



Agent-based model for the rescheduling of Individual and collective daily activities under uncertainties

Hui Zhao

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DE L'ÉTABLISSEMENT UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ
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Sciences Pour l'Ingénieur et Microtechniques

Doctorat d'Informatique

par

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**Agent-based Model for the Rescheduling of Individual and Collective Daily
Activities under Uncertainties**

Thèse présentée et soutenue à Belfort, le 3 Juillet 2020

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“To travel hopefully is a better than to arrive, and the true success is to labor.”

—Robert Louis Stevenson

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CONTENTS

I	Acknowledgements	iii
II	Context and Problem	1
1	General Introduction	3
1.1	Context and Motivation	3
1.2	General problem	4
1.3	Thesis Goals and Contribution	5
1.3.1	Individual activity rescheduling	6
1.3.2	Joint Trip Renegotiating	7
1.4	Thesis Structure	7
2	Context and Definitions	11
2.1	Introduction	11
2.2	Transport System	11
2.3	Activity Schedule	13
2.4	Activity rescheduling	15
2.4.1	Individual activity rescheduling problem	16
2.4.2	Joint trip renegotiating	17
2.5	Simulation and Multi-agent System	19
2.5.1	Fundamentals of Simulation	19
2.5.2	Multi-agent System	21
2.5.2.1	Definition of Agent	21
2.5.2.2	Definition of Multi-agent System	22
2.6	Agent-based Simulation	23

2.6.1	General Principles	23
2.6.2	Agent Behavior	25
2.6.3	Agent Environment	26
2.6.4	Interaction	26
2.7	Conclusion	28
3	Individual Activity Rescheduling	33
3.1	Introduction	33
3.2	Factors affect individual activity rescheduling	33
3.2.1	Static factors affecting the individual activity rescheduling	34
3.2.2	Dynamic factors affecting the individual activity rescheduling	35
3.3	Individual activity rescheduling choices	38
3.3.1	Time Adjustment	38
3.3.2	Route change	39
3.3.3	Location change	40
3.3.4	Summary of the Alternative Choices	41
3.4	Optimization Method for Individual Choices	42
3.5	Individual Activity Rescheduling Models	44
3.5.1	Agent-based Models of Individual Activity Rescheduling	44
3.5.2	Summary of Agent-based Individual Activity Rescheduling Models	46
3.6	Conclusion	48
4	Joint Trip Renegotiation	51
4.1	Introduction	51
4.2	Factors affect joint trip renegotiation	52
4.2.1	Static factors affecting joint trip renegotiation	52
4.2.2	Dynamic factor affecting joint trip renegotiation	54
4.3	Renegotiation Strategy	56
4.3.1	Strategy classification	56
4.3.2	Heuristic approach in the joint trip negotiation/renegotiation	58

4.4	Agent-based Models for Negotiation	59
4.4.1	Agent-based Multi-individual Negotiation	60
4.4.2	Agent-based Multi-team Negotiation	60
4.5	Agent-based models of the joint trip negotiation	63
4.5.1	Agent-based models of direct negotiation for the joint trip	63
4.5.2	Agent-based models of indirect negotiation for the joint trip	64
4.6	Conclusion	65
III	Individual and Collective Activity Rescheduling	67
5	Research Methodology and Contributions	69
5.1	Introduction	69
5.2	Hypothesis Research Questions	70
5.2.1	Individual Activity Rescheduling	71
5.2.1.1	Research Method: Agent-based Approach	71
5.2.1.2	Research Questions for Individual Activity Rescheduling	72
5.2.2	Joint Trip Renegotiating	74
5.2.2.1	Research Method: agent-based approach	74
5.2.2.2	Research Questions for Joint Trip Renegotiating	75
5.3	Contributions	76
6	Agent-based Rescheduling Model of Individual Activities	79
6.1	Introduction	79
6.2	Unexpected Events for Individual Activity Rescheduling	80
6.2.1	Event classification	80
6.2.2	Classification of unexpected events for individual activity rescheduling	81
6.2.2.1	External events	82
6.2.2.2	Internal event	83
6.3	Generation of Alternative Choices	84
6.3.1	Time Adjustment Module	85

6.3.2	Route change module	86
6.3.3	Location change module	87
6.3.4	Activity Drop Module	87
6.3.5	Customized alternative choice set	88
6.4	Individual Activity Rescheduling Model	89
6.4.1	Generation of a Temporary Schedule Set	92
6.4.2	Best Choice Selection	93
6.4.2.1	Optimization function	93
6.4.2.2	Penalty function	93
6.4.2.3	Schedule Probability	95
6.5	Conclusion	97
7	Model for the Renegotiation of the Joint Trips	101
7.1	Introduction	101
7.2	Definition of a Joint Trip Renegotiation	102
7.3	Joint Trip Renegotiation Problem	104
7.3.1	Unexpected events for joint trip renegotiation	105
7.3.2	Alternative choices generation	105
7.3.2.1	Route change module without location changing	106
7.3.2.2	Route change module with location changing	107
7.4	The Joint Trip Renegotiation Model	109
7.4.1	Agent-based Model for the Joint Trip Renegotiation	109
7.4.2	The Optimal Offer	113
7.4.3	Criteria for Evaluating an Offer	114
7.4.4	The Count offer (most suitable proposal)	115
7.5	Conclusion	116
8	Experimentation and Validation of the Rescheduling Models	119
8.1	Introduction	119
8.2	Individual activity rescheduling	119

8.2.1	Presentation of the application	119
8.2.2	Implementation of the application	121
8.2.2.1	Congestion Event	122
8.2.2.2	Activity duration event	123
8.2.2.3	Location event	124
8.2.3	Analysis of experimental results	126
8.3	Joint trip renegotiation	128
8.3.1	Presentation and implementation of the application	128
8.3.2	Analysis of experimental results	131
8.4	Conclusion	131
IV	Conclusion	133
9	General Conclusion	135
9.1	Summary of the contributions	135
9.2	Perspectives	137
9.2.1	Individual activity rescheduling considering sequence change	137
9.2.2	Joint trip renegotiating among more participants	137
9.2.3	Multiple unexpected events at a time	137
9.2.4	Deployment and validation with real data	138
V	Appendix	163
A	Data of road network	165
A.1	Road data in Individual activity rescheduling experiment	165
A.2	Road data in Joint trip renegotiating experiment	166
B	Core Resource code	169
C	Publications of the Author	175
C.1	Publications that are related to this PhD thesis	175

C.2 Other Contributions	176
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CONTEXT AND PROBLEM

GENERAL INTRODUCTION

1.1/ CONTEXT AND MOTIVATION

With the emergence of smartphones and location-based services, individual mobility prediction has become a critical enabler for a wide range of applications, like location-based advertising, early warning systems, and citywide traffic planning. A number of techniques have been proposed to either conduct spatio-temporal mobility prediction or forecast the next-place (Lv et al., 2016). Travel demand is derived from the demand for activities, in order to analyze the individual's mobility, the studies of daily activity scheduling have attracted researchers' attention. And, an individual's daily activity scheduling consists of both activity decisions and travel decisions (Bowman, 1998). The focus of the activity scheduling models is on predicting the out-of-home activities and the associated travel that required to execute these activities. That is, the primary focus is on predicting the activity attributes. And then, trips constitute the emergent outcome of the need to travel from one activity location to another. Indeed, trips can themselves be thought of as another peculiar of activity (Miller, 2019). Activity scheduling models must use microsimulation, since it is impossible to develop a daily (or another period) activity pattern for individuals in any other way, and the notion of somehow modelling activity patterns in some sort of aggregate, matrix-based way is simply inconceivable (Miller, 2019). There are many famous microsimulation activity scheduling models, such as ALBATROSS (Arentze and Timmermans, 2004), FEATHERS (Bellemans et al., 2010), MATSIM (Balmer et al., 2006), or TASHA (Roorda et al., 2008).

People's desire or the need to perform certain activities during the day drives the activity-scheduling decisions of each person. The need to deal with the daily plans that come with these decisions is ever-growing. Modelling these changes inside the daily plan has become more important in recent years with constant improvements in the transportation systems (Balać and Axhausen, 2016). Daily activity rescheduling has also become a key focus of travel behavior and decision-making research in the context of travel de-

mand prediction. Daily activity rescheduling is viewed as a key behavioral mechanism whereby individuals adapt their activities and travels in response to uncertainties (unexpected events), like congestion, mode change, or time conflicts. Activity rescheduling often involves a variety of decisions made over time and space and across individuals, affecting the timing, location, and interpersonal nature of observed human activities and travel (Clark and Doherty, 2008). Understanding the rescheduling process is considered as an important problem in the context of traffic management (Habib et al., 2013; Nijland et al., 2009). It is also important for evaluating adequately the impact of transportation policy measures toward reducing car use in the urban areas (Chen and Chao, 2011), or assisting urban and transportation planning to react to unexpected events (Chen et al., 2004), to cite few. The success of policies such as tolling, congestion pricing, and travel demand management depends on how people might adjust their daily activity and travel patterns to the enforced changes in their daily lives (Axhausen and Gärling, 1992).

In this thesis, we would like to establish [models to simulate the individual's decision-making process for daily activity rescheduling under unexpected events](#) during the execution of the planned activity schedule. In the following section, the general problem related to this context is stated.

1.2/ GENERAL PROBLEM

Daily activity rescheduling refers to an individual revising the original schedule in case of unexpected events. Before dealing with the activity rescheduling problem, there are several research questions needed to be considered:

- RQ1:** What is a daily activity rescheduling problem?
- RQ2:** What are the unexpected events, and how they affect the rescheduling process?
- RQ3:** Except for the unexpected events, what else affects the activity rescheduling decisions?
- RQ4:** Under unexpected event happening, what kind of choices the individual is faced to?
- RQ5:** Based on these alternative choices, how to choose the (quasi-)optimal one?
- RQ6:** How to establish a model to simulate the daily activity rescheduling decision process?

Within the domain of transportation science, and more specifically travel modelling and simulation, the agent-based modelling and simulation approaches have proven that they

are able to capture the necessary details at the microscopic level (entity behavior level) as well as to reproduce relevant, realistic phenomena at mesoscopic levels (Galland et al., 2014). These approaches are based on the definition of autonomous entities, named agents. They may represent drivers, vehicles, or other traffic participants. Combined with the questions above, this thesis wants to solve the two following general problems:

GENERAL PROBLEM 1

What is the agent-based model of the individual's decision-making process for the dynamic rescheduling of his/her daily activities under uncertain events from the environment?

GENERAL PROBLEM 2

How to simulate the agent-based model that is an answer to the first problem above?

1.3/ THESIS GOALS AND CONTRIBUTION

The main focus of this thesis is to explore the **travel behavior** of individuals. In order to solve the two problems above, the daily activity rescheduling process is decomposed into the individual activity rescheduling and joint trip renegotiating subprocesses. For each of these subprocesses, solo and joint trips/activities may be considered.

A trip/activity is considered to be solo if it is executed by a single person. If in a given schedule, there are all the solo activities/trips, under unexpected event disturbances, the activity rescheduling is made by the individual himself, without any interaction with another individual. This thesis regards it as **individual activity rescheduling**.

If two or more persons are participating in a trip/activity, it is considered to be joint. If in a schedule, there are one or more joint trips, then the participants in the joint trip need to make the joint decision on the trip's rescheduling by renegotiating. This thesis regards this situation as **joint trip renegotiating**. The problem of renegotiation of joint activities is outside the scope of this thesis, while the one for joint trips is included.

The unexpected events may affect a solo trip/activity or a joint trip. Under this condition, the thesis wants to reach the goal of:

THESIS GOAL

Establish an agent-based model to simulate the individual decision-making process under uncertainties, from the aspects of individual activity rescheduling and joint trip renegotiating.

Based on this thesis' general goal, and also the problem it wants to solve, this thesis mostly contributes to:

GENERAL CONTRIBUTION

Definition of the unexpected events, and establishment of models in order to simulate the driver's behavior under these unexpected events, from the view of individual activity rescheduling and joint trip renegotiating.

The detailed contributions of the thesis are briefly described into the two following sub-sections.

1.3.1/ INDIVIDUAL ACTIVITY RESCHEDULING

For individual activity rescheduling problem, the contributions of this thesis are:

- CI1. Classification of unexpected events in the context of individual activity rescheduling:** The disruptions from the real environment, which will affect an activity/trip, are mostly studied by other researches. This thesis classifies unexpected events as external events and internal events.
- CI2. Process for individual activity rescheduling:** The main focus of the proposed model is at exploring the interrelationship between a pair of activities. It is novel compared with the existing rescheduling models. It uses a decision tree to find the effect on the next activity because of the changing of the current activity.
- CI3. Penalty-based method for determining the best choice within the schedule alternatives:** Rather than just maximizing an activity utility, the optimization approach that is proposed in this thesis is based on the determination and the analyze of the differences between the original schedule and the new schedule. For all the alternative schedules, the penalty, which calculates the differences in terms of activity/trip, is used to score each schedule. The schedule with the lowest penalty is considered as the best choice (almost optimal).

CI4. Time change module: The previous researches regard the time of a day as a whole to maximize the schedule utility for this entire period. Since this thesis takes activity type into consideration, and study the change of activity one by one, a new time change module is proposed: by at least finishing the minimal duration of an activity. It adjusts the time attributes for the affected episode (trip-activity pair). The purpose of this module is to minimize the number of changed episodes in the planned schedule.

In this section, the contributions of this thesis to the individual activity rescheduling are briefly explained. In the next section, those related to joint trip renegotiation are provided.

1.3.2/ JOINT TRIP RENEGOTIATING

For the joint trip renegotiating problem, the contributions of this thesis are:

- CC1. A collaborative negotiation model for the adjustment of a joint trip:** The model considers the relationship between agents when providing an offer, and it considers the constraints of alternative places for the agents.
- CC2. Definition and usage of group time pressure:** It puts forward the group time pressure, which is the feeling of time threshold in a group, in the renegotiation process. The renegotiation model combines the group time pressure into the optimization method when making a concession to the agent's opponent.

1.4/ THESIS STRUCTURE

The structure of the thesis is shown in Figure 1.1 and explained into the rest of this section.

Chapter 2: To solve Question RQ1, this thesis firstly explains the daily activity rescheduling problem. According to the number of the person involved in the trip/activity, it classifies the rescheduling problem as a solo trip/activity rescheduling problem and joint trip renegotiating problem. Then, the basic terms in activity schedule, solo trip, and joint trip and the respective constraints are defined. This chapter presents the fundamentals of simulation, multi-agent systems and activity-based models.

Chapters 3 and 4: Before exploring the daily activity rescheduling problem, this thesis analyzes the current works related to it. It explains and discusses the current works related to individual activity rescheduling in Chapter 3 and joint trip renegotiation in Chapter 4. These two chapters explore and provide partial answers to Questions RQ2 to RQ6.

Chapters 5: After explaining the activity rescheduling problem and analyzing the state of the art of the related area, this thesis concludes the current works and proposes to use an agent-oriented modelling approach. Then, this chapter puts forward the models for solving the activity rescheduling problem. For individual activity rescheduling model, this chapter explores the relationship between a pair of connected activities. For joint trip renegotiating model, group time pressure is considered into renegotiation, which means to consider how the individual makes concessions when he feels time pressure during the renegotiation. Each model is detailed in the following two chapters.

Chapter 6: This chapter is dedicated to the individual activity rescheduling model. It explains the unexpected events in the rescheduling process (Question RQ2, Contribution CI1) and proposes a model for computing the alternative choices given to the individual and considering the unexpected events (Question RQ4, Contribution CI4). An agent-based model is established in order to simulate the individual rescheduling process (Question RQ6, Contribution CI2). A new penalty minimization method to obtain the optimal new schedule is also detailed (Question RQ5, Contribution CI3). In addition to the penalty, the proposed optimization method also considers the individual time pressure's effect on the decision (Question RQ3).

Chapter 7: This chapter is related to the joint trip renegotiation model. It analyzes the unexpected events in joint trip execution (Question RQ2) and defines the joint trip renegotiation according to the time period of the unexpected events' happen time. The joint trip renegotiating process (Question RQ6, Contribution CC1), and the participant's alternative choices in joint trip faced with unexpected events are detailed. When an unexpected event happens, except the time tolerance of arrival, the vehicle passenger can choose to drop off at a new location or a place near the planned location. The vehicle driver may have an alternative location as well. During renegotiation, a fitness function is used, which considers both the individual's and his opponent's optimal choices, to generate the count offer to his opponent (Question RQ5). In the fitness function, both of the opponents' incoming offer and group time pressure are considered (Question RQ3, Contribution CC2).

Chapter 8: In this chapter, traffic applications are provided, and their results are analyzed for the solo and joint activity rescheduling models above. For individual activity rescheduling model, experiments are realized and analyzed in order to highlight the different unexpected event's effects on the different types of activities. For joint trip renegotiating model, an example with a passenger and a driver with a joint trip is detailed. This example is discussed along time passing by, the offer changes between each round of renegotiation.

Chapter 9: This chapter gives a general conclusion and the perspectives related to this thesis.

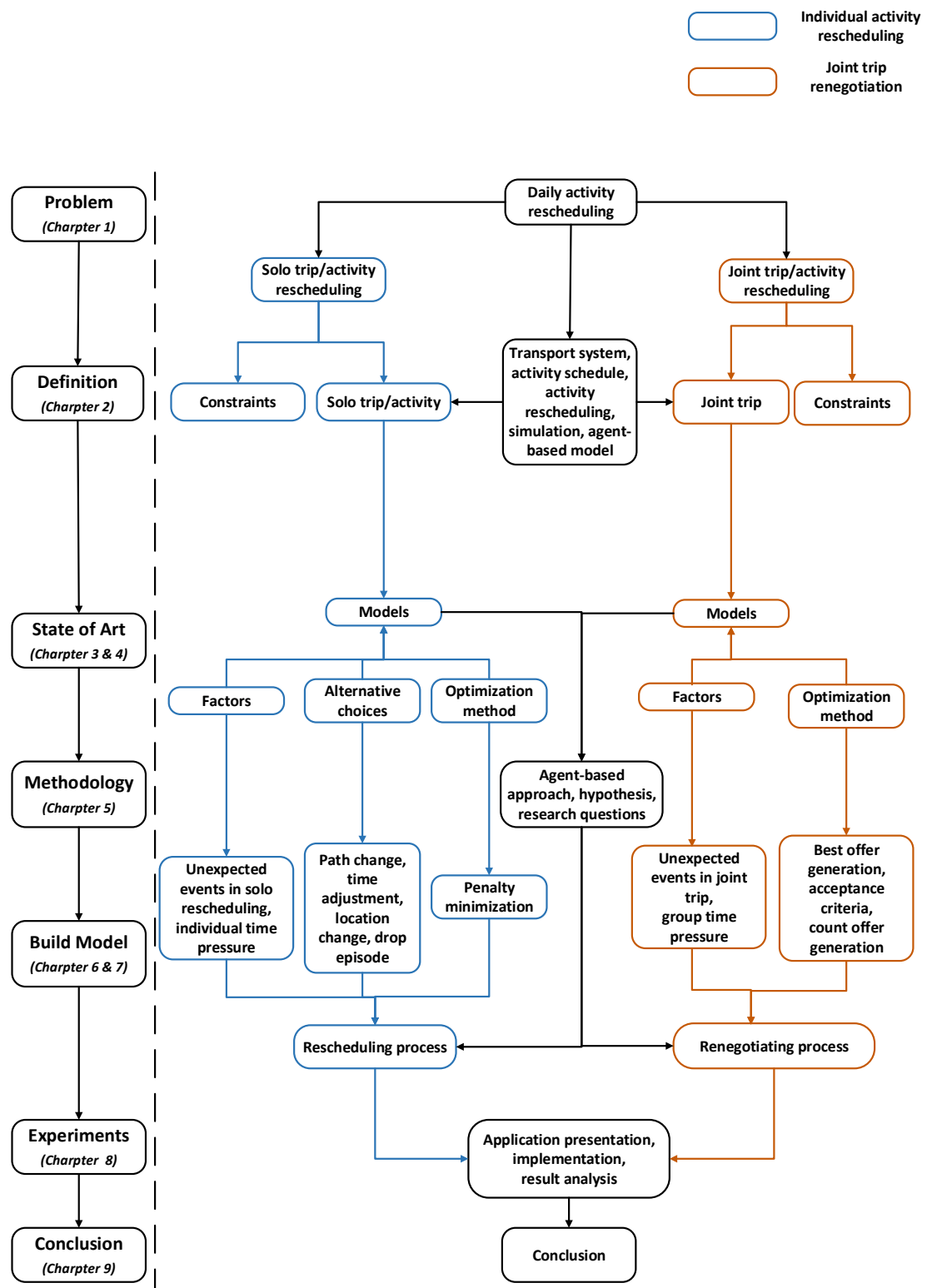


Figure 1.1: Structure of the thesis

CONTEXT AND DEFINITIONS

2.1/ INTRODUCTION

In the general introduction, the two following problems are stated: [General Problem 1](#): “what is the agent-based model of the driver’s decision-making process for the dynamic rescheduling of his/her daily activities under uncertain events from the environment?” and [General Problem 2](#): How to simulate the agent-based model that is an answer to the first problem above?.

In order to solve these general problems, we need to analyze the current works related to the problem. While, before that, it is necessary to define the basic definitions of the terms used in the thesis. We can see that it is significant to define the meanings and concepts related to the activity rescheduling, simulation, and agent-based modelling and simulation.

For activity rescheduling, the transport network is essential to make individual mobility decisions (Figure 2.1). The focus of this thesis is daily activity rescheduling decisions, the medium/long-term mobility decisions are not considered. Therefore, this chapter defines the activity rescheduling problem from the aspects of the transport system, activity schedule and activity rescheduling during the short term. Then, it introduces the fundamentals of simulation, multi-agent system, and agent-based simulation.

2.2/ TRANSPORT SYSTEM

In a transport system, there are mainly four basic elements (Benson and Whitehead, 2013):

- **Mode:** Modes refer to the specific class of transport vehicles that undertakes freight and passenger tasks. Modes are usually classed as road, air, sea, and rail. In some

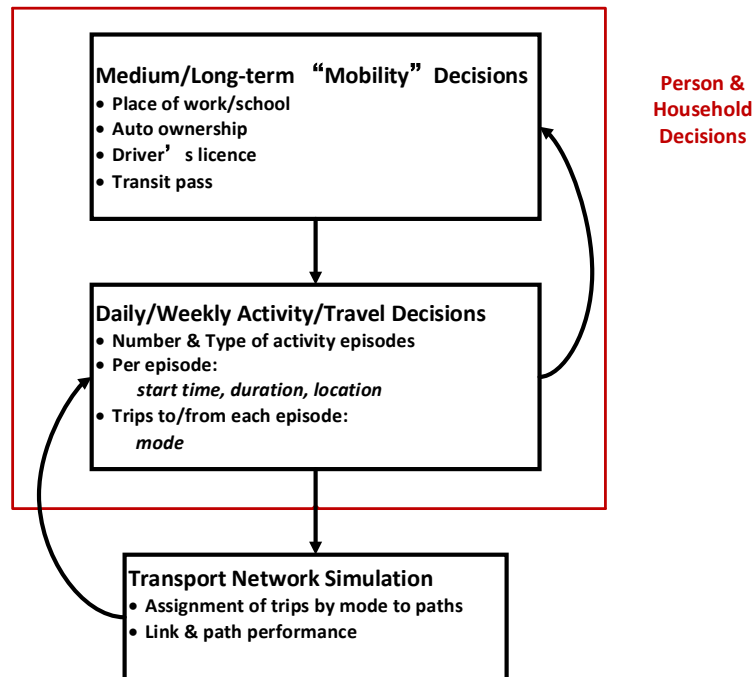


Figure 2.1: Architecture of activity/travel model system(Miller, 2019)

circumstances, road and rail are combined and jointly referred to as surface or land transport.

- **Way:** The term “way” refers to the type of track along which the various classes of transport vehicles travel. Ways include seaways, roadways, airways, and railways. Efficient ways reduce travel times, as well as the cost of travel.
- **Terminal:** In essence, terminals are points of interchange from one mode to another. Air terminals are examples of interchange points between air and road and, in some cases, rail and occasionally sea. In larger destinations, particularly those servicing an international market, airports are an important component of the destination’s transport system.
- **Technology:** Technological change determines modal competitiveness, price structures, speed, and comfort levels, as well as safety.

The focus of this thesis is the travel behavior of the “roadway”, which is involved in the element of “way” in the transport system. And most of the researches use nodes (terminals) and links/segments (the way) to represent a road network (Verbas et al., 2019; Lee et al., 2019).

Definition 1: Road Network

A road network r is composed by a set of nodes N_r that represents the road segments, and the set $P_r \subset N_r \times N_r$ that connects pairs of nodes in N_r . Then $r = \langle N_r, P_r \rangle$.

The travel behavior is to execute a trip on the road network. Knapen et al. (2014) put forward that a trip is characterized by a tuple $\langle \text{origine, destination, start time, duration, mode} \rangle$. In this thesis, we also consider the participants in the trip. Therefore we define a trip as:

Definition 2: Trip

The trip $v \in \mathbb{V}$ is characterized by its origin $o_v \in N_r$, start time $t_{vs} \in \mathbb{R}^+$, its duration $d_v \in \mathbb{R}^+$, its destination $l_v \in N_r$, its transportation mode $m_v \in \mathbb{M}$, the path of the trip $p_v \in \mathbb{P}_r$.

$$v = \langle o_v, t_{vs}, d_v, l_v, m_v, p_v \rangle \quad (2.1)$$

2.3/ ACTIVITY SCHEDULE

This section introduces the definitions of terms in an activity schedule: activity, episode, and schedule.

Aboutaib et al. (2018) define an activity as a quadruplet with activity purpose, location, start time, and location. (Policella et al., 2004) defines an activity as start time, duration, and end time. In this thesis, we also include the participants in the activity and the minimum duration to execute the activity.

Definition 3: Activity

Let an activity $a \in \mathbb{A}$ be defined by its start time $t_{as} \in \mathbb{R}^+$, its end time $t_{ae} \in \mathbb{R}^+$, such that $t_{ae} \geq t_{as}$, its location $l_a \in N_r$, the activity type $h_a \in \mathbb{H}$, the activity duration $d_a = t_{ae} - t_{as}$, and its minimal duration $MinD_a \in \mathbb{N}^+$, such that $MinD_a \leq d_a$.

$$a = \langle t_{as}, t_{ae}, l_a, h_a, MinD_a, d_a \rangle \quad (2.2)$$

Knapen et al. (2014) use episodes to describe an activity schedule. They put forward that a daily activity schedule consists of a sequence of episodes, and an episode is composed of an activity (Definition 3) and a trip (Definition 2) associated to it. The trip in the same episode has the same location as the connected activity. The arrival time of a trip is the start time of the connected activity in the episode. Therefore, the episode and activity schedule are defined by Definition 4 and Definition 5.

Definition 4: Episode

An episode $e \in \mathbb{E}$ consists of a trip $v_e \in \mathbb{V}$ and an activity $a_e \in \mathbb{A}$ such that the destination of v_e is the same as the location of the activity a_e . Therefore, $e = \langle v_e, a_e \rangle$, and $l_{v_e} = l_{a_e}$, $t_{v_s} + d_v = t_{a_s}$.

As mentioned above, an activity schedule consists of a sequence of episodes. Episodes are connected by their location and time. It is to say the end time of an activity is the start time of its next trip, and the location of an activity is the origination of its next trip.

Definition 5: Activity Schedule

Activity schedule $s \in \mathbb{S}$ is a sequence of episodes for a period.

$$s = \langle e_1, e_2 \dots e_n \rangle \text{ such that } n \geq 1 \quad (2.3)$$

In which, $l_{a_i} = o_{v_{i+1}}$, $t_{a_{e_i}} = t_{v_{s_{i+1}}}$, $i \geq 1$

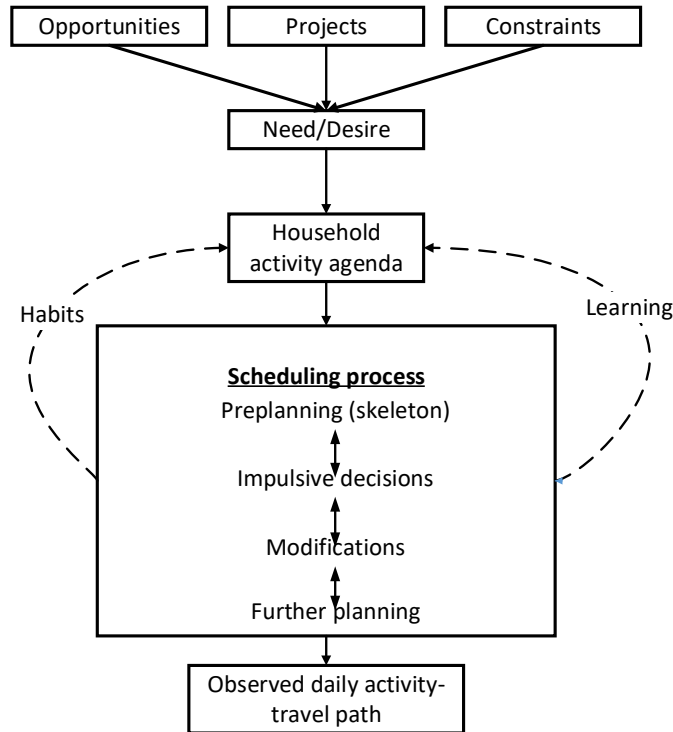


Figure 2.2: A conceptual framework of activity scheduling process (Doherty and Axhausen, 1999)

The activity schedule is obtained from the process of activity scheduling. Doherty and Axhausen (1999) describe the conceptual framework of the activity scheduling process (Figure 2.2). Additionally, Doherty and Miller (2002) define the activity scheduling progress

as a continuous process of planning, adaption, and revision of activities and travel over time, space, and across individuals leading to observed activity-travel patterns.

In this thesis, we define the activity scheduling as:

Definition 6: Activity Scheduling

Activity scheduling is the action to order a set of episodes in order to create a schedule s . In addition to the episodes' sequence, other constraints C are considered for re-ordering, e.g. travel time and vehicle capacity.

$$\begin{aligned} \text{schedule} : \mathcal{PE} \times \mathcal{PC} &\rightarrow \mathbb{S} \\ (E, C) &\mapsto \langle e_1, \dots, e_n \rangle \mid \left(\forall k \in (1; n], \forall a_j \in A, \right. \\ &\quad \left. t_{vs_{k-1}} + d_{v_{k-1}} + d_{a_{k-1}} \leq t_{vs_k}, \forall k \in (1; n] \right) \wedge C \end{aligned} \quad (2.4)$$

where \mathcal{PA} and \mathcal{PC} respectively denote all possible sets (or powersets) of activities and constraints.

2.4/ ACTIVITY RESCHEDULING

After the activity schedule is predicted, and during the execution process of the activity schedule, there may be unexpected events happening to disturb the planned activity schedule. Under this situation, activity rescheduling is triggered. Nijland et al. (2009) describe an example of an activity rescheduling problem: "Assume you intend to conduct activity A today. For the activity, including travel time, you have M minutes. You want to conduct the activity by transport mode T' . Unfortunately, today you have encountered a delay with as a consequence that the available time (for activity and travel) has been reduced to R minutes. After this, you should be back for another activity. What would you do in this situation?" The changed information on the schedule, which triggers the rescheduling process, is considered as uncertainties or unexpected events. In the above example, the unexpected event is the occurrence of a time delay related to a certain activity.

Unexpected events can be defined by a tuple, which consists of the activity/trip that is affected, the event location time (happen time), and the individual's aware time of the event (Rasconi et al., 2010).

Definition 7: Unexpected event

Assume an individual is informed there is an unexpected event at time t , the it will affect trip v_i or activity a_i , the changed information it involved is Δ . The content of Δ depends on the unexpected event, it is explained in detail in Section 6.2 and Section 7.3.1.

$$Event(t) = \langle v_i/a_i, \Delta, t \rangle \quad (2.5)$$

Dobler and Nagel (2016) explain that each within-day replanning action is categorized by two parameters: **the planned elements of the plan** (an activity or a trip) and **the point in time** when the replanned plan element is executed (right now or at a future point in time). If an activity is replanned, several changes are possible. Its start and end time can be adapted, and its location can be changed. It can be dropped, or created from scratch. For a trip, origin and destination, route, mode of transport, and departure time can be replanned. In this thesis, the informed time of the unexpected event is assumed to be the rescheduling time. Moreover, the rescheduling is defined as applying the changed matrix of \mathbb{R} to the planned schedule \mathbb{S} under the constraints of \mathbb{C} .

Definition 8: Activity Rescheduling

Activity rescheduling is the action to update an existing schedule, according to some constraints, and starting to adjust the schedule when unexpected events happen. In Equation 2.6, \mathbb{R} is the matrix attributes changes for uncompleted episodes, both trips and activities. \mathbb{RS} is the new schedule after the rescheduling process. Assume the episode i is affected by an unexpected event.

$$\begin{aligned} reschedule : \mathbb{S} \times \mathcal{PC} \times \mathbb{R} &\rightarrow \mathbb{RS} \\ (E, C, R) &\mapsto \langle e_i, \dots, e_n \rangle \mid \left(\forall k \in (i; n], \forall e_j \in E, \right. \\ &\quad \left. t_{vs_{k-1}} + d_{v_{k-1}} + d_{a_{k-1}} \leq t_{vs_k}, \forall k \in (i; n] \right) \wedge C \wedge R \end{aligned} \quad (2.6)$$

In the context of this thesis, the activity rescheduling problem is decomposed into individual activity rescheduling and joint trip renegotiating. The rest of this section explains them in detail, respectively.

2.4.1/ INDIVIDUAL ACTIVITY RESCHEDULING PROBLEM

For **individual activity rescheduling**, in case of an unexpected event, activity rescheduling takes place in either of the two cases: when there is more time available than originally planned and when there is less time available than originally planned. In the first situation, the individual must decide whether to add an activity, or simply start the next activity ear-

lier, or move activities that are scheduled at a later time earlier. Under the latter situation, the individual must decide whether to delete an existing activity, delay the next activity on the schedule, or modify some activities on schedule. In either case, the decision may perform one of the three possible rescheduling actions, including “adding a new activity”, “deleting an existing an activity”, or “modifying an existing activity” (Chen et al., 2004).

In the individual rescheduling problem, the rescheduling decision is made by the individual, which means there are just solo trips/activities in the schedule. Based on the definition of the trip (Definition 2) and activity (Definition 3), this thesis defines the solo trip/activity as:

Definition 9: Solo trip/activity

Assume the number of participants in a trip or an activity is v_{par}/a_{par} . If $v_{par} = 1$, the trip is a solo trip. And if $a_{par} = 1$, the activity is a solo activity. For a trip/an activity, if there is no mention about the participants, we assume it is a solo trip/activity by default.

2.4.2/ JOINT TRIP RENEGOTIATING

Chandrasekharan and Goulias (1999) put forward that a joint trip is a trip with other persons. It is related to a person’s social, economic, and demographic, his household, place of residence characteristics, transportation system level of service, and also his chosen activity and travel pattern. The joint trip is determined by the negotiation process of all the participants.

Definition 10: Negotiation

According to Pruitt (1981), negotiation is defined as the process in which a joint decision is made by two or more parties. The parties first verbalize contradictory demands and then move towards an agreement by process of concession-making or search for new alternatives.

A joint trip problem involves multiple individual paths corresponding to multiple origins and destinations. A classic two-person joint trip problem is shown in Figure 2.3. We assume that a joint trip covers both trip paths for a driver and a passenger. The passenger and driver depart from their own origination and arrive at an alternative meeting point 1. They take a joint trip to an alternative drop off place 2, and then separate and go to their own destination. Time-dependency is a common phenomenon, and joint travel is subject to coupling constraints restricting that individuals must be corporeally present at the same time and location.

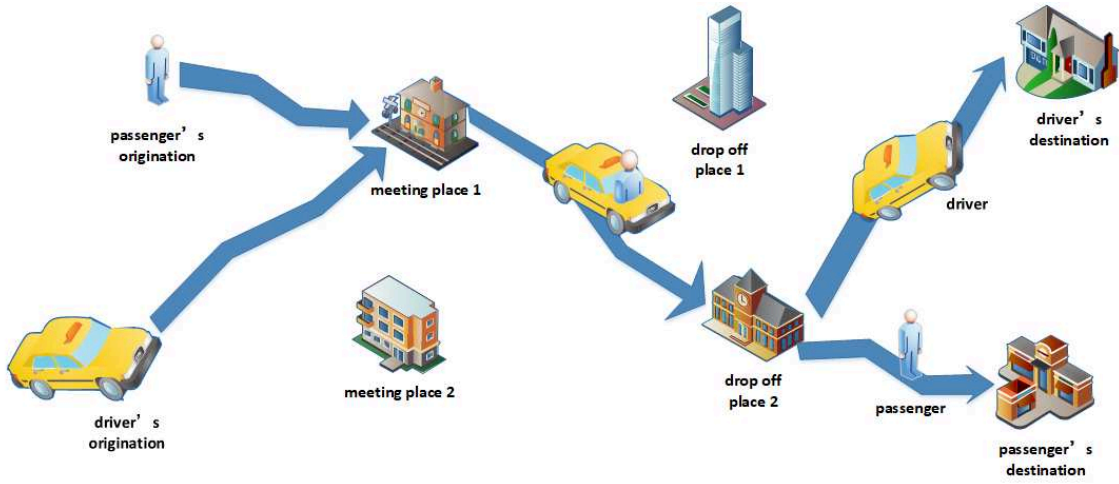


Figure 2.3: Classic two-person joint trip problem inspired by Liao (2019)

Based on the trip defined before (Definition 2), the joint trip is defined by considering the participants in the trip. In this thesis, we define the joint trip with two participants, in which one is the driver and another is the passenger.

Definition 11: Two-person joint trip

There is a driver i_d and a passenger i_p . We assume the origination of the joint trip is the meeting point o_v , the drop off place of the passenger is l_p , and the arrival time to the drop off place is t_{vPl} . The location of the driver is l_d , the joint trip start time and end time (arrival time of the driver) are t_{vs} and t_{vd} , and the path of this joint trip is $p_v \in \mathbb{P}_r$.

$$jv = \langle o_v, l_p, l_d, t_{vs}, t_{vPl}, t_{vd}, p_v, i_d, i_p \rangle \quad (2.7)$$

In a joint trip, unexpected events may be implied when a participant wants to change the planned joint trip's start time, arrival time, or the destination. Or, there is congestion during the execution of a joint trip, or there is a delay of departure. Under one of these situations, **joint trip renegotiating** is triggered. It needs to pursue a new solution in the face of each participant in the group.

Definition 12: Renegotiation (Tosselli et al., 2020)

The renegotiation process can be regarded as a certain repeated-negotiation game.

2.5/ SIMULATION AND MULTI-AGENT SYSTEM

This section introduces the fundamentals of both simulation and multi-agent system.

2.5.1/ FUNDAMENTALS OF SIMULATION

Simulation is a widely used method for implementing models of a wide variety of systems and behaviors. It is defined as:

Definition 13: Simulation (Shannon, 1977)

Simulation is a process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behaviour of the system or of evaluating various strategies (within limits imposed by a criterion or a set of criteria) for the operation of the system.

Definition 14: Simulation by (Miller, 2019)

It can be thought of as providing a computer-based “laboratory”, within which experimental investigations of a system’s behavior can be undertaken.

The objective of the simulation is to facilitate the understanding of the dynamics of a system and try to predict its evolution. Satisfying this objective requires the development of a model of the system to be studied, its execution on a computer, and the analysis of the results of this execution (Fishwick, 1997). And, the simulation model generally designates the set of mechanisms that manage changes in the state of the system. It corresponds to the set of laws, conditions, or constraints that define the behavior of the system, as well as the way in which its components are aggregated. The execution, meanwhile, must change the model of the system over time (Coquillard and Hill, 1997). To achieve this, it is generally associated with a set of tools that constitutes the simulator.

Definition 15: Simulation model

Miller (2019) propose that a simulation model should include the following characteristics:

- It is a numerical algorithm (as opposed to analytical approach) for modelling the system or behavior in question.
- Dynamic changes in system behavior are modelled over time, i.e. time is an explicit dimension within the model.
- The model is usually stochastic, i.e. random elements exist within the processes being modelled.
- The forecasted end state of the system being modelled is “evolved” rather than “solved for”.

Simulation models can be classified into three main types: macroscopic, microscopic, and mesoscopic.

Macroscopic simulation models are based on deterministic relationships between traffic, speed, and population density, constituting the crowd or simulated road traffic (Helbing and Treiber, 1998). The simulation of a macroscopic model focuses mainly on regions or populations rather than on individual behaviors. These models were originally developed to model traffic in transportation networks, such as highways, street networks, and rural roads. This approach allows the simulation of a very large population with a relatively low cost of computation. However, due to its high level of representation, the results are aggregated, imprecise, and linked to the size of the simulated population.

Microscopic simulation models focus on the movements of people on the basis of dynamic and individual behaviors, the behaviors of the following vehicle, and of change of lane to represent drivers, or the behaviors based on forces for the pedestrians (Reynolds, 1987; Thalmann and Musse, 2013; Dey and Roberts, 2007; Razavi et al., 2011; Galland et al., 2009). These models are effective for the evaluation of the congestion and saturation conditions of a system, the study of the topological configuration of the system, and the evaluation of the impacts of individual behaviors on this system. However, these models are difficult to implement, costly in terms of computation time, and can be difficult to calibrate.

The focus of this thesis is to simulate travel behavior decisions. And, among these three kinds of simulation models, microscopic simulation models are popular. “Micro” implies simulating a system in a high disaggregated way spatially, temporally, socio-economically, and in the representation of the process. Using Microsimulation to model the socio-

economic process, such as travel, is dated at least to the seminal work of Orcutt (1957).

Definition 16: Microsimulation (Jinjing et al., 2014)

A simulation-based tool with a micro unit of analysis that can be used for ex-ant analysis.

Miller (1997) proposes some important reasons to use microsimulation to deal with travel demand:

- a) Heterogeneity in trip-makers (attributes, preferences, context, history, behavior, etc.)
- b) Identification of detailed impacts of policies across people and locations.
- c) Modelling complex behavior.
- d) Potential to capture the memory, learning, and/or adaptation.
- e) Efficiency in data storage and processing.
- f) Emergent behavior.

Once one is microsimulation, a socio-economic system is a (relatively) small step to adopting a full agent-based microsimulation approach Miller (2019). And in the next section, we introduce the multi-agent system.

2.5.2/ MULTI-AGENT SYSTEM

Multi-agent systems (MAS) are considered to be a system made up of autonomous and independent entities, called agents, which interact to solve a problem or collectively perform a task. Thanks to the genericity of these concepts, the fields of application of MAS are vast (Jennings and Wooldridge, 1998). MAS also provides a framework for modelling and simulating complex systems. In particular, work in the area of traffic and crowd simulation illustrates the significant use of MAS. In the rest of this section, we define the agent and multi-agent system.

2.5.2.1/ DEFINITION OF AGENT

One of the most famous definitions of the concept of the agent was formulated by Russell and Norvig (1995). They consider an agent as “ Everything that can be seen as perceiving its environment using sensors and acting on this environment using effectors

autonomously”. This very general definition and deliberately minimalist in its formulation has been extended in particular Wooldridge and Jennings (1995).

Definition 17: Agent (Wooldridge and Jennings, 1995)

Agent is an entity that has the following properties:

1. **Autonomy:** agents operate without the direct intervention of humans or others, and have some kind of control over their actions and internal state;
2. **Social ability:** agents interact with other agents (and possibly humans) via some kind of agent communication language;
3. **Reactivity:** agents perceive their environment and respond in a timely fashion to changes that occur in it;
4. **Pro-activeness:** agents do not simply act in response to their environment. They are able to exhibit goal-directed behavior by taking the initiative;
5. **Mobility:** an agent has the ability to move around in an electronic network;
6. **Rationality:** an agent will act in order to achieve its goals, and will not act in such a way as to prevent its goals being achieved.

2.5.2.2/ DEFINITION OF MULTI-AGENT SYSTEM

Most authors generally agree to define a multi-agent system (MAS) as a system composed of agents, which communicate and collaborate to achieve specific individual and/or collective objectives. Communication implies the existence of shared space to support this communication. This space is part of a component of the system that is known as the environment (Weyns et al., 2005). We particularly consider the Definition 18 proposed by Ferber (1995), because it covers the different components of a multi-agent system.

Definition 18: Multi-agent System (Ferber, 1995)

A multi-agent system is a system made up of the following elements:

1. An environment, that is to say, a space generally having a metric.
2. A set of objects. These objects are located, that is to say that for any object, it is possible, at a given moment, to associate a position in the environment. These objects are passive, they can be perceived, created, destroyed and modified by agents.
3. A set of agents which are particular objects, which represent the active entities of the system.
4. A set of relations which unite objects (and therefore agents) between them.
5. A set of operations allowing agents to perceive, produce, consume, transform, and manipulate objects.
6. Operators who are responsible for representing the application of these operations and the reaction of the world to this attempt at modification, which we will call the laws of the universe.

2.6/ AGENT-BASED SIMULATION

Multi-agent simulation refers to microscopic or self-centred models (Amblard, 2003) and provides a process for modelling and simulating the dynamics of populations made up of interacting individuals. It uses the metaphor of autonomous agents and multi-agent systems as the basic model conceptualization. This means that a model consists of interacting agents situated in a simulated environment. Multi-agent simulation has been applied to a large number of fields such as robotics (Drogoul, 1993; Kitano et al., 1997), ethology (Drogoul and Picault, 1999), ecology and biology, or social sciences (Conte et al., 1998; Gilbert and Troitzsch, 2005). Agents may correspond to cities, blocks, platoons, households, individual travelers (drivers), vehicles, sensors, traffic signals, etc (Miller, 2019). In accordance with the multi-agent paradigm, the perspective adopted is at the level of the individual; the dynamics of the system come from interactions between individuals. The structure of the system is considered to emerge from these interactions.

2.6.1/ GENERAL PRINCIPLES

The model proposed by Michel (2004) for the modelling and simulation of multi-agent systems constitutes the basis for the design of a multi-agent simulator. It adopts a multi-view approach and distinguishes four fundamental aspects in a multi-agent simulation model:

- **Behaviors:** this aspect deals with the modelling of agents' deliberation processes (their "spirits").
- **Environment:** this point of view aims to define the different physical objects of the simulated world (the located environment and the "body" of the agents) as well as the endogenous dynamics of the environment.
- **Scheduling:** this aspect concerns the modelling of the flow of time and the definition of the scheduling used to execute the behavior of agents.
- **Interaction:** this view is more particularly interested in modelling the result of actions and interactions at a given time.

Figure 2.4 illustrates the relationships between these four fundamental aspects of a multi-agent simulation. The modelling and implementation of each of these aspects and their relationships are all delicate points, which raise the following issues:

- **Respect the locality constraint:** an agent is an entity whose perceptions and

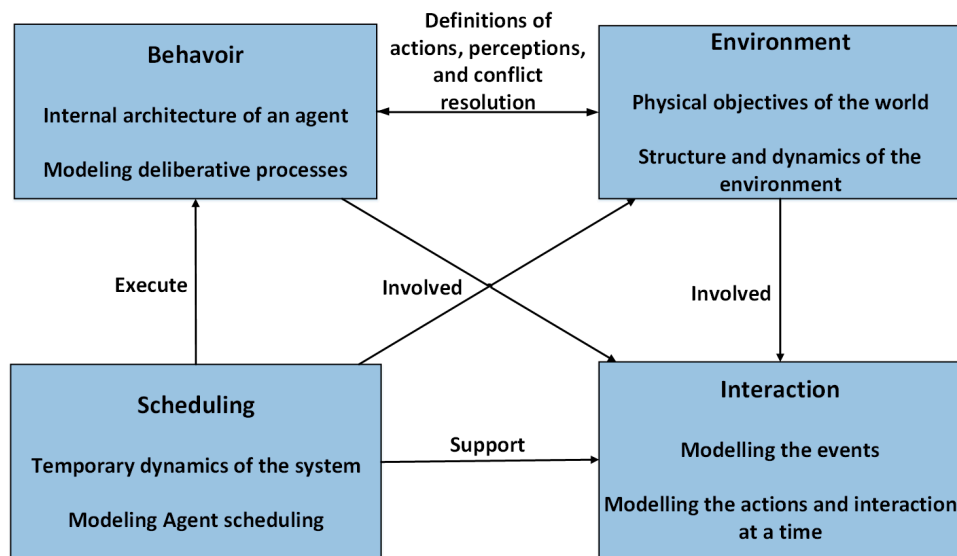


Figure 2.4: The four aspects of a multi-agent simulation model according to (Michel, 2004)

actions have only local significance. Two main approaches exist to respect this constraint:

- a) The discrete (environment-centred) approach where the discretization of the environment in the form of zones defines the granularity of the agents' perceptions and actions.
- b) The continuous (agent-centred) approach where the scope of each perception and of each action is the subject of a particular treatment which depends on the nature and characteristics of the agent concerned (Weyns et al., 2004).

These two approaches can also be combined:

- **Respect the environmental integrity constraint:** an agent must not be able to directly modify the state of the environment variables.
- **Simulation bias and simultaneity of actions:** To avoid introducing biases in the simulation, it is necessary to have a model for managing the action of agents and time, which allows the simultaneity of two events. A simulation model must not be linked to a particular layout (Zeigler et al., 2000). The order in which agents are activated affects the dynamics of the system and can lead to simulation bias.

In the rest of this section, we are particularly interested in the behavior of the agents and their interaction with each other.

2.6.2/ AGENT BEHAVIOR

The behavior of an agent tends to meet its objectives, taking into account the resources and skills at its disposal, and accessible representations and perceptions of the surrounding environment. The main assumption in the normative theory proposed by Hoogendoorn and Body (2002) is that all the actions of an agent, carrying out an activity or following a route, will have a utility (or dis-utility) for the agent. Individuals will be able to predict and optimize the total utility, taking into account the uncertainty on the expected travel conditions, similarly to the theory of the microeconomic consumer (Franck, 2002). By choosing from the available options, they try to achieve maximum net utility, which is the sum of the utilities of interpretation activities and the dis-utilities of efforts related to travel to places of activity. This notion is called the maximization of subjective utility: each individual has his own subjective vision of the situation. Our hypothesis is that all the agents moving in the simulated universe have behaviors tending to this maximization.

Usually, the agent model is decomposed into three layers (Michon, 1985; Hoogendoorn and Bovy, 2001, 2004; Montello, 2005):

- **Strategic layer:** At the strategic level, individuals decide what activities to perform in the universe. While some of these activities may be discretionary (for example, the purchase of a newspaper), others may be compulsory (validation of a ticket before accessing a train). All of the choices can be linked to environmental characteristics (type and location of stores, etc.). In this layer, agents generally use an action selection architecture.
- **Tactical layer:** The tactical level concerns the short or medium-term decisions to be taken by the agents using as a reference to the decisions of the strategic level. Based on the objectives given by the latter, the tactical layer model must build a detailed action plan. The locations of the different activities and the routes to reach these locations are determined at this level. The shortest path search algorithms can form the basis for calculating the paths to be taken in the form of a sequence of environmental zones.
- **Operational layer:** At the operational level, individuals make very short-term decisions. These decisions are guided by those provided by the previous layer. The models belonging to this layer decide the trajectory of an individual, its speed or its acceleration.

2.6.3/ AGENT ENVIRONMENT

The environment is commonly defined by everything around an agent. Weyns et al. (2005) give a global definition of the environment (Definition 19), without referring to a type of any particular agent. One of the main ideas is to delegate part of the responsibilities of the MAS to the environment, which integrates mechanisms providing services such as observability and accessibility to shared resources (Definition 18).

Definition 19: Environment (Weyns et al., 2005)

The environment is a first-order abstraction which provides the surrounding conditions for agents to exist and which acts as an intermediary for both agent interactions and access to resources.

2.6.4/ INTERACTION

In a multi-agent system, agents interact with one another by exchanging information in the form of definitions, assertions, and queries to achieve the goal or goals of the user or that of another agent (Ong and Ng, 1998). Communication and autonomy are basic capabilities of artificial agents (Wooldridge and Jennings, 1995), and the goals of a multi-agent system should be reached via the interaction of autonomous communicating agents (Weiss, 1999).

Definition 20: Interaction

An interaction is a semantic sequence of actions involving a fixed number of agents simultaneously. It describes how and under what conditions agents may interact with each other or with the environment. The conditions of interaction are the conjunction of (Kubera et al., 2011):

- **preconditions:** describe the logical or physical conditions required to initiate the interaction.
- **triggers:** describe the teleonomic part of the conditions: i.e., explicit or implicit goals this interaction aims at:
 - a) explicit goals are agents memory elements consumed by the interaction in order to move the reactive plan forward, like in reactive planning architectures;
 - b) implicit goals are stimuli reduced the interaction.

An interaction can be performed only if both its trigger and its preconditions are true. The

interaction between agents can be modelled abstractly as a set of protocols. Usually, the set of protocols are layered, thus allowing details of the agent interactions to be modelled gradually. The abstraction of complex multi-agent interaction behavior through layers of protocols allows them to be clearly specified and verified (Wen and Mizoguchi, 1999).

Definition 21: Protocol (Wen and Mizoguchi, 1999)

A protocol can be defined by a set of participants, a set of agreed messages, rules for actions based upon reception of a various message, and assumptions of the communication channel. Usually, they are modelled as a set of communicating processes executing concurrently.

In a multi-agent system, negotiation is a key form of interaction that enables groups of agents to arrive at a mutual agreement regarding some belief, goal, or plan, for example. Particularly because the agents are autonomous and cannot be assumed to be benevolent, agents must influence others to convince them to act in certain ways, and negotiation is thus critical for managing such inter-agent dependencies (Beer et al., 1999). Different from the nature definition (Definition 10), negotiation in a MAS context will always be specified by a protocol, it may be simple or sophisticated, deterministic or non-deterministic.

Definition 22: Characteristics of an agent negotiation (Beer et al., 1999)

Agent negotiation has three main characteristics:

- **Negotiation protocols:** They contain the set of rules that govern the interaction. This covers, the permissible types of participants (e.g., the negotiators and relevant third parties), the negotiation states (e.g., accepting bids, negotiation closed), the events that cause state transitions (e.g., no more bidders, bid accepted), and the valid actions of participants in particular states (e.g., which can be sent by whom, to whom and at when).
- **Negotiation objectives:** They are the range of issues over which agreement must be reached. These may be single issues, such as price, or multiple issues relating to price, quality, timing, etc. Also relevant here are the allowable operations on these objects.
- **The agents' reasoning models:** They provide the decision-making apparatus by which participants attempt to achieve their objectives. The sophistication of the model is determined by the protocol used, the nature of the negotiation object, and the range of operations that can be performed on it.

During the negotiation, cooperation is the fundamental characteristic of multi-agent sys-

tems where the overall system exhibits significantly greater functionality than the individual components (d’Inverno and Luck, 1996). In other words, cooperation underlines the structure of multi-agent systems. Multi-agent cooperation is an important content in multi-agent system research and, its study mainly aims the following: how to support people on tighter cooperation, researching into and explaining some cooperation behavior in human society, and how to solve some complex optimizing problem (Changhong et al., 2002).

In most literature, cooperation is regarded as common sense behavior and, they lateral explain the essence of cooperation through the studying on competition, antagonizing, conflict, negotiation, and coalition, all of which are closely related to the cooperation. In this thesis, we introduce three definitions of cooperation:

Definition 23: Cooperation (Smith and Davis, 1981)

One agent adopts the goal of another agent. Its hypothesis is that the two agents have been designed in advance, and there is no conflict goal between them. Furthermore, one agent only adopts another agent’s aim passively.

Definition 24: Cooperation (Luck and d’Inverno, 1995)

One autonomous agent adopts another autonomous agent’s goal. Its hypothesis is that cooperation only occurs between the agents, which have the ability to reject or accept the cooperation.

Definition 25: Cooperation (Changhong et al., 2002)

When one autonomous agent or one autonomous agent coalition adopts another autonomous agent’s or another autonomous agent coalition’s goal, the cooperation occurs between them.

The difference between the first two definitions above exists in whether cooperation can occur between non-autonomous agents. And, both of them are in the absence of considering agent coalition cooperation and agent coalition goals. This thesis agrees with Definition 25 by Changhong et al. (2002).

2.7/ CONCLUSION

This chapter defines the necessary terms used in the activity rescheduling problem and the agent-based simulation method that will be extensively used in the rest of this thesis.

This chapter defines the transport system (road network and trip), activity schedule (activity, episode, activity schedule, activity scheduling), activity rescheduling (unexpected

events, and activity rescheduling). The activity rescheduling process is decomposed into the individual activity rescheduling process, including the solo trip/activity, and the joint trip renegotiating process, including the negotiation, joint trip, renegotiation. Figure 2.5 provides an overview of the related concepts that are presented in this chapter.

In order to deal with the activity rescheduling problem, this thesis proposes to use the agent-based approach to simulate the activity rescheduling decision-making process. Therefore, this chapter defines the fundamentals of simulation. From the three kinds of simulation models: macroscopic, microscopic, and mesoscopic, microscopic is appropriate to solve the problem. According to Miller (2019), once one is a microscopic system, it is relatively adopted to use an agent-based approach. Consequently, the fundamentals of multi-agent systems and agent-based simulation are presented. Figure 2.6 provides an overview of the simulation agent MAS concepts that are presented in this chapter.

Based on the elements that are described in this chapter, state of the art related to the activity rescheduling problem is presented and discussed in Chapter 3 and Chapter 4.

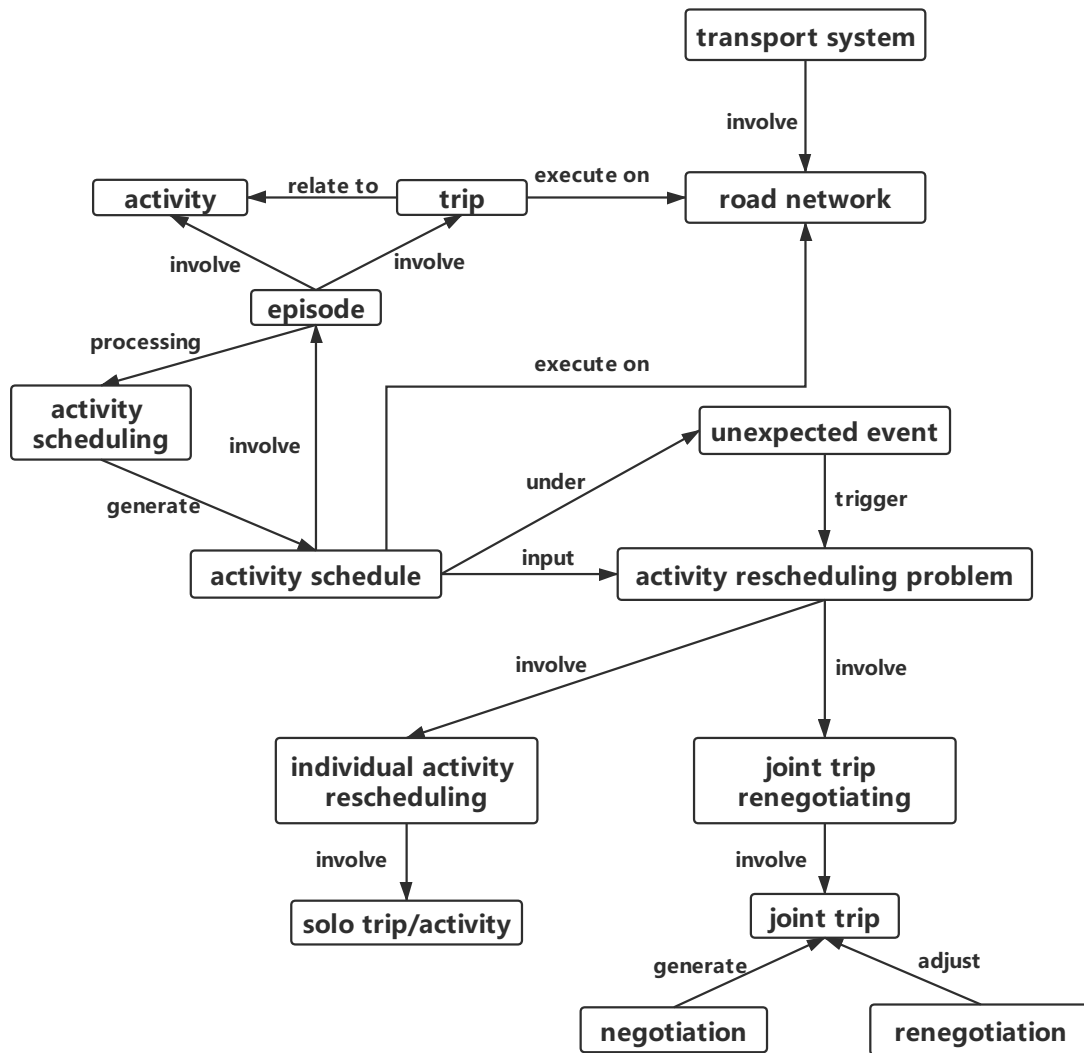


Figure 2.5: Terms related to activity rescheduling problem

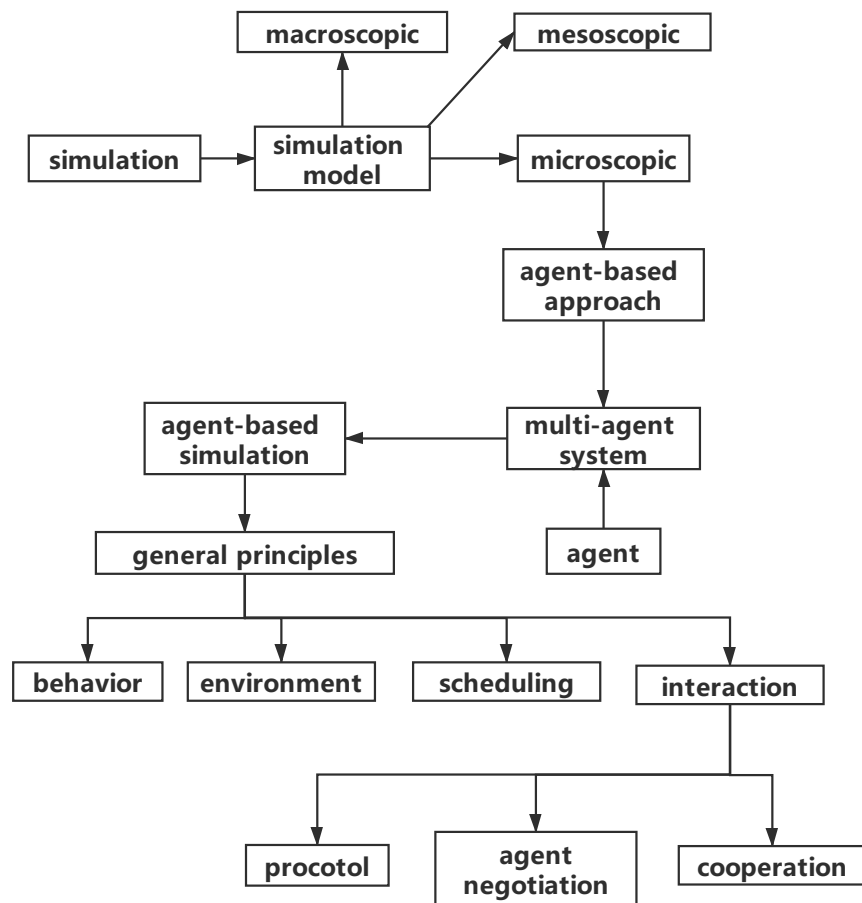


Figure 2.6: Summary of simulation and agent-based model

INDIVIDUAL ACTIVITY RESCHEDULING

3.1/ INTRODUCTION

After defining all the concepts and terms used in the thesis, this chapter introduces the current works for individual activity rescheduling problem. As explained in Section 1.2, Question RQ1 has been explained in Chapter 2. In order to move forward answers to the other research questions, this chapter introduces the factors that affect the individual activity rescheduling decision to solve Question RQ3. The models for alternative choices' generation in relation to Question RQ4 are presented. The existing optimization methods used to choose the optimal choice are presented in order to deal with Question RQ5. This chapter lists the current agent-based models related to the individual activity rescheduling problem in relation with Question RQ6.

3.2/ FACTORS AFFECT INDIVIDUAL ACTIVITY RESCHEDULING

Recall the definition of the rescheduling (Definition 8, page 16): **activity rescheduling is the action to update an existing schedule, according to some constraints, and starting to adjust the schedule when unexpected events happen**. According to the definition of activity rescheduling, there are several main elements involved: the individual himself, the original schedule, the unexpected event, and the constraints. In a schedule, there are trips and activities, and the trip is scheduled to take the individual from one location to another location to execute the activity. As for constraints, time is a moderately restricted resource in terms of human judgment and decision making (Saleem et al., 2011). Moreover, the activity rescheduling process under time suffers time pressure (see Section 3.2.2 for details). Therefore, we conclude the factors affecting the individual activity rescheduling are unexpected events, individual, activity attributes, and time pressure. This section classifies them into two categories: static factors and dynamic factor.

3.2.1/ STATIC FACTORS AFFECTING THE INDIVIDUAL ACTIVITY RESCHEDULING

The type of unexpected events (Joh et al., 2002b), as well as the attributes of the affected activities (Clark and Doherty, 2008) determine the effect of the events on the schedule. A factor is static when its effect does not change along with time passing by. In this thesis, static factors affecting rescheduling models are classified into three groups those are: unexpected event attributes, individual characteristics, and activity attributes.

- 1. Unexpected event attributes:** The impetus of change can directly relate to how activities are rescheduled. For example, the event of changing location may result in time change, mode change, or dropping the activity. Auld et al. (2008) study the different strategies dealing with different time conflict types. Olaru and Smith (2005) study the rescheduling because of a time delay. They put forward that if the time savings/delay is small, individuals are most likely to absorb the delay by changing the duration of the next activity or by making a small adjustment to the time of the day when subsequent activities start. Rasconi et al. (2010) define the events related to the location change, the time change, and the mode unavailability. For the multi-event situation, the authors analyze the awareness time of the event and deal with the one with the higher urgency, and then the rest of the events.
- 2. Individual characteristics:** Clark (2008) puts forward that there are mainly six main variables for individuals, which affect the human activity-travel rescheduling decision process. They are gender, age, income, employment status, household size, and household type. Chen et al. (2004) explain that, when faced with unexpected changes, the true changes in the unexpected event, and the changes observed by the individual may differ. People have different sensitivity when facing different attributes' changes, and their reaction will have a bias. Aggarwal (2019) studies the attitudinal choice models in human decision making, which reflect the individual's important impact on decision making. Nowadays, the choices models are able to represent a very broad range of human attitudinal characters. Schwanen et al. (2008) and Cresswell and Uteng (2016) study the gender's effect on mobility and put forward that men and women have different travel patterns, such as travel purpose, trip distance, transport mode, and other travel behavior. Nyaupane and Andereck (2008) study the factors affecting the rescheduling of leisure activities. They find out that persons with different genders and ages have different attitudes for time-cost and money-cost. By using fuzzy logic rules to explore the rescheduling decision upon unexpected variations in travel times, van Bladel et al. (2009) find that individual personal preference determines the rescheduling process.
- 3. Activity attributes:** The detailed attributes of activity are: purpose (type), duration,

time of day, day of the week, location, persons involved, distance travelled to access location, and whether other activities are performed simultaneously (multi-task). Mohammadian and Doherty (2006) analyze the effects of the past duration experiences on the current duration. Besides, the activity type has a strong effect on the rescheduling process. Activity types (or trip purposes) are key aspects of modelling travel behavior. van Bladel et al. (2009) explore the factors that affect activity rescheduling. The authors explain that the activity type has strong power on rescheduling, mandatory activities like working are rarely rescheduled. Moreover, the other activity attributes, together with situational and environmental circumstance, play an important role. Olaru and Smith (2005) find that the most important factors, which affect the rescheduling: the flexibility of the next activity and the magnitude of the time saving/delays.

Based on the current researches on these static factors, which affect the individual activity rescheduling decision, we conclude their influences as in Table 3.1, and summarized below:

- **Unexpected event:** It affects the alternative rescheduling choices. If under the multi-event simulation, time urgency should be taken into consideration. It means that the informed time of an unexpected event affects the alternative choices as well. In our model of individual activity rescheduling, we clearly define the alternative choices set under each kind of unexpected event (see Section 6.3.5 for details).
- **Individual characteristics:** They affect the strategy of the individual and his preference on the different alternative choices. We combine the individual's tendency to select each choice to the time pressure in our model (see Section 6.4.2.3 for details). Additionally, the relationship between the individual characteristics and time pressure is discussed in the following Section 3.2.2.
- **Activity type:** It is the main factor among the activity attributes that affect the individual activity rescheduling decision. In our research works, the relationship between a pair of connected activities is explored. In other words, both of the types of the affected activity and its next connected activity are considered in our model (see Section 6.4.2.1 for details).

3.2.2/ DYNAMIC FACTORS AFFECTING THE INDIVIDUAL ACTIVITY RESCHEDULING

A factor is dynamic when it affects the activity rescheduling dynamically, i.e. its value is changing as time passing by. During the activity rescheduling process, time pressure is a

<i>Static Factor</i>	<i>Elements in It</i>	<i>Its Influence</i>
unexpected event	the affected trip/activity, the changed information, informed time (Definition 7)	<ul style="list-style-type: none"> • type of unexpected event (the changed information) affects the alternative choices • type of unexpected event (the changed information) affects the rescheduling strategies • under multi-event situation, considering time urgency (informed time)
individual	gender, age, employment status, commute distance, race/ethnicity, hours, occupation and industry, household type, etc. (Schwanen et al., 2008; Clark, 2008)	<ul style="list-style-type: none"> • different people has a different sensitivity to unexpected events, resulting their bias on activity rescheduling decision • gender and age can affect the leisure activity rescheduling decision • individual's preference and attitude can affect activity rescheduling decision
activity	activity type, start time, duration, end time, minimum duration, location (Definition 3)	<ul style="list-style-type: none"> • past activity duration experience affect the duration adjustment of the affected activity • activity type (affected activity) has a strong effect on activity rescheduling decision • flexibility (activity type) of the next activity, which is the next activity related to the affected activity by the unexpected event

Table 3.1: Summary of static factors in individual activity rescheduling

significant dynamic factor.

Definition 26: Time Pressure (Rastegary and Landy, 1993)

Time pressure is defined as the difference between the amount of available time and the amount of time required to make a decision.

In ordinary language, synonyms of “pressure” include force, weight, stress, strain, anxiety, demands, difficulty, and so on. When making decisions, the factor that affects them is the feeling of time pressure, rather than the actual time pressure. Batool (2016) regards it as perceived time pressure (PTP) that “[...] is the feeling of individual of not being able to

reach a wanted level of utility at a certain time. This time deadline is specified by either a third party or individual himself. PTP is influenced by the psychological factors which are different for different individuals. The set of psychological variables consisted of locality, time pressure due to activity duration (if it is more than planned), income level, mode choice, preferred transport mode under time pressure, and gender difference.”

The rest of this section introduces the factors affecting time pressure and how time pressure affects the individual's decisions.

There are several researches about the factors affecting time pressure when making an activity rescheduling decision. Ringhand and Vollrath (2017) study driver's route choice under time pressure when waiting at traffic lights and additional. They mainly analyze the driver's characteristics when making route choices under time pressure. Time pressure is induced by instruction and continuous feedback during the experiment. Higgins et al. (2018) put forward that people's response to traffic congestion-related stressors differs by individual characteristics. They capture how exposure to traffic congestion events, the duration of this exposure, and individual trait susceptibility to congestion after the utility of commuting. Rastegary and Landy (1993) study the time urgency in decision making under time pressure. They consider the time urgency as an undiscovered variable which affects decision-making. According to that, the authors classify the individuals into two types: time-urgent and non-time-urgent. Time-urgent peoples perceive less time pressure and withstand a higher level of time pressure than less-urgent individuals.

As for the time pressure's effect on an individual's decision, Stern (1999) explains that in dynamic situations, time pressure is connected with the development of the situation itself. The author studies the time pressure's effect on decision-making under the situation of congestion. He explains that information retrieval under time pressure is assumed to be more selective. The decision-maker is assumed to retrieve fewer attributes, thus making fewer comparisons, and give higher weights to salient attributes. Since the focus is on the trip choice under time pressure, The author considers two types of choice models: before the trip and en-route. Saleem et al. (2011) study the correlation among time pressure, human judgment, and decision making. The author elaborates that during time restraint, decision-makers try to boost up the decision-making process, and if not possible, they shift toward the simplest strategy. In addition, when facing a high level of time constraint, a decision-maker focuses on negative information. By using a questionnaire, the author finds out that widely the human judgments are used for making a decision, and there is a positive correlation between time pressure and human judgment. Since the decision is based upon past experience, the age factor is essential when considering the human judgment.

Therefore, we conclude the aspects of time pressure as:

- **Factors affecting time pressure:** Cited researchers agree that individual characteristics have an influence on time pressure. Moreover, different people feel different time pressure under the same time constraint. In this thesis, we combine the individual characteristics into the calculation of time pressure (see Section 6.4.2.3 for details).
- **Time pressure's effect on the individual's decision:** The decision maybe not optimal. The alternative choices that the individual is faced with are more selective. In our research works, we assume that the time pressure affects each alternative choice's probability, i.e. the individual's preference (see Section 6.4.2.3 for details).

When an unexpected event happens, an individual is faced with a set of alternative choices. The factors mentioned above affect his tendency to select one of these choices, and therefore the strategy to select among these choices. The following section introduces the alternative rescheduling choices in the context of the individual activity rescheduling problem.

3.3/ INDIVIDUAL ACTIVITY RESCHEDULING CHOICES

All the rescheduling choices are included in the choice set of alternatives that is available to the individual when an unexpected event occurs. In a simulation model, such a choice set needs to be established based on the actual state (situation) of the involved individual, the disturbed travel plan (schedule), and the environment (unexpected event). Nijland et al. (2009) do a survey to investigate the individual's rescheduling choices when faced with unforeseen events. They list the following alternatives that populate the rescheduling choice set: **shortening** the duration, **cancelling** the activity, changing the **location**, and changing the transport **mode**. In our research works, trips by car are only considered. Therefore, the transport mode change is beyond the scope. Besides, the focus is to explore the travel behavior and to take into consideration the **path changes**.

The individual activity rescheduling choices that are considered in this thesis are: changing the time attributes (time adjustment), changing the trip route, changing the location, and drop the activity. We introduce the current research works related to each of these modules, except the module of activity dropping.

3.3.1/ TIME ADJUSTMENT

Time adjustment choice is to change the time attributes of the trip and activity in a daily activity schedule.

Knapen et al. (2018) use time deviation function to minimize the time pressure and waste of time (which can also be said as a void period). The paper considers the trip time, activity time, and void periods, which can occur immediately before and immediately after activities. The optimization method used is to minimize the time discrepancy between schedules.

Ruiz and Timmermans (2006) contribute to time changing on adding activity into a pair of consecutive activities in a schedule. By using a parametric hazard model, they find that individual characteristics of gender and the time of the day for the activity mostly affect the rescheduling decision rather than activity type.

Golshani et al. (2018) elaborate that activity start time and duration are key components in scheduling. By using a joint model that combines random utility maximization (RUM) and random regret minimization (RRM), they analyze the activity start time and duration from different time intervals in a day.

Meister et al. (2005) modify activity durations and departure times of activity plans, which are the agent-based representation of travel demand. They combine a broad search for alternative timing decisions with a goal-oriented search using a utility function. The idea is to replace a re-planning model that changed timing decisions randomly.

3.3.2/ ROUTE CHANGE

Route change choice is to change the route to a trip's destination in a daily activity schedule.

Verbas et al. (2019) study the routing model in POLARIS. The routing model the paper used is the point-to-point least time algorithm. For route involving passenger cars only, the standard Euclidean approach is used. Each routing agent has its own copy of the network.

Sokolov et al. (2017) design a model to find the optimal routes and departure times by using POLARIS.

Li et al. (2017) model the travel departure time and the optimal route along with considering the pricing strategy, income level, and trip purpose. De Jong et al. (2003) study the time of day sensitivities to travel time and cost changes. According to a preference survey, they find that if the travel time or cost in the peak increases, most travelers will shift to periods just before or after the peak. Jenelius et al. (2011) consider both travel time and delay cost in routing as well.

Gerostathopoulos and Pournaras (2019) propose a travel solution that considers different optimization objectives in the traffic domain and is able to deal with real-life incidents by self-adaptive collaborative planning. A car can choose between one of three available routers to obtain a route. The first router routes cars based on the minimum distance to the destination, the second by selecting the streets with maximum speed, and the third by considering both the maximum speed and the street length in routing.

3.3.3/ LOCATION CHANGE

The location change is to change the activity's location in a daily activity schedule, under the condition that the activity has an alternative location.

Horni et al. (2009) extend the location choice module to MATSim. For each MATSim agent and for each pair of fixed activities between which to insert a flexible one, a location choice set is generated on the fly using a space-time prism constrained by the available time budget. Whenever an agent is allowed to adjust its travel plan in a given MATSim iteration, the location choice model is evaluated. Finally, the MATSim iterations are expected to lead to a Nash equilibrium. The authors conclude that confining the agents' choices to a local range in each MATSim iteration by including the time-geographic approach is actually a useful step on the way to computability.

Horni et al. (2011) improve the destination choice model in MATSim as well. The paper explains that the original MATSim choice model is based on the local search, using utility maximization method. The huge number of available alternatives for all choice dimensions makes the introduction of optimizing mechanisms indispensable. By incorporating heterogeneity of individual error terms in an iterative model to the choice model, they ensure a stable choice for the same person making the same choice over the iteration.

Märki et al. (2014b) and Janzen and Axhausen (2017) introduce the location choice in C-TAP. And since C-TAP is a long-term model, therefore the seasonal factor is considered to choose a location. The attractiveness of the location consists of the individual's own perspective of the location, the quality, and the seasonal utility of the location. The activity is more likely to be executed at the location with high attractiveness values. The main steps in C-TAP to choose a location are: find all locations that provide the chosen activity and all modes that available; remove all locations that are not part of the agents' awareness; remove locations lower than duration target; compute the location attractiveness, and remove the locations where the attractiveness factor is too low; solve the optimization problem, and apply the optimal location and duration.

<i>Alternative Choice</i>	<i>Current Works</i>	<i>Proposal</i>
time adjustment	<p>most researchers take the schedule as a whole to make time adjustment, the method includes:</p> <ul style="list-style-type: none"> • time discrepancy minimization • schedule utility maximization 	this thesis provides each activity with a minimal duration, and adjusts the time attributes of a single activity under unexpected events.
route change	<p>for the researches finding the optimal route, we conclude them as:</p> <ul style="list-style-type: none"> • least time algorithm • shortest distance algorithm • combine the price cost to time or distance algorithm • provide the driver with several algorithm to choose at each time 	our model uses least time algorithm
location change	<p>most researchers use the time-space research to find the alternative locations, and to choose the optimal one, we conclude them as:</p> <ul style="list-style-type: none"> • maximize the utility of the location • maximize the attractiveness of the location 	our model uses the attractiveness maximization method, and the alternative location are provided with necessary parameters

Table 3.2: Summary of individual joint trip models

Märki et al. (2014a) use different parameters in location attractiveness in C-TAP models. They divide the location attractiveness as location effectiveness and individual perception. And the location effectiveness consists of congestion-sensitive location choice, weather-sensitive location choice, pattern-sensitive location choice, seasonal location choice, income-sensitive location choice, and habitual/explorative location choice.

3.3.4/ SUMMARY OF THE ALTERNATIVE CHOICES

Based on the current works on the alternative choices, we summarize them and propose our ideas in Table 3.2.

3.4/ OPTIMIZATION METHOD FOR INDIVIDUAL CHOICES

To optimize the alternative choices that are described in the previous section, an optimal method needs to be used. They are classified as utility maximization method, penalty (dissimilarity) minimization method, and hybrid methods. Each of these types of methods is discussed below:

1. Utility maximization: Generally, schedule utility consists of trip utility and activity utility, like the utility function used in MATSim (Zhang et al., 2013).

Arentze et al. (2005) calculate activity utility by using S-shaped utility function, and the travel utility involves effort and monetary costs, which is depending on the transport mode used. S-shaped utility is the most popular activity utility function in agent-based activity rescheduling models. Balac et al. (2018) use S-shaped utility function into MATSim.

Nijland et al. (2011) combine time pressure into S-shaped utility. By doing a survey and using MNL-model, they get the values related to each factor in the utility function. The authors find that compared with time pressure, activity duration has the most significant effect on the utility. Also, they measure the activity utility for different activity types.

Joh et al. (2003) also study time pressure's sensitivity to S-shape activity utility as well. Timmermans et al. (2001a) mainly study the anticipated time pressure's effect on the activity's utility. It classifies the individuals as risk avoiders and risk-takers, and under the different time-lack situation, different kind type of person has different preferences on the parameters of the utility function, like history used time, activity duration, and activity type.

Joh et al. (2001) mainly focuses on the individual characteristics and utility duration. They think that longer duration provides a higher level of utility. The paper simulates the rescheduling process induced by increased time pressure. The individual characteristics is reflected by the parameter setting of activity.

2. Penalty (dissimilarity) minimization: Joh et al. (2002a) propose a multidimensional sequence alignment method to measure differences in both sequential and inter-dependency information embedded in activity patterns. The heuristic method they used to measure the similarity, firstly aligning each attribute sequence separately using a conventional sequence alignment method, then integrating the operations that can be applied simultaneously, and finally assigning a single weighting value to the integrated operations unit as if it were a single operation.

Shamshiripour et al. (2019) elaborate that individuals try to minimize the change in their schedule when deciding on how to resolve a conflict forces the model to come up with schedules in which duration of activities are not increased compared to their duration before the change.

Allahviranloo et al. (2017) study the penalty from rescheduling activity patterns. They assume that the planned schedule patterns have the greatest utility, and changing the pattern can affect the utility. Operations of activity insertion, deletion, and substitution cause penalty, which are obtained by using PGA (parallel genetic algorithm). Pattern probability is calculated from the function combines utility and penalty, the pattern with the highest probability is the final decision.

3. Hybrid method: Xu et al. (2017) use dissimilarity to find the best schedule in HARP. The dissimilarity account in the paper is time allocation, activity engagement, and activity sequencing. Levenshtein distance between every pair of observations captures the dissimilarity between them. The longer the distance, the more dissimilar two patterns are. The authors also use a random utility maximization (RUM) to capture the activity type, location, and schedule patterns based on the constraint of the dynamic time budget over the day.

Axhausen et al. (2010) regard the utility as activity utility, travel utility, the penalty of waiting, and performing a short activity, and they put forward a negative factor to denote the negative influence on utility if the activity related facility is too crowded.

Joh (2004) combines the individual's preference into S-shaped utility. And the authors propose a multidimensional sequence alignment method to measure differences in both sequential and inter-dependency information embedded in activity patterns. The heuristic method they used to measure the similarity, firstly aligning each attribute sequence separately using a conventional sequence alignment method, then integrating the operations that can be applied simultaneously, and finally assigning a single weighting value to the integrated operations unit as if it were a single operation.

Based on the current works related to optimization for the individual rescheduling problem, we conclude them as:

- **Utility maximization:** there are mainly two utility method: random utility and S-shaped utility, the latter is the most popular used one among the researches.
- **Penalty minimization:** some researches use the dissimilarity of schedule patterns, under this condition, the multidimensional sequence method is mostly used, which considers both the order sequence and attributes change.

- **Hybrid utility-penalty:** this joint method combines the above two methods.

In this thesis, the penalty minimization method is used. Since the sequence change is not considered, the penalty is obtained from the episode attributes changes (see Section 6.4.2.1 for details). Additionally, the number of changed episodes is considered during the choosing process. The number of changed episodes, time pressure, and S-shaped utility are combined into the calculation of the probability of each alternative choice (see Section 6.4.2.3 for details).

Knowing the factors affecting the individual activity rescheduling decision, the alternative choices that an individual has under the unexpected event, and also the optimization method for selecting the optimal one among those choices, a model must be set up in order to simulate the decision-making. As explained before, the goal of this thesis is to use an agent-oriented approach in order to deal with this problem. Therefore, the next section of this chapter studies the current agent-based models that are solving the individual activity rescheduling problem.

3.5/ INDIVIDUAL ACTIVITY RESCHEDULING MODELS

This section introduces the popular agent-based models for individual activity rescheduling, and makes a summary of each model.

3.5.1/ AGENT-BASED MODELS OF INDIVIDUAL ACTIVITY RESCHEDULING

This section introduces the current popular agent-based models dealing with the individual activity rescheduling problem.

MATSim is an agent-based model, which simulates the short-time schedule. It was designed from the beginning to meet the challenges of simulating large scenarios to optimize travel demand (Balmer et al., 2006). It has modules for execution, scoring, and re-planning. Agents adapt their plans in response to the conditions that arise during the simulation. The rescheduling choices of changing route, time, and mode are considered in the model, and each choice is given a weight to score the utility. MATSim makes it possible to change the weight of each choice facet during the iterations. The final decision is obtained with the highest score (Zhang et al., 2013). The re-planning strategies in MATSim are mode, route, departure time, and secondary activities location choice. However, the sequence of activities in the daily agenda is kept unchanged. Hackney and Marchal (2011) combine the social network with MATSim to investigate what relationship emerges between socialization, geography, and travel behavior. They use five

experiments to testify the location choice, spatial social network, information exchange, the socializing reward for utility, and social network evolution. Ali (2016) integrates a customized re-planning module into MATSim to reflect different people's thinking about their time utility.

ADAPTS (Agent-based Dynamic Activity Planning and Travel Scheduling model) dynamically simulates activity and travel planning and scheduling. The simulation process includes three primary stages: (i) initialization of the simulation environment, (ii) household and individual planning at each time step, and (iii) trip vector and traffic assignment at each time step (Auld and Mohammadian, 2012). The fundamental concept underlying the framework of ADAPTS model is to treat activity planning events as individual discrete events within the overall simulation framework so that an activity schedule is created and modified over time. Individual attributes of each activity are not necessarily planned in any given order, which contrasts with the assumption usually made about the sequential planning process. The model assumes four activity attributes that are planned: destination, timing, mode, and party. When making rescheduling decisions, the first step is to consider the location and then to consider the mode choice, then the time choice, then the party composition (Auld and Mohammadian, 2009).

Aurora (Agent for Utility-driven Rescheduling Of Routinized Activities) is an agent-based and activity-based model, which extends the Albatross model, which is an activity-based model. Within-day rescheduling is its central character, and congestion is the mechanism by which agents interact. Aurora uses a heuristic method to build the choice set (Arentze et al., 2006). It assumes an existing schedule, the heuristic searches for and implements improvements by considering one operation at a time. The rescheduling operations include: inserting activities, substituting activities, re-posting activities, deleting activities, changing locations, changing trip-chaining choices, and changing transport modes. A single operation is repeated until no more improvement has been made. Also, Sun et al. (2005) extend the Aurora framework to deal with multiple uncertain events of travel information. They assume that the uncertainty regarding an event is mentally represented as a probability distribution across the outcomes of an event. The individual can update its belief of probability by using the Bayesian principle after each event.

FEATHERS is developed as an extension of ALBATROSS as well, and it incorporates activity rescheduling, learning process, and rerouting (Bellemans et al., 2010). It is an activity-based and agent-based model, which at the current time, is used to predict activities schedule. The schedule execution simulation and rescheduling are just the concepts, the models are not built.

C-TAP (continuous long-term demand model) model is used to simulate the dynamic situation in the long-term schedule. The series in C-TAP are defined by activity type, time

period, and travel time. The core idea of C-TAP is the usage of behavioral targets, which represent the motivation of agents to perform an activity. C-TAP enables the agents to react spontaneously to unexpected events since they can continuously adjust their decision based on changing environments. The kernel-based approach of target and look-ahead indices allows agents to consider different time horizons simultaneously (Janzen and Axhausen, 2015; Märki et al., 2014b).

Rasconi et al. (2010) regard the activities rescheduling problem as RPCSP (Resource-Constrained Project Scheduling Problem). The paper divides the activities rescheduling process as off-line and the on-line. The rescheduling process is in the on-line (active) phase, and the temporary constraints and events are in the off-line (proactive) phrase. The system allows several events to happen at the same time, and the time lag between the event aware time and location is regarded as urgency (computation time window). For changes from the previous schedule and the new temporary schedule is represented as a generic metric, the final decision is obtained by minimizing the value of the matrix. In activities rescheduling problem, RPCSP can be formalized as a tuple (V, C, R) , V is the set of activities, C is the set of temporal constraints that exist between activity pairs, and R is the set of renewable resources. The solutions under uncertainty have the same structure as well. The schedule P is realized by a graph $G_p = (V_p, R_p)$, activities are represented by nodes, and the edges connected them are time lags. The original schedule is the base problem P_{base} , events have the attributes of changed information, aware time and the location (which activity the event is located). To represent the solution of scheduling problem, partial order schedule (POS) is used. A POS provides the opportunity to reactively respond to external changes by simply propagating the effects of these changes over the simple temporal problem, and hence can minimize the need to recompute new solutions from scratch. Policella et al. (2004) use two algorithms to generate POS. Also, they put forward a method to evaluate the quality of POS.

3.5.2/ SUMMARY OF AGENT-BASED INDIVIDUAL ACTIVITY RESCHEDULING MODELS

Among all these agent-based individual activity rescheduling models, the rescheduling model in FEATHERS is at the state of concept, and it is not implemented yet. In this section, we conclude the goals, the advantages, and drawbacks of models of Matsim, ADAPTS, Aurora, C-TAP, and the model of Rasconi et al. (2010).

+ As shown in Table 3.3, Matsim is suitable to simulate large-scale simulation; ADAPTS mainly deals with the time adjustment for adding a new activity to the planned schedule; Aurora covers all alternative rescheduling choices; C-TAP proposes a way to deal with the

<i>Model</i>	<i>Goal</i>	<i>Advantages</i>	<i>Drawbacks</i>
Matsim	scheduling and rescheduling the activity and travel for one day	suitable for large-scale simulation; can dynamically reschedule activities	no sequence change in the choice set; event attributes, activity type and time pressure are not considered
ADAPTS	dynamically scheduling and rescheduling activity and travel from the horizon of activity	the rescheduling choices are regarded as separate discrete event, an activity schedule can be created and modified over time	activities swapping, multi-event, activity type and time pressure are not considered, mainly used to consider the event of adding an activity into the planned schedule
Aurora	simulates activity-travel scheduling and rescheduling decision in space and time	uses a heuristic algorithm to find the best rescheduling decision within all the possibilities	factors of event type, activity type, and time pressure are not considered; needs big computability
C-TAP	predicts and adjust the long-term schedule	allows the agent to adjust their schedule along with the environment's change; puts forward interesting parameters in optimization method	the rescheduling process is non-dynamic; cannot resolve within day rescheduling
Rasconi et al. (2010)	inspired by the job shop rescheduling model, the goal is to testify the robustness of a planned schedule	can be easily plugged in interchangeable components; solve multi-event situation	lack attributes of individual preference and activity type

Table 3.3: Summary of agent-based individual activity rescheduling models

location changing in long-term activity rescheduling; the model of Rasconi et al. (2010) analyzes more about unexpected events, and it is the only one which has the ability to deal with multi-event situations.

The main goal of our research works is dealing with the individual activity rescheduling

problem, explore the relationship between a pair of connected activities, and consider all the types of unexpected events as much as possible. Taking advantage of these above models and combining the goal to reach, a new individual activity rescheduling model is proposed in Section 6.4.

3.6/ CONCLUSION

The state of the art of the individual rescheduling problem is summarized in Figure 3.1.

Based on the presented works, the factors affecting the activity rescheduling decision are classified as a static or dynamic factors. The static factors consist of the attributes of the unexpected events, the individual, and also the activity. The dynamic factor that is considered in our research work is the time pressure, and the factors affecting the time pressure and its effect on decision-making are discussed.

Under the condition of unexpected events, the individual is faced with a set of alternative choices. To choose an optimal one among them, an optimization method needs to be used. This chapter introduces the alternative choices of adjusting time attributes of the episodes, changing the route of a trip, changing the location of an activity. These methods are classified as utility maximization, penalty minimization, or hybrid methods, and they are discussed.

Given all these aspects, the affecting factors, alternative choices, and optimization methods, a model is needed to simulate the rescheduling process. An agent-oriented approach is preferred, and the current popular agent-based activity rescheduling models are listed and discussed. The considered agent models are Matsim, ADATPS, Aurora, C-TAP, and the model of Rasconi et al. (2010).

Considering the analysis of state of the art related to the individual activity rescheduling problem, i.e, the advantages and disadvantages of each presented model, Chapter 5 summaries our detailed contributions, i.e, the general constraints, hypothesis, and refined research questions that provide answers to the general research questions that are presented in Chapter 1.

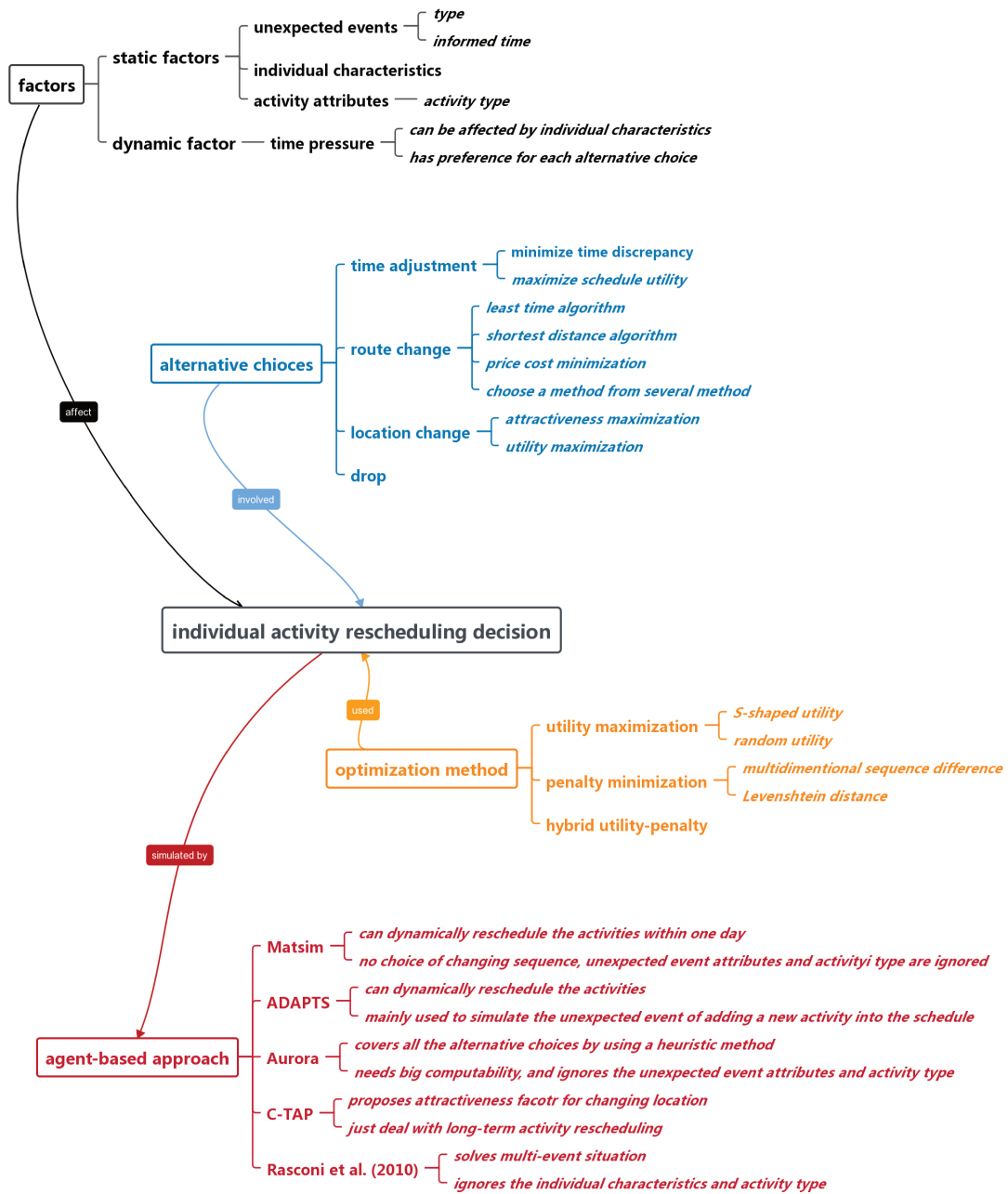


Figure 3.1: Summary of state of the art related to individual activity rescheduling problem

JOINT TRIP RENEGOTIATION

4.1/ INTRODUCTION

Activity rescheduling decision consists of individual activity rescheduling and joint trip renegotiating. After introducing and discussing in the previous chapter, the current works about the individual activity rescheduling problem, this chapter explores state of the art related to the joint trip renegotiating problem. As explained in Section 1.2, Question RQ1 has been explained in Chapter 2. Question RQ2: “what are unexpected events, and how they affect the rescheduling process;” and Question RQ4: “under unexpected event happening, what kind of choices the individual is faced,” are partly related to the joint trip renegotiating problem. For a planned joint trip, the uncertainties that may affect it are the congestion on a segment or the location change demand. If there are alternative locations for an activity, changing location is in the alternative choices under congestion as well. This thesis wants to study the offers exchange between the participants in the joint trip. Therefore, we just consider the congestion event. Under a congestion event, the alternative choices for a participant during the negotiation process can be learned from the alternative choices in the individual activity rescheduling problem (see Section 3.3 for details).

Considering Definition 12, page 18, that is “the renegotiation process can be regarded as a certain repeated-negotiation game”, state of the art on the renegotiating problem of the trips and activities is detailed in this chapter. This chapter firstly introduces the factors that affect the joint trip renegotiating decision to solve Question RQ3. It presents the strategies that are used to generate an offer during the renegotiation process (Question RQ5). Finally, the agent-based models used to solve this problem are detailed (Question RQ6).

4.2/ FACTORS AFFECT JOINT TRIP RENEGOTIATION

As we explained previously, renegotiation is a repeated game of negotiation. Therefore, we analyze the factors that affect the renegotiation from the view of negotiation. According to Definition 10, page 17, that is “negotiation is defined as the process in which a joint decision is made by two or more parties. The parties first verbalize contradictory demands and then move towards an agreement by process of concession-making or search for new alternatives”, it can be seen that the negotiation consists of at least two parties. Therefore, the characteristics of an individual, his opponent(s), and their relationship are significant during negotiation/renegotiation. Moreover, the attributes of the joint trip affect the renegotiation as well. What is more, like individual activity rescheduling, joint trip renegotiating suffers a time threshold, resulting in time pressure.

This section studies the factors affecting the joint trip renegotiating as individual characteristics, social relationships, joint trip attributes, and time pressure. They are classified as static factors and dynamic factors.

4.2.1/ STATIC FACTORS AFFECTING JOINT TRIP RENEGOTIATION

Static factors are the factors that are stable during the negotiation/renegotiation. These factors are classified as individual characteristics, social relationship, and joint trip attributes:

- 1. Individual characteristics:** Individual's characteristics consist of age, gender, job, personality, etc (Clark, 2008). They affect people's attitudes and preferences for the final decision in the negotiation/renegotiation. In group decision-making, the individual characteristics composed of both the person's own characteristics and the opponent's characteristics.

For the information obtained from others, the acceptance of the individual depends on the attributes of similarity to the other people, such as education, age, income, gender, and others. They may influence the extent to which a person relates to and identifies him or herself with the other (Han et al., 2011).

Malodia and Singla (2016) put forward that for carpooling, there are several attributes considered, walking time to the meeting place, wait time at the meeting place, travel cost and travel time. And the different individual has a different preference to attributes in the carpooling. Also, in a joint trip, individual with a different role, passenger or driver, have different emotions on trip attributes.

Zhu and Fan (2017) study participants' emotions during the joint trip negotiation.

The authors classify the emotions as positive and negative. Positive emotion is related to happiness and desirable, and it promotes thinking and socializing. They propose that compared to a car driver, passengers are not associated with positive emotions. And car driver controls more about the interaction during the joint trip.

2. Social relationship: Except for the individual characteristics, social networks affect negotiation as well. Social networks are a graph representation of individuals and their relationships. Each person has a set of acquaintances, which is defined by their personal social network, and the relationship consists of links in groups such as a family, work, and friends.

In a joint decision, the social relationship should be taken into consideration (Ronald et al., 2009). Participation in social and leisure activities is determined by one's friends and the groups that the one is a member of, i.e, their household, their workplace/school, sporting groups, voluntary organizations, and clubs.

Based on the social relationship, Kim and Fragale (2005) propose that the group members have different power and contribution in negotiation. The authors explain the bargaining zone as the minimum level of potential benefits. They analyze the relationship between the bargaining zone and the best alternative to the negotiated agreement (BATNA).

3. Joint trip attributes: For the joint trip negotiation/renegotiation, the joint trip attributes affect the final decision. The joint trip attributes consist of a location, which can reflect the purpose of the trip, a trip start time, duration, route, and involved participants (see Definition 11 page 18).

In the carpooling negotiation, (Huang et al., 2019) propose that individuals care most about the trip duration and trip cost. For different types of trip's purposes, individuals have different attitudes to carpool.

Gheorghiu and Delhomme (2018) argue that individuals are more likely to carpool to execute leisure or shopping activities. For the corresponding trips, individuals may have a bigger concession and more alternative choices during the joint trip negotiation/renegotiation, since these activities have certain flexibility. For the purpose of work or education, which has less flexibility, individuals would have a lower concession and fewer alternatives during the joint trip negotiation/renegotiation.

Based on the current researches on these static factors, which affect the joint trip renegotiating, we conclude their influence as in Table 4.1. In this thesis, we care about the unexpected event of congestion happening on a certain joint trip. Individual characteristics and social relationship are also considered in our model in Section 7.4.4.

<i>Static Factor</i>	<i>Elements in It</i>	<i>Its Influence</i>
individual	gender, age, employment status, commute distance, race/ethnicity, hours, occupation and industry, household type, etc. (Schwanen et al., 2008; Clark, 2008)	<ul style="list-style-type: none"> • affect his similarity to his opponent • different has different preference to attributes during the negotiation/renegotiation • the role of passenger/driver has different emotions to negotiate/renegotiate
social relationship	family, work and friends etc.(Ronald et al., 2009)	<ul style="list-style-type: none"> • different relationship has different power (benefit level) during negotiation/renegotiation
the joint trip	origination, start time, duration, location, mode, route, involved participants (Definition 10 page 17)	<ul style="list-style-type: none"> • purpose of the joint trip affect the individual's concession

Table 4.1: Summary of static factors in joint trip renegotiating

4.2.2/ DYNAMIC FACTOR AFFECTING JOINT TRIP RENEGOTIATION

A factor is dynamic when it changes among time passing by. Therefore, it affects joint trip renegotiation dynamically. In the context of this thesis, we propose that group time pressure the dynamic factor that affects the joint trip renegotiation. The group time pressure is different than the time pressure in individual activity rescheduling, and it is defined as:

Definition 27: Group Time Pressure

Because of the time threshold, the participants in a group feels different time pressure and then offers a different concession in the joint decision-making.

In group decision-making, involved persons need to negotiate with each other. Different people may feel different time pressure in the same group.

Lau et al. (2004) combine individuals' eagerness into time pressure when making negotiation decisions. And time pressure affects the degree and speed of the concession of the individual to his opponent's offer. Under certain of time pressure, a group member may have a different strategy to make a decision.

Sasaki (2011) explains that the essential problem on time-stressed collaborative decision making is the discovery and evaluation of the critical point of selection of proper strategies between collaboration and competition. The author proposes a computational theory to deal with the dynamic selection of strategies between collaboration and competition in

the decision-making process.

Kelly and Karau (1999) propose that group time pressure can narrow the attention in negotiation. AFM is an integration of prior individual-level research and theory on time pressure and performance with current group-level research on interaction and performance. The authors study the individual's preference and group decision both on low time pressure and high time pressure. And they find out that when the decisions are simple, time pressure restricts communication and increases consensus, which may facilitate efforts to make a decision efficiently. While, on more complex decisions, time pressure might lead to too few cues that are not necessarily diagnostic, leading to poorer decisions.

De Dreu (2003) focuses on information processing in negotiation under time pressure. He thinks that the effects on a time constrain on information processing in negotiation is due to a higher need for cognitive under high time pressure. Time pressure induces closing of the mind: people seek cognitive closure, stop considering multiple alternatives, engage in shallow rather than thorough and systematic processing of information, and they refrain from critical probing of a given seemingly adequate solution or judgment. In the high time pressure, people believe that this amount of time was relatively tight, while those in low time pressure are led to believe that this same amount of time was more than enough to reach an agreement.

Van der Kleij et al. (2009) compare the performance of negotiation under time pressure for face-to-face negotiation and radio communication and finds that there is no difference between them. And, the author puts forward that also high time pressure makes the team working a faster rate. While team members are less satisfied with the quality of the result and also the interactions between fellow team member.

We conclude the group time pressure's effect on joint trip renegotiating as:

- **decision speed:** group time pressure narrows the participant's attention to negotiate, it may speed up the decision-making process.
- **decision strategy:** under different group time pressure, participants may choose a different strategy to negotiate.
- **decision quality:** the decision under group time pressure, not only is affected by time pressure, but also by the type of the decision. Group time pressure affects the participant's concession degree to his opponent.

What is more, the individual characteristics affect the degree at which an individual feels about the group time pressure and the limited effect of the participants' negotiation behaviors on the group time pressure. In this thesis, we agree with the fact that group time

pressure affects the decision quality. The model of joint trip renegotiating in this thesis uses the parameter of group time pressure to decrease the decision utility.

4.3/ RENEGOTIATION STRATEGY

Taking into consideration the factors that are affecting the joint trip renegotiating decision, the participants need to choose a strategy to negotiate and reach the final decision. This section introduces three strategies: game theory, heuristic method, and argumentation-based approach (Rahwan, 2004).

4.3.1/ STRATEGY CLASSIFICATION

The classification of the negotiation strategies is outlined by Rahwan (2004) and detailed in the rest of this section.

Game theory: The work of Binmore and Vulkan (1999) is among the first work using game theory for automated negotiation. The authors put forward that game theory offers a very powerful tool for studying and engineering strategic interaction among self-interested computational agents in general, and to automated negotiation in particular. Classical game theory assumes that negotiate agents have unbounded computational resources, complete knowledge of the outcome space, and they are optimizers of the utility of the sense of ration-choice theory. In this case, the negotiation problem is often simplified, and some important pieces of information are not used. Therefore, it is possible that the optimal solution may be just some reference information instead of a viable solution (Leão e Silva Filho and Costa Morais, 2019).

Heuristic method: When agents relax some of the assumptions of game theory, particularly regarding unbounded rationality, they immediately fall outside the region of predictability of classical game theory. Heuristic is rules of thumb that produce good enough (rather than optimal) outcomes. Instead of exploring all possible deals, agents exchange offers based on heuristic functions that depend on time deadlines and resource availability. A number of heuristic methods have been employed in the negotiation framework by Sierra et al. (1999). It uses a gradual representation of the real world to provide good solutions, but not necessarily optimal ones. It is possible in heuristics to develop some ways to represent negotiations with their own characteristics. It is necessary to aggregate

some concepts and ideas to increase the possibility of getting closer to reality (Leão e Silva Filho and Costa Morais, 2019).

Argumentation-based approach: Jennings et al. (1998) put forward the argumentation-based approach to negotiate. In most game theory and heuristics models, agents exchange proposals. While, in argumentation-based method, it allows agents to give each other useful “hints” during negotiation. In this case, instead of providing a mere rejection of the opponent’s proposal, an individual can also provide the hints for a rejection or a critique of the proposal. Arguments can allow an agent to influence another agent’s preferences by providing the latter with new information. This may make it possible to change the other agent’s preferences or its perception of the negotiation space itself.

According to our state of the art in the area of joint trip negotiation/renegotiation, the most used strategies are game theory and heuristic method. Both of them assume that **agents know what they want**. In other words, agents have a precise and correct way of calculating the quality of the negotiation outcome, usually by using numerical utility functions. The major assumptions in game theory and heuristic method are:

- Agents exchange proposals, i.e, potential agreements or potential deals. Agents are not allowed to exchange any additional information other than what it is expressed in the proposal itself.
- Agents’ preferences over proposals are assumed to be proper in the sense that they reflect the true benefit that the agent receives from satisfying these preferences.
- Agents’ utilities or preferences are fixed. A rational agent would only modify its preferences upon receipt of new information.

Game theory researchers focus on reaching solutions at equilibrium under varied assumptions like unbounded computational resources, complete information, or some statistical information regarding the strategies and preferences of the other parties (Fatima et al., 2004). Additionally, since agents are heterogeneous, not all of the agents know the same strategies. Identifying which sets of strategies are known by each agent may be a hard task that can only be successful after several negotiations. The same goes for the knowledge regarding the opponents’ preferences, reservations values, and so forth. Only after several interactions and negotiations with the opponents, the agent may be able to come with an approximate model of the other agents. Hence, models that tackle uncertainty and limit the use of computational resources are mandatory for some situations. Heuristic models usually avoid the aforementioned assumptions. As a result, they usually

do not find equilibriums, but they obtain satisfactory results (Jennings et al., 2001). From this point, this thesis would like to explore the [heuristic approach](#) used in the joint trip negotiation/renegotiation.

4.3.2/ HEURISTIC APPROACH IN THE JOINT TRIP NEGOTIATION/RENEGOTIATION

As stated before, the heuristic approaches to optimize the final choice are mostly used in joint trip negotiation/renegotiation. In this section, the factors that are considered in previous researches for negotiation/renegotiation.

In the joint trip negotiation/renegotiation, there are two goals to reach: (i) the generation of an optimal offer, which maximize the participants' own utilities, and (ii) the generation of the count offer (response to the incoming offer), which considers the participants' concessions to their opponents. These two major goals are detailed below:

- **Generate the optimal choice (participant's own utility):** In order to find the optimal offer during the joint trip negotiation/renegotiation: Winter and Nittel (2006) use a two-way negotiation process, and the authors regard the trip duration as optimization criterion, i.e, the quality of the trip increases only as of the trip duration decreases.

Joksimovic et al. (2005) establish a three-level to generate the joint trip, the dynamic network loading, the route choice and departure choice, and the road pricing level. They study the individual's decision changing in response to the road price changing. The authors combine the dynamic road pricing into the utility of the choice model.

Kassler et al. (2012) combine QoE (quality of experience) into a utility function when choosing the optimal path for a joint trip.

Ghavami et al. (2016) consider both his own utility, and other agent's utility, and willingness to collaborate for the negotiation.

O'Connor et al. (2005) find that the quality of deals negotiators reach is significantly influenced by their bargaining experience.

- **Generate the fitness offer (make concessions considering the participant's opponent):** During the joint trip negotiation/renegotiation, when receiving an incoming offer, if the participant refused it after evaluating, he needs to generate a count offer. To generate the count offer, the participant needs not only considers his own preference, but also to make concessions based on the incoming offer.

Lau et al. (2004) use a fitness function to select the best offer in an agent's offer

set when negotiating. The fitness function considers both the agent's own utility, the opponent's offer, the time pressure along with time passing, and also the trade-off, which represents an agent's attitude to his opponent.

Boukhater et al. (2014) consider the trip distance, time cost, the fairness penalty, and preference cost into the fitness function during the joint trip negotiation process.

de Jonge and Sierra introduce a new family of negotiation algorithm for very large and complex agreement spaces, with multiple selfish agents, non-linear utility functions and a limited amount of time. They use two aspiration levels of utility, which considers both the agent's utility (involves the agent's preferences) and also the concession to the opponent.

In order to generate the optimal offer, a utility function is used. The associated utility maximization methods have been introduced in Section 3.4. In the context of the joint trip negotiation/renegotiation, these methods should consider the joint trip attributes and the individuals' preferences.

In order to generate the count offer, a fitness function needs to be used. Based on the above researches, several factors are considered when making concessions to generate the count offer:

- **The participant's own optimal offer:** The first thing is to consider the participant's own preference. Although he needs to compromise to his opponent, it is still essential to care his own utility.
- **The opponent's incoming offer:** The incoming offer reflects the opponent's preference, and the participant needs to take it into consideration as well.
- **Social relationship:** The relationship between agents determines the participant's attitude of concession when evaluating an incoming offer and providing a count offer.
- **Group time pressure:** Along with time passing by, the concession of the agent will change. The more closed to the deadline of negotiation, the more time pressure the agent feel to make the agreement.

4.4/ AGENT-BASED MODELS FOR NEGOTIATION

In this section, the agent-based models that are dedicated to negotiation among agents are described. They are classified into the agent-based multi-team negotiation and multi-individual negotiation models.

4.4.1/ AGENT-BASED MULTI-INDIVIDUAL NEGOTIATION

Multi-individual negotiation is popular in real life, for example, bargaining problem (buyer and seller), job shop scheduling problem, etc. It means that during the negotiation, the individual is on behalf of himself. He interacts with others to negotiate for his own benefit.

An agent-based multi-individual negotiation model should have the rules addressing the following issues (Jennings et al., 2001):

- **Rules for admission:** specify when an agent can participate in a negotiation dialogue and under what conditions.
- **Rules for participant withdrawal:** specify when a participant may withdraw from the negotiation.
- **Termination rules:** specify when an encounter must end (e.g, if one agent utters an acceptance locution).
- **Rules for proposal validity:** specify when a proposal is compliant with some conditions (e.g, an agent may not be allowed to make a proposal that has already been rejected).
- **Rules for outcome determination:** specify the outcome of the interaction.
- **Commitment rules:** specify how agents' commitments should be managed, whether and when an agent can withdraw a commitment made previously in the dialogue, how inconsistencies between an utterance and a previous commitment are accounted for, and so on.

4.4.2/ AGENT-BASED MULTI-TEAM NEGOTIATION

A negotiation team is a negotiation party that is formed by multiple individuals instead of just one individual. As a negotiation party, the team negotiates with other parties in order to reach a final agreement.

Definition 28: Negotiation Team

A negotiation team is a group of two or more interdependent persons who join together as a single negotiating party because their similar interests and objectives relate to the negotiation, and who are all present at the bargaining table (Thompson et al., 1996).

Humans may be slow at coming with a proper negotiated deal that accounts for everyone's preferences. This task may not be only slow, but also tedious since a conflict may be

present. And the agent-based automated negotiation approach is feasible to deal with such a problem.

Definition 29: Agent-based Negotiation Team

An agent-based negotiation team is a group of interdependent agents that join together as a single negotiation party due to their shared interests in the negotiation at hand (Sanchez-Anguix et al., 2013).

The reasons to employ an agent-based negotiation team may vary:

- i more computation and parallelization capabilities;
- ii unite agents with different expertise and skills whose joint work makes it possible to tackle complex negotiation domains;
- iii the necessity to represent different stakeholders or different preferences in the same party (e.g., organizations, countries, and married couple).

For the agent-based model of multi-team negotiation, three main tasks need to be solved:

- **Intra-team strategy:** There are negotiation protocols defining the rules of interaction to be followed by different parties. In a single-player party, the decisions are individually taken by one agent. However, when the party is formed by multiple individuals, it is necessary to decide on how, when, and what decisions are taken, and who takes those decisions. This is what is termed as an intra-team strategy or negotiation team dynamics.

Also, in the intra-team strategy, it is also necessary to make:

- a) **Role allocation:** It may be the case that some intra-team strategies additionally require role/task assignment (e.g., information retrieval and monitoring the market).

Nair et al. (2003) propose a framework that is capable of evaluating different role allocation and reallocation policies in cooperative teams by means of distributed Partially Observable Markov Decision Processes. This approach may be valid for intra-team strategies that require different roles. However, rewards stemming from role allocation may be uncertain in a negotiation team since agents are heterogeneous, and they may not know each other. Additionally, it is a cooperative approach that does not take into account the preferences of agents over tasks.

Hoogendoorn and Jonker (2006) present a negotiation framework for the allocation of tasks between agents. An agent can place requests for task distribution among other agents. Then, agents bid for being assigned to the tasks

of their interest. A negotiated approach is more convenient when agents are heterogeneous, and they have different preferences with respect to roles. However, in this approach, only bids are considered to assign tasks to agents. It does not take into account other factors like past experiences, trust, and reputation, etc.

b) Individual goal: With respect to role allocation, it should be pointed out that team members may also have their own individual goals.

Grosz et al. (2002) present a framework where agents have to reconcile the conflict between team commitments and individual actions. If an individual action reports benefits, and it is inconsistent with a committed team action, the agent can choose to de-commit and pursue its own self-interest. Authors propose the use of social norms, with associated punishments and rewards, to make team commitments prevail. However, social norms are difficult to deploy in a negotiation team unless a central authority exists. Even so, it may not be possible to determine whether or not team members are collaborating since other agents' preferences are not known.

- **Individual strategy:** Each team member should plan its individual strategy before heading into the negotiation. An intra-team strategy defines mechanisms for team decision-making, but they do not define how individual team members behave when playing those mechanisms. It is up to the agent to decide how to act inside the team: it can be more or less cooperative. The agent should also decide its attitude with the opponent. The two aforementioned factors will define the initial negotiation strategy of each team member.

Generally, the selection of the initial negotiation strategy is based on what is expected about the opponent and teammates. As stated in the previous section, one of our hypotheses is that the conditions of the negotiation environment play a key role in selecting which intra-team strategies are more appropriate for each specific situation. Thus, team members should also decide on their individual strategy based on the knowledge about the conditions of the negotiation. We consider that the mechanisms employed in other domains involving single-player parties are also applicable in this task. Hence, no special challenge arises.

- **Negotiation and adaptation:** The final phase is the negotiation itself. During this phase, team members should follow the planned intra-team strategies, individual strategies, and negotiation protocols. However, negotiation is a dynamic process that may not work as planned (e.g., opponents not behaving as one initially thought, team members performing below/above one's expectations, and team members leaving the team). Therefore, it may be necessary that each team member adapts

its own negotiation strategy, and that the team replans some of the aspects related to team composition and team dynamics.

Both agent-based multi-individual negotiation models and multi-team negotiation models have been used in the transportation area by researchers. The goal of this thesis is to study the individual daily activities, to simulate the joint trip renegotiating process by using an agent-based approach. Therefore, the agent-based multi-individual negotiation method is appropriate in the context of this thesis. In the following section, the current works on the joint trip renegotiation by using agent-based multi-individual negotiation methods are described.

4.5/ AGENT-BASED MODELS OF THE JOINT TRIP NEGOTIATION

The previous researches are mainly focused on the prediction of a joint trip. Since renegotiation can be regarded as a kind of repeated-negotiation, the agent-based models of the joint trip negotiation and renegotiation are presented in the rest of this section.

4.5.1/ AGENT-BASED MODELS OF DIRECT NEGOTIATION FOR THE JOINT TRIP

Using an agent based-based approach to deal with joint trip negotiation has been studied by numerous researchers.

Galland et al. (2013); Hussain et al. (2016); Liao (2019); Hussain et al. (2017) use an organizational agent-based model to simulate the negotiation of a joint trip. Social organization limits the communication requirements to individuals with similar characteristics. The carpool organization contains the carpooling agents. Carpooling agents can negotiate with each to get an agreement according to similarity constraint. The success of a negotiation is the trip start time between the tolerant time of all the agents.

Zhang et al. (2003) use a two-level framework to simulate the complex negotiation process. The upper-level deals with the formation of high-level goals and objectives for the agent. They use the MQ framework for this level. The author uses TEAMS framework to simulate the lower level, which deals with feasibility and implementation operations. The framework is suitable for multi-agent and multi-task negotiation.

Winter and Nittel (2006) use an ad hoc shared-ride system to solve the trip-planning task for a joint trip. They propose a distributed system of autonomous agents solving trip planning locally. Within an ad hoc mobile geo-sensor network, agents are capable of self-positioning and collect data about the current network, plan a trip, and select a driver

to car riding. It uses a two-way trip negotiation process that increases efficiency.

Banerjee and Srivastava (2015) design a system that models daily carpool scheduling as a repeated stochastic game played among willing carpoolers, which allows for individual choices and promotes carpooling as an equilibrium outcome. The paper allows each user to leverage its network to form daily carpools with peers in a distributed manner.

Lenar and Sobecki (2007) describe the classical negotiation process by using a negotiation algorithm block diagram. They clearly describe the negotiation process between two agents when receiving an incoming offer. The agent firstly identifies if it reaches the deadline or not. If no, then go to the step of evaluating the offer, and deciding if it is necessary to provide a counter offer or not. To effectively simulate the process, the author uses a recommended method to improve the negotiation process.

4.5.2/ AGENT-BASED MODELS OF INDIRECT NEGOTIATION FOR THE JOINT TRIP

Ghavami et al. (2016) define the facilitator agent, the listen agent, and the speaker agent in their negotiation model. The facilitator agent provides a plan and regards it as “on the table plan”, the model randomly determines who is speaker agent in each round. Speaker agent revises the current plan based on his own plan revision strategy, name it as “revised plan”. Each listen agent expresses his opinion about the plan by considering his own and other agents’ evaluation values, he constructs a social utility value for the revised plan.

Feng et al. (2015) use barge-terminal negotiation schema to simulate the coordination decision-making between agents. There are two ontologies to organize the agents’ negotiation. The mutual ontology ensures the understanding between multiple agents that use different personal ontology. Personal ontology abstracts the logic and strategic knowledge of an agent. The agent is embedded with computing engine, performing a certain amount of calculation tasks; negotiation engine, guiding the agent to understand incoming messages; and intelligence engine, providing the agent with the intelligence to be capable of adapting to its opponent’s behavior.

In this thesis, we would like to use the agent-based direct negotiation method to solve the joint trip renegotiating problem. Each individual can provide his offer directly to his opponent. Within the agent-based direct negotiation methods, the organizational agent-based models are mainly used to generate a joint trip. The organization is used to store the roles and information of all the participants in the joint trip. The focus of this thesis is the enroute-renegotiation, in which the trip is during execution, and the role of a participant is determined. Therefore, the organizational agent-based approach is not appropriate. We propose to agent-based direct negotiation model to simulate the joint trip renegotiating

problem.

4.6/ CONCLUSION

Figure 4.1 provides a summary of the state of art related to the joint trip renegotiating problem.

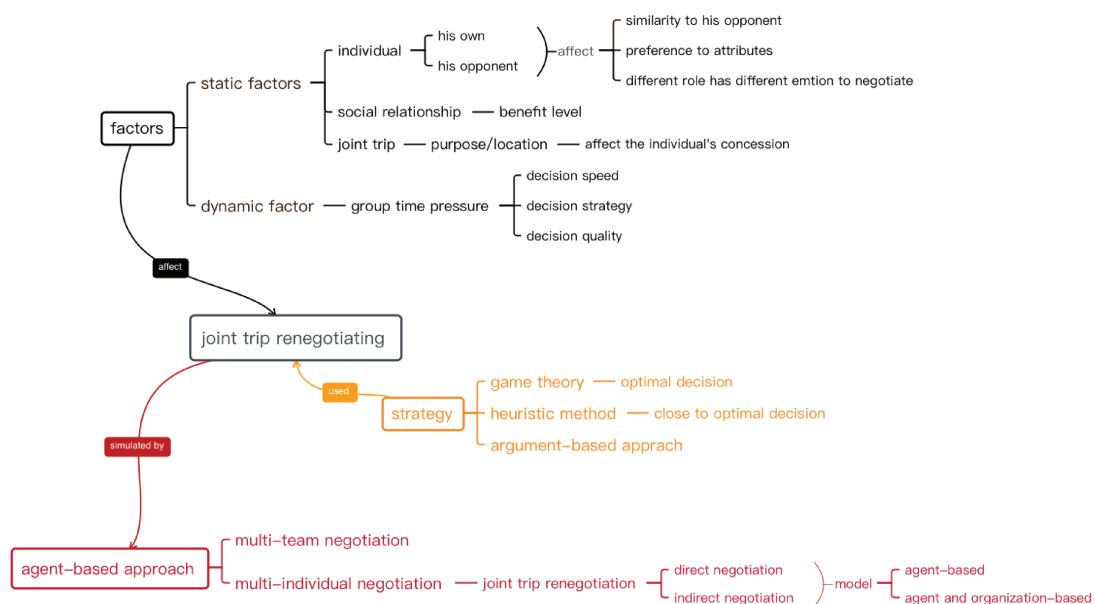


Figure 4.1: Summary of state of the art of joint trip renegotiating problem

Based on the works related to the joint trip renegotiation, the factors affecting the joint trip renegotiating decision are static and dynamic. The static factors consist of the individual's characteristics, social relationship, and trip's attributes. The dynamic factor is limited to group time pressure, and the effects of this group time pressure on the joint decision as well are discussed.

The unexpected event considered in the joint trip renegotiation is congestion. Under congestion, the participants involved in a joint trip need to renegotiate the trip, the arrival time, the path, and the location. During renegotiation, a strategy is necessary. This chapter introduces three negotiation strategies: game theory, heuristic methods, and argumentation-based approaches. The heuristic method is selected in order to solve the joint trip renegotiating problem. After analyzing the research works on the heuristic methods that are related to the topic, the utility function and fitness functions are described. The utility functions are used to generate the optimal offer. The fitness functions are used to generate the count offer to make concessions to the refused incoming offers.

In order to simulate the joint trip renegotiation process between the participants, several agent-based approaches are introduced. They are classified as agent-based multi-individual negotiation and agent-based multi-team negotiation models. The agent-based multi-individual negotiation models are appropriate. They are classified into direct negotiation methods and indirect negotiation methods. The agent-based direct negotiation model is selected in order to simulate the joint trip renegotiating problem.

Considering the analysis of state of the art related to the joint trip renegotiation problem, Chapter 5 summaries our detailed contributions, i.e, the general constraints, hypothesis, and refined research questions that provide answers to the general research questions that are presented in Chapter 1.



INDIVIDUAL AND COLLECTIVE ACTIVITY
RESCHEDULING

RESEARCH METHODOLOGY AND CONTRIBUTIONS

5.1/ INTRODUCTION

The goal of this chapter is to provide the contributions in order to answer to the [general problem](#) of daily activity rescheduling.

As we explained before, this thesis divides the daily activity rescheduling as individual activity rescheduling and joint trip renegotiating. From the summary and discussion of current works on activity scheduling problem (Chapter 3), it can be seen that for the individual activity rescheduling, most works adjust the whole schedule to respond to the unexpected events. Among the daily activity rescheduling models, MATSIM (Balmer et al., 2006) can deal with activity rescheduling problem, while it is to adjust the schedule before the execution. C-TAP (Märki et al., 2014b) also solves the activity rescheduling problem, but its focus is long-term activities. For the daily activity rescheduling problem during the schedule execution, ADAPTS (Auld and Mohammadian, 2009) and HARP (Gan and Recker, 2008) solve it by inserting an activity into the original schedule.

According to Chapter 4, research works on joint trip renegotiating contribute to the negotiation of generating the joint trip. Although renegotiation can be regarded as a repeated-negotiation problem, there are still differences from the renegotiation and negotiation, such as the input, constraints, affected factors, and also the negotiation strategy.

Recall the general problem of this thesis from Chapter 1:

- **General problem 1:** what is the agent-based model of the driver's decision-making process for the dynamic rescheduling of his/her daily activities under uncertain events from the environment?
- **General problem 2:** how to simulate the agent-based model that is an answer to

the first problem above?

In order to deal with these problems, we firstly propose the general constraints as following. We assume that there is limited time to make the activity rescheduling decision; only several types of flexible activities have alternative locations; and the activity should be executed during the open time of its located facility. After that, we propose in the next section the hypothesis of this thesis and the research questions to validate this hypothesis. In the last of this chapter, we simply conclude the contributions of this thesis.

CONSTRAINT 1: LIMITED DECISION TIME

For activity rescheduling, there is a time threshold to make the decision. The activity rescheduling decision should be made before the end of the affected episode, or within the limited decision time. The time threshold of making decisions depends on the informed time of the unexpected event.

CONSTRAINT 2: LIMITED ALTERNATIVE LOCATIONS

For an activity like education or work, there are no alternative locations. For other activities, the alternative location is decided by the activity type and facilities on the road network, such as shopping, drop-off, bank, etc.

CONSTRAINT 3: ACTIVITY EXECUTION DURING FACILITY OPEN TIME

The activity should be executed during the open time of located facilities, such as the open time of the market, bank, gym, etc.

5.2/ HYPOTHESIS RESEARCH QUESTIONS

The individual's movement behaviors are complex, and multiple factors may contribute to them, including social relationships among individuals, various geographical circumstances, and transport facilities (Yang et al., 2010). Travel behavior and decision-making in the rescheduling model clearly display all of these characteristics.

Travel behavior has been widely studied by using agent-based technology (Bazzan and Klügl, 2014). Agent-based approaches to travel simulation have shown that they are able to capture necessary details at the entity level as well as to reproduce relevant,

realistic phenomena. Agents are explicitly presented as active, heterogeneous entities in an environment representing the road network where they may exhibit arbitrary complex information processing and decision making. Their behavior, especially those resulting in simulated movement, can be visualized, monitored, and validated at the individual level, leading to new possibilities for analyzing, debugging, and illustrating traffic phenomena. In particular, one may identify a number of motivations for using agents and multi-agent system technologies in activity rescheduling decision-making process:

- 1) Because of self-organization capability, the agent-based approach can provide adaptive and robust services.
- 2) Autonomous agents provide an appropriate basis for modelling heterogeneous systems. Every entity possesses its individual architecture, state representation, and behaviour.
- 3) Agents and their interaction can be described using high-level abstractions.
- 4) Multi-agent system technologies allow coping with variable structures of the system in an elegant and efficient way.
- 5) The agent metaphor used for modelling a traffic participant or decision-makers can capture complex constraints connecting all problem-solving phases.

HYPOTHESIS

The agent-based model can simulate both individual activity rescheduling and joint trip renegotiating to respond to unexpected events during the execution of the planned schedule (or a joint trip).

5.2.1/ INDIVIDUAL ACTIVITY RESCHEDULING

To support the hypothesis above, this section explains the research method used in this thesis and proposes the refined research questions related to the general problems.

5.2.1.1/ RESEARCH METHOD: AGENT-BASED APPROACH

As explains in Hypothesis, the agent-based model is suitable to simulate the individual activity rescheduling problem. As illustrated in Figure 5.1, each agent is able to monitor its own context or environment, to retain its memory of past events, its tastes, and

preferences, etc., to keep track of its relationships and interactions with other agents and to make decisions about (and eventually execute) its daily activity and travel patterns. Within the confines of an individual agent, these decisions may be relatively simple and straightforward to model, given that the agent's decision-making context, memory, etc. are all explicitly “known” (at least within the simulated universe). Complexity within the overall travel markets still exists, largely in terms of the interaction between all the travel decision-makers. Indeed, they actually execute their activities' schedules and compete for road space (Habib and Miller, 2008).

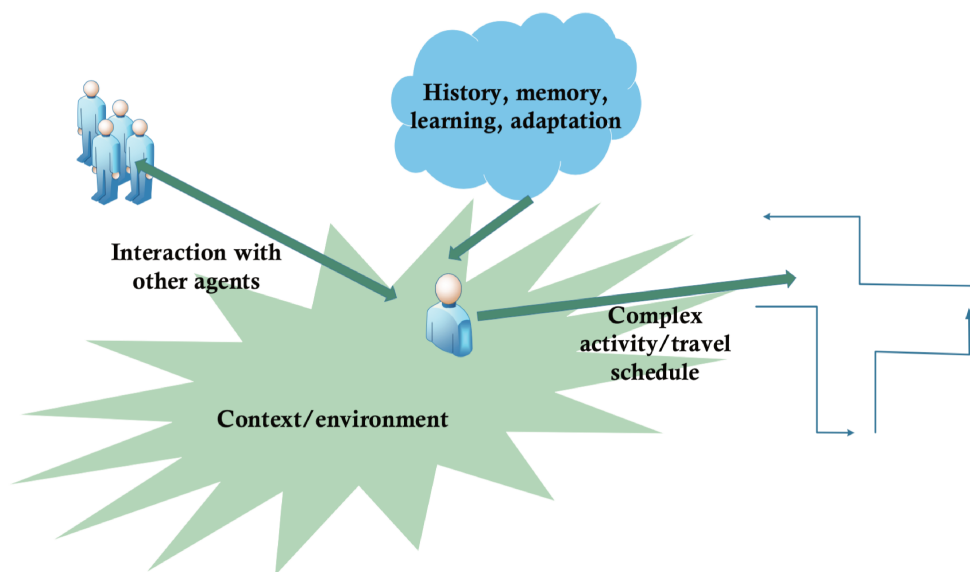


Figure 5.1: Agent-based modelling according to Bazzan and Klügl (2014)

5.2.1.2/ RESEARCH QUESTIONS FOR INDIVIDUAL ACTIVITY RESCHEDULING

Knowing that the individual activity rescheduling process is triggered by unexpected events, the Refined Research Question 1 is formulated as follows:

REFINED RESEARCH QUESTION 1

How to define the unexpected events in individual activity rescheduling?

According to the definition of the unexpected event (Definition 7 page 16), it is a triple tuple that consists of the trip/activity it affects, the informed time, and the changed information from the environment it obtains, which will affect the trip/activity. The most important part of an unexpected event is the changed information that it contains. In order to define

what kind of unexpected event should be considered in individual activity rescheduling, it is necessary to analyze what kind of changed information affects the planned individual daily activity schedule. As explained in the definition of the agent (Definition 17 page 22), agents have reactivity, i.e, they perceive their environment and respond in a timely fashion to changes that occur in it. Therefore, the agent-based approach has the ability to model and simulate the unexpected events in the individual activity rescheduling problem.

When an unexpected event happens, the individual needs to make the adjustment in his activity schedule to respond to it. Considering this, Refined Research Question 2 is formulated as follows:

REFINED RESEARCH QUESTION 2

How to generate the alternatives for building a new schedule, and choose the optimal one?

The alternative choices that the individual can have a need to take consideration of the above constraints. The location change choice exists only when there are alternative locations for the activity (Constraint 2), and the time adjustment should be within the time constraint, e.g, the activity should be executed within the open time of located facility (Constraint 3). What is more, as explained in Section 3.2, the unexpected events affect the activity rescheduling decision-making, and mainly the alternative choices. The types of unexpected events should also be taken into consideration when generating the alternative choice set for a given time. As for how to choose the optimal one, the constraint of decision time should be considered (Constraint 1). In Section 3.2, time pressure affects an individual's preferences for each choice. And, time pressure is raised from the time threshold.

To choose the optimal schedule, an optimization method should be used. Since the agents' behaviors are goal-directed, and they have self-organization capability, the agent-based approach can provide the service of making the decision according to the context and some rules (alternative choices and optimization method).

In order to solve the individual activity rescheduling, the main focus of this thesis is to explore the interrelationship between a pair of activities, and then we propose the Refined Research Question 3:

REFINED RESEARCH QUESTION 3

What is the relationship between a pair of connected activities, and how to support this relationship into the rescheduling process?

As we introduce in Section 3.2, the activity type has a strong effect on the activity rescheduling decision; Not only the activity type of the affected one, but also the activity type of the connected one. To solve this problem during the decision-making process, especially in the time adjustment module, it is preferred to adjust the time attributes of each episode, respectively. Secondly, to reflect the interrelationship between a pair of connected activities, we combine the parameters of the activity types into the optimization method of choosing the optimal choice from a choice set. As we explained in Refined Research Question 2, the agent-based model can support this method.

After considering all the parts of individual activity rescheduling, such as unexpected events, alternate choices, and optimization method, this chapter puts forward the Refined Research Question 4 related to the individual activity rescheduling problem:

REFINED RESEARCH QUESTION 4

How to simulate the individual activity rescheduling decision process?

An agent-based model is needed to simulate the individual activity rescheduling process. In the proposed model, it should clearly define when the activity rescheduling process starts; How it builds the alternative choice set; How to choose the optimal one; How to move to the next step after applying the new schedule; And when the simulation ends. Unexpected events, originally planned schedule, constraints, each alternative choice module, and optimization method are combined into the model.

5.2.2/ JOINT TRIP RENEGOTIATING

In order to solve the joint trip renegotiating problem, this section explains the associated research method used in this thesis and the refined research questions related to this problem.

5.2.2.1/ RESEARCH METHOD: AGENT-BASED APPROACH

To deal with the negotiation and renegotiation, the interactions between individuals are needed. As explained in the above hypothesis, agent-based modelling (ABM) is a suitable paradigm for the modelling of systems composed of interacting autonomous entities called “agents”. Moreover, ABM is a suitable approach for simulating human systems (Bonabeau, 2002), and has been successfully applied in negotiation and renegotiation of

joint trips (Sanchez-Anguix et al., 2013).

The advantages of using an agent-based approach to deal with negotiation/renegotiation are: (i) more computation and parallel capabilities; (ii) each agent has different expertise and skills; and (iii) it can represent different preferences. Wooldridge (2009) puts forward that agent interactions have several components: the negotiation set (possible proposals), a protocol (model), strategies, and a rule to determine that the interaction is complete.

5.2.2.2/ RESEARCH QUESTIONS FOR JOINT TRIP RENEGOTIATING

Within the set of all the possible unexpected events related to a joint trip, this thesis only considers the traffic congestion. When congestion happens within a joint trip, the participants need to renegotiate the trip. The first point to negotiate is how to exchange offers between the participants, e.g, the negotiation set (alternative proposals) and strategies in agent interactions. The Refined Research Question 5 is formulated as:

REFINED RESEARCH QUESTION 5

How to generate the alternative offers and count offer for an agent in a joint trip?

For a driver, he needs to consider if there are alternative locations (Constraint 2), and the activity time should be within the open time of the activity located facility (Constraint 3). For a passenger, he can choose to change to another location (if there is). Or, he can change to another drop off place, which is near the original location, and within his distance tolerance. If, during the renegotiation, a participant refuses the incoming offer from his opponent, he needs to generate a count offer. According to Constraint 1, there is a limited decision time to renegotiate. Under this condition, the participants suffer group time pressure. As we explain in Section 4.2, group time pressure affects a participant's concession degree to his opponent. Also, his concession is determined by the social relationship with his opponent. Therefore, a function needs to be used to generate count offer, which considers the participant's concession.

Knowing the exchange offers between the participants in a joint trip renegotiation, the agent interactions consist of a protocol and a rule in order to determine when the interaction is completed. Then, the Refined Research Question 6 is proposed:

REFINED RESEARCH QUESTION 6

How to simulate the joint trip renegotiating process?

An agent-based model is used to simulate the joint trip renegotiation process. In the proposed model, the times at which the renegotiation starts and ends are defined. Moreover, the proposed model should determine which one is the first to provide an offer, and the rule in order to choose the first offer among the alternative offers. When a participant receives an incoming offer, the model has the rule to evaluate if the offer is accepted or not.

5.3/ CONTRIBUTIONS

The goal of this thesis is to establish an agent-based model to simulate the individual decision-making process under uncertainties, from the aspects of individual activity rescheduling and joint trip renegotiating. To reach this goal, this chapter puts forward the general constraints, hypothesis, and also refined research questions, as illustrated in Figure 5.2.

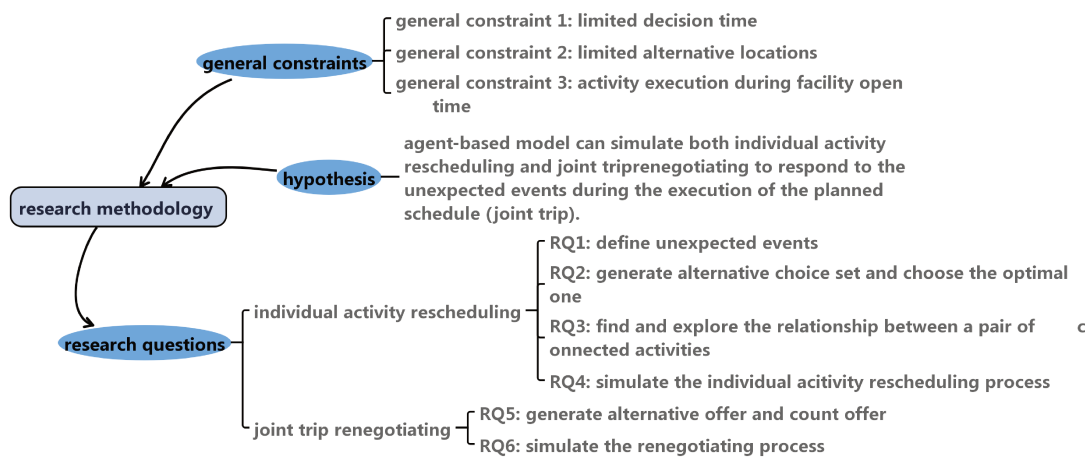


Figure 5.2: Summary of the research methodology

The following chapters of this thesis detail our contributions to solve the general problems and to respond to the refined research questions above. The contributions of this thesis are organized as follows:

- **Chapter 6:** It defines the unexpected events in individual activity rescheduling and proposes an agent-based model to simulate the activity rescheduling decision-making process. A specific module for time adjustment is proposed. Additionally, a penalty-based optimization method to find the optimal choice within the possible new schedules is detailed.

- **Chapter 7:** It defines the joint trip renegotiation process according to the unexpected events' happen time. It also distinguishes the differences between joint trip negotiation and renegotiation. This chapter explores the details in the renegotiation process from the affected factors, constraints, alternative choices, best offer for an individual and adjustment of the count offer (fitness offer) from the opponents.
- **Chapter 8:** This chapter presents the experiments in order to validate the proposed models in the two previous chapters. For the model of individual activity rescheduling, the effects of different unexpected events on the rescheduling decision are discussed. Additionally, the activity type's effect on the rescheduling decision is also discussed. For the model of joint trip renegotiating, an experiment with one passenger and one driver is presented. The offers that are exchanged by the passenger and driver are detailed.

AGENT-BASED RESCHEDULING MODEL OF INDIVIDUAL ACTIVITIES

6.1/ INTRODUCTION

When an unexpected event happens, the individual receives the information of the unexpected event and takes actions to respond to, i.e, rescheduling his planned schedule. After rescheduling, he continues to execute his new schedule by traveling the trips and running the activities. These principles are illustrated in the use case diagram in Figure 6.1. This figure also highlights that the individual is assimilated into an autonomous agent.

This chapter firstly describes the classification and comparison of several events, i.e, the long-term, short-term, and emergency events. Within this classification, each event

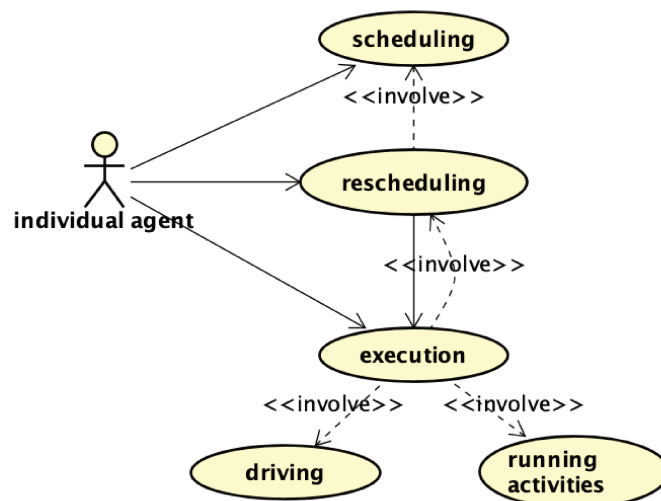


Figure 6.1: Use-case of Individual Activity Rescheduling

for individual activity rescheduling is defined as an external or internal event. The second contribution of this chapter is the definition of modules for determining alternative choices. Specifically, the modules of time adjustment, route change, location change, and episode dropping are detailed.

This chapter also puts forward that faced with a different type of events, a different type of activity has different choices' set to reschedule. An agent-based model is established in order to simulate the individual activity rescheduling process using a penalty-based optimization method.

6.2/ UNEXPECTED EVENTS FOR INDIVIDUAL ACTIVITY RESCHEDULING

Firstly, this chapter classifies the events and then explains the unexpected events that may happen during the individual activity rescheduling process.

6.2.1/ EVENT CLASSIFICATION

Events are the causes of changing the original schedule. Each event involves the changed information, which may affect the schedule and time attributes. In this thesis, the events are classified as long-term, short-term, and emergency events. Long-term events, which can also be called *life events*, usually happen before the execution of the schedule and affect the daily activity pattern (Müggenburg et al., 2015). For example, a new market is opening, the child changed to another school, a person changed his work position, or the family has a new car. These events are always the causes of habitual behavior changes, rather than daily activity-travel behaviors. The activity rescheduling under this situation is *non-dynamic*. Long-term events are not considered as unexpected events.

Short term events are *unexpected events*, which are characterized by uncertainties happening during the execution of the activity schedule; these constitute the main causes of dynamic activity rescheduling. The considered environment is composed of the road network, facilities where the activities are executed, and the individual's social network.

We regard the short-term events as external and internal events in this thesis. An *external event* is an event obtained from the environment. It is also a reason to trigger the rescheduling process. The *internal event* happens because of the change inside the schedule, e.g, change of the current episode affecting its next episode. In this thesis, e_i is the *current* episode that the model simulates. e_{i-1} is the *previous* episode and e_{i+1} is the *next* episode compared to e_i . Activities in the episodes e_i and e_{i+1} are connected

(a pair of). Therefore, e_i and e_{i+1} are connected episodes. For two connected episodes, if a change occurs in the attributes of the current episode, it may have an effect on the attributes of the next episode.

Emergency situations are not covered by this research. Examples for emergency events are environmental disasters, e.g, earthquakes, thunderstorms or Volcano eruptions, or industrial catastrophes, e.g, nuclear or chemical plant explosions, terrorist attacks, or wars (Keller et al., 2014). In this thesis, we take the premise that the **objectives** leading to a daily plan are not affected by the **need** for rescheduling.

The classification of the event types and characteristics is shown in Figure 6.2.

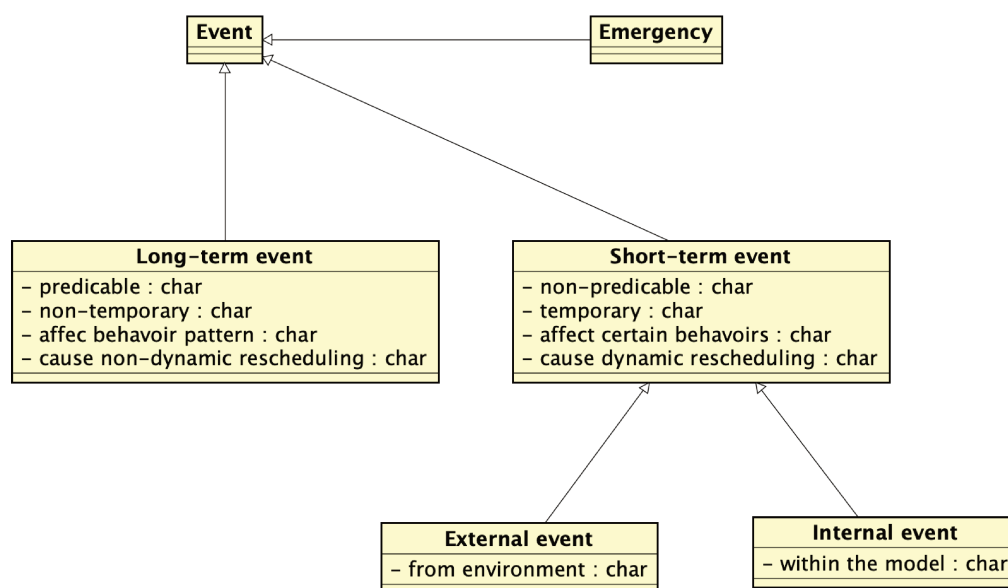


Figure 6.2: Classification of events types and their main characteristics

6.2.2/ CLASSIFICATION OF UNEXPECTED EVENTS FOR INDIVIDUAL ACTIVITY RESCHEDULING

For unexpected events, an external event is assumed to be triggered once at a time, and no multi-external-events happen simultaneously. While internal events may happen at the same time. We conclude the external event and internal event, and we define them according to the attributes of the activity and trip.

For the time attribute changes, the start time of the trip/activity **just considers the delay situation**. If a trip/activity is brought forward, for the episodes after it, there is no influence. For the uncompleted episodes before it, the rescheduling process is the same as the rescheduling under the situation of trip/activity starting delay. What should also be noted

is that in our model, there is no time lost between episodes and between the trip and activity. It means that the end time of a trip is the exact start time of the activity in the same episode. And, the end time of an activity is the start time of its next trip or episode.

A tuple $Event(t)$ represents an unexpected event, which means an event is triggered at time t . In the rest of this chapter, it is assumed that $Event(t)$ affects the episode i .

6.2.2.1/ EXTERNAL EVENTS

External events are the changed information obtained from the environment. We classified them as **travel change event** and **activity change event**:

- **Travel Change Event:** The unexpected events that contain the changing attributes of travel is called the **travel change event**.

For all the attributes in a trip, the origin and destination are determined by its previous activity and the activity in the same episode. An origin change is caused by the location change of its previous activity. It means the cause of changing origination comes from the rescheduling process, not the outside environment. It is an internal event, and it is discussed in Section 6.2.2.2. The destination of a trip is the location of the activity in the same episode. And a trip is to transfer the individual to the activity location to execute the activity. Generally, we assume that for the unexpected event from the environment, the event of changing a trip location is the result of changing an activity location. There, we regard the unexpected event of changing trip location as changing activity location in the **activity change event**. The duration change refers to congestion, and it is called a **congestion event**. Assume there is congestion on the segment seg_j on the route for the trip v_i , the congestion road data on this segment is seg_j^e , and the individual is informed by this congestion at time t , then we define this Equation 6.1 defines this event.

$$Event(t)^{congestion} = \langle v_i, seg_j^e, t \rangle \quad (6.1)$$

For the change of travel start time, if the travel begins earlier, it will not affect the connected activity. If it starts later, it can be called as **travel delay event**. In Equation 6.2, the trip start time is delayed by ΔT_{vDelay} . This event happens before the planned start time of this trip.

$$Event(t)^{travelDelay} = \langle v_i, \Delta T_{vDelay}, t \rangle, t < t_{vs_i} \quad (6.2)$$

- **Activity change event:** The unexpected events that change the attributes of activ-

ity are called **activity change events**. The classification of activity change events is based on the attribute of the activity as well. Regarding time changes, the event of start time delay is considered. Under this situation, the unexpected event happens before the planned start of the activity. If the activity is delayed, the unexpected event is called an **activity delay event**. In Equation 6.3, the start time of activity i is delayed by ΔT_{aDelay} .

$$Event(t)^{activityDelay} = \langle a_i, \Delta T_{aDelay}, t \rangle, t < t_{as_i} \quad (6.3)$$

For the duration change of activity, the unexpected happens before the planned end time of the activity. It is called an **activity duration event**. In Equation 6.4, the duration of activity i extends by ΔT_{da} than expected.

$$Event(t)^{activityDuration} = \langle a_i, \Delta T_{da}, t \rangle, t < t_{ae_i} \quad (6.4)$$

For the location change of activity, in Equation 6.5, the planned activity changes to a new location l_{new} before the arrival to the planned location. This unexpected event is called an **activity location event**.

$$Event(t)^{location} = \langle a_i, l_{new}, t \rangle, t \leq t_{as_i} \quad (6.5)$$

6.2.2.2/ INTERNAL EVENT

After adjusting the affected episode (current episode) to respond to the external events, the changes in the current episode may affect the next episode. The relationship between a pair of episodes is that the end time and location of an episode's activity is the start time and origin of its next episode's trip. If there is a temporary conflict between the planned start time and location with new changes for the next episode's trip, then an internal event automatically generated.

What is more, in one episode, if changing the attributes of a trip, it may have an effect on its connected activity. This situation is not considered as an internal event in this thesis, since we regard the episode as the object in the schedule. And, we want to explore the changed episodes in the schedule. Therefore, we analyze the internal event from the aspects of the trip start time and trip origin.

As for the internal event of trip start time delay, for the affected episode e_i , $T_i = 1$ means there is a time conflict between the activity a_i and its next trip v_{i+1} . The changed end time of the activity t'_{ae_i} is later than the planned start time of the next trip $t_{vs_{i+1}}$. And, the start

time of the next trip is delayed by $\Delta T_{vDelay} = t_{vs_{i+1}} - t_{ae_i}$. Otherwise, $T_i = 0$.

$$T_i = \begin{cases} 1 & \text{if } t_{ae_i} > t_{vs_{i+1}} \\ 0 & \text{else} \end{cases} \quad (6.6)$$

When the location of the current activity is changed as l'_i , the origin of the next trip $o_{v_{i+1}}$ is changed as well. And, then an internal trip origin event occurs. $L_i = 1$ means the location change of the activity i , and the new trip origin is $o_{v'_{i+1}} = l'_i$.

$$L_i = \begin{cases} 1 & \text{if } l_i \text{ is changed} \\ 0 & \text{else} \end{cases} \quad (6.7)$$

For the situation of $T_i = 1$ and $L_i = 0$, we regarded it as **internal trip delay event**, as show in Equation 6.8.

$$Event(t)^{internalTripDelay} = \langle v_{i+1}, \Delta T_{vDelay_{i+1}} \rangle \quad (6.8)$$

If $L_i = 1$ and $T_i = 0$, it is called **internal trip origination event**, as show in Equation 6.9.

$$Event(t)^{internalTripOri} = \langle v_{i+1}, o'_{v_{i+1}} \rangle \quad (6.9)$$

If both $T_i = 1$ and $L_i = 1$, it means both the start time and origination of next trip should be rescheduled, this situation is called **internal trip multi-change event**, as shown in Equation 6.10.

$$Event(t)^{internalTripMulti} = \langle v_{i+1}, T_{vDelay_{i+1}}, o'_{v_{i+1}} \rangle \quad (6.10)$$

6.3/ GENERATION OF ALTERNATIVE CHOICES

Four modules are defined in order to make a rescheduling decision for the affected episode in our model: time adjustment module, route change module, location change module, and activity drop module.

Changing mode, adding an activity, or substituting activities are not considered in this thesis. The inputs of each reschedule choice module are the attributes of the affected episode. The outputs of the reschedule module are the temporary new attributes of the rescheduled episode. The time and location are represented as t' and l' .

For all these kinds of events, time attributes are all changed. Unexpected events, i.e, **congestion event**, **travel delay event**, **activity duration event**, and **internal trip delay event**,

are directly time-related events. In the **internal trip multi-change event**, both the origin and time attributes are directly changed, and origin is the main reason to consider. Regarding the **activity location event** and **internal trip origination event**, time is not directly related. While, along with the location/origin changing, time attributes of the affected episode will change as well.

6.3.1/ TIME ADJUSTMENT MODULE

The time adjustment module is adjusting the time attributes and neither the planned path nor location of the planned episode. The time module is used to optimize the time attributes of the affected episode, and the goal of this module is to at least finish the minimal activity duration of the affected episode.

For the four types of directly time-related external events, **trip start delay event** and **internal trip delay event** have the same changed information. We consider them as one when making choices. Therefore, for the time change module, we consider the **congestion event**, **travel delay event**, and **activity duration event**. They are analyzed in Figure 6.3 and detailed below:

- **Trip delay event:** This event can only happen before the start of the affected episode, $t_{event} < t_{vs}$. If the trip is delayed for ΔT_{vdelay} . The trip start time is $t'_{vs} = t_{vs} + \Delta T_{vdelay}$, activity start time is $t'_{as} = t'_{vs} + d'_v$. If it is trip start time event, or in-delay event, $d'_v = d_v$. If it is in-both event, d'_v is obtained from Section 6.3.2. The new activity end time is as Equation 6.11.

$$t'_{ae} = \begin{cases} t_{ae} & \text{if } t_{ae} - t'_{as} \geq MinD_a \\ t'_{as} + MinD_a & \text{else} \end{cases} \quad (6.11)$$

- **Congestion event:** The location and trip start time keep same, $l' = l$ and $t'_{vs} = t_{vs}$. The trip duration is $d'_v = d_v + \Delta T_{congestion}$. And the activity start time $t'_{as} = t'_{vs} + d'_v$. The activity end time is as Equation 6.11.
- **Activity duration event:** It means the activity takes longer than expected, if the duration of the activity is extended to ΔT_{da} , and the new activity end time is:

$$t'_{ae} = t_{ae} + \Delta T_{da} \quad (6.12)$$



Figure 6.3: Time attributes change under directly time-related unexpected events

6.3.2/ ROUTE CHANGE MODULE

A location change results in a route change. While the route change occurs not only because of location change. No matter under what kind of unexpected events, an individual can change the route as he wants. The location change module is discussed in Section 6.3.3. In the module of route change, the agent re-plans the route with the same destination location as in the planned schedule. For a segment j , which connects a pair of nodes on the road map, travel time is defined as t_j ; road capacity as c_j ; road intensity as c'_j ; and the road free flow time as t_j^f . The free flow time is the travel time when the road is empty.

$$t_j = t_j^f \left[1 + \alpha \left(\frac{v_j}{c_j} \right)^\beta \right] \quad (6.13)$$

For all the paths connected from a node to another node on the road map, travel time is the shortest time along these paths. According to Kelly and Karau (1999), the valued of α and β are 0.15 and 4, respectively, in Equation 6.13. If choosing a new route, the t_{as} will

be changed, and t_{ae} may change as well. Assume there are i alternative routes, and a route has j paths. The new activity start time $t'_{as} = t + d'_v$, with:

$$d'_v = \text{Min} \sum_{j=1}^i t_j \quad (6.14)$$

And the activity end time t'_{ae} is Equation 6.11, page 85.

6.3.3/ LOCATION CHANGE MODULE

When choosing a location, the agent's perception of the location, quality of the location, and the seasonal influence are considered as location attractiveness ϕ (Janzen and Axhausen, 2017). The agent's perception of the location means the individual's awareness of the location. The location quality is people's appreciation of the location. Seasonal influence is the season's effect on the location, such as beaches are not appreciated in cold months.

In this thesis, we focus on the daily activity rescheduling rather than the long-term rescheduling. Therefore, seasonal influence is not considered. And we consider the activity utility since the distance of the location will affect the duration of the travel, and then affect the activity duration. Let $q(l)$ be the quality of the location, $q(l) \in [0, 1]$; $p(l)$ be the location perception of the agent, $p(l) \in [0.9, 1.1]$; u_i be the activity utility if choosing location l_i ; d_{ai} be the duration of the activity. Assuming that the destination location of the activity is l_i , all the time attributes of the episode can be obtained from Section 6.3.2. For example, the travel time to the new location, the activity start time, the activity duration. The new activity duration time becomes $d_{ai} = t'_{ae} - t'_{as}$. The utility function used in this thesis is based on duration as defined by De Dreu (2003). The utility of the activity executed at the location l_k is u_{i_k} , it is represented by the Equation 6.30, page 96.

As we mentioned above, a location's attractiveness is ϕ , and assume there are several alternative locations for an activity, the best choice is the location with the highest attractiveness. For an activity i , its choice of a new location k is as follows:

$$\text{maximize } \phi(l) = q(l_k) \times p(l_k) \times u_{i_k} \quad (6.15)$$

6.3.4/ ACTIVITY DROP MODULE

When rescheduling, there is a choice to drop/give up the activity, if and only if it is not a mandatory activity, e.g, work or education. If an activity is dropped, the trips associated

with this activity have to be merged to be canceled together (Dobler and Nagel, 2016).

6.3.5/ CUSTOMIZED ALTERNATIVE CHOICE SET

For a type of activity, such as shopping, working, or hiking, its alternative choices are different under an unexpected event. For example, the work activity cannot be dropped, the hiking activity cannot change its mode, etc. The unexpected event affects alternative choices as well. For instance, if the unexpected event happens during the trip, the trip start time cannot be changed. If the unexpected event happens during the activity, the route, location, and trip time attributes cannot be changed. Therefore, we provide alternative choice sets for different types of activities (Table 6.1). Activities are classified as: work, education, social visit, bring/get, daily shopping, leisure, service, and others. We also provide alternative choice sets for different types of unexpected events (Table 6.2).

<i>Activity Type</i>	<i>Choice Module</i>
work, education	Time, Route
social visit, bring/get	Time, Route, Drop
daily shopping, leisure, service, others	Time, Location, Drop, Router

Table 6.1: Activity type related to choice modules

<i>Event Type</i>	<i>Choice Module</i>
activity location event	Route, Drop
internal trip origination event, internal trip multi-change event	Route, Location, Drop
congestion event	Time, Route, Drop
trip delay event, internal trip delay event	Time, Location, Drop
activity duration event	Time, Drop

Table 6.2: Event type related to choice modules

As we explained, when an unexpected event happens on an episode, both the type of unexpected event and the activity type determine the alternative choice set. We define the alternative set for a certain activity under a certain unexpected event as the customized rescheduling alternative choice set. The customized rescheduling alternative choice is the intersection of the equipped modules of event type and activity type. Our model will apply each choice in the alternative choice set for the affected episode. The final choice chosen by the individual is the corresponding choice nodes in the optimal schedule. They are explained in the next section.

6.4/ INDIVIDUAL ACTIVITY RESCHEDULING MODEL

This section introduces the rescheduling process when an unexpected event happens; and then establishes an agent-based model to simulate this process. The first step for rescheduling is to input the necessary basic data, e.g, individual characteristics, planned schedule, and external events. When an unexpected event is triggered, the corresponding affected activity and the rest of the uncompleted activities in the schedule need to be rescheduled. The activity rescheduling process is as follows:

- **Step 1:** Input the planned schedule data, and the characteristics of external events.
- **Step 2:** Execute the episodes in the schedule, wait for the trigger of unexpected events. Go to the Step 3 at the time of the awareness of an unexpected event.
- **Step 3:** Reschedule the episode affected by the event and the rest of the episodes in the schedule. Get the customized reschedule choice modules for current episode according to the activity type, and choose the right time sub-module according to the event time level.
- **Step 4:** Apply the customized choice to the affected episode, and to identify it is the last episode in the schedule or not, if yes, go to Step 7, if not, go to Step 5.
- **Step 5:** Identify the next trip/activity is affected or not after applying the choice modules in the decision tree. If yes, go to Step 6, if not, go to Step 7.
- **Step 6:** Set the conflict of optimized current episode and next episode as an internal event, and go to Step 3.
- **Step 7:** Get a set of temporary schedules, and calculate the cost of each schedule. Apply the new schedule with the least cost. If there is only one episode in the schedule, execute the affected episode, and simulation ends. If not, go to Step 2. Since there is the drop module in the alternative choice set, there is no consideration of rescheduling failed. Drop the affected episode means the rescheduling process is failed to some extent.

After explaining the individual activity rescheduling process, the assumptions and constraints that are included in the model are:

- **Assumptions:** In the agent-based model simulating the individual activity rescheduling problem, we have made the following assumptions:
 - i. Agent has a set of actions to respond to the unexpected event.

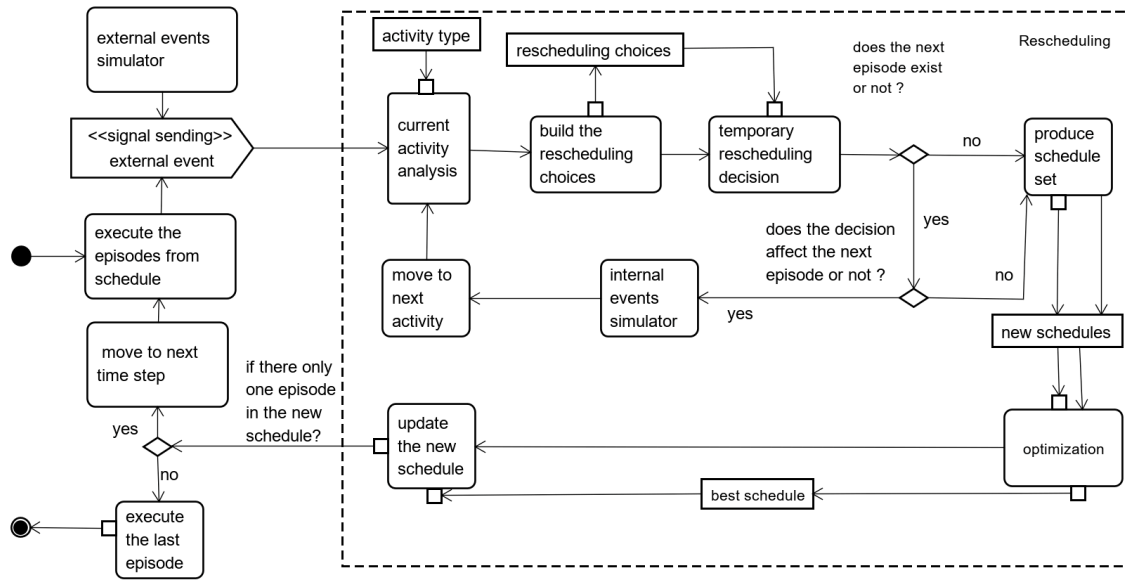


Figure 6.4: Schematic representation of rescheduling process faced with unexpected events

- ii. Agent has a preference for each temporary schedule, and it changes as time passing by.
 - iii. Agent has a utility function to score the temporary schedule, and it does not change over time.
 - iv. There is no interrelationship between the attributes when calculating the penalty. And the weight for penalizing each attribute change is equal.
 - v. Agent tries to keep the similarity to his planned schedule, and he is resistant to make changes.
- **Constraints:** The constraints consist of the connections of the trip and activity, and the time constraints related to facilities.

a) Location consistency: the location of the activity is the origination of the next trip.

$$l_{ai} = o_{v(i+1)} \quad (6.16)$$

b) Trip constraints: if using a public transport mode, the start time and the end time of the trip should be within the time usage of the transport mode, like bus, metro, or trains. Since this thesis just considers the individual car-driving, there is no constraint for car using, except for the driver's license.

c) Activity constraints: for an activity, it should be executed within the open time of the facility it is located. Assume the open time and close of the corre-

sponding location are l_{ot} and l_{ct} .

$$t_{as} \geq l_{ot} \quad (6.17)$$

$$t_{ae} \leq l_{ct} \quad (6.18)$$

The individual activity rescheduling process is defined based on the above general steps, assumptions, and constraints. Figure 6.4 shows up the activity diagram of this process. The process is triggered by an unexpected event. The agent has a set of choices to choose to make a response. These choices are determined by the event and activity types. If the change of the current episode affects the next episode, the internal event simulator is also triggered. Then, the model continues to reschedule the new affected episode as well. The process is specified in Algorithm 1. It is an adaptation of the C-TAP algorithm. The algorithm of the C-TAP is in Algorithm 2 (Larsen and Pranzo, 2019). In the C-TAP Algorithm 2, whenever an agent finishes the execution of an activity, the function *MakeDecision* (line 4) computes the next activity based on its current state, which has to be updated before (line 3). After that, the activity is executed until the computed execution end. In our rescheduling Algorithm 1 page, 91, the agent makes the final decision after rescheduling all the uncompleted activities, and then he chooses the optimal new schedule.

Algorithm 1 Core Rescheduling Algorithm

Input: an *externalEvent* and an original schedule

Output: a new schedule

```

1: while simulation is not ended do
2:   Event  $\leftarrow$  externalEvent
3:   newschedule  $\leftarrow$  schedule
4:   for all episodes not being executed do
5:     Event affect affectedEpisode
6:     choiceSet(affectedEpisode)  $\leftarrow$  choiceCustomized
7:     execute(agent, affectedEpisode)
8:     if nextEpisode be Affected then
9:       affectedEpisode  $\leftarrow$  nextEpisode
10:      Event  $\leftarrow$  internalEvent
11:    end if
12:  end for
13:  Calculate cost C of all the temporaryscheduleset
14:  newschedule  $\leftarrow$  MinimizeC(temporaryscheduleset)
15: end while
  
```

The most important parts in the process are the generation of the temporary schedule set and the choice of the optimal one from this set (the blue lines in Algorithm 1). These two parts are explained in detail in the next sections.

Algorithm 2 Core C-TAP Rescheduling Algorithm (Larsen and Pranzo, 2019)

```

1: while simulation end not reached do
2:   for all agent with no activity do
3:      $state \leftarrow UpdateAgentState(agent)$ 
4:      $nextActivity \leftarrow MakeDecision(agent, state)$ 
5:      $agent.execution(nextActivity)$ 
6:   end for
7:    $nextTimeStep = minimum(all\ execution\ endpoints)$ 
8:   process to  $nextTimeStep$ 
9: end while

```

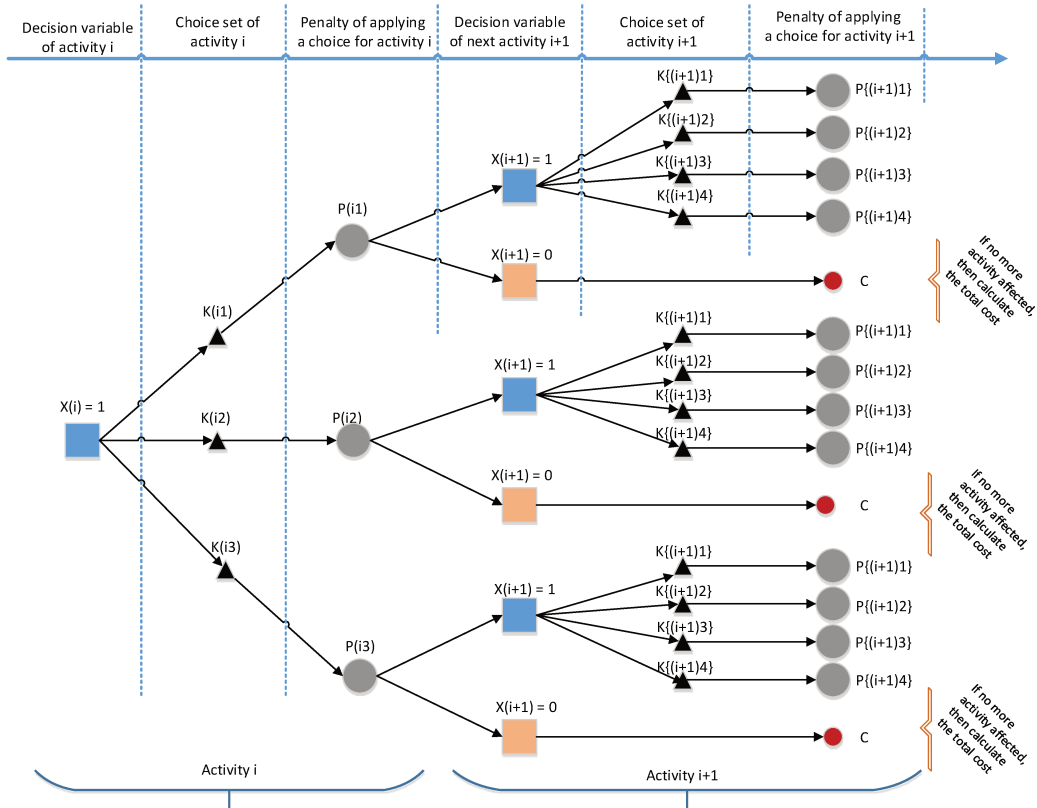


Figure 6.5: Decision tree based on choice modules

6.4.1/ GENERATION OF A TEMPORARY SCHEDULE SET

One of the most important parts in the activity rescheduling algorithm is to generate the temporary schedule set.

In our model, the temporary schedule set is obtained by building a decision tree, as illustrated in Figure 6.5.

When an unexpected event happens, the affected episode has a set of the customized alternative choice set (Section 6.3.5). If applying for a choice, there exists a penalty to

calculate the attributes changes (Section 6.4.2). The changes that are affecting the next episode are identified. If one exists, the next episode is equipped with his customized alternative choice set, following the same choice generation method that is explained above. The decision tree building stops when the last possible activity is reached, or when there is no influence on the next episode.

According to the decision tree, the schedule set can be obtained. The resource Java code of the decision is in Section B.1 (page 169).

6.4.2/ BEST CHOICE SELECTION

After generating the temporary schedule set as described in the previous section, one schedule among the computed ones must be selected. An optimization method is then used in order to find the (quasi-)optimal one. Indeed, according to the hypotheses in Chapter 5, the changes between the planned schedule and the new schedule should be minimized based on the activity utility. Therefore, a penalty-based function is defined in order to score each temporary schedule. The penalty scores are combined with the schedule probability in order to determine the optimal schedule proposal.

6.4.2.1/ OPTIMIZATION FUNCTION

As mentioned above, the model regards the optimal schedule as the least penalty change, which consists of schedule attributes change, and the most probability, which is related to schedule utility.

Assume the temporary schedule set consists of K_s schedules. For a schedule s , there is schedule possibility r_s to choose, and its penalty is P_s . Therefore, the optimal schedule in the schedule set is as follows:

$$\text{minimize } C = \sum_s^{K_s} P_s \times (1 - r_s) \quad (6.19)$$

6.4.2.2/ PENALTY FUNCTION

The penalty function is used to calculate the changes of attributes between the planned schedule and the new schedule. As shown in Equation 6.20, the schedule penalty is scored as the attributes changes of the episode i , which is affected by the external event. The penalty also involves the changes of other episodes in the planned schedule, which is triggered by the internal event. Between these episodes, which are affected by an internal

event, there is a penalty parameter w_{i+1} . It corresponds to the penalty of changing a type of activity and affecting another type of activity.

$$P_s = \sum_{k=1}^{K_i} \{P_{ik} \times x_{ik} + \sum_{i+1}^N \sum_{k=1}^{K_{i+1}} w_{i+1} \times P_{(i+1)k} \times x_{(i+1)k}\} \quad (6.20)$$

In the Equation 6.20,

- x_{ik} : The decision variable x_{ik} equals to 1, when the agent choose the rescheduling choice k for episode i .
- $x_{(i+1)k}$: The decision variable $x_{(i+1)k}$ equals to 1, when it is affected by the change of previous episode i .
- w_{i+1} : Set w_{i+1} as the penalty parameter for changing the episode i with the activity type parameter b_i , and then affecting the next episode $i + 1$ with the flexibility $b_{(i+1)}$.

$$w_{i+1} = \frac{b_{i+1}}{b_i} \quad (6.21)$$

- P_{ik} : Assume P_i as the penalty for changes in episode i after applying the choice k .
- K_i : There are K_i choices for episode i , and K_{i+1} choices for episode K_{i+1} . Therefore, the number of alternative schedules in the decision tree is $K_s = K_i \times K_{i+1} \times \dots \times K_N$.

The decision variables x_{ik} and $x_{(i+1)k}$ should satisfy the following conditions. For an activity, it can only choose one rescheduling method at a time.

$$\sum_{k=1}^{K_i} x_{ik} = 1 \quad (6.22)$$

Using the decision tree to determine if the current decision affects the next decision or not, and calculate the penalty of each node in the tree, the final solution is the schedule with the minimal penalty. x_{i+1} exists only if the change of in the previous episode i can affect the later episode $i + 1$. x_{i+1} is defined as:

$$x_{i+1} = \begin{cases} 1 & \text{if } T_i + Ori_i \geq 1, \text{ and } i < N \\ 0 & \text{else} \end{cases} \quad (6.23)$$

The schedule penalty consists of path penalty, time penalty, and location penalty. The weights ω_1 , ω_2 and ω_3 are assumed to be equal to 1 in the context of this research work. Further experiments may be applied in order to calibrate and determine the best weights

according to the application context.

$$P_i = \omega_1 P_{path} + \omega_2 P_{time} + \omega_3 P_{location} \quad (6.24)$$

- **Path penalty:** Let n be the number of edges in the original path of a trip, and Δn be the number of changed edges for the same trip. Basically, the path penalty is the average number of differences in terms of edges between the two paths.

$$P_{path} = \frac{\Delta n}{n} \quad (6.25)$$

- **Time penalty:** Time penalty is to calculate the changes of the trip start time, activity start time, and also activity end time. t_{vs} , t_{as} , t_{ae} are the planned trip start time, activity start time, and activity end time. And t'_{vs} , t'_{as} , t'_{ae} are the new trip start time, activity start time, and activity end time in the optimal schedule after rescheduling.

$$P_{time} = \frac{|t_{vs} - t'_{vs}|}{t_{ve} - t_{vs}} + \frac{|t_{as} - t'_{as}| + |t_{ae} - t'_{ae}|}{t_{ae} - t_{as}} \quad (6.26)$$

- **Location penalty:** Location penalty is to present the attractiveness changes of the location. As we explained above, $\phi(l)$ represents the attractiveness of the location l , and we regard $\phi'(l)$ as the attractiveness of the new location in the optimal schedule after rescheduling progress.

$$P_{location} = \frac{|\phi(l) - \phi'(l)|}{\phi(l)} \quad (6.27)$$

6.4.2.3/ SCHEDULE PROBABILITY

The most popular function of choice probability is a logit in (MNL) (Batool, 2016). For a schedule s in a temporary schedule set composed of K_s schedules, its probability is defined by Equation 6.28.

$$r_s = \frac{e^{\mu V_s}}{\sum_{k=1}^{K_s} e^{\mu V_k}} \quad (6.28)$$

V_s is the utility of alternative schedule s , and the size of the schedule set is K_s .

$$V = \sum_{a=1}^A U_a \quad (6.29)$$

U_a is the activity utility, which is related to the activity type and duration; A is the number of activities in the alternative schedule. U_a is defined in Equation 6.30 according to Gärling

et al. (1999).

$$U_a = \frac{U_{min} + U_{max} \exp(a + bD_a)}{1 + \exp(a + bD_a)} \quad (6.30)$$

In this equation, D_a is the actual duration of activity a . U_{min} is an individual's evaluation of the situation if the activity duration is zero. In most of the cases, $U_{min} = 0$, because not conducting the activity often merely means the absence of benefits. And, in this thesis, we have selected $U_{max} = 10$. a is set for each activity separately to reflect an assumed normal duration for the activity; b is the parameter to represent the flexibility.

In Equation 6.28, Chen et al. (2016) propose that μ to represent the task complexity and time pressure in the choice situation (Equation 6.31). TC is task complexity, λ denotes the parameter for the task complexity, which has a negative sign. TP is the parameter of time pressure in a choice situation, δ denotes the parameter for the linear component of the time pressure index, θ denotes the parameter for the quadratic component of the time pressure index. ω gives the strength of the interaction effect of activity complexity and time pressure. According to Chen et al. (2016), $\omega = 0$, it means the task complexity and PTP have no correlation. And they set $\lambda = -0.0101$, $\delta = 2.03$, $\theta = -3.36$, and these values will be applied in this thesis as well. The difference between this thesis and Chen et al. (2016) is the meaning of task complexity. For all the alternative choices, each choice is associated with a task complexity. In Chen et al. (2016), task complexity is related to the number of activities and travel alternatives. Considering that an individual has the resistance to change the planned schedule, and there is an original schedule, the goal of this thesis is to minimize the dissimilarity between the original and schedules. We propose the task complexity as the number of changed activities between the original schedule and the new schedule. The more changed episodes in a temporary new schedule, the bigger the task complexity.

$$\mu = e^{\lambda TC + \delta TP + \theta TP^2 + \omega TC \times TP} \quad (6.31)$$

For the time pressure TP , we define there is limited rescheduling time RST , and the time left to make the rescheduling decision is DT . It is formally defined in Equation 6.32.

$$TP = \begin{cases} 1 - \frac{DT}{RST} & \text{if } DT < RST \\ 0 & \text{if } DT \geq RST \end{cases} \quad (6.32)$$

In Equation 6.32, we assume that if the left time to make the decision is bigger than the limited decision time, the individual will not suffer time pressure. And otherwise, the individual will feel time pressure, and it will affect his decision-making. The time left for the decision DT depends on the event situation. For example, if the individual figures that he

needs more time to finish an activity, and the decision should be made before the start of the next episode. If the individual is informed that there is congestion during the route, he needs to reschedule his path or the connected activity before he reaches the congestion segment. In this thesis, we explain it in the experiments especially.

6.5/ CONCLUSION

This chapter contributes to the research questions proposed in Chapter 5. These different contributions are summarized below. We make a summary of the content of this chapter in Figure 6.6

RRQ1 - HOW TO DEFINE THE UNEXPECTED EVENTS IN INDIVIDUAL ACTIVITY RESCHEDULING?

ANS1: This chapter firstly classifies the event as the long-term event, short-term event, and emergency event. Short-term event is regarded as the unexpected event in this thesis. It is the short-term event which affects the individual's daily behavior on a certain day, rather than activity patterns. Then the events are classified as the external or internal events. It is assumed that the unexpected events that are coming from the environment are external events. Because of changing an affected episode under an external event, other episodes in the schedule are affected. Under this situation, the changed information comes within the rescheduling process. This change information is propagated as internal events. Both external and internal events are analyzed and discussed regarding their impact on the trips and activities.

RRQ2 - HOW TO GENERATE THE ALTERNATIVE CHOICE SET AND CHOOSE THE OPTIMAL ONE?

ANS2: This chapter puts forward four choice modules: time adjustment, route change, location change, and drop the episode. In the time change module, time change is determined according to the types of unexpected events. Additionally, the individual has the implicit objective to finish the affected activities with the minimum duration. The route change module minimizes the travel time, and the location change module maximizes the location attractiveness. We use the attractiveness factor to measure the location, and the individual will choose the location with the best attractiveness (if there are alternative locations for the affected episode). Also, for the flexible activities, the individual has the right to drop the episode under unexpected event happening. What is more, the customized

choice set is determined by the type of unexpected event and the type of the affected activity.

When an unexpected event occurs, the alternative schedule set is generated by building a decision tree. For each of these alternative schedules, a penalty score is computed, as well as a probability of execution. The penalty score measures the changes between the planned schedule and the new schedule. The schedule probability is calculated by using the schedule utility, and combining time pressure and task complexity. The optimal schedule is obtained considering the penalty score and schedule probabilities, such that the penalty is minimized and the probability maximized.

RRQ3 - WHAT IS THE RELATIONSHIP BETWEEN A PAIR OF CONNECTED ACTIVITIES, AND HOW TO SUPPORT THIS RELATIONSHIP INTO THE RESCHEDULING PROCESS?

ANS3: In this thesis, the relationship between a pair of connected activities is explored and discussed. If a certain type of activity has changed, the consequence and the effects on the following activities in the schedule are defined and discussed. The activity type parameter is introduced into the penalty function in order to study this relationship.

RRQ4 - HOW TO SIMULATE THE INDIVIDUAL ACTIVITY RESCHEDULING DECISION PROCESS?

ANS4: The individual activity rescheduling process is defined in this chapter. According to the state of the art, the agent-based modeling approach. An agent-based model is proposed for simulating the individual activity rescheduling process. The activity rescheduling process is triggered by an external event occurs. The inputs of our model are the data of the individual himself, the planned schedule, the road network, and the information related to the unexpected events, i.e, the external events. The output of our agent model is the rescheduled new schedule, after executing all the episodes in the schedule under the unexpected events.

According to the general problems that are explained in Chapter 1, the rescheduling problem has two major components. The first component is dedicated to the individual activity rescheduling, and it is explained in this chapter. The second component is the renegotiation among the participants to the joint trips. This part is detailed and discussed in the following chapter.

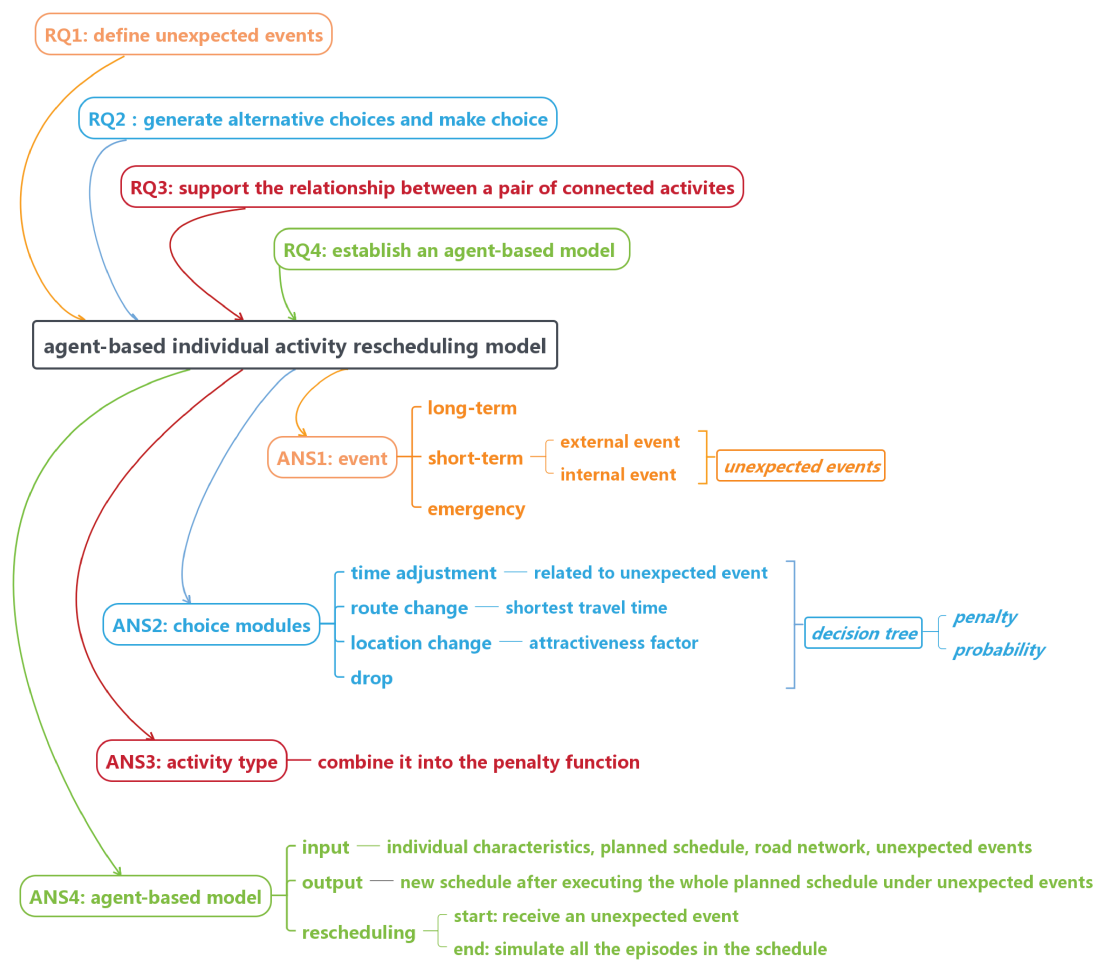


Figure 6.6: Summary of the agent-based individual rescheduling model

MODEL FOR THE RENEGOTIATION OF THE JOINT TRIPS

7.1/ INTRODUCTION

As explained in Chapter 1, the need to perform certain activities during the day drives the activity-scheduling decisions of each person. Activity rescheduling is viewed as a key behavioral mechanism whereby individuals adapt their activities and travels in response to uncertainties (unexpected events), like congestion, mode change, or time conflicts. As previously described, the daily activity rescheduling process is decomposed into the individual activity rescheduling (that is discussed in the previous chapter) and joint trip renegotiating subprocesses (that is the purpose of the current chapter).

After its initial determination through negotiation among the participants, a joint trip is executed on the road network. When unexpected happens, the participants need to renegotiate to adjust the joint trip. After renegotiation, the participants continue the trip and run their own activities when the trip is finished. The use-case of the joint renegotiation is shown in Figure 7.1.

This chapter firstly defines the principles of a joint trip renegotiation. The negotiation and renegotiation mechanisms are discussed and compared in order to highlight their key differences. According to the time property of the unexpected events, the joint trip renegotiation may be pre-renegotiation or enroute renegotiation. The first type of renegotiation is executed before the joint-trip has started. The second type is related to the adaptation of the joint trip when it is executed. The focus of this thesis is on the en-route renegotiation. In order to solve the en-route joint trip renegotiation, this thesis considers congestion as the main type of unexpected event that occurs during the joint trip. A model for generating the offers (alternative choices) to the participants is proposed. An agent-based model is proposed in order to simulate the joint trip renegotiation process

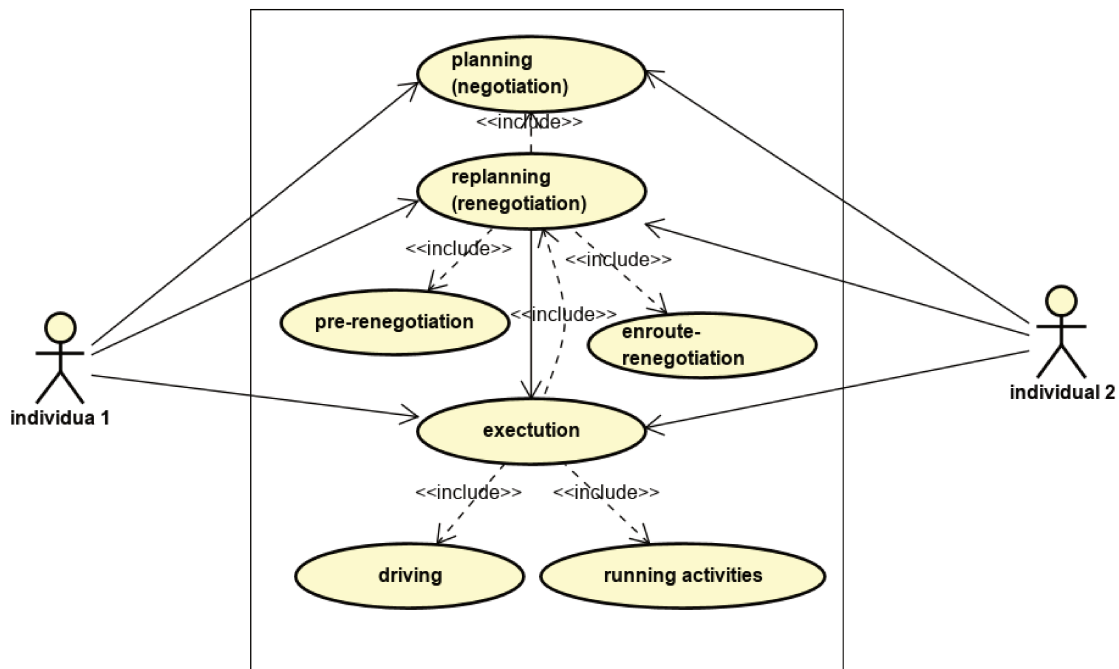


Figure 7.1: Use-case of the joint trip renegotiation

based on the previous model related to alternative choices' generation. In our proposal, each participant is an agent. Basically, the agent's behaviors address the issues of when the renegotiation process begins and ends, how participants make the renegotiation, and what is the outcome of the model.

7.2/ DEFINITION OF A JOINT TRIP RENEGOTIATION

Before defining and explaining both negotiation and renegotiation concepts, this section presents a small example that is illustrated in Figure 7.2. Several time zones are associated with a joint trip. The time period of planning the joint trip is regarded as [Zone 1](#); the time period of executing the joint trip is regarded as [Zone 2](#). The period between [Zone 1](#) and [Zone 2](#) is assumed to be empty time. An additional assumption is related to a possible but limited decision time to make the negotiation decision.

Joint trip [negotiation](#) is the process of generating a joint trip that only happens during [Zone 1](#), i.e, the negotiation process is finished before the execution of the joint trip. The goal of this initial negotiation is to generate a joint trip, which can meet the requirements of all of the individuals, i.e, find an equilibrium solution to the joint trip problem. The inputs of the negotiation are the individual profile and constraints. If the negotiation fails, the joint trip can be dropped. Additionally, if the time needed to negotiate is more than the limited

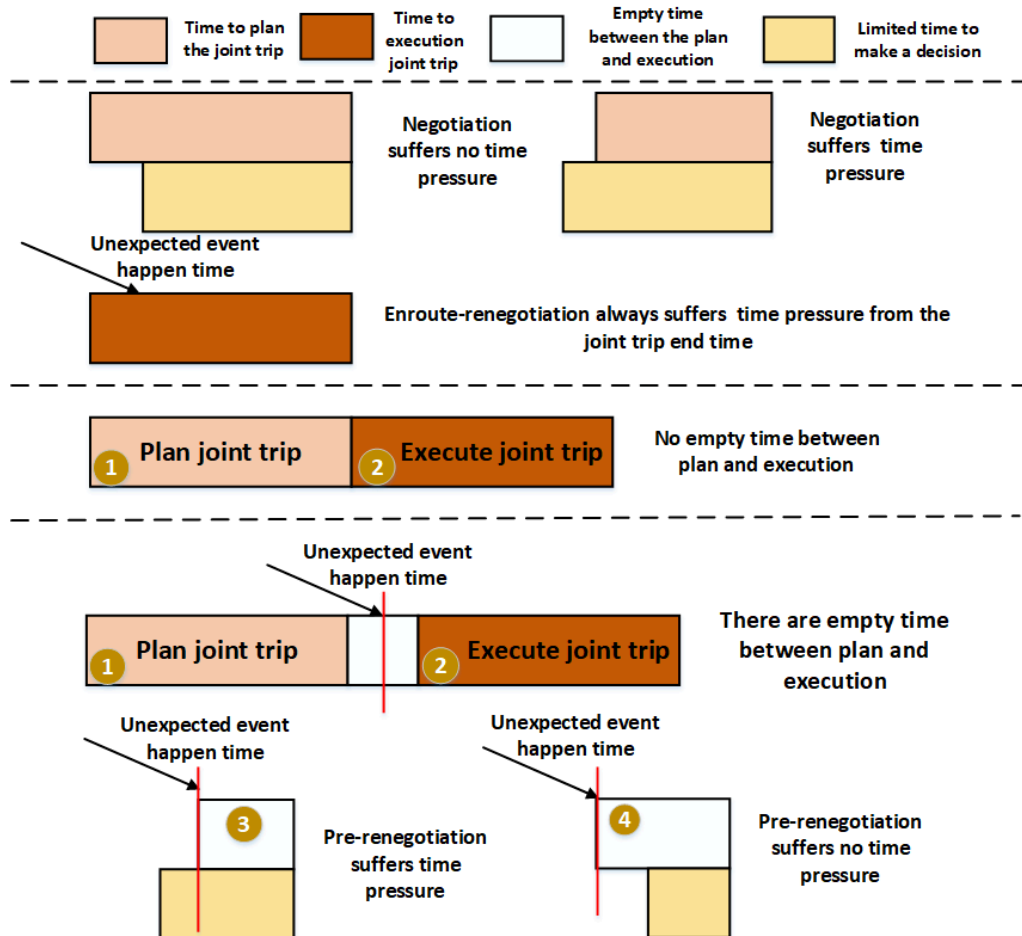


Figure 7.2: Time zones of the joint trip

decision time, negotiation suffers no time pressure. If the time needed to negotiate is less than the limited decision time, negotiation suffers time pressure to get an agreement.

Joint trip **renegotiation** is the process of adjusting the planned joint trip because of unexpected events. If the unexpected event happens before the joint trip's execution, which means it happens during the empty time, it is regarded as pre-renegotiation. Let r be the time left to renegotiate, from the unexpected event happening time to the start time of the joint trip. If r is less than the limited decision time, the process is in **Zone 3**. In this case, the renegotiation process suffering the time pressure of the limited decision time. If r is more than limited decision time, the process is in **Zone 4**. In this case, the participants have enough time to renegotiate until to the final decision. Whatever the value of r , the participants always have the opportunity to agree on the cancellation of the joint trip. If the unexpected event happens during the joint trip execution (**Zone 2**), it is regarded as the enroute-renegotiation. Participants always feel the time pressure since the renegotiation is going to the end time of the joint trip. Both pre/enroute renegotiation have the

same inputs, the planned joint trip, individual's profile, and constraints. The global renegotiation goal is to minimize the impact caused by unexpected events and maximize the participants' utility (Tosselli et al., 2020).

The comparison of negotiation and renegotiation processes is shown in Figure 7.3. This comparison highlight the motivation for negotiation, the inputs, time horizon, alternative choices, and goals that are related to both processes.

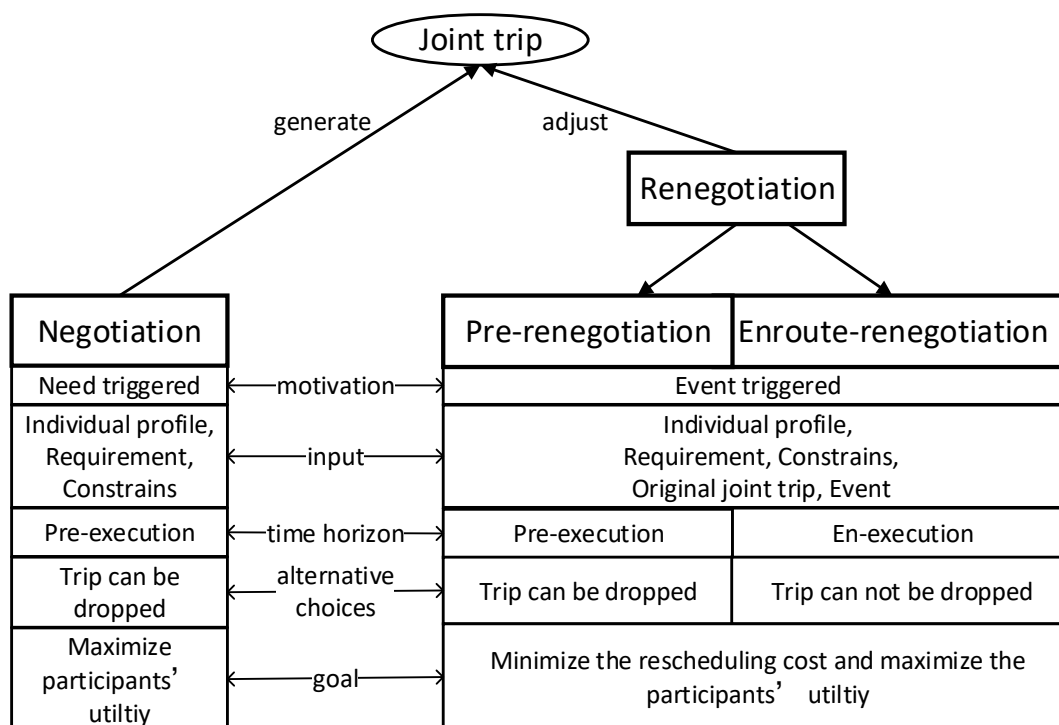


Figure 7.3: Comparison of negotiation and renegotiation

The next section introduces the unexpected events for the renegotiation problem; and the choices the participants have under these unexpected events.

7.3/ JOINT TRIP RENEGOTIATION PROBLEM

The goal of this thesis is to study the individual's travel behavior. And, the joint trip enroute-renegotiation is our main focus. For a joint trip, which is during the execution process, which kind of unexpected events will affect it, and how individuals respond to it? This section discusses and provides answers to the above two questions.

7.3.1/ UNEXPECTED EVENTS FOR JOINT TRIP RENEGOTIATION

The focus of this thesis is the simulation of the enroute-renegotiation process. During the joint trip's execution, the unexpected events, which affect it, contain information, which changes the attributes of the joint trip.

According to the definition of the joint trip (Definition 11, page 18), a joint trip is composed of the origin, the destination, the start time, the duration, the transport mode, the path, and the participants. Since the trip is already started, the origin, start time, and transport mode cannot be changed, i.e, the information of an unexpected event cannot affected them. Moreover, we assume the joint trip cannot be dropped during the joint trip execution process. The participants will make concessions trying to get an agreement. Therefore, the number of participants is not affected. Two types of events may affect the duration of a joint trip: [joint trip congestion](#) and [joint trip destination change](#). The first corresponds to a delay in the trip that is due to road traffic congestion. The second occurs when a participant involved in the joint trip changes his trip destination. Both [joint trip congestion event](#) and [joint trip destination event](#) may affect the path of the joint trip.

In this thesis, we would like to explore how the passenger and the driver exchange information between each other. And we take the [joint trip congestion event](#) as an example to study. If the activity a participant executes has alternative locations, this condition will also be taken into consideration of alternative choices under the congestion event. Therefore, we choose joint trip congestion event, rather than the destination event.

Assume, for a joint trip, there is congestion on a segment seg_j in a trip. The congestion road data for this segment is seg_j^e , and this event is informed at time t .

$$Event(t) = \langle seg_j^e, t \rangle \quad (7.1)$$

7.3.2/ ALTERNATIVE CHOICES GENERATION

When an unexpected event happens during the joint trip, the participants can choose to change to another route to arrive at the planned location or to change to another new location (if the activity has alternative locations). No matter to change the location or not, the route is always changed. In order to support the renegotiation process, the passenger and the driver should have a set of alternative choices after the event occurred. The joint trip is shared by both the passenger and the driver. Therefore, we assume that they share the same alternative offer set. It means that the alternative choices of both the driver and the passenger are merged. Based on this set of all the possible choices, each individual may decide what is the best choice to maximize his own utility function and the collective

utility also. The question arising is: how to generate accessible choices? In order to give an answer, different choices modules are proposed in the rest of this section in order to generate the different offers for the passenger and the driver.

7.3.2.1/ ROUTE CHANGE MODULE WITHOUT LOCATION CHANGING

This route change module in the joint trip renegotiating problem is an extension of the route change module that is used in the individual activity rescheduling model and presented in Section 6.3.2.

If there is an unexpected event affecting the joint trip duration, the driver and passenger can choose still go to the planned location, and they change a new route to reach it. In Figure 7.4, there is congestion on the segment seg_{3-4} , the passenger and driver can choose other alternative paths (orange colors in Figure 7.4)to reach the passenger's location. Since the way the driver's location has no road condition change, the path from the passenger's location to the driver's location keeps the same as planned. We assume the best route among the alternative routes is the one with the shortest travel time, as explained in Equation 6.13, page 86.

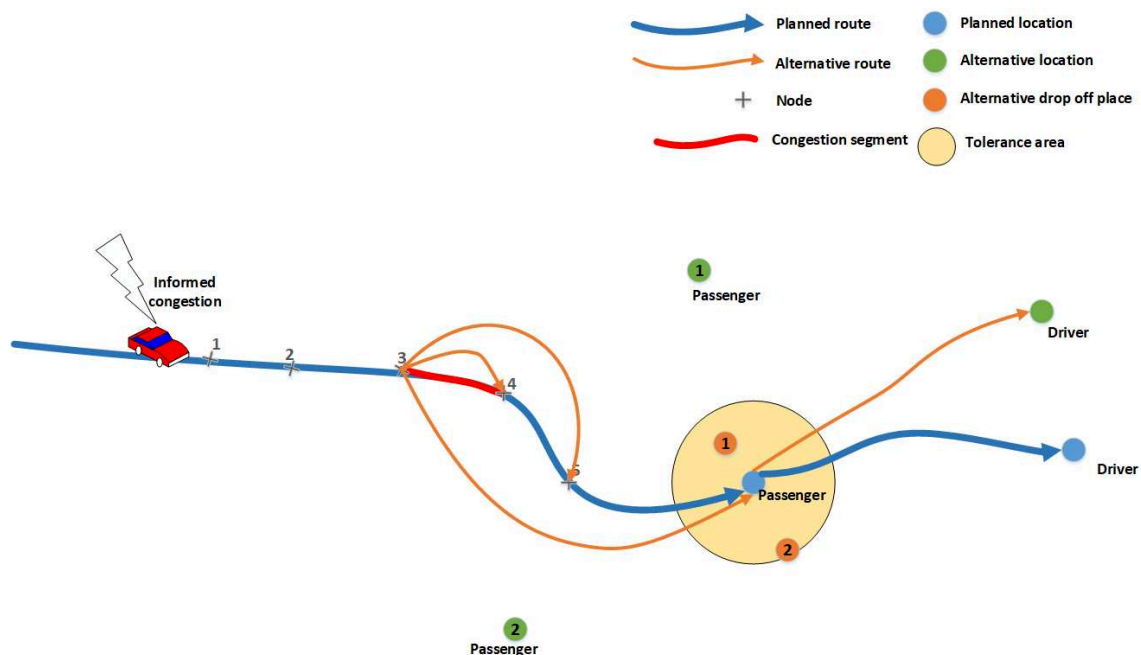


Figure 7.4: Alternative path choices for the joint trip

7.3.2.2/ ROUTE CHANGE MODULE WITH LOCATION CHANGING

If the activity may take place at different locations (or alternative drop off places for the passengers), the optimal route to reach each new alternative location is computed from the aspects of **passenger** and **driver**.

These two points of view are defined in the modules below:

- **Driver location:** For the driver, the alternative location is determined by the type of the activity, which is connected to the joint trip. The flexible activities, such as shopping or other leisure activities, are typical activities with alternative locations. While for mandatory activities like education and working, there are no alternative locations to choose from.

Assume the joint trip start point is A ; trip destination point (driver's location) is B , drop off place (passenger's location) is S ; l_i an alternative location for the driver. What should be noticed is that since the trip is started, and the route before the unexpected informed time cannot be adjusted. The joint trip start point is the point when the unexpected event is informed in this case, rather than the real trip start point. This example scenario is illustrated in Figure 7.5.

The optimal route to reach the alternative location l_i is $d(A, S) + d(S, l_i)$. $d(A, S)$ and $d(S, l_i)$ are the shortest travel time between the two points. They are obtained from the Equation 6.13, page 86.

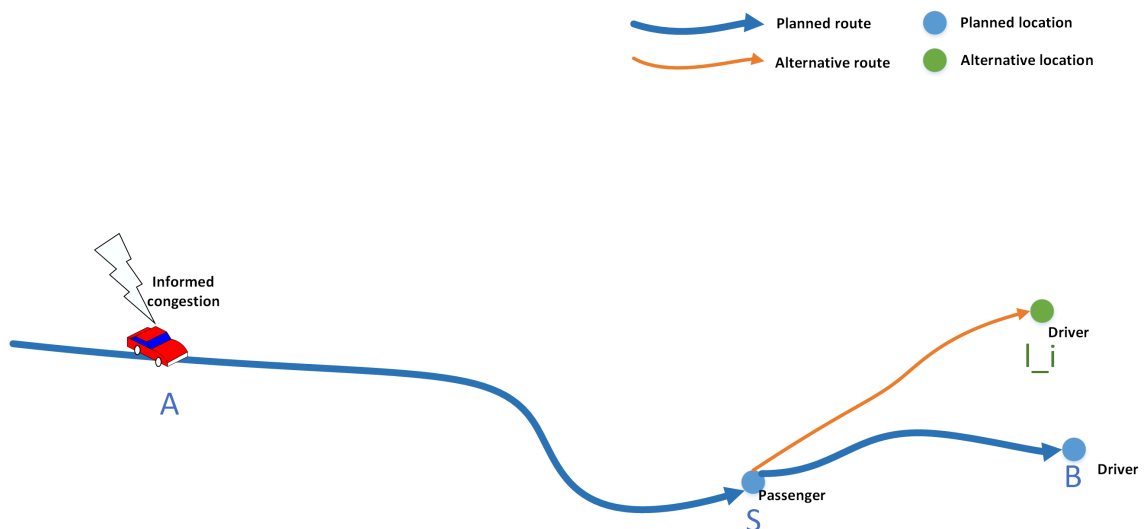


Figure 7.5: Driver's alternative location in a joint trip

The path similarity of the location l_i is given by Equation 7.2:

$$\text{sim}^d(l_i) = \frac{d(A, l_i)}{d(A, S) + d(S, l_i)} \quad (7.2)$$

- **Passenger location:** For the passenger, a new drop-off point or a totally new location could be chosen (Figure 7.6). As for the former, assume K is the acceptable distance for the agent to drop-off and to reach the destination by walking or bicycle. On the road map, for all the points within the K distance constitute the is called the **tolerance area**. Any point in this area could be chosen as an alternative drop-off point. The alternative location is determined by the type of activity connected to the joint trip.

Under a congestion event, the alternative choices for the passenger and the driver (both alternative locations and paths) are shown in Figure 7.7. In a driver's offer, both the passenger's location/drop off place, and his own location are considered. While, in a

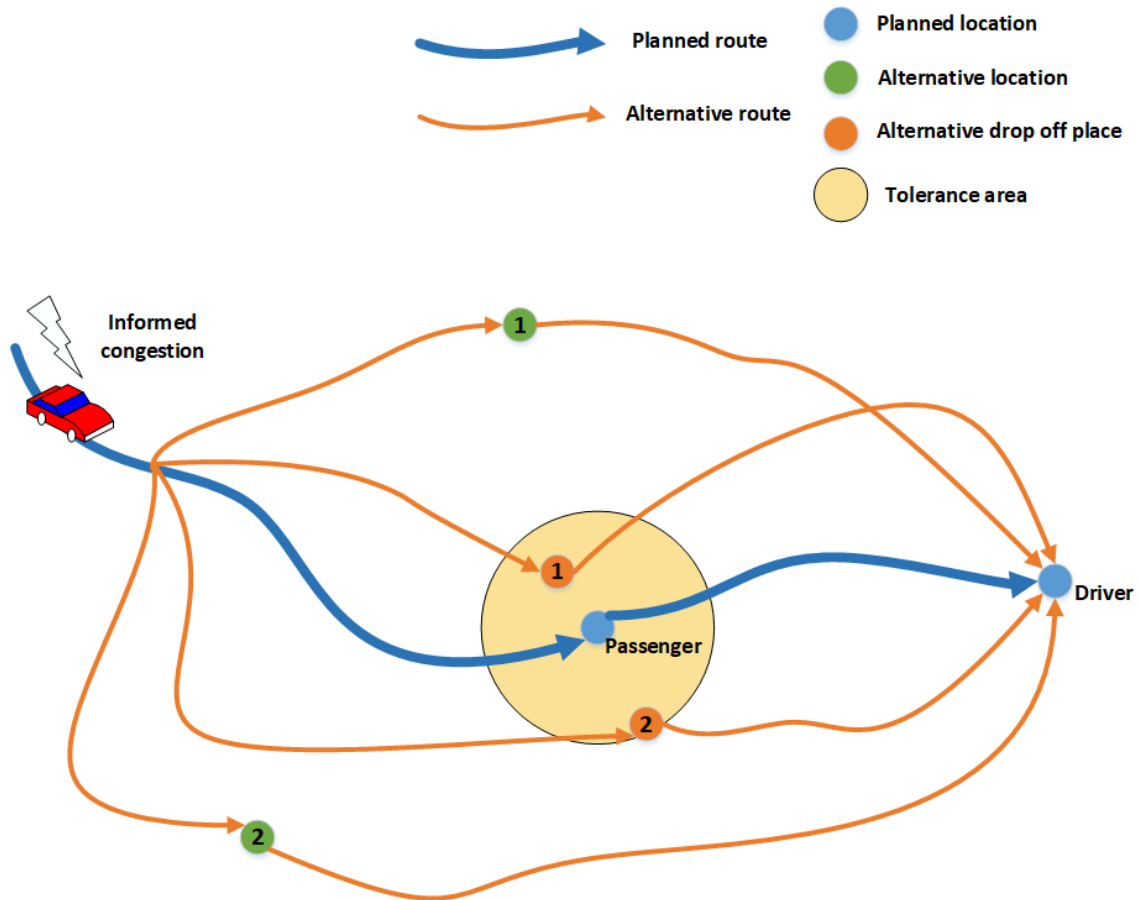


Figure 7.6: Passenger's alternative location/drop off place in a joint trip

passenger's offer, only the passenger's own location/drop off place is taken into consideration. The Java resource of generating alternative offers for a joint trip is in B.2 (page 171).

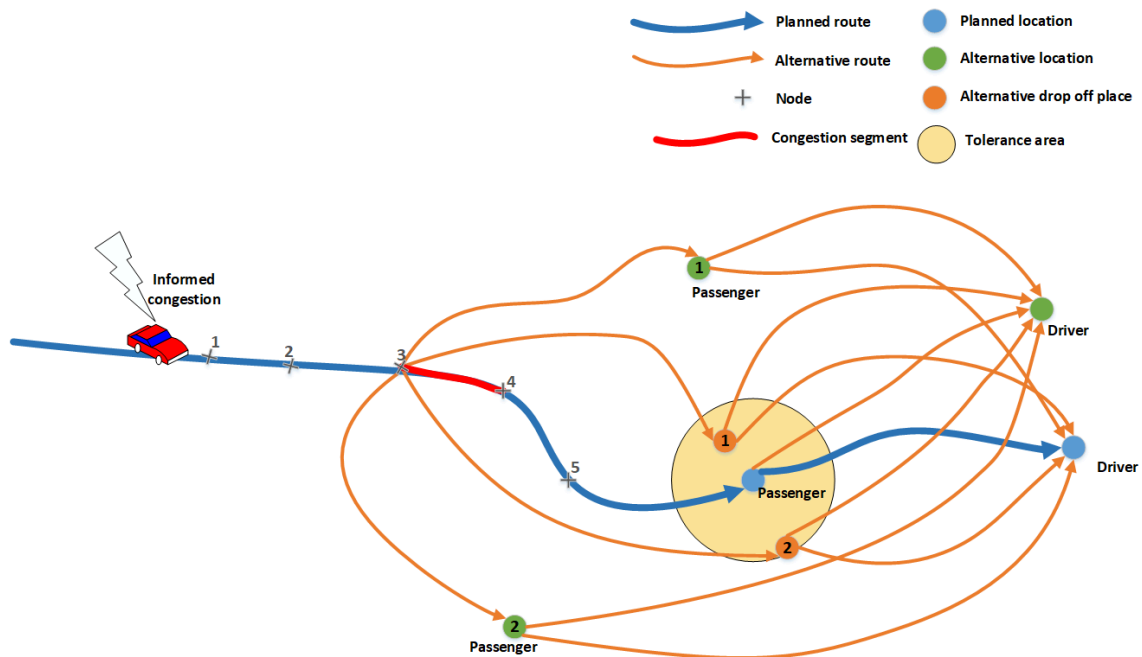


Figure 7.7: Alternative location choices for the passenger and the driver in a joint trip

7.4/ THE JOINT TRIP RENEGOTIATION MODEL

When the unexpected event occurs, the passenger and driver have a set of alternative choices. Based on these, an agent-based model is proposed in order to simulate the renegotiation between the passenger and the driver, by focusing on the communication protocol and its relationship with the agent behaviors. The rest of this section presents the agent-based model and explains the offers that are exchanged between the agents.

7.4.1/ AGENT-BASED MODEL FOR THE JOINT TRIP RENEGOTIATION

In the agent-based model for the joint trip enroute renegotiation, agents are not allowed to drop the trip during the trip execution. If they cannot get an agreement when the renegotiation deadline is reached, they will just accept the last offer before the deadline. The inputs of the model are the attributes of the joint trip, the characteristics of participants in the trip, the road network, the alternative locations of the activity, to which the joint trip is connected to, and the unexpected event.

During the execution of the joint trip, if a participant is notified about an unexpected event, then the renegotiation process is triggered. The detailed process of the joint trip renegotiation is as follows:

- **Step 1:** The agent, which receives the unexpected event, is the initiator agent. It will send the event information to another agent (listen agent). The listen agent waits for the renegotiation deadline RST .
- **Step 2:** The initiator and listen agents generate a set of alternatives offers $o(offer)$ about the location, route, and arrival time. The initiator agent chooses the best choice o_{max} , and send it to the listen agent. If the negotiation deadline is reached, go to Step 6. If not, go to Step 3.
- **Step 3:** The listen agent evaluates its acceptance of the offer by using criteria. If it accepts the offer, go to Step 6. If not, go to Step 4.
- **Step 4:** The listen agent generates the most suitable offer $o_{suitable}$, stores it in its offer history $history(offer)$; and sent it to the initiator agent.
- **Step 5:** The initiator agent evaluates the listen agent's proposal as well; and evaluates if the renegotiation time deadline is reached or not. If yes, go to Step 6. If not, go the Step 3.
- **Step 6:** The agents accept the latest incoming offer, and update the changed joint trip information into their own schedules.

After explaining the joint trip renegotiating process, the assumptions and constraints that are applied in the model are explained below, as well as the details on the proposed agent-based model.

- **Assumptions:** In the agent-based model simulating the joint trip renegotiating problem, the following assumptions are applied:
 - i) Agents are not selfish. In the first round of renegotiation, the agent offers its optimal offer. After that, it makes concessions to its opponent combining its own preferences and the incoming offer.
 - ii) Each agent has a set of actions at its disposal, such as generate offer sets, send message and receive message to his opponent, etc. It can take them to adjust its trip.
 - iii) There is a utility function known by each agent. Agents calculate the alternative offer using their own utility function. The utility function does not change over time.

- iv) There is a limited decision time to make the renegotiation process. It is equal for all the agents that are participating in a single negotiation process. It may be of a different value for each negotiation group. The renegotiation should be finished before the end of the trip, or within the limited decision time.
 - v) Agents communicate by exchanging messages. In the agent-oriented paradigm, there is no central agent, and hence the control is decentralized.
 - vi) The renegotiation cannot failed since the trip cannot be dropped. The agents accept the last offer before the end of decision time if they cannot get an agreement.
 - vii) There is no mediator to help the renegotiation.
- **Constraints:** The constraints that are considered in the model are related to the alternative location/drop off places for the participants in the joint trip.

The alternative locations depend on the type of activity.

The alternative drop off place is determined by the passenger, based on the available roads in the road network.

Each person has specific preferences related to the tolerance area. The drop off place is obtained by selected one within the tolerance on the road network.

- **The agent-based model:** We assume there are two agents in the joint trip, they are the driver and the passenger. In. this thesis, we propose the driver is always the one receive the unexpected event. The driver is the initiator agent.

As illustrated in Figure 7.8, when the initiator agent receives the unexpected events, it sends the event information to the listen agent. Both initiator and listen agents generate a set of temporary offers *o(offer)*, and then the initiator agent choose the offer with the highest utility. This selected offer is used for building a new joint trip that is sent to the listen agent. After evaluating the acceptance of the incoming offer, both the agents update the joint trip information. If the listen agent agrees to accept, and the renegotiation process ends. If not, the listen agent will generate the best fitness offer and provides it to the initiator agent. Then, the second round of renegotiation is started, regard all the agents as listen agents, and evaluate the renegotiation deadline and acceptance of the incoming offer. In thesis, the driver is the initiator who provides the offer in the first round. And the Java resource of the renegotiating process is shown in B.3 (page 172).

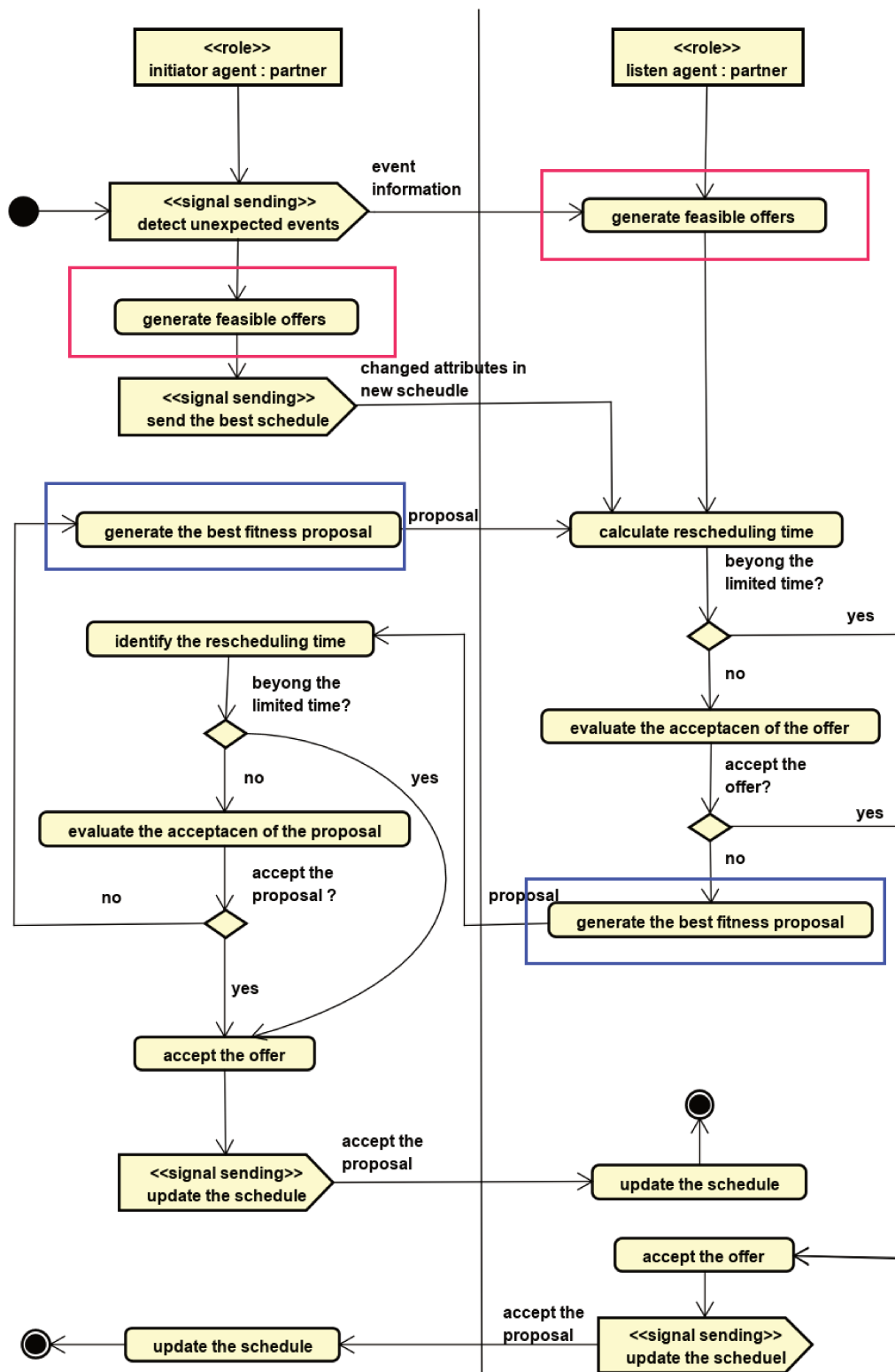


Figure 7.8: Renegotiation process during the execution of joint trip

7.4.2/ THE OPTIMAL OFFER

As explained in the agent-based model above, during the first round of the renegotiation, the agent sends its best offer to its opponent. Every agent knows his own utility function to score the alternative offers. Both the passenger and the driver know their own optimal offer o_{max} among the alternative offers.

According to De Dreu (2003), a utility function considers the location utility, the activity start time in a day, the activity in the schedule, and the activity duration. In this thesis, the considered utility function used in this thesis considers factors of location, activity start time (trip end time), and activity duration. A new way is used to present the location parameter, in order to use the degree of lateness for the activity start time parameter, and use the activity utility function, which is related to activity type and duration.

1. Driver's utility function: Let U^d be the driver's utility to score an offer, it is defined as:

$$U^d = f^d(l_i) \times f^d(t) \times U_{ad} \quad (7.3)$$

- $f^d(l_i)$: represents the discount influence of the alternative location l_i . If the driver's location is not changed, we set $\omega = 1$, if the driver's location is changed, we set $f^d(l) = \omega$, and $\omega = 0.8$ in this section. Except considering the location, the driver will also consider the path similarity (Equation 7.2, page 108).

$$f^d(l_i) = sim^d(l_i) \times \omega \quad (7.4)$$

- $f^d(t)$: is the discount function of the arrival time of the driver, which is also the start time of the driver's connected activity. t_s^d is the real arrival time of the driver, T_s^d is the planned arrival time of the driver, and D^d is the planned duration of his activity ad . Then the planned activity end time for driver is $T_e^d = T_s^d + D$.

$$f^d(t) = \begin{cases} 1 & \text{if } t_s^d \leq T_s^d \\ \frac{T_e^d - t_s^d}{T_e^d - T_s^d} & \text{if } t_s^d > T_s^d \end{cases} \quad (7.5)$$

- U_{ad} : is the utility of the driver's activity ad . Let a and b be the parameters related to the duration and activity type of the activity; and d be the real activity duration. $d = T_e - t_s$, We set $U_{min} = 0$ and $U_{max} = 10$.

$$U_a = \frac{U_{min} + U_{max} \exp(a + bd)}{1 + \exp(a + bd)} \quad (7.6)$$

2. Passenger's utility function: Let U^p be the passenger's utility to score an offer, it

is defined as:

$$U^p = f^p(l_i) \times f^p(t) \times U_{ap} \quad (7.7)$$

- $f^p(l_i)$: represents the discount influence of the alternative location l_i of the passenger. In our model, we assume that the passenger does not care about the detailed path, he just cares about his location/drop off place. The driver cares about his path similarity to the passenger (Equation 7.4).

$$f^p(l_i) = \alpha_i x_l + \beta_i x'_l \quad (7.8)$$

In Equation 7.8, α is the parameter of distance from the l_i to the original location. $x_l = 1$ if the original location is not changed, the passenger just choose a new drop off place near the original location, and otherwise $x_l = 0$. Let $dis(lp_i, S)$ be the distance from the alternative drop off lp_i and the original destination S . The tolerance distance $K = 1km$ in this section, and $dis(lp_i, S) < K$.

$$\alpha_i = \frac{K - dis(lp_i, S)}{K} \quad (7.9)$$

β is the parameter of changing another location, which means passenger's resistance to change to a new location. In this section, we set $\beta = 0.65$. $x'_l = 1$ means when the original location is changed, and otherwise $x'_l = 0$. The passenger can only choose one choice at a time, to change the original location or not, therefor:

$$x_l + x'_l = 1 \quad (7.10)$$

- $f^p(t)$: is the discount function of the arrival time of the passenger, which is the also the start time the his connected activity. It can take advantage of Equation 7.5.
- $sim^p(l_i)$: is the passenger's path similarity in the joint trip. It is obtained from Equation 7.8.
- U_{ap} : is the utility of the passenger's activity ap . It can be obtained from Equation 7.6.

7.4.3/ CRITERIA FOR EVALUATING AN OFFER

When an agent receives an offer, it needs to evaluate the offer in order to accept or refuse it. In the set of the alternative offers $o(offer)$, o_{max} is the offer with the highest utility $o_{opponent}$ is the incoming offer from the opponent. The agent should accept the incoming offer if it meets one of the following criteria:

C1: The agent should accept the incoming offer $o_{opponent}$, if it produces the maximal utility, $u_{o_{opponent}} \geq u_{o_{max}}$;

C2: The agent should accept the incoming offer $o_{opponent}$, if it is within its previous proposals $history_{offer}$, $o_{opponent} \in history_{offer}$.

What is more, it should be noticed that, in a driver's offer, $o^{driver} = (beginpoint, passenger's\ location, driver's\ location, path)$. And in a passenger's offer, $o^{passenger} = (beginpoint, passenger's\ location, path)$. Therefore, when the passenger sends an offer to the driver, if the driver has an alternative location, he will choose the offer with higher utility as the incoming offer he considers. For example, the passenger sends an offer $o^{passenger} = (1, l_p)$ to the driver. For the driver, he has the planned location l_d and the alternative location l_{dl} . If $u(l_{dl}) \geq u(l_d)$, the driver will regard the incoming offer as $o_{opponent} = (1, l_p, l_{dl}, path)$.

7.4.4/ THE COUNT OFFER (MOST SUITABLE PROPOSAL)

According to the above criteria, if the agent accepts the incoming offer from its opponent, the offer is updated to both of their trips. If the agent refuses the incoming offer, it needs to provide a count offer to its opponent. In this thesis, it is named the **most suitable offer** or the **best fitness offer**. The fitness offer $o_{suitable}$ is used to balance o_{max} and $o_{opponent}$. The distance from a fitness offer to o_{max} and $o_{opponent}$ can be measured based on a standard distance function. In each renegotiation round, the offer vectors o_{max} and $o_{opponent}$ may change. In other words, an agent is learning and adapting its knowledge to his opponent's preferences gradually.

To generate the best fitness offer, there are three important issues that should be taken into consideration (Kelly and Karau, 1999): an agent's own payoff, the most recent counter offer, and the time pressure. We use the fitness function $f()$ to balance the incoming offer and the agent's own optimal offer. Among agent's all alternative offers $o(offer)$, the offer with the best fitness is the most suitable offer. For an alternative offer o_o , its fitness value is $f(o)$.

$$f(o) = \gamma \times TP(t) \times \frac{U_{o_o}}{U_{o_{max}}} + (1 - \gamma \times TP(t)) \times (1 - \frac{dist(\vec{o}_o, \vec{o}_{opponent})}{MaxDist|A|}) \quad (7.11)$$

In the fitness function $f(o)$ (Equation 7.11), the parameters inside are explained as follows:

- γ : $\gamma \in [0, 1]$ is the trade-off factor to control the relative importance of optimising one's own payoff. It is determined by the social relationship that corresponds to the

agent's attitude, from fully self-interested ($\gamma = 1$) or fully benevolent ($\gamma = 0$).

- **$TP(t)$** : is the agent's time pressure felt at time t , RS is the time left to finish the renegotiation, and RST is the limited time to make the renegotiating decision. $TP(t)$ is defined by:

$$TP(t) = 1 - \left(\frac{ST}{RST} \right)^{\frac{1}{e}} \quad (7.12)$$

In Equation 7.12, e is the eagerness of the agent. For different persons, the value of e varies. The smaller the value of e , the less the agent is feeling time pressured. It is more likely to maintain its own preference until the deadline is approaching.

- **$dist(\vec{o}_o, \vec{o}_{opponent})$** : is the distance between the offer o_o and his incoming offer $o_{opponent}$. Euclidean distance method is used to measure the distance between the two offer vectors.

$$dist(\vec{o}_x, \vec{o}_y) = \sqrt{\sum_{i=1}^A w_i (d_i^x - d_i^y)^2} \quad (7.13)$$

In Equation 7.13, for the distance between two offers x and y , the element $w_i \in (0, 1]$ is an agent's valuation for a particular attribute $a_i \in A$. In this thesis, only the location and the arrival time are concerned. The parameter related to the location is represented by $f(l_i)$, and the arrival time (trip end time) is represented by $f(t)$. Set w_t as the agent's preference for the factor of arrival time, and w_l is his preference for the location factor. Therefore, the distance evaluation becomes:

$$dist(\vec{o}_x, \vec{o}_y) = \sqrt{w_t (f(t)^x - f(t)^y)^2 + w_l (f(l_i)^x - f(l_i)^y)^2} \quad (7.14)$$

- **$MaxDist|A|$** : represents the maximal distance of a geometric negotiation space. In the first round of initiator agent, $MaxDist|A| = dis(\vec{o}_o, \vec{o}_{opponent})$, since there is no opponent offer. Therefore, the best offer at the first round is the offer with highest utility. Since the only two parameters under consideration are the location and arrival time of the activity, this arrival time is the end time of the joint trip, and the location is represented by path similarity.

7.5/ CONCLUSION

This chapter contributes to the research questions proposed in Chapter 5. These different contributions are summarized below. We make a summary of the content of this chapter in Figure 7.9.

RRQ5 - HOW TO GENERATE THE ALTERNATIVE OFFERS AND COUNT OFFER FOR AN AGENT IN A JOINT TRIP?

ANS5: In this thesis, we consider the congestion event for the joint trip. Under this situation, a model for computing the alternative offers for the driver and passenger is proposed. For the location change, if there is an alternative location, the driver can choose to change to another location. For the passenger, it can choose to change to a new location, or a new drop off place near the original location. The new drop off place is determined by the agent's tolerance area under the constraints imposed by the road network.

For an incoming offer from an opponent, if the offer is refused, the driver/passenger needs to make concessions and provides a count offer to its opponent. The count offer, we regard it as the most suitable offer or best fitness offer. To generate the offer, we consider the group time pressure, the social relationship, the optimal offer of the participant himself, and also the incoming offer. The participant makes concessions to balance himself and his opponent.

RRQ6 - HOW TO SIMULATE THE JOINT TRIP RENEGOTIATING PROCESS?

ANS6: An agent-based model is proposed in order to simulate the joint trip renegotiating problem. The inputs of the model are the data of the joint trip, the participants, the road network, and the unexpected events. The output of the model is the new joint trip after renegotiating. There is a limited decision time to make the renegotiation. While the renegotiation will not be failed, even the participants cannot get the agreement within the limited time. The trip cannot be dropped. Consequently, the participants will accept the latest offer before the end of the limited decision time.

They suffer time pressure because of this time limitation. During the first round of renegotiation, the driver/passenger sends their optimal offers among their alternative choice sets. The opponent evaluates the offer by comparing the offer utility to its own schedule utility. If the offer is refused, the opponent should offer a count offer, as we answered in the above question. The renegotiation ends when the participants get an agreement or the decision time is reached.

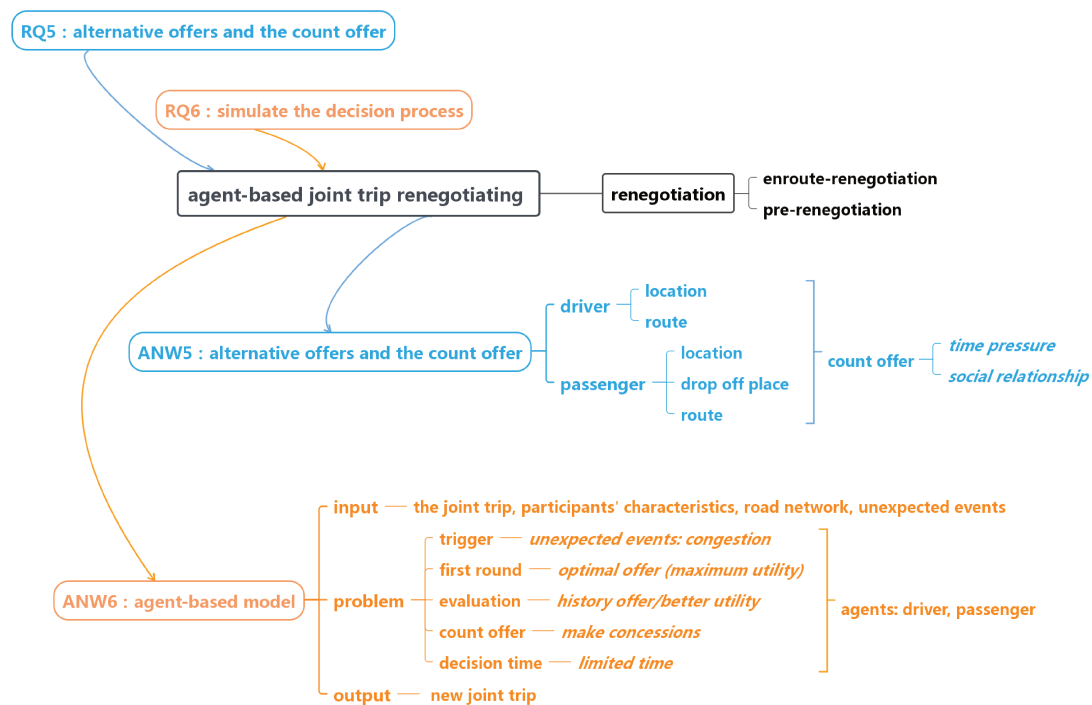


Figure 7.9: Summary of the agent-based joint trip renegotiating model

EXPERIMENTATION AND VALIDATION OF THE RESCHEDULING MODELS

8.1/ INTRODUCTION

In the previous chapters of this thesis, we explained the problem we want to solve, the state-of-art related to the problem, the methodology to solve the problem, and also the models to simulate the problem. Two agent-based models are proposed in order to simulate the daily activity rescheduling process. One is dedicated to the individual activity rescheduling problem, and the second is dedicated to the joint trip renegotiating problem.

This chapter provides experiments to validate the models we propose and also to analyze the parameters in the models.

8.2/ INDIVIDUAL ACTIVITY RESCHEDULING

This section presents an experiment to validate the agent-based individual activity rescheduling model. It uses a predefined planned schedule and a simple road network. Several unexpected events are considered. The effect of the unexpected events on the individual activity rescheduling. The relationship between a pair of connected activities under a certain unexpected event is studied and discussed.

8.2.1/ PRESENTATION OF THE APPLICATION

The activities list used in the simulation model was defined by Knapen et al. (2018). The simulation model includes several parameters for which values are provided in Table 8.1 and initially defined by Timmermans et al. (2001b). The columns ID and name columns contain the identifier and the activity's name, respectively. The duration column is the

expected duration of the activity. $MinD$ describes the minimal duration, such that $MinD \leq Duration$. Columns a and b represent the parameters for an activity used in the utility function, as we explained in Equation 6.30, page 96. Column “Opening Time” shows the period during which the activity’s facility is open.

<i>ID</i>	<i>Name</i>	<i>Duration</i>	<i>MinD</i>	<i>a</i>	<i>b</i>	<i>Opening-Time</i>
0	home					
1	Bring/get1	2	1	-20.151	0.102	
2	Work	238	238	-41.747	0.220	9:00–20:00
3	Shop1	45	40	-8.056	0.088	8:30–22:00
4	Shop2	15	10	-6.365	0.075	9:00–22:00
5	Bring/get2	33	15	-20.151	0.102	
6	Home2	30	0	-3.662	0.073	
7	Visit	60	30	-20.258	0.120	
8	Home3	395	0	-3.662	0.035	

Table 8.1: Original individual daily activity schedule and activity parameters

The individual begins his travel from home at 8:00, and then he arrives at the location of *bring/get1* to execute his *activity1*. After a duration of 2 minutes, the individual travels to *work* and executes the *activity2* for 238 minutes. Then, he goes to finish his *activity3* at *shop1* for 45 minutes and the *activity4* at *shop2* for 15 minutes. After that, he goes to the location of *bring/get2* to do his *activity5* for 33 minutes. Then he goes back *home* doing the *activity6*. After 30 minutes staying at *home*, he travels from *home* to the location of *visit* doing the *activity7* for 60 minutes. Then, he goes back *home* executing *activity8*.

A simple road map is used to put the activities on. The road map of the planned route is drawn in Figure 8.1. In the map, the nodes and segments between two points are illustrated. Road data at the planned stage is shown in Table A.1, page 165. The travel time is obtained from Equation 6.13, page 86. As explained in Equation 6.13, the travel time of a segment is determined by the free travel time, the road intensity, and capacity. The travel time of all the segments in experiments is obtained according to Equation 6.13 based on the road data.

<i>Planned Location</i>	<i>Alternative Locations</i>	<i>Quality</i>	<i>Perception</i>
Shop1	Alter1Shop1	0.9	0.9
	Alter2Shop1	0.7	1
Shop2	Alter1Shop2	0.8	1.1
	Alter2Shop2	0.7	0.9

Table 8.2: Parameters of alternative locations for shop activities

In the context of this application, two alternative location for the activities *Shop1* and *Shop2*

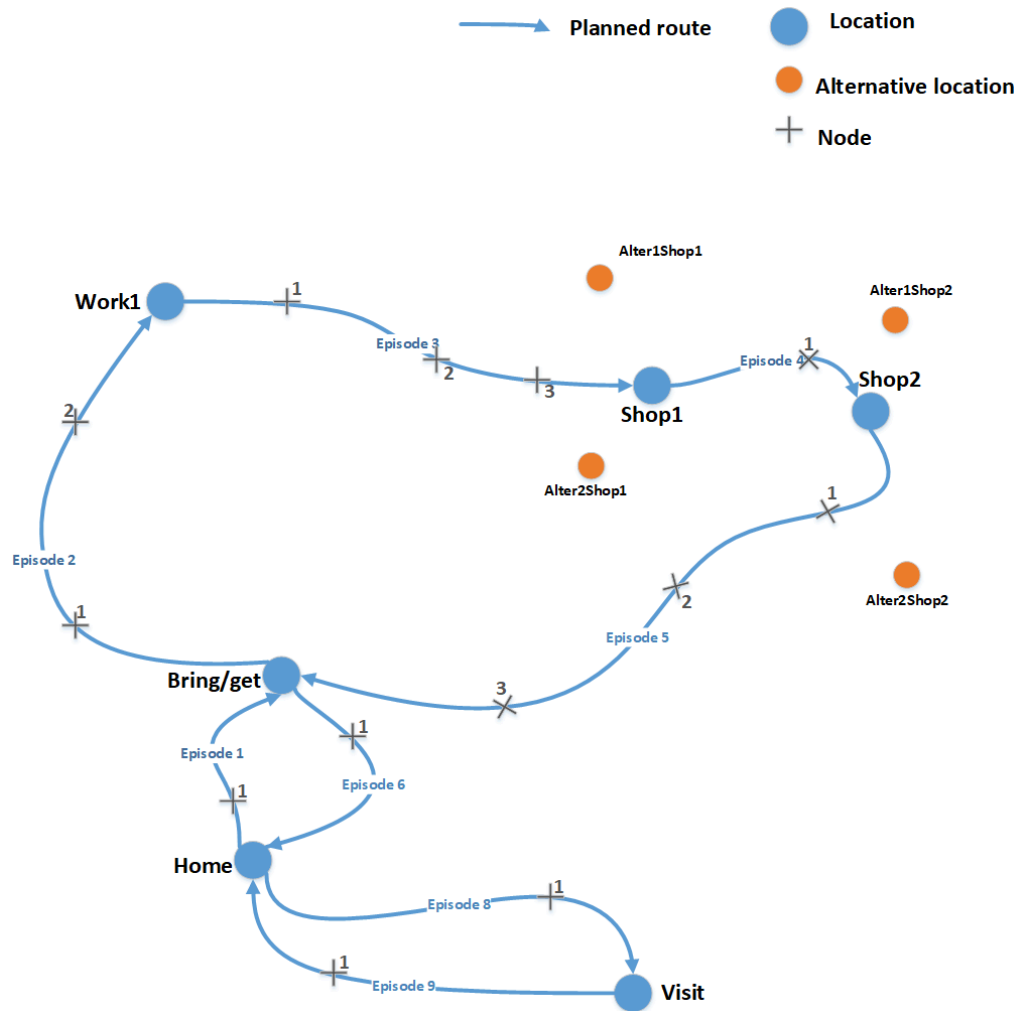


Figure 8.1: The original schedule of a certain day

are defined, and shown in Table 8.2. As we have explained in Equation 6.15, page 87, each alternative location has the parameters of individual's perception and the location's quality. And the value of quality is within $[0, 1]$, the value of perception is within $[0.9, 1.1]$.

8.2.2/ IMPLEMENTATION OF THE APPLICATION

In this section, we provide details of the unexpected events and the road network. The unexpected event of congestion on the way of *work* is considered. Additionally, the event related to the activity duration extension of *shop1*, as well as the location change of *shop1* are included in the experiment.

8.2.2.1/ CONGESTION EVENT

In this section, the congestion event along the path to *work* is defined.

The location of the congestion to *work* is at the segment seg_{2-w} . The congestion is informed at 8 : 05. Therefore, this congestion event is defined as:

$$event^{congestion}(8:05) = \langle a_2, seg_{2-w}^e, 8:05 \rangle \quad (8.1)$$

The congestion data (free travel time, road intensity, road capacity) for this segment is defined by:

$$seg_{2-w}^e(20, 280, 200) \quad (8.2)$$

According to the route map on Figure 8.2, the decision should be made before the individual arrives at the node 2 (t_2^{bw}) on the way from *bring/get* to *work*, if all the alternative choices on the road network are considered. Therefore, the decision-making time under this situation is defined as (see Equation 6.32, page 96):

$$DT = t_2^{bw} - 8:05 \quad (8.3)$$

The segment data for alternative routes are illustrated in Figure 8.2 and detailed in Table A.2, page 166.

ID	Planned Location	New Location	Planned Trip Period	New Trip Period	Planned Activity Period	New Activity Period
2	work	work	8:06–8:39	8:06–8:44	8:39–12:37	8:44–12:42
3	shop1	shop1	12:37–13:15	12:42–13:20	13:15–14:00	13:20–14:00
4	shop2	shop2	14:00–14:06	14:00–14:06	14:06–14:21	14:06–14:21
5	bring/get2	bring/get2	14:21–14:48	14:21–14:48	14:48–15:21	14:48–15:21
6	home2	home2	15:21–15:25	15:21–15:25	15:25–15:55	15:25–15:55
7	visit	visit	15:55–16:05	15:55–16:05	16:05–17:05	16:05–17:05
8	home3	home3	17:05–17:25	17:05–17:25	17:25–24:00	17:25–24:00

Table 8.3: Rescheduling results under congestion to *work*

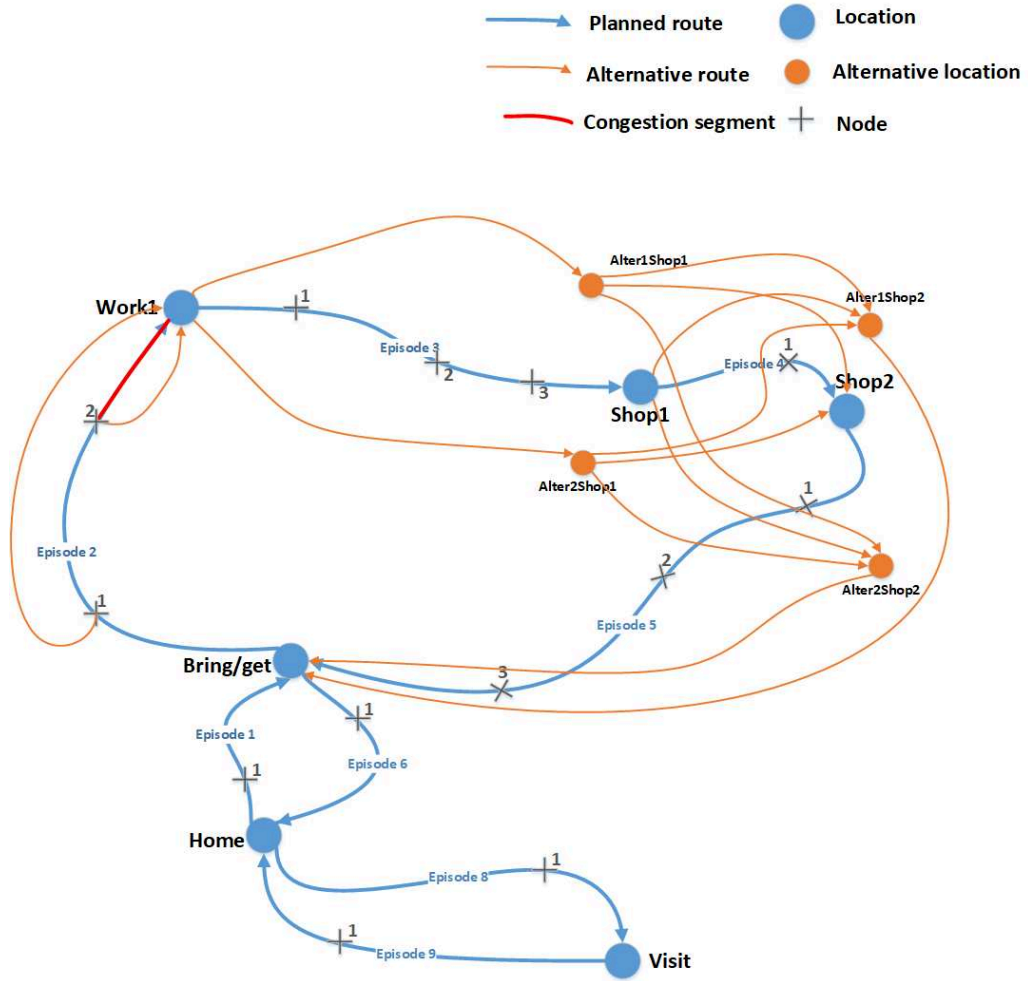


Figure 8.2: Road network under a congestion to work

8.2.2.2/ ACTIVITY DURATION EVENT

In this section, the duration extension event to activity *shop1* is studied. The alternative choices on the road map are shown in Figure 8.3. The data of the road network is the same as the congestion event to work, which is defined in Table A.2, page 166.

This event is informed at 13 : 45. The *shop1* duration is extended about 15 minutes. The event is defined as:

$$event^{duration}(13:45) = \langle a_3, 15, 13 : 45 \rangle \quad (8.4)$$

The decision should be made before the end time of the *shop1*. As we defined in Definition 3, page 13, t_{ae} is the end time of the activity a . Therefore, we use t_{a_3e} representing the end time of the activity a_3 , the *shop1* activity. Therefore, the decision-making time under

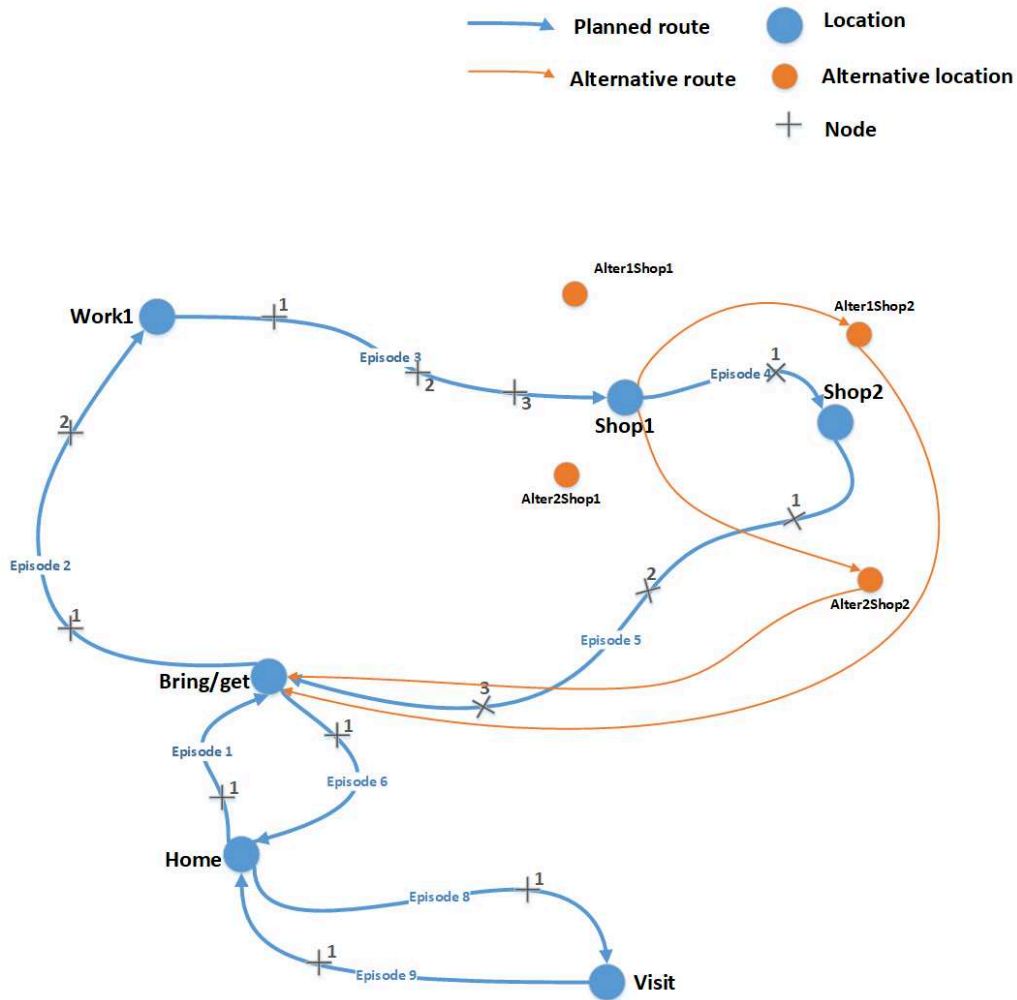


Figure 8.3: Road network under shop1 duration extending

this situation (see Equation 6.32 page 96) is defined as:

$$DT = t_{a_3e} - 13:45 \quad (8.5)$$

8.2.2.3/ LOCATION EVENT

In this section, the event of changing location of *shop1* to *A1S1* is defined. The alternative choices map is shown in Figure 8.4. The data of road network is defined in Table A.2 and Table A.3. This event is informed at 12:35. It is defined as:

$$event^{location}(12:35) = \langle a_3, A1S1, 12:35 \rangle \quad (8.6)$$

According to the route map in Figure 8.4, the decision should be made before the individ-

ID	Planned Location	New Location	Planned Trip Period	New Location	Planned Activity Period	New Activity Period
3	shop1	shop1	12:37– 13:15	12:37– 13:15	13:15– 14:00	13:15– 14:15
4	shop2	shop2	14:00– 14:06	14:15– 14:21	14:06– 14:21	14:21– 14:31
5	bring/get2	bring/get2	14:21– 14:48	14:31– 14:58	14:48– 15:21	14:58– 15:21
6	home2	home2	15:21– 15:25	15:21– 15:25	15:25– 15:55	15:25– 15:55
7	visit	visit	15:55– 16:05	15:55– 16:05	16:05– 17:05	16:05– 17:05
8	home3	home3	17:05– 17:25	17:05– 17:25	17:25– 24:00	17:25– 24:00

Table 8.4: Rescheduling results under *shop1* duration extension

ual arrives at the node 2 (t_2^{ws}) on the way from *work* to *shop1*, if all the alternative choices on the road network are considered. The decision-making under this situation is defined as (see Equation 6.32, page 96):

$$DT = t_2^{ws} - 12:35 \quad (8.7)$$

The simulation results are shown in 8.5. Since the event begins at *shop1*, only the results from *shop1* are provided.

ID	planned location	reschedule location	planned trip period	reschedule location	planned activity pe- riod	planned activity pe- riod
3	shop1	A1S1	12:37– 13:15	12:37– 13:27	13:15– 14:00	13:27– 14:07
4	shop2	Shop2	14:00– 14:06	14:07– 14:17	14:06– 14:21	14:17– 14:27
5	bring/get2	bring/get2	14:21– 14:48	14:27– 14:54	14:48– 15:21	14:54– 15:21
6	home2	home2	15:21– 15:25	15:21– 15:25	15:25– 15:55	15:25– 15:55
7	visit	visit	15:55– 16:05	15:55– 16:05	16:05– 17:05	16:05– 17:05
8	home3	home3	17:05– 17:25	17:05– 17:25	17:25– 24:00	17:25– 24:00

Table 8.5: Rescheduling results under *shop1* location changing to A1S1

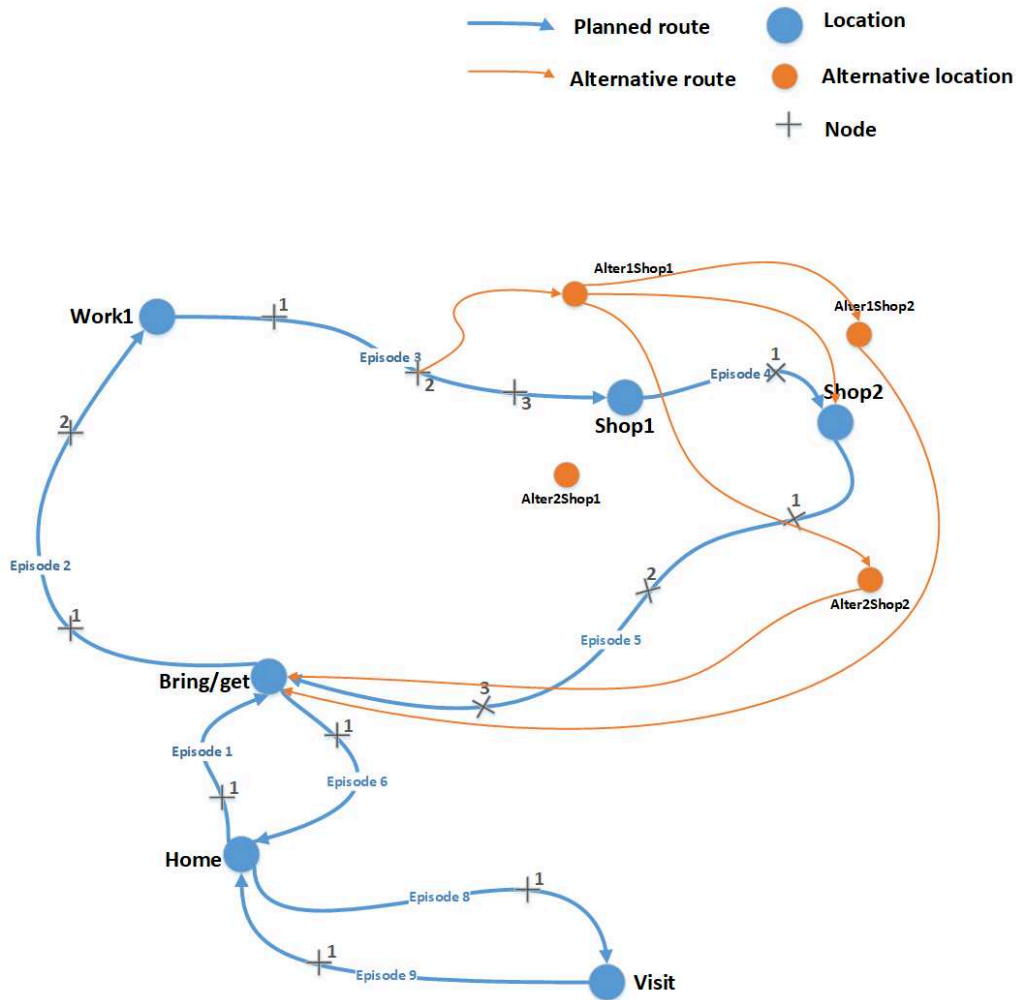


Figure 8.4: Road network under shop1 location changing

8.2.3/ ANALYSIS OF EXPERIMENTAL RESULTS

- Congestion Event:** We can see that the planned duration from *bring/get* to *work* is 33 minutes. And because of the intensity of the segment seg_{2-w}^{bw} , the travel duration of this trip is extended to 41.5. Under this congestion event, the individual chooses another path, which takes less travel time than the congestion segment. They are the segments seg_{b-1}^{bw} and seg_{1-w}^{bw} . This new path takes 38 minutes, which is 5 minutes later than the planned travel time. Because the minimal activity duration of *work* is equal to the planned duration, the start time and end time are both delayed 5 minutes. The start time and end time of the trip from *work* to *shop1* are delayed 5 minutes as well. Since the activity duration of the *shop1* is flexible, *shop1* shortens its duration to 5 minutes. Then, the rest of the activities in the schedule stay the same as in the planned schedule. It should be noticed that there is another choice to go to an alternative location of *shop1*: *A2S1*. It takes 20 minutes to travel, which is 8

minutes less than the planned travel time. But, the original location *shop1* can finish its minimum duration. If changing to a new location, there is a bigger penalty than changing activity duration. Therefore the individual still keeps his original destination location to *shop1*.

- **Activity duration event:** The activity duration of *shop1* is extended about 15 minutes. Consequently, the begin time and end time for traveling to *shop2* are delayed about 15 minutes. Since there are 5 minutes of flexibility for the activity duration, *shop2* shortens its duration to 10 minutes from 15 minutes. The begin time and end time for traveling to *bring/get2* are delayed about 10 minutes. The duration flexibility can cover the change of 10 minutes. Therefore, the start time of *bring/get2* is delayed about 10 minutes. The end time of *bring/get2* and the rest activities do not change in the planned schedule. In addition, there is an alternative location for *shop2*, which takes less travel time, and the individual does not choose that because the penalty caused by location changing is too high.
- **Activity location change:** We change the location of *shop1* to *A1S1* in the experiments. The travel time to *A1S1* is extended about 12 minutes. And the activity of *shop1* shortens to its minimal duration, let say 40 minutes. The time delay is reduces to 7 minutes. There is another time delay of 4 minutes caused by the *A1S1* to *shop2* compared to original *shop1* to *shop2*. Consequently, there is a total of 11 minutes delay, which is reflected at the start time and the end time of the travel from *shop2* to *bring/get2*. The duration flexibility of the activity *bring/get2* can cover this time changes. Therefore, the end time of the activity *bring/get2* and the rest of the activities in the schedule keep unchanged.

From these three points, it can be seen that the individual would like to change time attributes and an alternative path to his planned location. Although there are alternative choices to change to a new location, which may take shorter travel time. Because of the location changing penalty, the individual still chooses the original activity location.

For these three experiments, there is no choice of dropping an episode either. The reason might be that dropping an episode causes more utility loss compared to adapt the episode attributes. There is another point that can verify the importance of the activity utility. The informed times of these events are changed in the experiments, which cause more time pressure. Under such conditions, the simulation results are identical. The reason is that the activity utility has a higher priority in our model.

8.3/ JOINT TRIP RENEGOTIATION

This section describes experiments for validating the agent-based joint trip renegotiating model. A planned joint trip and a simple road network are used. Experiments in this section consider traffic congestion on the joint trip. Offers exchanged between the driver and the passenger are discussed, as well as the detailed parameters of the model.

8.3.1/ PRESENTATION AND IMPLEMENTATION OF THE APPLICATION

The application that is used in these experiments is the one illustrated in Chapter 7. There is a planned joint trip, which involves a passenger and a driver. During the joint trip execution, there is congestion on the route to the passenger's destination. It will cause the travel time extension. The passenger and the driver need to renegotiate the arrival time of the passenger, the paths, and the location/drop off places of the passenger. If the driver has an alternative location, he will also take in into his consideration. When the congestion event is informed, we assume that the driver is the first one to propose an offer. If the passenger refuses, he needs to provide a counter offer to the driver, which can balance the passenger's optimal offer and the incoming driver's offer.

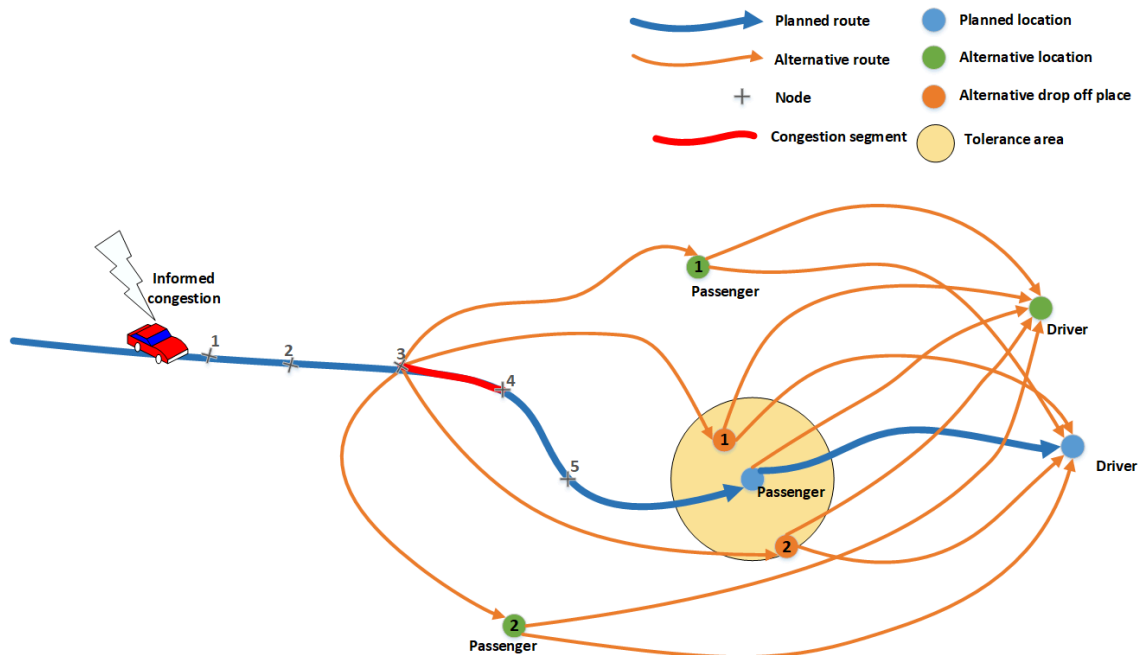


Figure 8.5: Alternative location/drop off choices for joint trip

Assume the joint trip begins at 10 : 00, and it arrives at the passenger's location at l_p , and the passenger begins his activity for a duration of 40 minutes. Therefore, $a = -30.5$ and

$b = 1.206$, which are the activity parameters (Equation 7.6).

The passenger's eagerness is $e^p = 50$, which affects the his group time pressure (Equation 7.12, page 116). And, the concession degree to the driver is $\gamma = 0.8$, which affects the fitness value when generating the count offer (Equation 7.11, page 115). His preference to the time and location is $w_t^p = 1$ and $w_l^p = 1$ (Equation 7.14, page 116), which are also used to score the fitness value.

After dropping off the passenger, the driver continues to his own location l_d , and then he begins his activity for a duration of 55 minutes. Therefore, the driver's activity parameters are $a = -10.2$ and $b = 0.8$ (Equation 7.6, page 113).

The driver's group time pressure parameter, eagerness is $e^d = 10$ (Equation 7.12, page 116). His concession degree to the passenger is $\gamma = 0.6$. It affects the driver's evaluation of fitness value (Equation 7.11, page 115) if he refuses the passenger's offer and needs to provide a count offer. The driver's preference to the time and location are $w_t^d = 1$ and $w_l^d = 1$ (Equation 7.14, page 116), which are also used to score the fitness value.

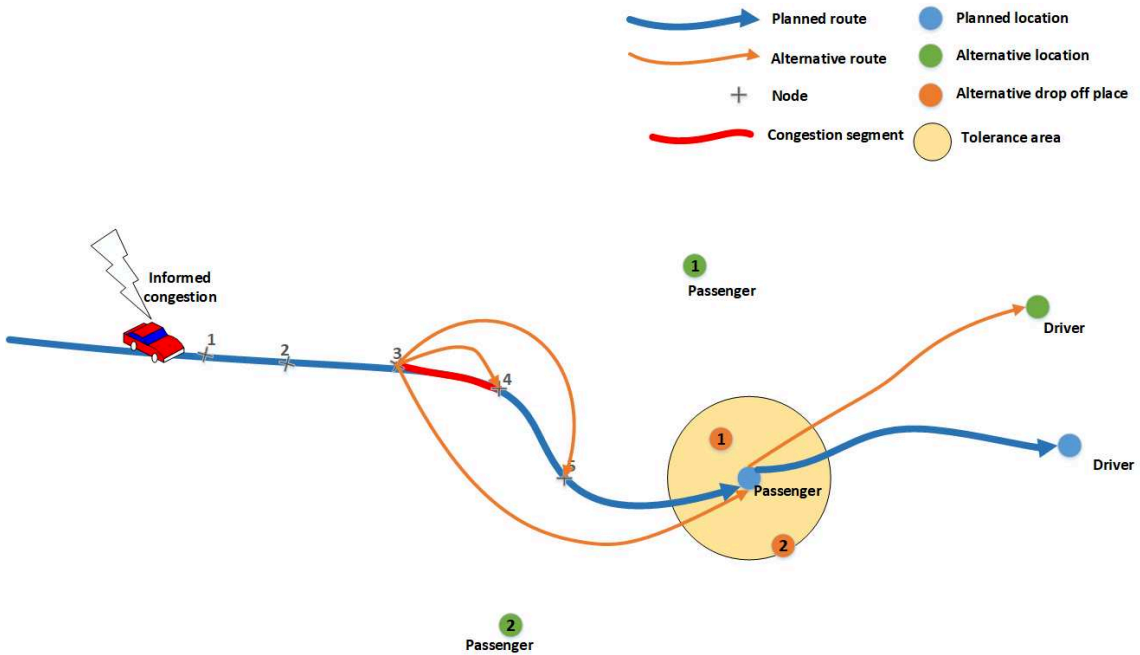


Figure 8.6: Alternative path choice for joint trip

The planned route is the blue line as showed in Figure 8.5 and Figure 8.6. The segment data for the planned joint trip are defined in Table A.4, page 167. We assume there is a congestion in the segment seg_{3-4} , and it is informed at 10 : 00. The event is defined as:

$$event^{congestion}(10:00) = \langle seg_{3-4}^e, 10:00 \rangle \quad (8.8)$$

The free travel time of the segment seg_{3-4} is 10, and the road intensity and capacity for this segment is 185 and 110. Therefore, the data for this congestion segment is (the travel time is obtained from Equation 6.13, page 86):

$$seg_{3-4}^e = (10, 185, 110) \quad (8.9)$$

As illustrating in Figure 8.5, two alternative drop off places (the orange dots in the circle, l_{pdo1} and l_{pdo2}), and two alternative locations (green dots, l_{pl1} and l_{pl2}) for the passenger are defined. For l_{pdo1} and l_{pdo2} , their distances to the planned locations are 0.3km and 0.2km, respectively. They are used to calculate the parameter of choosing a drop off place for the passenger (Equation 7.9, page 114).

An alternative location (green dot, l_{dl}) for the driver is defined. It can be seen on Figure 8.6 that alternative paths from node 3 to 4, 3 to 5, and 3 to l_p (the orange lines) are defined. The alternative route data are defined in Table A.5, page 167.

In the conditions above, if all the alternative offers in the road map are considered, the decision should be made before arriving to the node 3, which is t_3 . Therefore, in the group time pressure Equation 7.12, page 116, the left time for decision-making is:

$$ST = t_3 - 10:00 \quad (8.10)$$

In addition, each time the driver/passenger evaluates the incoming offer, he will firstly check the limited renegotiating time is reached or not. Time is passing by as the renegotiation executing. Therefore, we provide the renegotiating time of each round. We assume that the generating an count offer time, for the driver, we set 2 minutes, for the passenger, we set 1.5 minutes.

Message	Be- ginning Point	Passen- ger's Lo- cation	Arrival time	Driver's Location	Arrival time
planned joint trip	L_1	L_p	10:47	L_d	11:02
1-driver-send-optimal offer	L_1	L_{pl1}	10:53	L_d	11:03
passenger-refuse					
2-passenger-send-count offer	L_1	L_{pdo1}	10:48	L_d	11:09
driver-refuse					
3-driver-send-count offer	L_1	L_{pdo2}	10:45	L_d	11:05
passenger-accept					

Table 8.6: Offer change between the driver and passenger

8.3.2/ ANALYSIS OF EXPERIMENTAL RESULTS

In the utility function of the passenger and the driver, they all have their own location function. For the driver, the discount parameter of changing a new location is $\omega = 0.8$ (Equation 7.4, page 113). Therefore, in the results of the joint trip experiment, the driver is more likely to choose his original planned location.

For the passenger, there is a discount parameter of changing a new location is $\beta = 0.65$ (Equation 7.8, page 114). In addition, the passenger also has the choice of changing a new drop off place. The parameter of changing the drop off place depends on the distance from the drop off place to the original planned location (Equation 7.14). The passenger's preference to change a new location or a new drop off place depends on the value of the discount parameter. In our experiment, the passenger more likes changing his drop offer place.

8.4/ CONCLUSION

This chapter presents experiments to validate the models of the individual rescheduling process and the joint trip renegotiating decision-making. Simulation is realized, including the congestion events, location change events, and duration extension events for the individual activity rescheduling model. Additionally, the congestion event is included in the experiments related to the joint trip renegotiating model. Both in the two models, the location changing is not preferred by the decision-makers. Decision-makers care more about the activity utility.

To conclude this chapter, let us remind the hypothesis and research questions made for this thesis. The hypothesis is “the agent-based model can simulate both individual activity rescheduling and joint trip renegotiating to respond to the unexpected events during the execution of the planned schedule (or a joint trip)”. The research questions of the individual activity rescheduling and the joint trip renegotiating are:

RRQ1: How to define the unexpected events in individual activity rescheduling?

RRQ2: How to generate the alternative choice set and choose the optimal one?

RRQ3: What is the relationship between a pair of connected activities, and how to support this relationship into the rescheduling process?

RRQ4: How to simulate the individual activity rescheduling decision process?

RRQ5: How to generate the alternative offers and count offer for an agent in a joint trip?

RRQ6: How to simulate the joint trip renegotiating process?

The conclusion is, therefore, that the hypothesis made according to our problematic is validated because the experiments define the unexpected events and provide the alternative choices for the individual in the individual activity rescheduling model and the participants in the joint trip renegotiating model. They simulate the results of a new schedule or a new joint trip successfully. For the research question RRQ3, it is closely related to the activity type. The activity type is not only being represented in the utility function, but also reflected in the minimal duration and alternative choices (can be dropped or not, have alternative locations or not) in our model. While, since the utility loss of dropping and the penalty of location changing, the experiments result just show the time changing relations of a pair of connected activities.

IV

CONCLUSION

GENERAL CONCLUSION

9.1/ SUMMARY OF THE CONTRIBUTIONS

During the past decade, individual mobility prediction has become a critical enabler for a wide range of applications, like location-based advertising, early warning systems, and citywide traffic planning. In this context, people perform activities and to travel from one activity point to the next one. It leads to building daily plans that should be changed dynamically due to uncertainties (unexpected events), like congestion, mode change, or time conflicts (Balać and Axhausen, 2016). These dynamics changes are addressed by daily activity rescheduling methods and processes. Daily activity rescheduling is a complex problem, which should consider the uncertainties that may happen during the schedule execution, the individual's characteristics, and also his response to the uncertainties.

This thesis proposes to use an agent-based model to model and simulate the activity rescheduling decision-making process. The agent-based method can capture the details of the complicated environment, including the road network and the associated events. In this context, agents are representing the individuals. Indeed, they can perceive their environment and respond to the changes in it. They are also able to interact with the other agents in order to find suitable schedules in the case of joint activities.

In order to establish the agent-based model for activity rescheduling decision-making, this thesis explores the aspects of individual activity rescheduling and joint trip renegotiating. After a review of related works, the thesis' research questions are refined and detailed, as well as the related hypotheses. The contributions of this thesis are:

- **Individual activity rescheduling model:** Events that may append into the system are classified in order to define the unexpected events that must be considered in the individual activity schedule executing process. This thesis establishes an agent-based in order to simulate the individual activity rescheduling decision-making. The

model considers the interrelationship of a pair of activities. The alternative schedules are generated by using a decision tree, and customized alternative choice modules are applied. In the time adjustment module, a minimal activity duration is proposed in order to allow the individuals to finish an activity with minimal duration. In the case the activity cannot be terminated, it is dropped. Moreover, a penalty-based method is introduced for choosing the optimal new schedule under unexpected events. It calculates the penalty score of each alternative schedule and considers the weight of an alternative schedule by defining and using a related utility function. This latter combines the time pressure and the number of changed episodes.

- **Joint trip renegotiation model:** This thesis establishes an agent-based model to simulate the joint trip renegotiating process, which involves one passenger and one driver. In this thesis, the renegotiation never fails. If it cannot be achieved within the limited rescheduling time, the participants accept the last offer before reaching the deadline. The participants share a set of alternative choices, which is determined by the activity type and the road network (alternative paths, alternative locations, and drop off places). The passenger and the driver have their own utility functions to score these choices. The first round of the negotiation is offering a quasi-optimal offer. If the opponent refuses it, he needs to generate a counter offer and send it back to the initial proposer. The counter offer balances the agent's own optimal offer and the incoming offer from the opponent. Our model considers the social relationship and the group time pressure when making concessions.

In order to validate the proposed models, typical applications are presented in Chapter 8. They are based on a simple road network that is not a key element in the context of this research work. Three kinds of unexpected events are considered: the congestion event, the activity duration extension, and the location-change event. For the joint trip renegotiating model, this thesis offers a joint trip, the activities connected to this joint trip, and the related road situation. The offer exchanges between a passenger and a driver are presented, analyzed, and discussed in the context of traffic congestion for reaching the passenger's destination. The results of the experiments show that the decision-makers are not likely to change their planned locations. They prefer to adjust time attributes. What is more, time pressure does not play a big role in our experiments. It is explained by the fact that the activity utility has a higher priority in our model. In the near future, we would like to develop a heuristic-based model to explore the time pressure's effect on the decision-making process.

9.2/ PERSPECTIVES

The proposals within this thesis constitute a step towards the development of the agent-based models dealing with the daily activity rescheduling problem. To go further, we foresee four perspectives. One is related to the individual activity rescheduling model, one is about the joint trip renegotiating model, and the rest two are proposed to fix the several limitations of the proposed models.

9.2.1/ INDIVIDUAL ACTIVITY RESCHEDULING CONSIDERING SEQUENCE CHANGE

In this thesis, we consider the within-day activity dynamic rescheduling. Our model considers alternative choices as more as possible to respond to unexpected events. Therefore the location change, the path change, and the kinds of time attribute change are supported by the proposed model. However, the sequence changes are out of our model, like adding an activity or substituting activities.

If we extend our model being able to change the activity sequence, the distance change of the substituted activities should be considered in the penalty functions. Additionally, there should be activity storage to provide the possibility of adding an activity to the planned schedule, or to replace an activity in the back-up. Nevertheless, when we think about adding an activity, the anticipated time pressure, which is caused by adding too many tasks in the schedule, is an interesting factor that should be noticed. Finally, doing several activities simultaneously is also an interesting direction to explore.

9.2.2/ JOINT TRIP RENEGOTIATING AMONG MORE PARTICIPANTS

In our model of the joint trip renegotiation, there is one passenger and one driver. In reality, there may be more passengers with different destination locations.

Under this situation, the driver needs to consider the requirements of several passengers at the same time. He may have different degrees of concessions to different people, which may depend on the social relationship. Moreover, if we consider the travel cost in the utility function, it is also a factor that affects the driver's concession degree to participants.

9.2.3/ MULTIPLE UNEXPECTED EVENTS AT A TIME

In both the individual activity rescheduling model and the joint trip rescheduling model, a single unexpected event is considered at a time, and the models make the response to this unexpected event at the time they are informed.

Multiple events at the same time may be taken into consideration as well. When several unexpected events are informed at the same time, the individual needs to implement a strategy to deal with these events. He can consider these events within the alternative choices, or make a priority among them, solving them one by one.

9.2.4/ DEPLOYMENT AND VALIDATION WITH REAL DATA

In our experiments, the road data and the data of the individual's preferences are proposed to run and validate the models. Real dynamic road data can be obtained through some related applications as IoT systems or smart cities. The alternative drop off places for the passengers can be generated by using the real road network data, the available points by searching in the tolerance area. Moreover, the individual's preferences to the attributes in the schedule, the activity variables in the utility function, and participants' concession to a kind of social relationship can be obtained from surveys.

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LIST OF FIGURES

1.1	Structure of the thesis	9
2.1	Architecture of activity/travel model system(Miller, 2019)	12
2.2	A conceptual framework of activity scheduling process (Doherty and Axhausen, 1999)	14
2.3	Classic two-person joint trip problem inspired by Liao (2019)	18
2.4	The four aspects of a multi-agent simulation model according to (Michel, 2004)	24
2.5	Terms related to activity rescheduling problem	30
2.6	Summary of simulation and agent-based model	31
3.1	Summary of state of the art related to individual activity rescheduling problem	49
4.1	Summary of state of the art of joint trip renegotiating problem	65
5.1	Agent-based modelling according to Bazzan and Klügl (2014)	72
5.2	Summary of the research methodology	76
6.1	Use-case of Individual Activity Rescheduling	79
6.2	Classification of events types and their main characteristics	81
6.3	Time attributes change under directly time-related unexpected events . . .	86
6.4	Schematic representation of rescheduling process faced with unexpected events	90
6.5	Decision tree based on choice modules	92
6.6	Summary of the agent-based individual rescheduling model	99
7.1	Use-case of the joint trip renegotiation	102
7.2	Time zones of the joint trip	103

7.3	Comparison of negotiation and renegotiation	104
7.4	Alternative path choices for the joint trip	106
7.5	Driver's alternative location in a joint trip	107
7.6	Passenger's alternative location/drop off place in a joint trip	108
7.7	Alternative location choices for the passenger and the driver in a joint trip .	109
7.8	Renegotiation process during the execution of joint trip	112
7.9	Summary of the agent-based joint trip renegotiating model	118
8.1	The original schedule of a certain day	121
8.2	Road network under a congestion to work	123
8.3	Road network under shop1 duration extending	124
8.4	Road network under shop1 location changing	126
8.5	Alternative location/drop off choices for joint trip	128
8.6	Alternative path choice for joint trip	129

LIST OF TABLES

3.1	Summary of static factors in individual activity rescheduling	36
3.2	Summary of individual joint trip models	41
3.3	Summary of agent-based individual activity rescheduling models	47
4.1	Summary of static factors in joint trip renegotiating	54
6.1	Activity type related to choice modules	88
6.2	Event type related to choice modules	88
8.1	Original individual daily activity schedule and activity parameters	120
8.2	Parameters of alternative locations for shop activities	120
8.3	Rescheduling results under congestion to <i>work</i>	122
8.4	Rescheduling results under <i>shop1</i> duration extension	125
8.5	Rescheduling results under <i>shop1</i> location changing to <i>A1S1</i>	125
8.6	Offer change between the driver and passenger	130
A.1	Route segments for the planned schedule	165
A.2	Road data the alternative route and locations under a congestion to <i>work</i> .	166
A.3	Road data the alternative route under the <i>shop1</i> location changing	166
A.4	Segments for the joint trip	167
A.5	Segments for the alternative route for the joint trip	167
A.6	Segments data for the driver's route	167

LIST OF DEFINITIONS

1	Definition: Road Network	13
2	Definition: Trip	13
3	Definition: Activity	13
4	Definition: Episode	14
5	Definition: Activity Schedule	14
6	Definition: Activity Scheduling	15
7	Definition: Unexpected event	16
8	Definition: Activity Rescheduling	16
9	Definition: Solo trip/activity	17
10	Definition: Negotiation	17
11	Definition: Two-person joint trip	18
12	Definition: Renegotiation (Tosselli et al., 2020)	18
13	Definition: Simulation (Shannon, 1977)	19
14	Definition: Simulation by (Miller, 2019)	19
15	Definition: Simulation model	20
16	Definition: Microsimulation (Jinjing et al., 2014)	21
17	Definition: Agent (Wooldridge and Jennings, 1995)	22
18	Definition: Multi-agent System (Ferber, 1995)	22
19	Definition: Environment (Weyns et al., 2005)	26
20	Definition: Interaction	26
21	Definition: Protocol (Wen and Mizoguchi, 1999)	27
22	Definition: Characteristics of an agent negotiation (Beer et al., 1999)	27
23	Definition: Cooperation (Smith and Davis, 1981)	28
24	Definition: Cooperation (Luck and d’Inverno, 1995)	28

25	Definition: Cooperation (Changhong et al., 2002)	28
26	Definition: Time Pressure (Rastegary and Landy, 1993)	36
27	Definition: Group Time Pressure	54
28	Definition: Negotiation Team	60
29	Definition: Agent-based Negotiation Team	61

V

APPENDIX

DATA OF ROAD NETWORK

In this appendix, the road data for the planed route and alternative route under unexpected events are provided, which consists of the free flow time of a segment, the flow and capacity of a segment.

A.1/ ROAD DATA IN INDIVIDUAL ACTIVITY RESCHEDULING EXPERIMENT

The planned travel time of the trip in the original is in Table A.1. The total travel time of segments equals to the trip travel time. The data of a segment is represented by a tuple $seg(freetravelttime, roadintensity, roadcapacity)$. We highlight the segment which the congestion event will occur (blue color).

<i>trip</i>	<i>planned travel time</i>
<i>home-bring/get</i>	$seg_{h-1}^{hb}(2, 30, 60), seg_{1-b/g}^{hb}(2, 30, 60)$
<i>bring/get-work</i>	$seg_{b/g-1}^{bw}(5, 37, 74), seg_{1-2}^{bw}(8, 45, 90), seg_{2-w}^{bw}(20, 100, 200)$
<i>work-shop1</i>	$seg_{w-1}^{ws}(5, 37, 74), seg_{1-2}^{ws}(5, 37, 74), seg_{2-3}^{ws}(4, 35, 70),$ $seg_{3-s}^{ws}(14, 74, 148)$
<i>shop1-shop2</i>	$seg_{s1-1}^{ss}(2, 30, 60), seg_{1-s2}^{ss}(4, 35, 70)$
<i>shop2-bring/get</i>	$seg_{s2-1}^{sb}(6, 40, 80), seg_{1-2}^{sb}(7, 43, 86), seg_{2-3}^{sb}(5, 37, 74),$ $seg_{3-b/g}^{sb}(9, 47, 94)$
<i>bring/get -home</i>	$seg_{b/g-1}^{bh}(2, 30, 60), seg_{1-h}^{bh}(2, 30, 60)$
<i>home - visit</i>	$seg_{h-1}^{hv}(4, 35, 70), seg_{1-v}^{hv}(6, 40, 80)$
<i>visit - home</i>	$seg_{v-1}^{vh}(9, 47, 94), seg_{1-h}^{vh}(11, 55, 110)$

Table A.1: Route segments for the planned schedule

We set the seg' as the alternative route data for a congestion segment. For the condition of under a congestion to work, the road network is as Table A.2:

route	segment data
bring/get-work	$seg_{1-w}^{bw} (33, 150, 300), seg_{2-w}^{bw'} (25, 115, 230)$
work-alter1shop1	$seg_{w-A1s1}^{wA1s1} = (45, 300, 320)$
work-alter2shop1	$seg_{w-A2s1}^{wA2s1} = (20, 100, 200)$
shop1-alter1shop2	$seg_{s1-A1s2}^{sA1s2} = (4, 35, 70)$
shop1-alter2shop2	$seg_{s1-A2s2}^{sA2s2} = (7, 80, 74)$
alter1shop1-shop2	$seg_{A1s1-s2}^{A1s1s2} = (10, 100, 160)$
alter1shop1-alter1shop2	$seg_{A1s1-A1s2}^{A1s1A1s2} = (6, 90, 86)$
alter1shop1-alter2shop2	$seg_{A1s1-A2s2}^{A1s1A2s2} = (10, 60, 120)$
alter2shop1-shop2	$seg_{A2s1-s2}^{A2s1s2} = (5, 37, 74)$
alter2shop1-alter1shop2	$seg_{A2s1-A1s2}^{A2s1A1s2} = (3, 40, 80)$
alter2shop1-alter2shop2	$seg_{A2s1-A2s2}^{A2s1A2s2} = (4, 50, 100)$
alter1shop2-bring/get	$seg_{A1s2-b/g}^{A1s2B} = (33, 200, 300)$
alter2shop2-bring/get	$seg_{A2s2-b/g}^{A2s2B} = (23, 105, 210)$

Table A.2: Road data the alternative route and locations under a congestion to *work*

For the condition of under the location of *shop1* changing to *A1S1*, the road network is as Table A.3.

route	segment data
work-A1s1	$seg_{2-A1s1}^{sA1s1} = (33, 160, 320)$

Table A.3: Road data the alternative route under the *shop1* location changing

A.2/ ROAD DATA IN JOINT TRIP RENEGOTIATING EXPERIMENT

For the joint trip, the planned travel time of the segment in the joint trip is as Table A.4.

Under the congestion event, the segment data for the alternative routes are in Table A.5. In addition, seg'_{3-4} means another new alternative path for this congestion segment.

The direct route for the driver, which mean he drivers from the joint trip beginning to his own location without considering the passenger's location is in Table

<i>segment</i>	<i>data</i>
1 – 2	$seg_{1-2} = (5, 25, 50)$
2 – 3	$seg_{2-3} = (18, 80, 160)$
3 – 4	$seg_{3-4} = (10, 55, 110)$
4 – 5	$seg_{4-5} = (8, 45, 90)$
5 – l_p	$seg_{5-l_p} = (6, 28, 56)$
$l_p - l_d$	$seg_{l_p-l_d} = (15, 75, 150)$

Table A.4: Segments for the joint trip

<i>route</i>	<i>segment data</i>
3-4	$seg'_{3-4} = (18, 80, 160)$
3-5	$seg_{3-5} = (25, 120, 240)$
3- $l_{passenger}$	$seg_{3-l_p} = (30, 160, 320)$
$l_{passenger} - l_{dl}$	$seg_{l_p-l_{dl}} = (20, 100, 200)$
3- l_{pl1}	$seg_{3-l_{pl1}} = (20, 100, 200)$
$l_{pl1} - l_{driver}$	$seg_{l_{pl1}-l_d} = (20, 100, 200)$
3- l_{pl2}	$seg_{3-l_{pl2}} = (28, 140, 280)$
$l_{pl2} - l_{driver}$	$seg_{l_{pl2}-l_d} = (18, 80, 60)$
3- l_{pdo1}	$seg_{3-l_{pdo1}} = (25, 120, 240)$
$l_{pdo1} - l_{driver}$	$seg_{l_{pdo1}-l_d} = (22, 110, 220)$
3- l_{pdo2}	$seg_{3-l_{pdo2}} = (20, 100, 200)$
$l_{pdo2} - l_{driver}$	$seg_{l_{pdo2}-l_d} = (25, 120, 240)$
$l_{pl1} - l_{dl}$	$seg_{l_{pl1}-l_{dl}} = (10, 50, 100)$
$l_{pl2} - l_{dl}$	$seg_{l_{pl2}-l_{dl}} = (18, 80, 60)$
$l_{pdo1} - l_{dl}$	$seg_{l_{pdo1}-l_{dl}} = (20, 100, 200)$
$l_{pl2} - l_{dl}$	$seg_{l_{pl2}-l_{dl}} = (23, 115, 230)$

Table A.5: Segments for the alternative route for the joint trip

<i>route</i>	<i>segment data</i>
1 – l_{driver}	$seg_{1-l_d} = (40, 290, 580)$
1 – l_{dl}	$seg_{1-l_{dl}} = (55, 320, 640)$

Table A.6: Segments data for the driver's route

CORE RESOURCE CODE

This chapter provides the Java code of the important part in the individual activity rescheduling model and the joint trip renegotiating model.

Listing B.1: Java code of the decision tree in individual activity rescheduling process

```

if (currentSchedule.findNextActivity(nextActivity) == null) {
    List<Choice> choices =
        currentSchedule.makeAllPossibleChoices(nextActivity,
            currentLocation);
    choices.sort((choice1, choice2) -> {
        try {
            return Double.compare(choice1.getPenalty() * (1 -
                choice1.getPossibility(choices, currentTimeForProcessing,
                    deadline)),
                choice2.getPenalty() * (1 -
                    choice2.getPossibility(choices,
                        currentTimeForProcessing, deadline)));
        } catch (Exception e) {
            e.printStackTrace();
        }
        return -1;
    });
    bestEpisode.add(choices.get(0).getNewSchedule()
        .getActivityBasicList().get(choices.get(0)
            .getNewSchedule().getActivityBasicList()
                .size() - 2));
    bestEpisode.add(choices.get(0).getNewSchedule()
        .getActivityBasicList().get(choices.get(0)
            .getNewSchedule().getActivityBasicList()
                .size() - 1));
} else {
    for (List<ActivityBasic> tmp : tmpResult) {

```

```

        Schedule tmpSchedule = currentSchedule.copy();
        tmpSchedule.replaceActivity(findFormerActivityBasic(nextActivity),
            nextActivity, tmp);
        List<Choice> choices = tmpSchedule.makeAllPossibleChoices(
            tmpSchedule.findNextActivity(nextActivity),
            ((Travel) tmp.get(0)).getRoute().getDestination());
        for (Choice choice : choices)
            choice.setOriginalSchedule(currentSchedule);
        double C = 0;
        for (Choice c : choices) {
            double penalty = c.getPenalty();
            double possibility = c.getPossibility(choices,
                currentTimeForProcessing, deadline);
            C += penalty * (1 - possibility);
        }
        if (C < bestC) {
            bestC = C;
            bestEpisode = tmp;
        }
    }
}

result.addAll(bestEpisode);
currentSchedule.replaceActivity(findFormerActivityBasic(nextActivity),
    nextActivity, bestEpisode);
if (currentSchedule.findNextActivity(nextActivity) != null) {
    result.addAll(getBestChoice(nextActivity, ((Travel)
        bestEpisode.get(0)).getRoute().getDestination(), currentSchedule,
        deadline));
}

return result;
}

public List<Choice> makeAllPossibleChoices(Activity nextActivity, Location
    currentLocation) throws Exception {
    List<List<ActivityBasic>> list = makePossibleActivityList(nextActivity,
        currentLocation);
    List<Choice> result = new ArrayList<>();
    for (List<ActivityBasic> path : list) {
        Schedule newSchedule = this.copy();
        newSchedule.replaceActivity(findFormerActivityBasic(nextActivity), null,

```

```

        path);
        Choice choice = new Choice(this, newSchedule);
        result.add(choice);
    }
    return result;
}

```

Listing B.2: Java code of the generation of the alternative offers for the joint trip

```

public List<Offer> makeOfferList(Event event, List<Location> restrictions,
    List<Location> alternatives) throws Exception {
    List<Offer> offerList = new ArrayList<>();
    List<Travel> path =
        schedule.findPathToNextActivity(event.getTargetActivity());
    List<List<Route>> newPathList = new ArrayList<>();
    if (alternatives != null && alternatives.size() > 0) {
        for (Location destination : alternatives) {
            List<List<Route>> tempPathList = new ArrayList<>();
            if (restrictions == null || restrictions.size() == 0) {
                tempPathList = schedule.getMap().findAllPossibleRoutes(null,
                    path.get(0).getRoute().getSource(), destination, false);
            } else {
                List<List<Route>> frontPaths = new ArrayList<>();
                for (Location tempDestination : restrictions) {
                    frontPaths.addAll(schedule.getMap().findAllPossibleRoutes(null,
                        path.get(0).getRoute().getSource(), tempDestination, false));
                }
                for (List<Route> frontPath : frontPaths) {
                    Location tmpSource = frontPath.get(frontPath.size() -
                        1).getDestination();
                    List<List<Route>> tempPostPath =
                        schedule.getMap().findAllPossibleRoutes(null, tmpSource,
                            destination, false);
                    for (List<Route> backPath : tempPostPath) {
                        List<Route> p = new ArrayList<>(frontPath);
                        p.addAll(backPath);
                        tempPathList.add(p);
                    }
                }
            }
            newPathList.addAll(tempPathList);
        }
    }
}

```

```

    }
} else {
    newPathList = schedule.getMap().findAllPossibleRoutes(null,
        path.get(0).getRoute().getSource(), path.get(path.size() -
            1).getRoute().getDestination(), false);
}
for (List<Route> newPath : newPathList) {
    List<ActivityBasic> newTravelPath = new ArrayList<>();
    for (Route r : newPath)
        newTravelPath.add(new Travel(r));
    Schedule newSchedule = schedule.copy();
    newSchedule.replaceActivity(path.get(0), path.get(path.size() - 1),
        newTravelPath);
    Offer offer = new Offer(schedule, newSchedule);
    offer.setUtility(getUtility(offer));
    offerList.add(offer);
}
return offerList;
}

```

Listing B.3: Java code of the renegotiating process of the joint trip

```

if (proposerIsDriver) {
    if (proposingTimer >= driverResponseTime) {
        System.out.println("\nCurrent offer: ");
        System.out.println(currentOffer.summary());
        boolean accepted = schedule.getPassenger().accept(currentOffer);
        if (accepted) {
            System.out.println("ORDER ACCEPTED\n");
            schedule.applyOffer(currentOffer);
        } else {
            currentOffer =
                schedule.getPassenger().response(schedule.getCurrentTime(),
                    currentOffer);
            proposerIsDriver = false;
            proposingTimer = 0;
        }
    }
} else {
    if (proposingTimer >= passengerResponseTime) {
        System.out.println("\nCurrent offer: ");
    }
}

```

```
System.out.println(currentOffer.summary());
boolean accepted = schedule.getDriver().accept(currentOffer);
if (accepted) {
    System.out.println("ACCEPTED\n");
    schedule.applyOffer(currentOffer);
} else {
    currentOffer =
        schedule.getDriver().response(schedule.getCurrentTime(),
            currentOffer);
    proposerIsDriver = true;
    proposingTimer = 0;
}
}
```

PUBLICATIONS OF THE AUTHOR

In this appendix, the list of the publications of HUI ZHAO are provided. The publications are listed in two categories: (i) the publications that are directly related to the content of this thesis, and (ii) the publications that are not directly related to the content of this thesis, but to which HUI ZHAO has provided a concrete contribution. The following table summarizes the total number of publications of HUI ZHAO.

Numbers of publications of HUI ZHAO	
Indexed International journals with reading committee	2
International conference with reading committee	2
International conference without proceeding	1
National conference with reading committee	1

C.1/ PUBLICATIONS THAT ARE RELATED TO THIS PHD THESIS

Numbers of publications related to this PhD thesis	
International conference with reading committee	2
National conference with reading committee	1

2020

- Hui ZHAO, Yazan MUALLA, Stéphane GALLAND, Igor TCHAPPI HAMAN, Tom BELLEMANS and Ansar-UI-Haque YASAR. “**Decision-Making under Time Pressure when Rescheduling Daily Activities**”. In the 11th International Conference on Ambient Systems, Networks and Technologies (ANT), May, Warsaw, Poland, 2020.

2018

- Hui ZHAO, Stéphane GALLAND, Luk KNAPEN, Tom BELLEMANS and Ansar-ul-haque YASAR. **“Agent-based Dynamic Rescheduling of Daily Activities”**. In the 8th International Symposium on Frontiers in Ambient and Mobile Systems, pp. 979-984, Porto, Portugal, 2018. DOI: 10.1016/j.procs.2018.04.100

2017

- Hui ZHAO, Stéphane GALLAND, Tom BELLEMANS and Ansar-UI-Haque YASAR. **“Towards the Individual-centered Re-scheduling of Activities”**. In the FUTUR-MOB17 Workshop, Montbéliard, France, 2017.

C.2/ OTHER CONTRIBUTIONS

Numbers of other publications	
Indexed International journals with reading committee	2
International conference without proceeding	1

2020

- Stéphane GALLAND, Yazan MUALLA, Igor TCHAPPI HAMAN, Hui ZHAO, Sebastian RODRIGUEZ, Amro NAJJAR and Nicolas GAUD. **“Model Transformations from the SARL Agent-Oriented Programming Language to an Object-Oriented Programming Language”**. In the International Journal on Agent-Oriented Software Engineering, pp. 1-38, 2020.
- Stéphane GALLAND, Yazan MUALLA, Hui ZHAO, Sebastian RODRIGUEZ, Amro NAJJAR and Nicolas GAUD. **“Model Transformations from the SARL Agent-Oriented Programming Language to an Object-Oriented Programming Language”**. Oral presentation in the special track of the 8th International Workshop on Engineering Multi-Agent Systems (EMAS 2020) that is dedicated to published AOSE papers, 8–9 May, Auckland, New Zealand, 2020.

2018

- Igor TCHAPPI HAMAN, Stéphane GALLAND, Vivient corneille KAMLA, Jean-claude KAMGANG, Cyrille merleau NONO SAHA and Hui ZHAO. **“Holonifica-**

tion Model for a Multilevel Agent-based System. Application to Road Traffic”. In the Int. Journal of Personal and Ubiquitous Computing, 2018. DOI: 10.1007/s00779-018-1181-y

Title: Agent-based Model for the Rescheduling of Individual and Collective Daily Activities under Uncertainties

Keywords: Agent-based model, Daily activity schedule, Individual activity rescheduling, Joint trip renegotiating, Unexpected events

Abstract:

Daily activity schedule are popular for people during daily life. While, when executing the schedule on the real road network, there are always some disruptions disturbing the planned schedule. To deal with this problem, daily activity rescheduling is necessary. This thesis regards the disruptions from the activity schedule execution environment as unexpected events (uncertainties). It establishes agent-based models to simulate the activity rescheduling decision process from the aspects of individual activity rescheduling and joint trip renegotiating.

For the individual activity rescheduling, the model in this thesis wants to explore the relationship between a pair of episodes (two connected episodes) under unexpected events. Therefore, activity type is an important factor to consider. This thesis uses the decision tree to search all the alternative choices, and then it calculates the penalty after applying for the choices for each episode. For the joint trip renegotiating problem, when unexpected events happens, such as congestion, the driver and

passenger need to renegotiate the drop off place and arrival time. The passenger drop off place may be a place near to his original location, or a new location. This thesis proposes a tolerance distance to find the alternative drop off place, and it uses the utility function to calculate the score of each alternative choice. Also, during the renegotiation process, this thesis considers the relationship between the passenger and driver, and also the time pressure. Both of them affect the person's concession degree to his opponent.

The goal of this thesis is to simulate the activity rescheduling decision and its focus is the travel behavior. It defines the unexpected events that may occur during the activity schedule execution process, and it establishes models to deal with both the individual activity rescheduling decision-making process and joint trip renegotiating process. It would like to provide a method to simulate the rescheduling decision-making mostly closed to the reality, while, it still needs to be validated to the real case in the near future.

Titre : Modèle multi-agent pour la re-planification des activités individuelles et collectives quotidiennes dans un environnement perturbé

Mots-clés : Modélisation multi-agent, Plan d'activités quotidiennes, Re-planification des activités individuelles, Re-négociation de trajets partagés, Événements imprévus

Résumé :

Dans leur vie quotidienne, chaque personne réalise un plan d'activités individuelles et collectives. Lors de l'exécution de ce plan, certaines perturbations impliquent la nécessité de modifier le plan. Dans cette thèse ces perturbations sont assimilées à des événements captés par les individus. Une approche de modélisation multi-agent est utilisée afin de reproduire par simulation le processus de re-planification des activités tant du point de vue individuel que collectif.

Dans ce cadre, la relation entre une paire d'épisodes (trajet et activité) successifs est étudié lorsque le plan est confronté à des perturbations. Cette thèse utilise un arbre de décision pour construire

l'ensemble des planifications possibles, ainsi que leurs pénalités respectives pour chaque épisode. Concernant la re-négociation des trajets partagés, le conducteur et le passager doivent renégocier les lieux de déposes et l'heure d'arrivée, en minimisant la distance entre ces lieux. Ainsi, une distance de tolérance est utilisée pour trouver le lieu alternatif, ainsi qu'une fonction d'utilité pour calculer le score de chaque choix alternatif. De plus, au cours du processus de re-négociation, la relation entre le passager et le conducteur est étudiée, notamment du point de vue de la pression temporelle. Ceci affecte le degré de concession du conducteur et du passager vis-à-vis des propositions de son partenaire.