situations, RUs are either communicating or forcing a solution to their conflict.

In conclusion, when Traffic Code is followed, interactions are not studied. Incidents are collected and studied only when:

i. Traffic code is not followed
ii. Road Users are interacting with each other according to Multiple Road User Interaction definition
iii. Number of Road Users is 3 or greater (RU ≥ 3)
iv. Road Users are active, in the sense that they are actively trying to perform a maneuver and are not for example “stuck in traffic”

2.3. Establishing Interaction Patterns

In total 81 Incidents were recorded. After the Incidents and their characteristics were gathered, they were studied in order to produce a methodological categorization of occurring interaction patterns.

By studying each incident in detail, it occurs that the majority of RUs are acting to resolve the Incident efficiently, bending the rules at the same time. RUs tend to use maneuvers that other RUs are performing to their advantage. Several different scenarios can occur when RUs behave like that. A RU may use another RU's maneuver to complete his or her maneuver, or have his or her maneuver interrupted as a result of two other interacting RUs. When juxtaposing these incidents, one can find reoccurring behaviors.

As RU behavior can be varied, it is important that the right tools can be established in order to methodologically describe different interactions. The proposed idea is that every presented incident can be described by a set of defined interaction patterns, which can either intertwine forming major incidents where more than 3 road users are involved, or fail, in which case while there was intention to follow a pattern a solution between the road users couldn't be found.

Below we will compare similar incidents in order to understand how they can form behavioral patterns. It is also proposed how these patterns may combine or fail.

2.3.1. Identifying Interaction Patterns

For the 1st behavioral pattern, in Incident 5, C1 has stopped before the intersection, waiting for an opportunity to cross. Beside him, BC2 is also waiting to cross the intersection. M3 is approaching the intersection. C1 has perceived M3 to be in a safe distance for him to cross. As he gets started, BC2 also starts to cross using C1 as protection. C1 and BC2 have safely crossed the intersection, and are followed by M3 who turns left.

In comparison, Incident 38 involves C1, who backs up towards the intersection, providing cover for C2 against M3. After C1 backs up, C2 crosses the intersection. Then C1 finishes his maneuver, continuing down the main road, while M3 overtakes him from his right.

Figure 15: 1st type of behavioral pattern - Incidents 5 & 38 described on the left and right column respectively

In incidents 7 and 44 we can identify a second behavioral pattern. In incident 7, both C1 and C3 have stopped before entering the intersection, with C1 going first. In the meantime, M2 quickly approaches the intersection, and follows C1 closely, so that he may also cross the intersection with him. This scenario is repeated in incident 44, with TR1 crossing the intersection while C3 is approaching. M2 has stopped right by TR1, and follows TR1 as soon as he starts his maneuver.

Figure 16: 2nd type of behavioral patter - Incidents 7 & 44 described on the left and right column respectively

A third reoccurring behavior can be seen in incidents 9 and 24. Incident 9 involves C1 who has entered the intersection and has stopped right in the middle, as oncoming C2 who is on the main road and takes a left turn. Behind him, C3 gets blocked by both C1 and C2 and has to wait for them to clear the road. In incident 24 C1 performs a parking maneuver, making C2 maneuver in order to overtake him. Meanwhile, M3 cannot move and has to wait for both C1 and C2 to complete their maneuvers.

Figure 17: 3rd type of behavioral pattern - Incidents 9 & 24 described on the left and right column respectively

For the 4th behavioral pattern, in Incident 3, P2 takes advantage of the low speed of passing cars (C1 and C2) so that he can cross the road in between them. Similarly, in incident 8, BS2 takes advantage of the interaction between P1 and C3 to turn in front of C3.

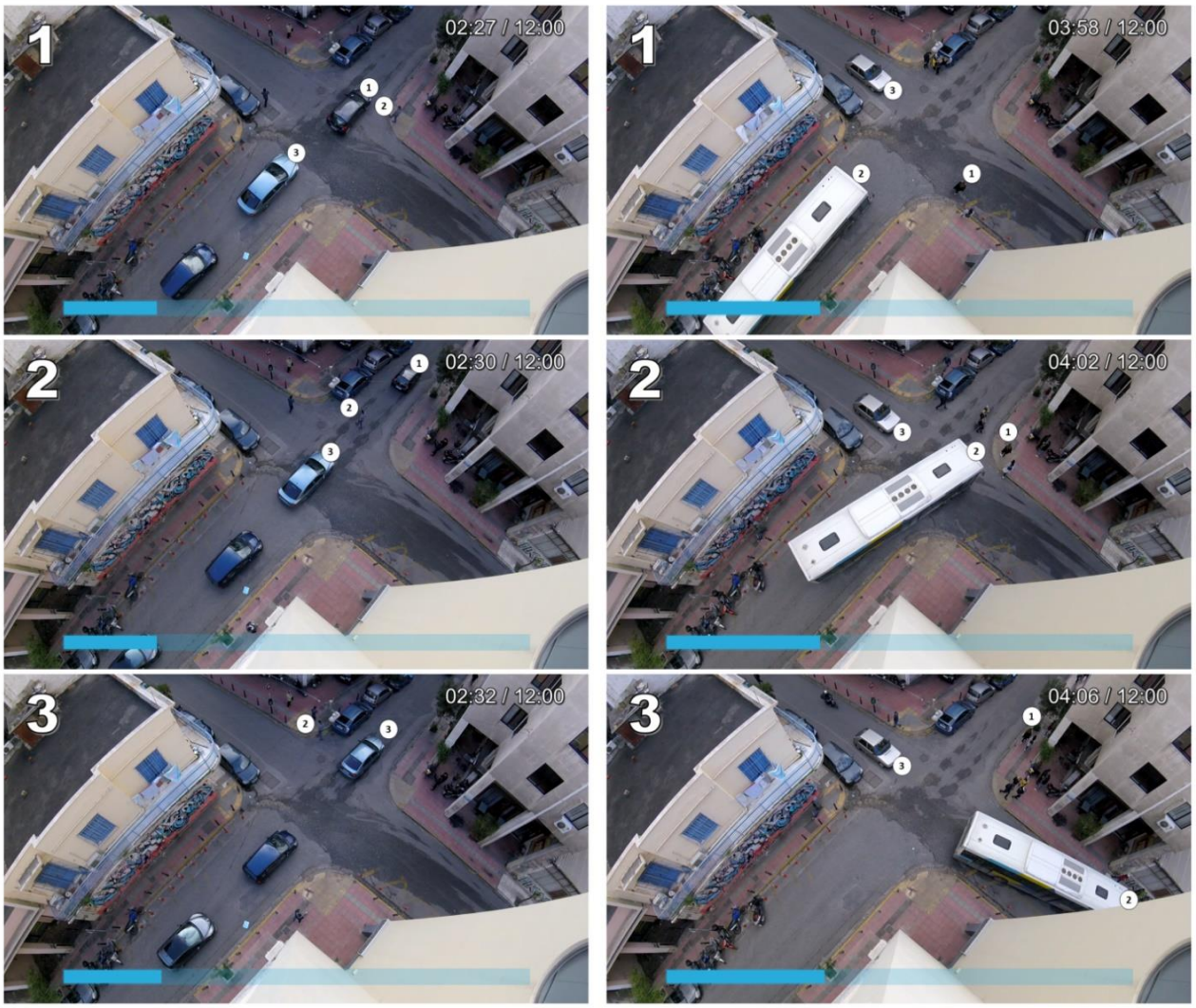


Figure 18: 4th type of behavioral pattern - Incidents 3 & 8 described on the left and right column respectively

Finally, in incident 35, P1 crosses the road while M3 stops on the right side of the road and M2 passes through right between them. In comparison, in incident 39, RUs also interact in a convenient way. C1 makes a left turn allowing C2 to turn right and P3 to cross the road at the same time.

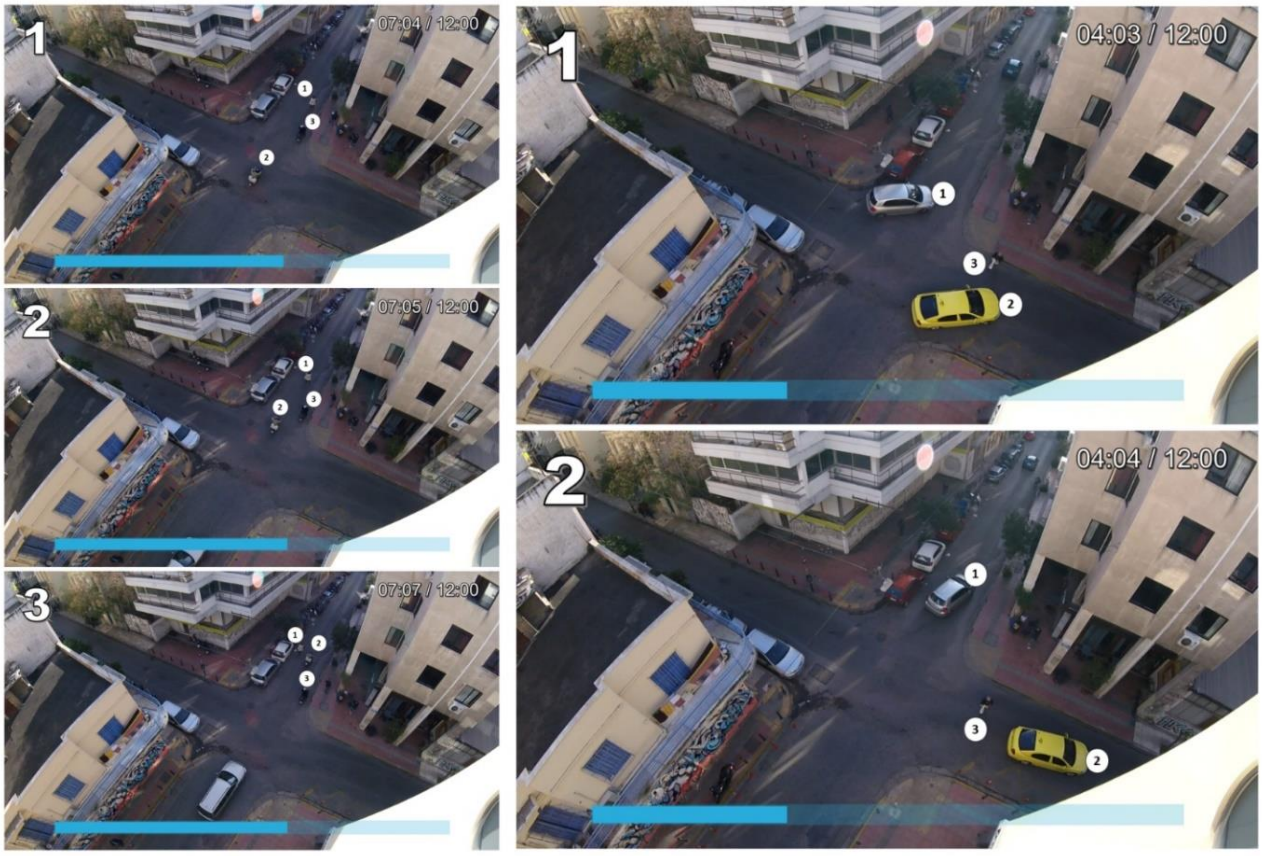


Figure 19: 5th type of behavioral pattern - Incidents 35 & 39 described on the left and right column respectively

Each reoccurring behavioral pattern can be considered as a category, which will from now on be referred to as **Interaction Pattern**. The Patterns that were initially created were based on 3-way interactions that stood out from the recorded incidents. From the 81 Incidents that were gathered, five different patterns were noted:

1) Masking
2) Tailing
3) Blocking
4) Exploiting
5) Coordinating

The patterns and their structure will be presented in detail in the Results section.

2.3.2. Multiple Interaction Patterns

The patterns presented above can form a basis of describing more complicated interactions. In incidents with more than 3 road users involved, it is observed that multiple interactions in the same space and time span can be isolated. These interactions can be described individually but are interdependent and can

form major interactions. For example, in incident 20 shown in figure 12 shown in chapter 2.2.1.3, we can identify two different 3-way interactions taking place successively:

i. The first interaction takes place between P1, M2 and C4. M2 uses crossing P1 as cover to cross the intersection ahead of C4. This interaction follows the 1st behavioral pattern described in chapter 2.3.1.
ii. The second interaction takes place between M2, C3 and C4. C3 exploits the halt of C4 due to crossing M2 to also cross the intersection, in the expense of C4. This interaction follows the 4th behavioral pattern described in chapter 2.3.1.

In incident 21 shown in figure 13 shown in chapter 2.2.1.3, we can also identify two successive 3-way interactions. C5 intends to turn but BC3 is blocking his path. BC3 crosses the intersection and so P3 and C4 use BC2 as cover to also cross. As a result, we have two 3-way interactions between C5, BC2, P3 and C5, BC2, C4 that follow the 1st behavioral pattern.

2.3.3. Failed Interaction Patterns

It is worth mentioning that although behavioral patterns can be identified in certain incidents, the RUs involved couldn't reach a solution in regards to the respective pattern. In these incidents, the RU that has intent to initiate the patterned interaction cannot follow through because he is forced by other RU's maneuvers.

Such a situation can be seen in the following incident. C2 is on the main road approaching the intersection. M1, who is on the secondary road and also approaches the intersection, accelerates and crosses ahead of C2. P3 is watching that interaction, and steps on the road to also cross, using M1 as cover. However, soon after M1 crosses the intersection C2 accelerates and crosses the intersection ahead of P3.

The setup for this incident is remindful of the 1st behavioral pattern described above in chapter 2.3.1. The difference is that while there was intention from P3 to follow the pattern, there were factors that prevented him from doing that – in this instance C2's acceleration.

Figure 20: Incident 33 - Failed Attempt at following the 1st behavioral pattern

3. Results

Focusing on interactions with three or more road users, 81 incidents where three or more road users interact were identified. After reviewing these incidents, 12 of them were eliminated, with the other 69 forming the final table. The table consists of rows, each on designated for a specific incident, and columns, which are used to describe the incident.

3.1. Road User Interaction Patterns

In this chapter we introduce the behavioral patterns described in chapter 2.3.1 as standardized Interaction Patterns able to describe a variety of 3-way or multiple road user interactions.

The RUs involved in these interactions are assigned with specific roles. It is important to note that different types of RUs can have different roles in every patterned interaction.

3.1.1. Exploiting

In Exploiting incidents, road user involvement follows a predefined format, in which a RU called the Exploitor, is using another RU, the Passive RU, in order to benefit from a 3-way interaction between them and a third RU, the Exploitee.

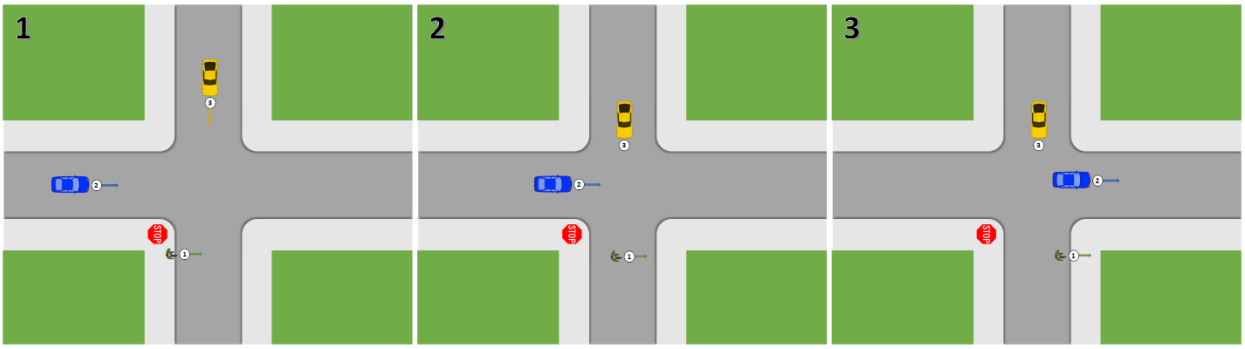


Figure 21: RU 1 (pedestrian): Passive RU, RU 2 (blue car): Exploitor, RU 3 (yellow car): Exploitee

In the mock-up incident presented above, the blue car is the exploitor, while the yellow car is the exploitee and the pedestrian is the Passive RU. The pedestrian is indeed passive to this interaction, as his maneuver is affected nor from the exploitor neither from the exploitee. Nevertheless, his presence and his action is integral to the 3-way interaction to take place, as he gives the exploitor reason to perform his maneuver.

In incident 8 we can see a car (C3 – Exploitee) stopping because of a pedestrian crossing the road (P1 – Passive RU), and a bus (BS2 – Exploitor) finds the opportunity to turn ahead of C3.

Figure 22: Incident 8 - Exploiting

A similar situation occurs in incident 54 shown below. C1 (Passive RU), who is on the secondary road, turns on the main road ahead of C3 (Exploitee), as the latter is at a safe distance. P2 (Exploitor) use the fact that C3 has to reduce speed so that they can cross the road.

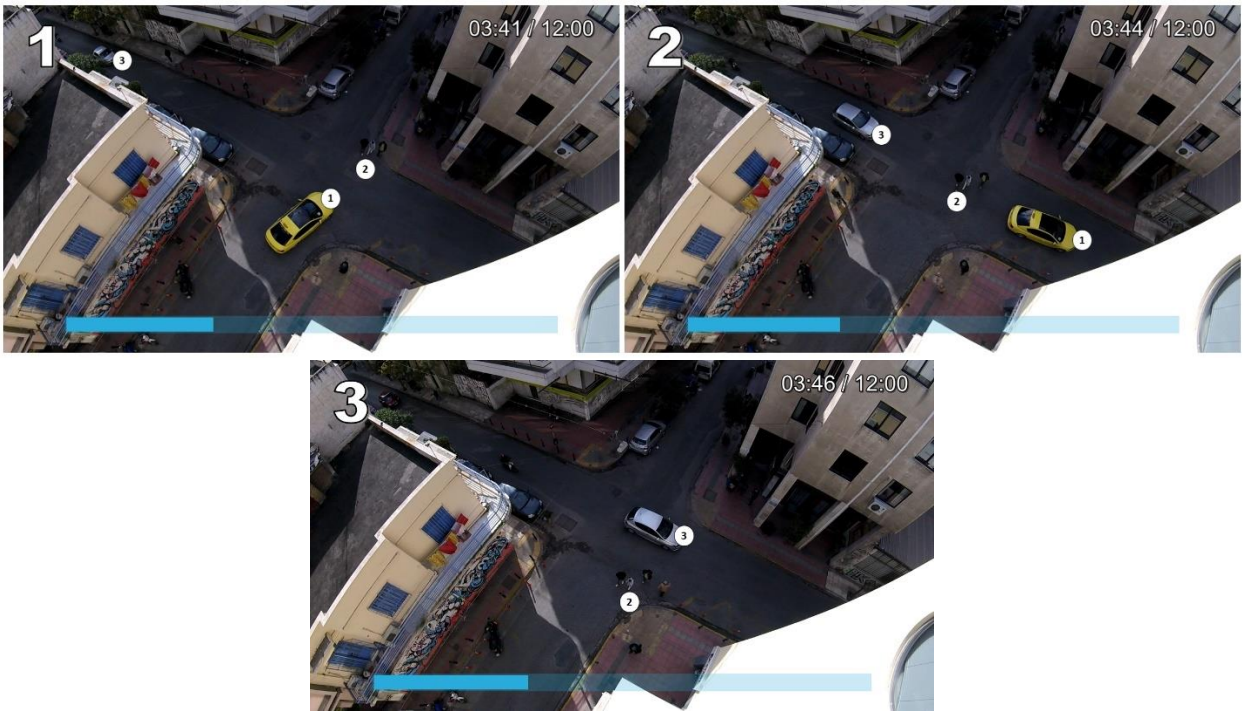


Figure 23: Incident 54 - Exploiting

Table 1: RU Roles in exploiting incidents 8, 54

Role of Road User	Incident 8	Incident 54
Exploitor	BS2	C1
Exploitee	C3	C3
Passive RU	P1	P2

It is important to note that in exploiting incidents, while the Road Users involved have defined roles, the way in which they interact cannot always be defined. In the following chapters are presented interaction patterns (Masking, Tailing) which, besides defined roles, also have a distinct way in which they interact.

3.1.2. Masking

Masking incidents are a form of exploiting, in which the manner of interaction is more strictly defined. In these incidents, RU 1 (blue car), called the Mask, is crossing the path of RU 3 (yellow car), the Exploitee, and RU 2 (motorist) who is called the Masker is using the Mask as a cover to also cross.

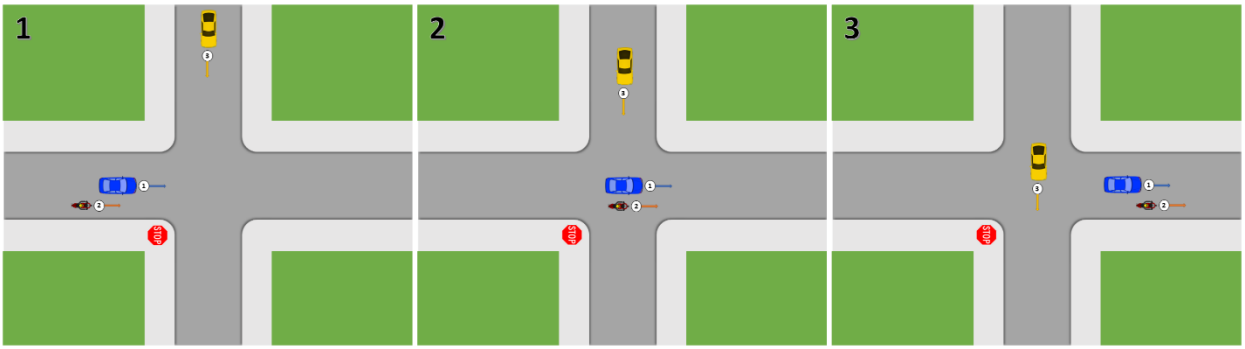


Figure 24: RU 1 (blue car): Mask, RU 2 (motorist): Masker, RU 3 (yellow car): Exploitee

In masking incidents, the Exploitee is usually forced to stop or reduce speed, as the Mask is cutting him off. The Masker is not contributing in hindering the exploitee's maneuver, as his focus is in copying the Mask's maneuver and using the latter as cover.

In incident 5 presented in chapter 2.3.1., we can see a similar scenario unfolding. C1 is the Mask, M2 is the masker and M3 is the Exploitee.

It is interesting to compare the types of RUs that participate in incident 5, with those in incident 2. In the latter, a pedestrian (P2 - masker) is using another pedestrian (P1) as a mask. Oncoming motorists (M3, M4) play the role of the Exploitee.

Figure 25: Incident 5 - Masking

Figure 26: Incident 2 - Masking

Table 2: RU Roles in masking incidents 2, 5

Role of Road User	Incident 5	Incident 2
Mask	C1	P1
Masker	M2	P2
Exploitee	M3	M3, M4

3.1.3. Tailing

Tailing incidents are a form of exploiting incidents. In these incidents, a RU called the Tailee, is crossing the path of another RU, the Exploitee, and a third RU called the Tail is following the Tailee closely to also cross.

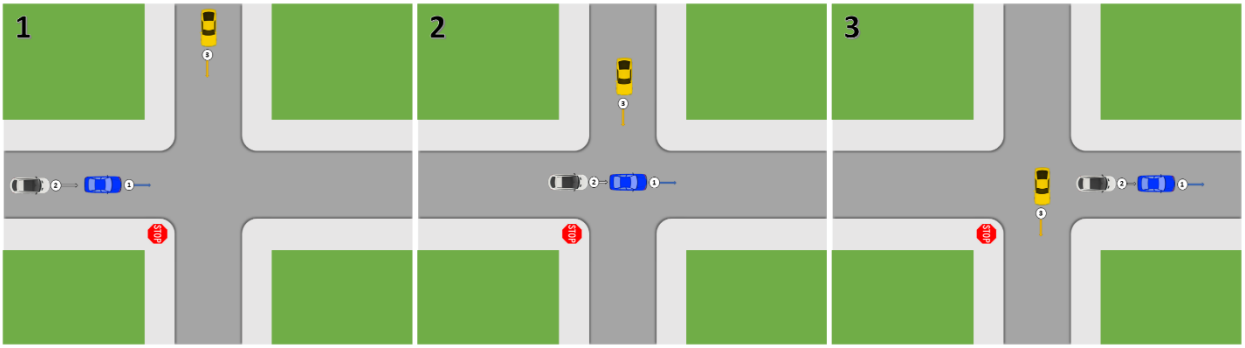
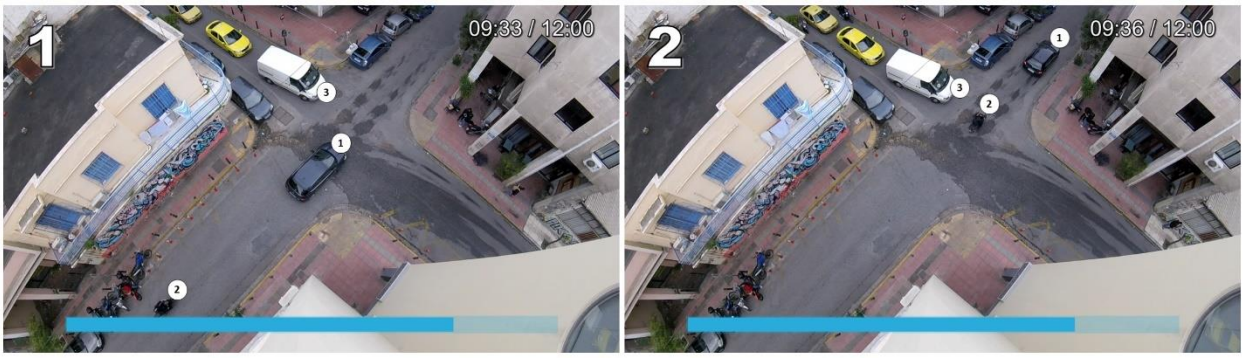


Figure 27: RU 1 (blue car): Tailee, RU 2 (white car): Tail, RU 3 (yellow car): Exploitee

In Tailing incidents, the Exploitee is forced to stop or reduce speed, as the crossing RU has cut him off. The crossing RU that made the Exploitee stop may be either the Tail or the Tailee.

In incident 7 presented in chapter 2.3.1, we can see a similar scenario unfolding. C1 is the Taille, M2 is the Tail and C3 is the Exploitee.



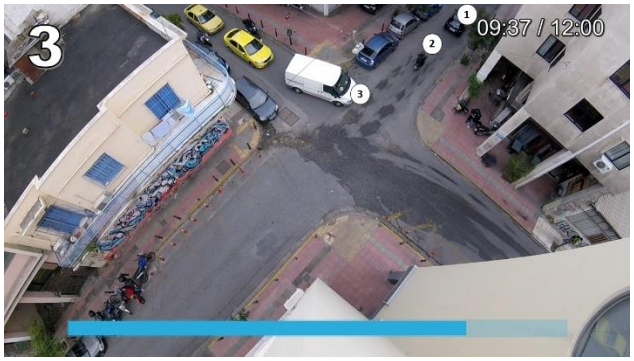


Figure 28: Incident 7 - Tailing

In incident 19 shown below, M1 is on the edge of the intersection, intending to turn right onto the main road. Oncoming are M2 and right behind him is C3. As M2 does not occupy a lot of space on the road, M1 can make his move, turning right and accelerating to keep up with M2, in a way tailing him ahead of C3. So in this scenario M1 is the Tail, M2 the Tailee and C3 the Exploitee.

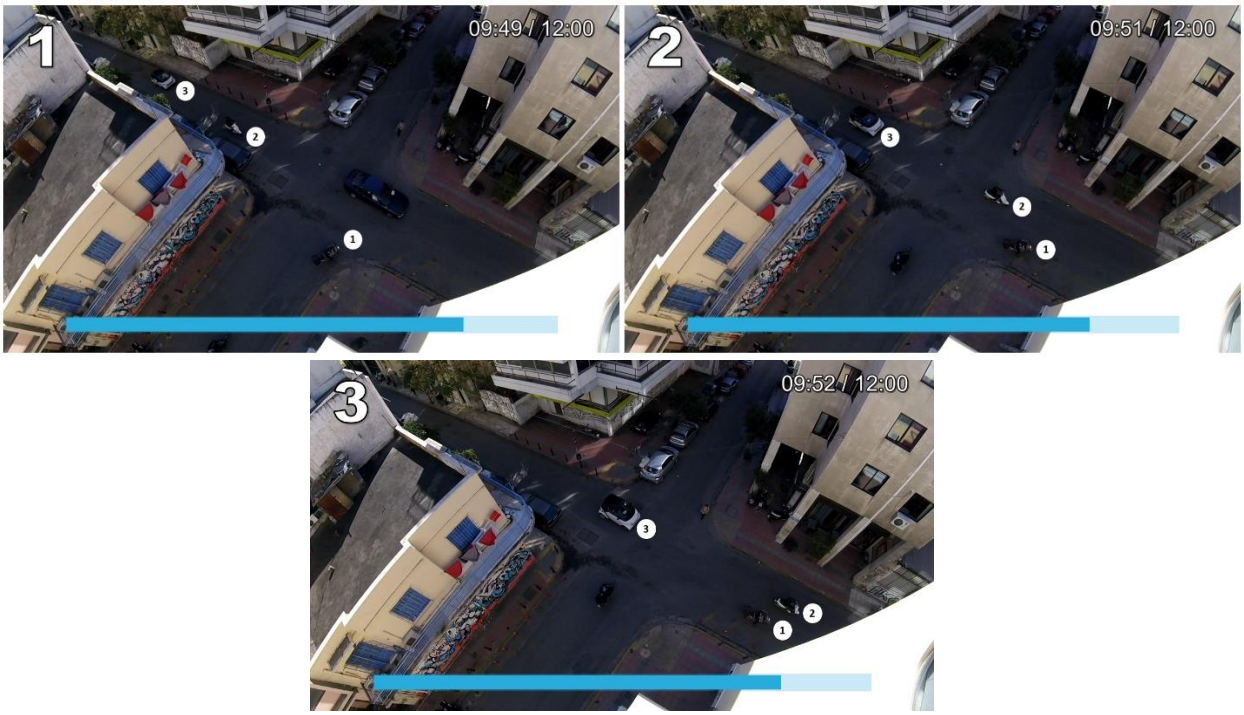


Figure 29: Incident 19 – Tailing

Table 3: RU Roles in tailing incidents 7, 19

Role of Road User	Incident 7	Incident 19
Tailee	C1	M2
Tail	M2	M1
Exploitee	C3	C3

3.1.4. Blocking

In Blocking incidents, two RUs called the Active and the Passive Blocker, are interacting in a way that a third RU, the Blockee, is blocked.

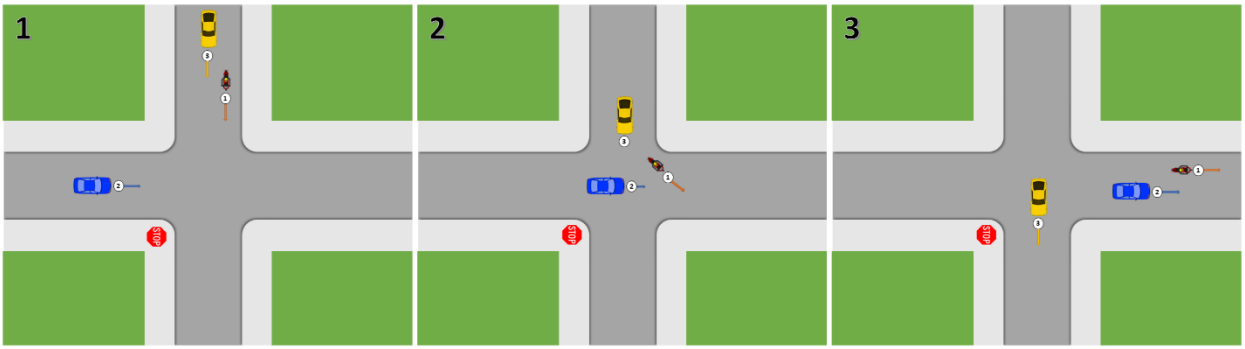


Figure 30: RU 1 (motorist): Passive Blocker, RU 2 (blue car): Active Blocker, RU 3 (yellow car): Blockee

The Blocking Interaction Pattern is structured differently than the patterns presented above. The roles played by the involved RUs are defined, but the manner in which those RUs interact is vague.

An example shown in chapter 2.3.1. is incident 9, where C1, who is on the main road and approaching the intersection, is turning left, while C2 has entered the intersection and is waiting for C1 to complete his maneuver before following him. As a result, C3 who is also on the main road behind C1, gets blocked by C2 and has to wait for him to complete his maneuver before crossing the intersection. In this example C2 and C1 are the active and passive blocker respectively, whereas C3 is the blockee.

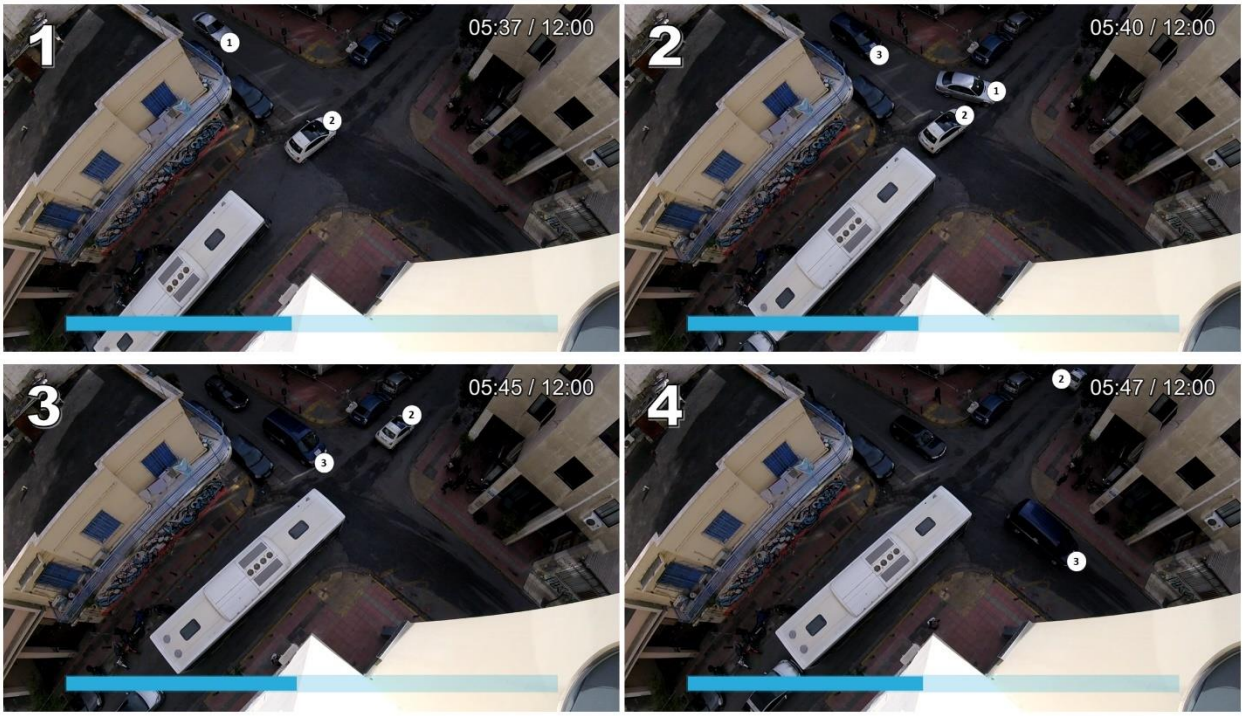


Figure 31: Incident 9 – Blocking

In another blocking incident, shown below, C1 is on the main road approaching the intersection, with M3 following him. M3 tries to overtake from the left unsuccessfully, and decides to overtake from the right. Meanwhile, oncoming M2 accelerates and overtakes both of them, blocking M3's maneuver. In this incident M3 takes the role of the blockee, while M2 and C1 are the active and passive blockers respectively.

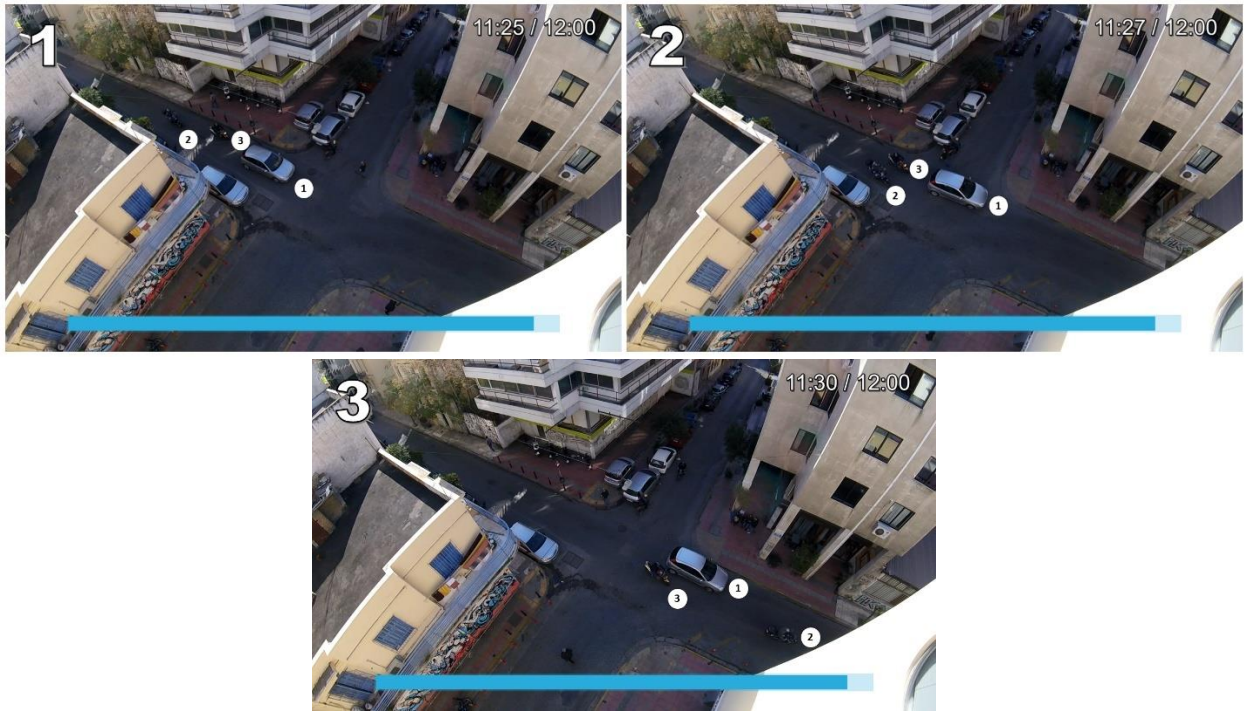


Figure 32: Incident 30 - Blocking

Table 4: RU Roles in blocking incidents 2, 30

Role of Road User	Incident 9	Incident 30
Active Blocker	C2	M2
Passive Blocker	C1	C1
Blockee	C3	M3

3.1.5. Coordinating

In Coordinating incidents, all involved RUs are interacting in a way that every conflict is resolved seamlessly.

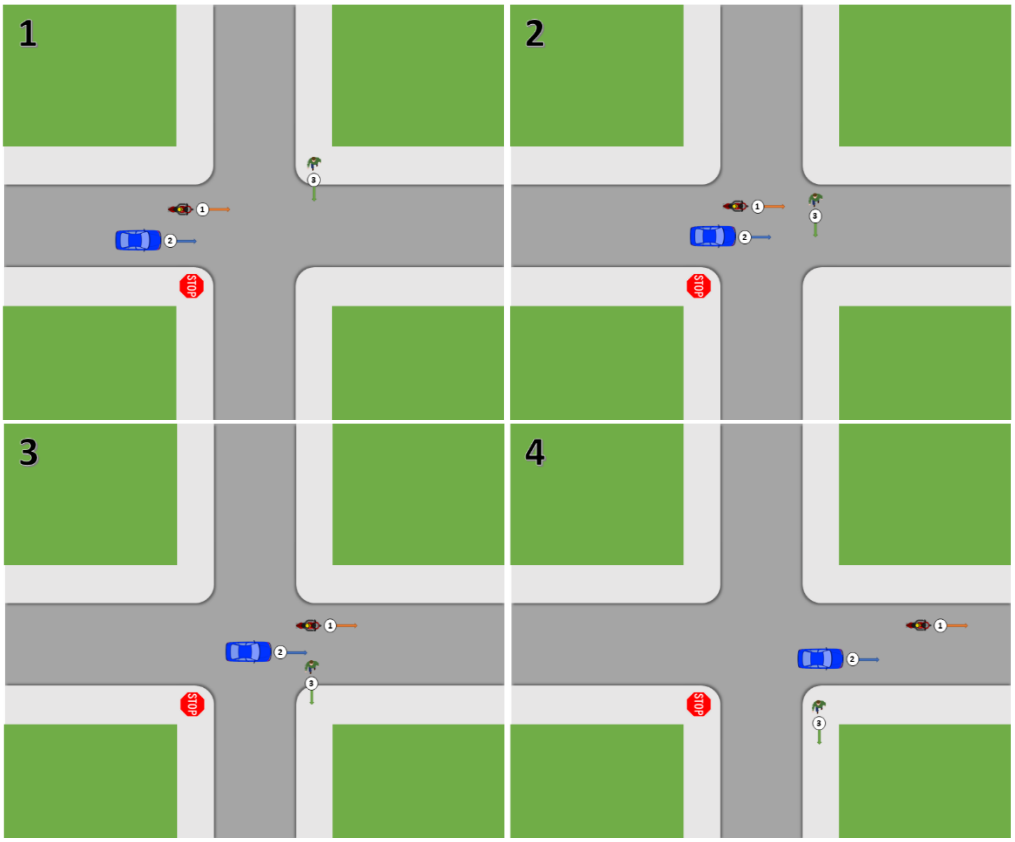


Figure 33: Coordinating Interaction Pattern

In this interaction pattern no roles are assigned to involved RUs, as the incidents that follow this pattern share one common theme, in the way that all maneuvers are performed without interruption and all conflicts are resolved seamlessly.

For example, in incident 39 below we can see two cars (C1 and C2) turning at the same time in different directions, allowing a pedestrian (P3) to cross the road also at the same time.

Figure 34: Incident 39 - Coordinating

In another incident shown below we can see pedestrians and motorcycles interacting and coordinating. In incident 10 shown below M1 is on the main road crossing the intersection normally, and P2 crosses the road as there is no vehicle crossing his path. As soon as M1 enters the intersection M3 accelerates to cross and goes behind P2 to continue his maneuver. After M1 has passed by M4 aslo crosses the road as it is clear.

Figure 35: Incident 10 - Coordinating

3.2. Interactions with Multiple Interaction Patterns

The Patterns introduced above may occur in 3-way interaction incidents, but they can also combine to form 4-way or 5-way interactions. Multiple Interaction Patterns are formed between Masking, Tailing, Blocking and Exploiting incidents.

For example, in incident 20, a pedestrian (P1) decides that the oncoming car (C4) is at a safe distance for him to cross the road. A tricycle (M2), which is waiting by P1, uses P1 as a mask to also cross the road. This interaction follows the Masking Pattern, with P1 being the mask, M2 the masker and C4 the Exploitee. While P1 and M2 perform their maneuvers, C4 has arrived close to the intersection and slows down. Another vehicle (C3), which is coming from the secondary road, sees that C4 hesitating to enter the intersection. C3 exploits the 3-way interaction that took place in front of him to cross the intersection ahead of C4, who has the right of way. That interaction can be patterned with Exploiting, with C3 being the Exploitor, P1 and M2 the Passive RUs and C4 the Exploitee.

Figure 36: Incident 20 - Multiple Interaction Patterns

Table 5: RU Roles in Multiple Interaction Pattern Incident 20

Road User \ Pattern	Masking	Exploiting
P1	Mask	Passive RU
M2	Masker	Passive RU
C3	-	Exploitor
C4	Exploitee	Exploitee

The same pattern can also occur multiple times throughout an incident. This happens in incident 47, where three different Exploiting Incidents take place. M1 is behind M5 and C6, and decides to maneuver

in order to overtake them both. Meanwhile C2 and C3 find time and space to turn and cross respectively. Here we recognize two exploiting interactions, the one between C2 (exploitor), M1 and C6 (exploitees) and M5 (Passive RU), and the other between C3 (exploitor), M1 and C6 (exploitees) and M5 (Passive RU). After M1 overtakes, M5 stops on the edge of the intersection, forcing C6 to also stop. C4 exploits stopped RUs to turn. That is the third exploiting interaction, taking place between C4 (exploitor), C6 (exploitee) and M5 (Passive RU).

Figure 37: Incident 47 - Multiple Interaction Patterns

Table 6: RU Roles in Multiple Interaction Pattern Incident 47

Road User \ Pattern	Exploiting	Exploiting	Exploiting
M1	Exploitee	Exploitee	-
C2	Exploitor	-	-
C3	-	Exploitor	-
C4	-	-	Exploitor
M5	Passive RU	Passive RU	Passive RU
C6	Exploitee	Exploitee	Exploitee

3.3. Interactions with Failed Interaction Patterns

In several incidents, while the pattern of the Patterns is recognized, it can occur that the incident didn't finish with the expected outcome. These patterns are called Failed Interaction Patterns. Below are presented examples of incidents where Road Users intend to but fail to perform a patterned maneuver.

3.3.1. Failed Masking

In incident 33, C2 has stopped on the edge of the intersection, allowing M1 to go ahead and cross it. P3 tries to use M1's maneuver to cross the intersection, but as a pedestrian he can't match the vehicles' speed. C2 accelerates and M3 has to wait until the road is clear to cross.

Had P3 been able to keep up with M1, he would be the Masker, M1 would be the Mask and C2 the Exploitee.

Figure 38: Incident 33 - Failed Masking

3.3.2. Failed Tailing

A failed attempt at Tailing can be seen in incident 53. C1 accelerates and crosses the intersection ahead of C2, who has the right of way. C3 does not engage in a tailing maneuver as C2's momentum doesn't let him.

Had C3 forced his way through he would be considered a Tail, while C1 would be the Tailee and C2 would have to stop or reduce speed, taking up the role of the Exploitee.

Figure 39: Incident 53 - Failed Tailing

3.3.3. Failed Blocking

In incident 6, C1 is moving on the main road, while multiple RUs surround him, potentially ready to maneuver at his expense. M2 is overtaking from the right, P3 is on the road and BS4 intends to turn right. C1 proceeds carefully and doesn't let anyone obstruct his advance.

If any of the RUs maneuvered in a way that hindered the advance of RU 1, the dynamic of the incident would change and with it the outcome, making this a Blocking Incident.

Figure 40: Incident 6 - Failed Blocking

3.3.4. Failed Exploiting

In incident 40, C3 and M4 can see M1 obstructing M2's advance, and intend to enter the intersection. M2, who is right behind M1, overtakes from the right and makes use of the horn, as to prevent C3 and M4 from taking advantage of his delayed arrival.

Figure 41: Incident 40 - Failed Exploiting

In an alternate outcome, in which either on of RU3 and RU4 force their way through the intersection, RU2 and/or RU1 have to stop. RU1 would be the Passive RU, RU2 the Exploitee and RU3 and RU4 would take up the role of the Exploitor. It is interesting to note, that in a scenario where RU4 follows RU1 on his left turn, and RU3 turns right, this failed exploiting incident would turn into a multiple incident, with one tailing incident (RU1 as the tailee, RU4 as the tail, RU2 as the expolitee) and a masking incident (RU4 as the mask, RU3 as the masker and RU2 as the exploitee.

3.3.5. Failed Multiple Interaction Pattern

In this incident multiple failed patterns are observed.

As M2 approaches the intersection P1 are still crossing the road and M2 tends to the right of the road to avoid them. C3 is aware of both M2 and P1, but oncoming M4 is not. M2 enters the intersection, and notices M4 who is not slowing down. M1 makes use of the horn to avoid a potentially dangerous situation.

Figure 42: Incident 32 – Failed Masking and Failed Exploiting

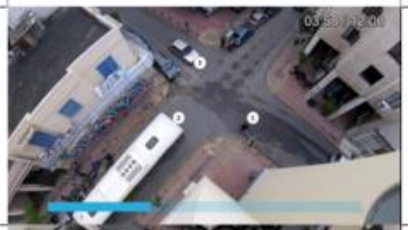
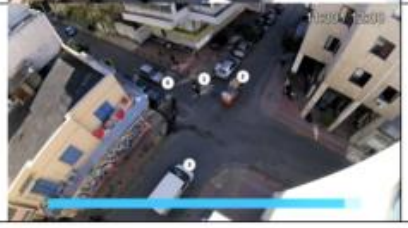
If RU4 had cross the road at the expense of RU3, this would result in an exploiting incident, with RU4 as the exploitor and RU2 as the exploitee. As an aftermath of that interaction, RU3 would possibly use RU4 as protection to perform his maneuver, resulting in a masking incident.

3.4. Incidents Table

The incidents presented in chapter 3 are summarized in the following table. The table consists of the data types that were described in chapter 2.2.1 as well as the Interaction Patterns that form the incidents.

An extended version of this table with all the gathered incidents can be found in the appendix.

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
2		4	P1	P2	M3	M4	–	–	P1 crosses the road as soon as it clears. P2 follows P1's lead and uses him as a "mask". Soon after M3 and M4 appear and continue their route while pedestrians have completed their crossing maneuvers.	MASKING	–	–	–
5		3	C1	BK2	M3	–	–	–	C1 want to cross the intersection. M3 is in safe distance so C1 proceeds with maneuver. BK2 follows on the side of C1 using him as a "mask" to cross the road safely.	MASKING	–	–	–
6		4	C1	M2	P3	BS4	–	–	C1 slows down while approaching the intersection, as there's a conflict of interest with other RUs: M2 wants to overtake, P3 appears to want to cross the road, BS4 wants to cut him off to go in front of him. In the end	FAILED BLOCKING	–	–	–
7		3	C1	M2	C3	–	–	–	C3 gives C1 the right of way. C1 crosses the intersection while M2 follows closely using his momentum to cut C3 off.	TAILING	–	–	–

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
8		3	P1	BS2	C3	–	–	–	C3 notices P1's intention to cross the road and gives the right of way. BS2 takes advantage of that interaction to make a turn.	EXPLOITING	–	–	–
9		3	C1	C2	C3	–	–	–	C2 sees C1 and tries to force him to give the right of way. C1 doesn't budge and makes his turn. C2 has to stop in the middle of the intersection, blocking the wat of oncoming C3.	BLOCKING	–	–	–
10		4	M1	P2	M3	P4	–	–	M1 is on the main road and crossing the intersection. M3 has to wait for M1 to pass before crossing, giving P2 the opportunity to cross. When M3 crosses the intersection P2 has has cleared M3's path. Meanwhile P4 is waiting for M1 to complete his maneuvre before crossing the road.	COORDINATING	–	–	–
19		3	M1	M2	C3	–	–	–	M2, followed by C3, approaches the intersection while keeping a safe enough distance for M1 to tail him.	TAILING	–	–	–
20		4	P1	M2	C3	C4	–	–	P1 cross the intersection with C4 being in a safe distance. M2 uses them as a mask, and C3 tails M2 to cross.	MASKING	TAILING	–	–

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
30		3	C1	M2	M3	–	–	–	C1 crosses the intersection at a slow pace. M3's intention is to overtake C1, but becomes aware of oncoming M2 who uses momentum to overtake. M2 passes first and M3 follows with an overtaking maneuver.	BLOCKING	–	–	–
32		4	P1	M2	C3	M4	–	–	As M2 approaches the intersection P1 are still crossing the road and M2 leans to the right of the road to avoid them. C3 is aware of both M2 and P1, but oncoming M4 is not. M2 enters the intersection, and notices M4 who is not slowing down. M1 makes use of the horn to avoid a potentially dangerous situation.	FAILED MASKING	FAILED EXPLOITING	–	–
33		3	M1	C2	P3	–	–	–	C2 stops before entering the intersection, allowing M1 to cross first. P3 attempts to also cross, but C2 accelerates and forces his way through.	FAILED MASKING	–	–	–
39		3	C1	C2	P3	–	–	–	C1 is turning allowing C2 to also turn. P3 uses their maneuvers to start crossing the road.	COORDINATING	–	–	–
40		4	M1	M2	C3	M4	–	–	M2 follows M1 closely waiting for an opportunity to overtake him. Eventually M1 turns left and M2 passes through from the right. At that moment C3 and M4 are slowly entering the intersection trying to cross, so M2 makes use of the horn to go first.	FAILED EXPLOITING	–	–	–

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
41		4	M1	BS2	M3	C4	–	–	C4 is halted in front of the intersection. M1 overtakes from the left but BS2 has already started his maneuver to turn. M3 is also trying to exploit the situation to cross the intersection, but he has limited view of M1.	EXPLOITING	EXPLOITING	–	–
47		6	M1	C2	C3	C4	P5	C6	M1 is behind M5 and C6, and decides to maneuvre in order to overtkae them both. Meanwhile C2 and C3 find time and space to turn and cross respectively. After M1 overtakes, M5 stops on the edge of the intersection, forcing C6 to also stop. C4 exploits stopped RUs to turn.	EXPLOITING	EXPLOITING	EXPLOITING	–
53		3	C1	C2	C3	–	–	–	C1 accelerates to cross the intersection. C2 is close and reduces speed, but doesn't let C3 tail C1 and continues his course.	FAILED TAILING	–	–	–
54		3	C1	P2	C3	–	–	–	C3 is at a safe distance for C1 to turn ahead of him. C1 turns and P2 exploit the fact that C3 has to reduce speed to cross the road.	EXPLOITING	–	–	–

4. Discussion

In this chapter the above findings are expanded and discussed, in order to gain more insight as to what they mean and they can be studied further.

Through the proposed methodology we got familiar with the three-way interaction, and got introduced to 5 different interaction patterns. These patterns were conceptualized through video observation, and therefore the only obvious similarity between them is that they occur in the same environment. Upon further examination, a connection between the patterns can be established.

The type of road users is also an interesting topic of discussion. Certain road users are more prone to engage in certain patterns than others, or take up certain roles in said patterns.

Furthermore, the patterns identified take place throughout the studied incidents, either as a single 3-way interaction or combined in a multiple road user interaction.

Finally, we introduce three more interaction patterns, which got eliminated due to the proposed set of rules surrounding the methodology.

4.1. Interaction Pattern Categorization

The interaction patterns presented in chapter 3, besides occurring in the exact same environment, share similarities in structure and conceptual correlation.

As has been mentioned above, the studied incidents involve atypical interactions. That is interactions where the rules of road users were not strictly followed. The presented patterns can be organized through a stratified model [12] that is explained below. The categories into which the five interaction patterns are divided are:

- Unobstructed Coordination
  In this pattern category the involved road users perform their maneuvers, without interrupting each other. All road users are either aware of each other, or move in a way that is not obstructing to the others. The only interaction pattern that falls into this category is **Coordinating**. The incidents falling into this category were not studied further, and it remains to be seen whether the Road Users involved in such interaction patterns are following defined roles and specific ways of interacting.

- Obstructed Coordination
  In this pattern category one or more road users perform maneuvers, which result in interrupting other road users' maneuvers. The interrupting RUs may or may not have intention of obstructing the interrupted RUs. In that way the interaction patterns are divided into two subcategories:

    - Unintended Interruption

In this category a road user's maneuver may get interrupted by other road users' maneuvers, without the latter having intention to affect the former. The interaction pattern falls into this category is **Blocking**.

- Intended Interruption
  Here a road user may opt to perform a maneuver, in order to take advantage of a situation and gain a head start against another road user. The interaction patterns that fall into this category is **Exploiting**, while **Masking** and **Tailing** are a form of the Exploiting interaction pattern.

The concept explained above is depicted in the following diagram.

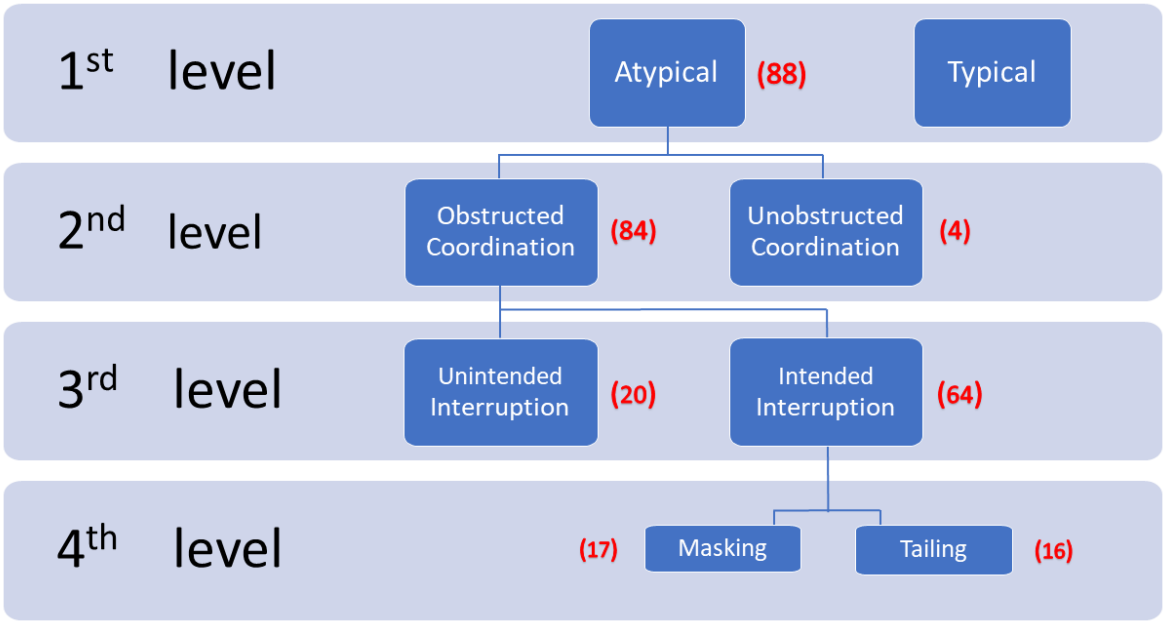


Figure 43: Interaction Pattern Categorization

Each category of the above infographic is presented with a number. This number refers to the times that interaction patterns occur throughout the 69 gathered incidents. For example, in the Intended Interruption category, 64 three-way interactions were identified, of which 17 belong to the Masking and 16 to the Tailing interaction pattern.

In this infographic the Exploiting, Blocking and Coordinating interaction patterns are absent. That is because these patterns unfold in ways that are not as defined as the Masking and Tailing patterns, and therefore need further analysis. About half of the unaccounted intended interruption interactions fall into the exploiting category. The proposed model of this study, which is summarized in the infographic above, can be expanded by creating new patterns and categories from studying different environments and cracking down on urban interactions. By studying closely incidents that fall into the Blocking, Coordinating or Exploiting interaction patterns, new interaction patterns can be created, where both the roles of the involved road users and the way in which they interact can be defined.

4.2. Extracting Incident Data

When the incidents of interest are gathered and data are produced in the proposed way, as introduced in chapters 2.2.1 and 2.3, a lot of diverse information can be extracted.

For the purpose of further study upon the method, it is worth noting several information regarding the details which describe the incidents. Such information involves the number of patterned interactions identified, the type of road users and the frequency in which these types are involved.

Table 7: Interaction Pattern Frequency

Number of Total Incidents	69
Single Pattern Incidents	37
Multiple Pattern Incidents	22
Failed Pattern Incidents	10
Number of Pattern Occurrence	88
Masking	17
Tailing	16
Exploiting	31
Blocking	20
Coordinating	4
Failed Interaction Patterns	11
F. Masking	3
F. Tailing	1
F. Exploiting	5
F. Blocking	2

Noting the frequency in which every road user type appears in the studied incidents can be beneficial to gaining deeper understanding of the environment. Below is presented the total amount of road users who participate in the incidents and whether their initial position was on the main or the secondary road.

Table 8: Road User Type Frequency and Initial Position

Number of Road Users	248
Car	121
Motorcycle	64
Pedestrian	53
Bicycle	3
Truck	2
Bus	5

Road Users on the Main Road	141
Road Users on the Secondary Road	107

Finally, in the table below is presented the amount of road users per type and position on the road. The position is the same as the number with which every road user was assigned upon describing the incident (chapter 2.2.1.3).

Table 9: Road User Type Frequency per Position through Incident

		RU Type						
		C	**M**	**P**	**BC**	**TR**	**BS**	**Total RUs**
Position	**1**	37	15	15	0	2	0	69
	2	27	25	12	3	0	2	69
	3	34	15	18	0	0	2	69
	4	17	6	7	0	0	1	31
	5	4	1	2	0	0	0	7
	6	2	1	0	0	0	0	3

4.3. Eliminated Interaction Patterns

This study concluded in five interaction patterns, which fit the proposed model and its parameters. More patterns were identified, which were eliminated during the process of fitting the interaction in the model.

4.3.1. Preventing

In Preventing incidents, a road user may perform a maneuver, taking all the other RUs into account, in order to avoid a collision.

Figure 44: Preventing Interaction Pattern

In this interaction pattern, while RU 2 is interacting with both other RUs, the latter are passive to the whole incident, and there is no immediate result to the interaction. It can be considered that the preventer (RU 2) is having two separate interactions with each RU respectively.

For example, in the following incident, RU 3 decides to change course, but he has to take maneuvering road users 1 and 2 into account, before completing his maneuver, otherwise the interaction would be confrontational.

Figure 45: Preventing Incident Example

In the study, this specific incident was considered to follow the Blocking interaction pattern, in the way that C3's maneuver was blocked by the other two road users, with C1 being the passive blocker and M2 the active blocker.

4.3.2. View Obstruction

In View Obstruction incidents, two road users are maneuvering independently. Their courses eventually collide, but a third RU is obstructing visual contact between them and so their maneuvers won't be interrupted until they can see each other.

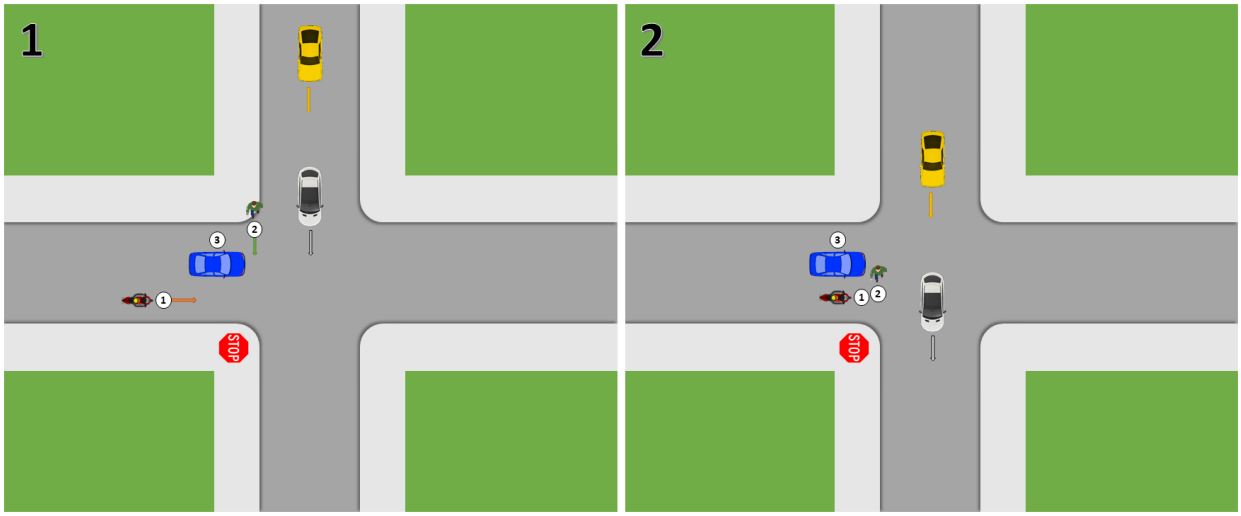


Figure 46: View Obstruction Incident Pattern

This type of interaction isn't considered for the proposed model for two reasons

1) In most cases, the road user that is obstructing visual contact is standing still, and so can't be considered as an active road user.
2) In all the incidents that were studied, the other two road users are not interacting with the view obstructer, and so following the definition of the three-way interaction the incidents cannot be considered as such.

For example, in the following incident, RU 1 are crossing the intersection, and oncoming RU 2, who is also intending to cross the intersection, cannot see RU 1 because RU 3 is blocking visual contact. RU 1 and 2 meet and RU 2 waits for RU 1 to finish their maneuver before continuing.

Figure 47: View Obstruction Incident Example

4.4. Method Expansion

While closely studying an intersection in central Athens, a variety of interaction patterns were extracted. Some of them follow the proposed model, while others were eliminated due to not fitting the model's parameters.

While the core of the proposed methodology stays the same, many variables can change, in order to produce more interaction patterns and get a better understanding of the interactive behavior of road users. The variable can either be the environment, or the rules and assumptions regarding the data gathering and which type of interactions are of interest.

Findings of this study can also be combined with data gathered from actual road users. Using eye tracking technology or simulation methods to gain deeper knowledge of real-life incidents can affect the further development of autonomous driving.

4.4.1. New Interaction Patterns

New Interaction Patterns can be identified and recorded by expanding the study. For example, an Interaction Pattern that is not discussed in this study, is the overtaking maneuver.

Overtaking a lead vehicle against an oncoming one in a two lane highway, is a highly complex task that is affected both by (i) the overtaking driver's initial judgment (i.e., prior to overtaking initiation) about whether there is sufficient time to complete a driving maneuver before colliding with an oncoming vehicle or the vehicle being overtaken (Gray and Regan, 2005; Hills, 1980), and (ii) the dynamic nature of the hazards during the overtaking (e.g., sudden appearance of a new oncoming car), leading to some modifications or even to a drastic change of the initial maneuvering plan (Clarke et al., 1998, 1999). [13]

This interaction can involve multiple road users, and usually takes place in avenues or highways. In our particular urban setting, overtaking maneuver is usually performed by motorists. It could not be examined in this study as a three-way interaction, as there was no incident of multiple RU interaction that occurred.

It is apparent that to identify new interaction patterns, change in variables is very important. The study parameters can vary in terms of:

1) Road Type
   As explained above, an interaction pattern that wasn't identified in this study's urban environment can easily be observed in a setting such as a highway. A change in road type or environment is important to the expansion of the current study. Such an example can be seen in figure 48 below. [14]

2) Road Characteristics
   Besides the type of road that an interaction may take place, it is also important to note the specific road characteristics. Road signs, parked vehicles, crosswalks, traffic lights, potholes and other natural potholes, these are parameters that consist a road and can affect the type of interactions taking place, or the frequency of them.

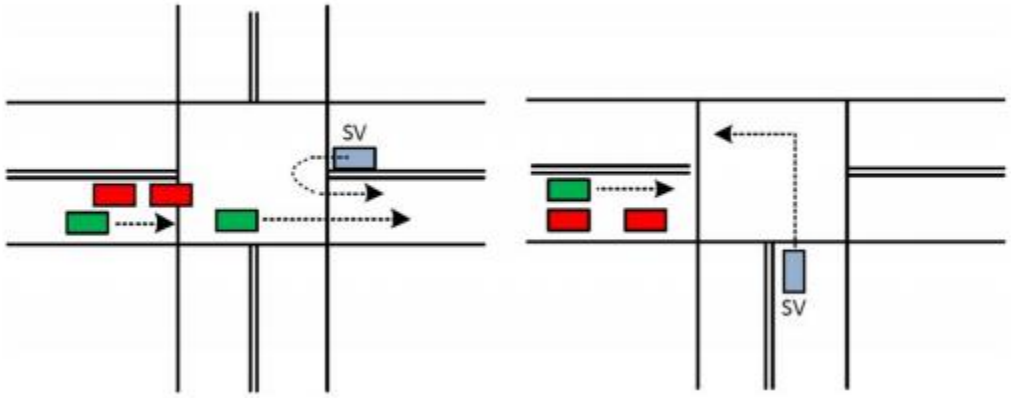


Figure 48: Interactions that may occur in a two-laned intersection

4.4.2. Technological Integration

Observing traffic videos is one way to study road incidents, but there are a more ways. The use of survey forms, human field observations at a target location, and user interviews have been extensively used in the transportation field. More contemporary techniques leverage intelligent transportation systems (ITS). Instrumented vehicles, simulation environment and diver simulators have been very popular in human driving studies due to their ability to setup and examine a scenario precisely. Instrumented vehicles are typically the vehicles fitted with different type of sensors such as cameras, GPS and LiDAR to collect comprehensive time series information on the behavior of a test driver or adjacent vehicles. [7]

By involving one or more of these methods in analysis, further concepts can be explored, such as the critical road user of the incident, i.e., the road user whose actions are mostly responsible (critical) for the incident to materialize. Other useful data that can be measured are causes of incident, the awareness of the involved road users, or the "cost" that a road user has to pay because of his involvement.

Through RADAR or LiDAR technology and advanced algorithms, AVs can navigate themselves by recognizing drivable paths, road signs and traffic lights, vehicles, obstacles, driving hazards and other surrounding elements. For example, in the following screenshot of videos released by Tesla, it can be seen through an interface the number of indicators and how Autonomous Driving has evolved to the point that it can include a heavy amount of data in its decision making. In that instant alone, the vehicle is able to calculate moving and parked vehicles, distances, road path, stopping points, traffic lights, road condition, and others.

The basis of this study is useful in itself, if it can be integrated in current AV technology and how the vehicle perceives its environment. What is interesting to point out through the Tesla footage, is that there are no apparent social criteria taken into account, and therefore no appropriate indications given to the self-driving vehicle. By using the patterns found by this or further study, prediction models and algorithms can be developed, thus assisting autonomous driving. By probability-based models, algorithms can interpret other vehicles' movements and predict that a certain interaction is going to take place. The

probabilities themselves can be extracted by closely examining interaction patterns and incident data, as was done in this study.

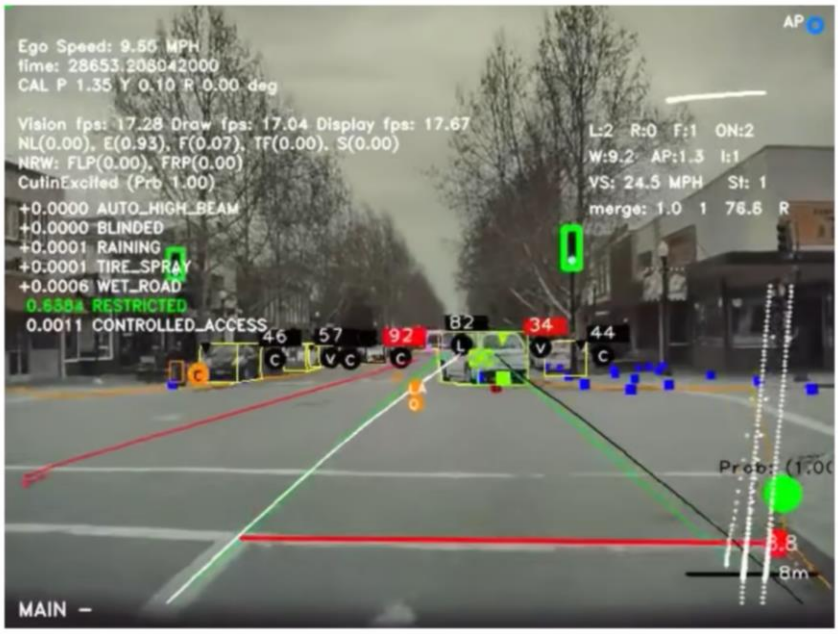


Figure 49: Screenshot of Tesla Autopilot Calculations

4.4.3. Expanding Rules and Assumptions

Manipulating the rules of this model allows us to gather more incidents, or narrow down the incidents of interest. The approach on which interactions are of interest can either be loose or strict.

As was stated in chapter 2.2.2, the incidents examined through this study meet the following criteria:

i. Traffic code is loosely followed, but not outright violated
ii. Road Users are interacting with each other according to Multiple Road User Interaction definition
iii. Number of Road Users is 3 or greater (RU ≥ 3)
iv. Road Users are active, in the sense that they are actively trying to perform a maneuver and are not for example “stuck in traffic”

Research on occurring road incidents and road user interactions can be conducted with less of those criteria, if the aim is to study incidents in a more spherical way. For example, interactions between two road users could also be studied and categorized in a similar way, and Traffic Code can be completely disregarded. In that way the gathered incidents can be more diverse, while more data and observations can be extracted.

Going the opposite directions, new criteria can be added to those mentioned, as to focus on a specific incident and interaction types. Furthermore, incidents and interactions can be narrowed down by filtering the incident data, such as road user type, position, number, etc.

5. Conclusion

In this study we took a look at current AV research and focused on a challenge it faces, the integration of social background into AV design. We also proposed a method of studying 3-way interactions between different types of road users in an urban intersection, through video observation. Furthermore, a deeper look into the structure of the proposed interaction patterns was taken and, finally, we discussed ways of expanding the current method and applying it in different settings using more tools for data gathering.

The proposed method has potential to be used in two areas of AV development:

1) Prediction Algorithms: In this kind of algorithms, a ballistic object is identified, and several data regarding the object are gathered (type, velocity, distance, probability of movement, direction of movement). By studying interaction patterns of past incidents, we can contribute to creating stronger probabilities of movement in certain occurring scenarios.

2) By understanding human behavior on the road and how road users perceive their environment and act, we can understand what is expected of a self-driving vehicle from other road users. AV behavior and communication with human road users has been a matter of discussion by many researchers. If we can understand what kind of interactions is a road user expecting to have with other road users, then we are closer to seamless AV integration on the road.

Nevertheless, for this method to be useful in algorithmic structure and AV design, a lot more work is due. More video footage, different road settings (highways, roundabouts), different road parameters (traffic lights, lanes), more road user types, all those can contribute to forming new interaction patterns which, through use of new technology, can be understood more deeply and configured as to be used in algorithmic structures.

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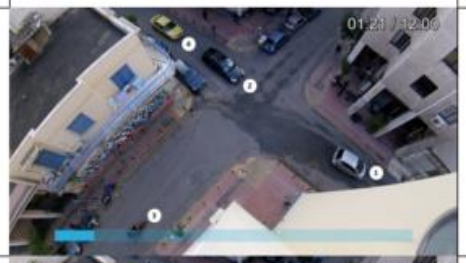
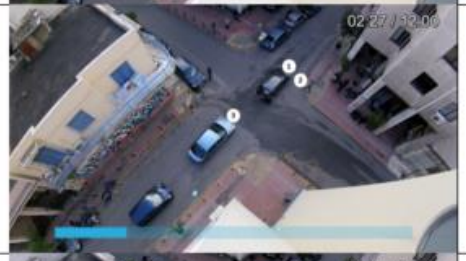
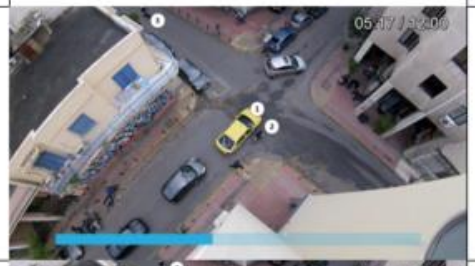
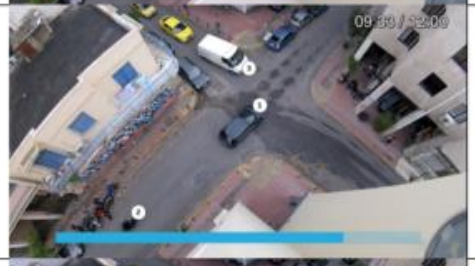
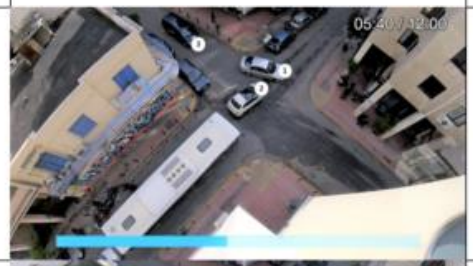
Appendix

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
1		4	C1	C2	M3	C4	–	–	C1 finds space to turn and go in front of C2. That maneuver causes C2 and C4 to slow down. C2 continues his course while M3 exploits the space between C2 and C4 to go through.	EXPLOITING	–	–	–
2		4	P1	P2	M3	M4	–	–	P1 crosses the road as soon as it clears. P2 follows P1's lead and uses him as a "mask". Soon after M3 and M4 appear and continue their route while pedestrians have completed their crossing maneuvers.	MASKING	–	–	–
3		3	C1	P2	C3	–	–	–	P2 takes advantage of the line's low speed to cross the road between C1 and C3.	EXPLOITING	–	–	–
4		5	M1	M2	P3	–	–	–	M2 slows down so he can gain awareness for involved RUs. M1 exploits the created space and crosses the intersection. M2 follows and P3 cross the road as soon as it clears.	EXPLOITING	–	–	–

**Data availiable upon request*

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
5		3	C1	BK2	M3	–	–	–	C1 want to cross the intersection. M3 is in safe distance so C1 proceeds with maneuver. BK2 follows on the side of C1 using him as a "mask" to cross the road safely.	MASKING	–	–	–
6		4	C1	M2	P3	BS4	–	–	C1 slows down while approaching the intersection, as there's a conflict of interest with other RUs: M2 wants to overtake, P3 appears to want to cross the road, BS4 wants to cut him off to go in front of him. In the end C1 proceeds cautiously and passes through unhindered.	FAILED BLOCKING	–	–	–
7		3	C1	M2	C3	–	–	–	C3 gives C1 the right of way. C1 crosses the intersection while M2 follows closely using his momentum to cut C3 off.	TAILING	–	–	–
8		3	P1	BS2	C3	–	–	–	C3 notices P1's intention to cross the road and gives the right of way. BS2 takes advantage of that interaction to make a turn.	EXPLOITING	–	–	–

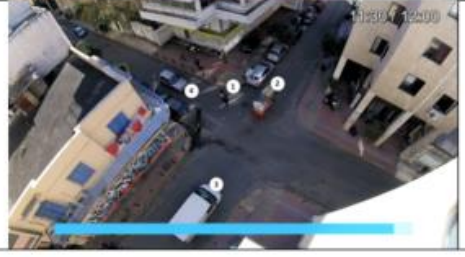
**Data availiable upon request*

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
9		3	C1	C2	C3	–	–	–	C2 sees C1 and tries to force him to give the right of way. C1 doesn't budge and makes his turn. C2 has to stop in the middle of the intersection, blocking the wat of oncoming C3.	BLOCKING	–	–	–
10		4	M1	P2	M3	P4	–	–	M1 is on the main road and crossing the intersection. M3 has to wait for M1 to pass before crossing, giving P2 the opportunity to cross. When M3 crosses the intersection P2 has has cleared M3's path. Meanwhile P4 is waiting for M1 to complete his maneuvre before crossing the road.	COORDINATING	–	–	–
11		4	P1	M2	M3	P4	–	–	P1 crosses the road, and does so in time for M2 to turn unobstructed. Meanwhile M3 approaches the intersection passing in front of P4 who has already started crossing the road. While M3 slowly crosses the intersection, P1 and M2 have cleared his path allowing him to complete his maneuver.	COORDINATING	–	–	–
12		3	C1	C2	P3	–	–	–	C1 is on the main road, while C2 wants to cross his path. At the same time P3 makes a gesture towards C1. C1 proceeds cautiously until he's clear. C2 crosses the intersection soon after and P3 holds his position.	FAILED EXPLOITING	–	–	–

**Data availiable upon request*

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
13		4	C1	P2	P3	C4	–	–	P2 wants to cross the road, and does as soon as C1 turns. When P2 almost reaches the sidewalk, P3 makes a late attempt to use P2 as a mask, but is left unprotected in front of oncoming C4, who has to check his speed.	MASKING	–	–	–
14		3	C1	C2	P3	–	–	–	C2 gets blocked by P3 who tries to force his/her way across the road, allowing C1 to turn.	EXPLOITING	–	–	–
15		3	C1	P2	P3	C4	–	–	C1 crosses the intersection and then P2 crosses the road. P3 uses P2 as a "mask" and crosses the road, while C4 is closing in. C4 has to wait both pedestrians to cross the road.	MASKING	BLOCKING	–	–
16		3	C1	C2	C3	–	–	–	C1 slows down and turns. C2 uses the opportunity to turn and cut C3 off.	EXPLOITING	–	–	–

**Data availiable upon request*

Incident Number	Bird's Eye View	Number of Road Users	Type of Road User 1	Type of Road User 2	Type of Road User 3	Type of Road User 4	Type of Road User 5	Type of Road User 6	Incident Description	Interaction Pattern 1	Interaction Pattern 2	Interaction Pattern 3	Interaction Pattern 4
17		3	TR1	C2	C3	–	–	–	C3 stops and lets TR1 cross the intersection. C2 exploits that interaction to turn.	EXPLOITING	–	–	–
18		5	C1	P2	C3	P4	C5	–	P4 and C1 are communicating. After their interaction ends and C1 crosses the intersection, P2 cross the road at the expence of C5. Later C4 appears and takes position ahead of C5 exploiting the previous interactions.	EXPLOITING	EXPLOITING	–	–
19		3	M1	M2	C3	–	–	–	M2, followed by C3, approaches the intersection while keeping a safe enough distance for M1 to tail him.	TAILING	–	–	–
20		4	P1	M2	C3	C4	–	–	P1 cross the intersection with C4 being in a safe distance. M2 uses them as a mask, and C3 tails M2 to cross.	MASKING	TAILING	–	–

**Data availiable upon request*

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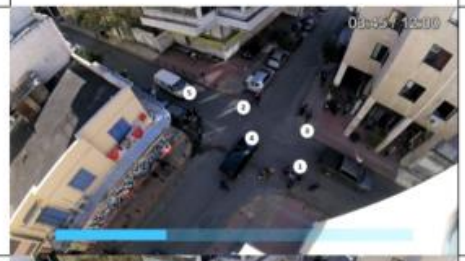
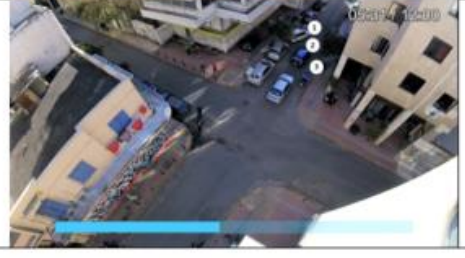
21		6	P1	BK2	P3	C4	C5	–	C5 approaches the intersection and wants to turn, but has to stop because BK2 is blocking his path. BK2 exploits that to cross the intersection. C4 and P3 use BK3 and P1 as a mask to also cross the intersection.	MASKING	MASKING	–	–
22		4	C1	C2	P3	C4	–	–	C1 is turning and C2 stops because there is a pedestrian (P3) in a potentially dangerous position. C4 has to stop because there is no possibility of crossing or overtaking. Finally C1 turns, C2 crosses and P3 exploits C4's halt to cross the intersection.	BLOCKING	EXPLOITING	–	–
23		3	P1	C2	C3	–	–	–	P1 is crossing the road forcing C3 to stop. C2 takes advantage of the interaction to cross the intersection.	EXPLOITING	–	–	–
24			C1	C2	M3	–	–	–	C2 stops because C1 is performing a parking maneuver. M3 tries to overtake C2 from the right side, but gets blocked as C2 is maneuvering to overtake C1.	BLOCKING	–	–	–

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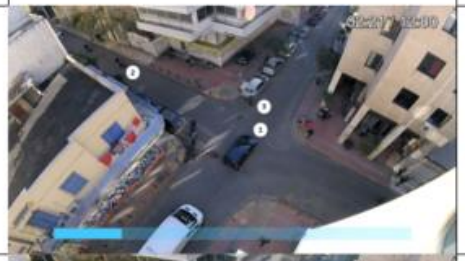
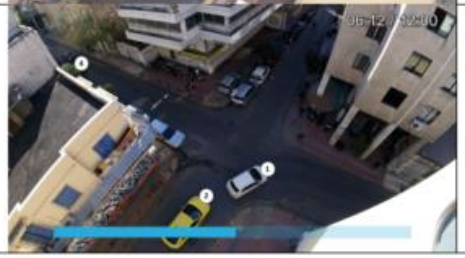
25		3	C1	M2	P3	–	–	–	C1 notices that M2 is at a safe distance for him to cross the intersection. On the other side of the intersection P3's intention is to cross the road. Eventually P3's maneuvre is blocked by the accelerating C1, who tries to avoid a potentially dangerous interaction with M2.	BLOCKING	–	–	–
26		3	C1	M2	M3	–	–	–	M3 is in a safe distance for C1 to turn right. M2 uses C1 as a mask and after turning together they take parallel positions on the road. M3 catches up, tries to overtake but gets blocked by C1 and M2.	MASKING	BLOCKING	–	–
27		4	M1	BK2	C3	M4	–	–	C3 is slowly entering the intersection, and M1 exploits that to cross. At the same time M4 is overtaking C3 from the left but is forced by M1 to allow him first. Finally BK2 is using M1 as a mask to also cross the intersection.	EXPLOITING	MASKING	–	–
28		4	C1	C2	C3	C4	–	–	C1 sees oncoming C4 being at a safe distance for him to turn ahead of C4. C2 makes a late attempt to tail C1, forcing C4 to deccelerate. C3 takes advantage of C4's halt to turn ahead of him.	TAILING	EXPLOITING	–	–

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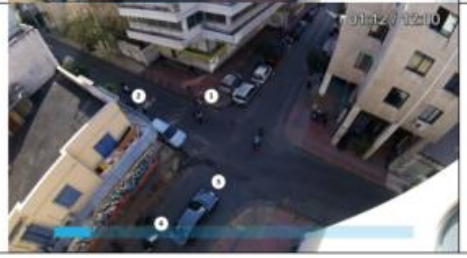
29		5	P1	C2	P3	P4	C5	–	P1 cross the road seeing C5 is at a safe distance, allowing C2 to use P1 as a mask to turn. P3 tail P1 to also cross the road, and C4 uses P4 as a mask to cross the intersection.	MASKING	TAILING	MASKING	–
30		3	C1	M2	M3	–	–	–	C1 crosses the intersection at a slow pace. M3's intention is to overtake C1, but becomes aware of oncoming M2 who uses momentum to overtake. M2 passes first and M3 follows with an overtaking maneuver.	BLOCKING	–	–	–
31		3	M1	P2	C3	–	–	–	C3 approaches the intersection slowly and M1 finds opportunity to cross first. Opposite from M1 pedestrians (P2) cross the road. To prevent an accident M1 maneuvers to avoid them while crossing. Meanwhile the whole interaction blocks C3.	BLOCKING	–	–	–
32		4	P1	M2	C3	M4	–	–	As M2 approaches the intersection P1 are still crossing the road and M2 leans to the right of the road to avoid them. C3 is aware of both M2 and P1, but oncoming M4 is not. M2 enters the intersection, and notices M4 who is not slowing down. M1 makes use of the horn to avoid a potentially dangerous situation.	FAILED MASKING	FAILED EXPLOITING	–	–

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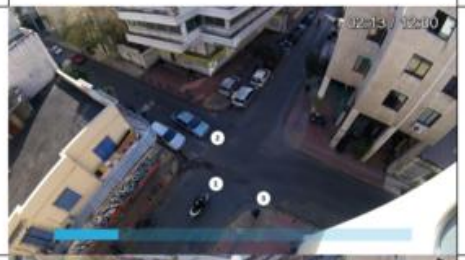
33		3	M1	C2	P3	–	–	–	C2 stops before entering the intersection, allowing M1 to cross first. P3 attempts to also cross, but C2 accelerates and forces his way through.	FAILED MASKING	–	–	–
34		3	C1	M2	P3	–	–	–	P3 is walking in the middle of the road as C1 closes in on him. Oncoming M2 tries to overtake C1 who is moving slowly, but C1 leans to the left of the road in order to overtake P3. As a result M2 reduces speed and follows behind C1.	BLOCKING	–	–	–
35		3	P1	M2	M3	–	–	–	P1 is walking on the side of the road ahead of M3, who is stopped. At the moment that M2 crosses the intersection, P1 is crossing the road. By the time M2 overtakes M3, P3 has crossed the road and M2 continues his course.	COORDINATING	–	–	–
36		4	M1	C2	C3	C4	–	–	M1 approaches the intersection intenting to turn left. C2 is slowly entering the intersection with intent to follow M1. After the latter turns, C2 is stopped in the middle of the intersection blocking oncoming C3, who has to stop. C2 crosses the intersection and C4 exploits C3's halt to turn right	BLOCKING	EXPLOITING	EXPLOITING	–

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37		4	P1	M2	P3	C4	–	–	M1 wants to cross the road but is waiting C4 to pass through. C4 gives the right of way and P1 crosses, with M2 using him as a mask to also cross. P3 exploits the created situation to also cross the road.	MASKING	EXPLOITING	–	–
38		3	C1	C2	M3	–	–	–	C1 is reversing towards the main road cutting off M3 and providing C2 the chance to cross the intersection.	MASKING	–	–	–
39		3	C1	C2	P3	–	–	–	C1 is turning allowing C2 to also turn. P3 uses their maneuvers to start crossing the road.	COORDINATING	–	–	–
40		4	M1	M2	C3	M4	–	–	M2 follows M1 closely waiting for an opportunity to overtake him. Eventually M1 turns left and M2 passes through from the right. At that moment C3 and M4 are slowly entering the intersection trying to cross, so M2 makes use of the horn to go first.	FAILED EXPLOITING	–	–	–

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41		4	M1	BS2	M3	C4	–	–	C4 is halted in front of the intersection. M1 overtakes from the left but BS2 has already started his maneuver to turn. M3 is also trying to exploit the situation to cross the intersection, but he has limited view of M1. Eventually M1 has to wait	EXPLOITING	EXPLOITING	–	–
42		4	C1	P2	C3	C4	–	–	C4 slows down before entering the intersection, giving C1 the opportunity to cross it. P2 use C1 as a mask to cross the road and C3 tails C1 to cross the intersection.	MASKING	TAILING	–	–
43		3	TR1	M2	C3	–	–	–	TR1 stops before crossing the intersection, and M2 waits by him to tail him. C3 is at a safe distance, so TR1 crosses followed by M2.	TAILING	–	–	–
44		3	C1	M2	C3	–	–	–	C1 crosses the intersection with C3 being at a safe distance. M2 uses C1 as a mask to also cross.	MASKING	–	–	–

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45		3	P1	C2	C3	–	–	–	C2 is at a safe distance for C3 to turn right, but P1 crosses the road blocking C3's maneuver. After P2 crosses, C2 is too close to the intersection and C3 misses the opportunity to turn ahead of him.	BLOCKING	–	–	–
46		3	C1	M2	C3	–	–	–	M2 is approaching the intersection, while C3 is behind him unable to overtake. C1 exploits the low speed of the two road users to cross the intersection	EXPLOITING	–	–	–
47		6	M1	C2	C3	C4	P5	C6	M1 is behind M5 and C6, and decides to maneuvre in order to overtkae them both. Meanwhile C2 and C3 find time and space to turn and cross respectively. After M1 overtakes, M5 stops on the edge of the intersection, forcing C6 to also stop. C4 exploits stopped RUs to turn.	EXPLOITING	EXPLOITING	EXPLOITING	–
48		6	C1	C2	M3	P4	C5	M6	C1 is turning, forcing C4 and C5 to stop. C2 and M3 take advantage to cross the intersection. Oncoming M6 is blocked by stopped M4 and C5.	EXPLOITING	EXPLOITING	BLOCKING	–

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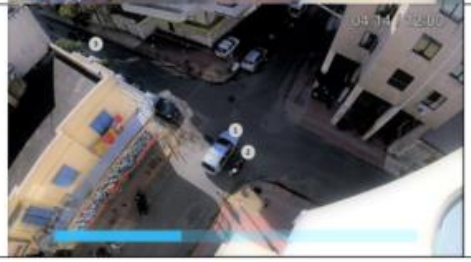
49		3	C1	C2	C3	–	–	–	C1, who is followed by C3, crosses the intersection at low speed. C2 exploits the line's low speed to tail C1 and turn ahead of C3.	TAILING	–	–	–
50		4	C1	M2	P3	C4	–	–	C4 stops before entering the intersection as C1 is blocking his way. M2 takes advantage of created space to cross the intersection. After M2 has crossed traffic has cleared and C1 moves off and C4 slowly enters the intersection. P3 exploit C4's low speed to cross the road.	EXPLOITING	EXPLOITING	–	–
51		3	C1	C2	C3	–	–	–	C1, who is followed by C3, crosses the intersection at low speed. C2 exploits the line's low speed to tail C1 and turn ahead of C3.	TAILING	–	–	–
52		3	C1	M2	C3	–	–	–	C3 is at safe distance for C1 to cross the intersection. C1 crosses with M2 by his side using him as a mask.	MASKING	–	–	–

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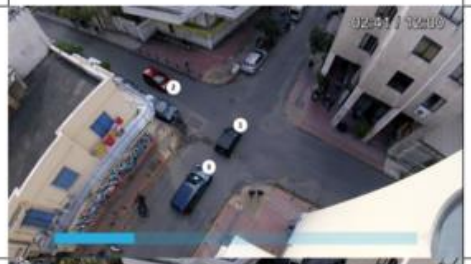
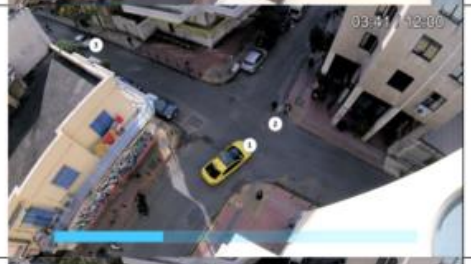
53		3	C1	C2	C3	–	–	–	C1 accelerates to cross the intersection. C2 is close and reduces speed, but doesn't let C3 tail C1 and continues his course.	FAILED TAILING	–	–	–
54		3	C1	P2	C3	–	–	–	C3 is at a safe distance for C1 to turn ahead of him. C1 turns and P2 exploit the fact that C3 has to reduce speed to cross the road.	EXPLOITING	–	–	–
55		5	P1	C2	C3	C4	P5	–	C2 is at a safe distance for P1 to cross the road. C4 also wants to exploit C2's distance from the intersection to turn ahead of him, but gets blocked by crossing P1. P5 also miss the chance to take advantage of interactions to cross the road.	FAILED EXPLOITING	FAILED EXPLOITING	–	–
56		3	C1	M2	C3	–	–	–	C1 is entering the intersection while M2 and C3 are closing in. C1 slowly crosses the intersection, forcing M2 to perform an evading maneuver. C3 slows down as he's being blocked by C1 in front of him and M2 on his right.	BLOCKING	–	–	–

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57		3	M1	P2	BS3	–	–	–	P2 takes advantage of halted traffic to cross the road, while motorists M1 and M2 overtake from the right side of traffic. P2 and M1 meet halfway through P2's manuever, and M1 goes through first, while M2 tails him.	TAILING	–	–	–
58		3	P1	M2	C3	–	–	–	M2 intends to turn left. C3 is halted in the middle of the intersection leaving M2 little space to move through. Oncoming P1, who cross the intersection diagonally, block M2's path.	BLOCKING	–	–	–
59		3	P1	M2	BS3	–	–	–	BS3 is stuck in traffic while M2 is on course to overtake him from the right side. P1 enter the intersection and cross diagonally, since traffic is stopped. Eventually P1 cross first and M2 has to wait for them.	BLOCKING	–	–	–
60		4	C1	M2	M3	M4	–	–	Motorcade in the main road is stopped due to traffic. C1 exploits the space in the middle of the intersection to cross. M2 and M3 try to tail C1, meeting oncoming M4, who lets them complete their maneuver.	TAILING	TAILING	–	–

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61		3	C1	M2	C3	–	–	–	C3 decides to alter his route. C1 turning left and M2 crossing the intersection block his maneuver.	BLOCKING	–	–	–
62		6	M1	C2	C3	P4	M5	C6	C6 is approaching the intersection with M5 behind him. M1 finds the opprtunity to cross the intersection before them, and C2 tails M1 to also cross. C6 stops as there is traffic ahead of the intersection, and C3 takes advantage to cross, forcing M5 to reduce speed. At the same time P4 uses C3 as a mask to cross the road, but C3 is obstructing visual contact between P4 and M5. P4 completes his maneuver before M5 can reach him.	TAILING	EXPLOITING	MASKING	BLOCKING
63		4	C1	C2	M3	C4	–	–	C1 uses the created space to turn right and get ahead of C2. C2 closes in and stops in the middle of the intersection, blocking M3 and C4 who both intent to cross the intersection. Finally both crossing RUs find space to complete their maneuver.	BLOCKING	BLOCKING	–	–
64		3	M1	P2	C3	–	–	–	C3 is stopped in the middle of the intersection. P2 cross the intersection diagonally, while M1 crosses the intersection from the opposite side. C3 is obstructing visual contact between P2 and M1 at the start of their maneuvers.	FAILED BLOCKING	–	–	–

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65		5	C1	C2	C3	M4	–	–	C4 and C5 are stopped on either side of the intersection due to traffic. C1 uses the space between to cross and C2 and C3 tail C1.	TAILING	TAILING	–	–
66		5	M1	P2	M3	P4	C5	–	P2 is crossing the road and M1 is overtaking stopped cars. C5 is obstructing visual contact between them. Same incident takes place with P4 and M3 involved with C5 again as the visual obstructor.	FAILED TAILING	–	–	–
67		4	M1	M2	M3	C4	–	–	C4 tries to tail vehicle ahead of him but gets blocked by oncoming motorists M1 and M2. M3 takes advantage of the blocking incident to overtake C4.	BLOCKING	EXPLOITING	–	–
68		3	C1	C2	P3	–	–	–	C1 crosses intersection while C2 approaches. P3 tries to use C1 as a mask but C1 is too fast for him. C2 catches up to P3 and the latter loses the opportunity to cross the road first time.	FAILED MASKING	–	–	–
69		4	P1	C2	P3	C4	–	–	C2 reaches the intersection intenting to turn left. Crossing P1 blocks his path, and C2 exploits C4's halt to cross the intersection ahead of C4. After C2 has crossed P3 also exploit C4's halt to cross the road.	EXPLOITING	EXPLOITING	–	–

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