### Contents

Ι	Int	roduc	tion	1		
1	Introduction					
	1.1	Motiva	ation	5		
	1.2			6		
	1.3		structure	8		
	1.4		ation List	9		
	1.5		ch Projects	10		
II	$\mathbf{St}$	ate of	the Art	11		
<b>2</b>	Aut	onomo	ous Driving and Its Context	13		
	2.1	Autom	nated Vehicles	14		
		2.1.1	ADAS and surroundings perception	17		
		2.1.2	Computing systems	18		
		2.1.3	Communications	20		
	2.2	Simula	ation for traffic management	21		
		2.2.1	Introduction to Traffic Simulation	22		
		2.2.2	Types of Traffic Simulators	22		
		2.2.3	Applications of Traffic Simulation	22		
		2.2.4	Traffic-Light Simulator	23		
		2.2.5	Simulation of Urban MObility-SUMO	24		
	2.3	_	Intersections: Strategies and Challenges	25		
		2.3.1	Centralized Control of Intersections	$\frac{-3}{27}$		
		2.3.2	Distributed Control of Intersections	31		

### CONTENTS

		<ul> <li>2.3.3 Traffic Control Failures</li></ul>	34 36 40		
	2.4	2.3.5 Intersections with Multiple Lanes	43		
Π	ΙDe	evelopment	45		
3	Dis	tributed Intersection Management Approach	47		
	3.1	Distributed Intersection Management (DIM)	48		
		3.1.1 Traffic flow	49		
		3.1.2 Autonomous vehicles	49		
		3.1.3 Communications	50		
		3.1.4 Behavioral roles	51		
		3.1.5 Negotiation between autonomous vehicles	53		
	3.2	Experiments	57		
	3.3	Conclusions	66		
4	Extension of the DIM algorithm for implementing control failures				
	4.1	Model DIM Implementation in the Presence of Communication			
		Failures	70		
		4.1.1 Communication failures	71		
	4.2	Experiments	72		
		4.2.1 Experiments on communication failures	73		
	4.3	Conclusions	75		
5	Ma	naging emergencies in DIM algorithm model	77		
	5.1	Emergency Vehicles Model	78		
		5.1.1 Emergency Vehicles	79		
	5.2	Experiments	81		
		5.2.1 Results with low complexity	82		
		5.2.2 Results with high complexity	86		
	5.3	Conslusions	98		

### CONTENTS

6	Implementation of DIM algorithm in high-complexity en-			
	viro	nmen	ts: Multi-lane cities.	101
	6.1	Multi	-lanes	. 102
	6.2	DIM a	algorithm in multi-lanes	. 103
		6.2.1	New behavioral role	. 104
		6.2.2	Negotiation between autonomous vehicles (multi-lanes	) 105
	6.3	Exper	riments	. 111
		6.3.1	Vehicle occurrence density distribution per lane	. 111
		6.3.2	Experiment applying the "Uniform" density distribution	on.114
		6.3.3	Experiment applying the "Biased" density distribution	n. 119
		6.3.4	Experiment applying the "Random" density distribution	on.124
	6.4	Concl	lusions	. 129
	<i>T</i> ~	-		101
Τ/	/ Co	onclu	sions and future work	131
7	Conclusions and future work			
	7.1	Concl	lusions	. 134
	7.2	Futur	re work	. 138
$\mathbf{B}_{\mathbf{i}}$	bliog	graphy	7	141

# List of Figures

2.1	Automated driving levels. Created by the author	16
2.2	Example of the "Traffic-Light" Simulator Developed by Zapotecatl (Adapted from [65])	24
3.1	Example of the perception radius and the communication radius.	50
3.2	Examples of the roles played by a vehicle	52
3.3	vehicle $a_i$ playing role $N_v$ sharing information with vehicle $a_j$ playing role $N_v$ in a conflict way intersecting their communication ra-	
	dius $(C_r^{a_i} \text{ and } C_r^{a_j})$	53
3.4	Reach priority to cross - low density	54
3.5	$a_i$ will avoid to cross on intersection $k$ if $a_i + 1$ is in $e$	55
3.6	The queue of vehicles in lane 1 has priority to cross over vehicles in	
	lane 2 according to the rule Reach priority to cross in high densities.	56
3.7	Experimental Results: City Simulation with 4 Intersections	59
3.8	WaitingTime vs Density. City Manhattan style of 4 intersections.	60
3.9	Experimental Results: City Simulation with 25 Intersections	61
3.10	WaitingTime vs Density. City Manhattan style of 25 intersections	62
3.11	Experimental Results: City Simulation with 100 Intersections	63
3.12	WaitingTime vs Density. City Manhattan style of 100 intersections	64
3.13	Experimental Results: City Simulation with 225 Intersections	65
3.14	WaitingTime vs Density. City Manhattan style of 225 intersections.	66
4.1	Semi-centralized model	74
4.2	DIM model	75
5.1	SUMO simulator showing an intersection with regular vehicles (yellow) and emergency vehicles (red)	83

### LIST OF FIGURES

5.2	Models comparison without emergency vehicles	84
5.3	Models comparison with emergency vehicles	85
5.4	Flow vs Density on city with 4 intersections. Models without emergency vehicles	88
5.5	Velocity vs Density on city with 4 intersections. Models without emergency vehicles	88
5.6	Waiting Time vs Density on city with 4 intersections. Models without emergency vehicles	89
5.7	Flow vs Density on city with 25 intersections. Models without emergency vehicles	90
5.8	Velocity vs Density on city with 25 intersections. Models without emergency vehicles	90
5.9	Waiting Time vs Density on city with 4 intersections. Models without emergency vehicles	91
5.10	Models comparison in flow, with emergency vehicles at 1% and 9% on two different cities	92
5.11	Models comparison in velocity, with emergency vehicles at 1% and 9% on two different cities	93
5.12	WaitingTime vs Density on city with 4 intersections and 1% Emergencies	94
5.13	WaitingTime vs Density on city with 25 intersections and 1% Emergencies	95
5.14	WaitingTime vs Density on city with 4 intersections and 9% Emergencies.	95
5.15	WaitingTime vs Density on city with 25 intersections and 9% Emergencies	
6.1	A multi-lane street in the SUMO simulator	103
6.2	$a_i$ is a vehicle in role $SN_v$	104
6.3	"Uniform" density distribution at 30% per street	111
6.4	"Biased" density distribution at 30% per street	112
6.5 6.6	"Random" density distribution at 30% per street Flow results with "Uniform" density distribution: city with 4 in-	113
	tersections	114

### LIST OF FIGURES

6.7	Flow results with "Uniform" density distribution: city with 16	
	intersections	115
6.8	Velocity results with "Uniform" density distribution: city with 4	
	intersections	116
6.9	Velocity results with "Uniform" density distribution: city with 16	
	intersections	117
6.10	Waiting-Time results with "Uniform" density distribution: city	
	with 4 intersections	118
6.11	Waiting-Time results with "Uniform" density distribution: city	
	with 16 intersections	118
6.12	Flow results with "Biased" density distribution: city with 4 inter-	
	sections	120
6.13	Flow results with "Biased" density distribution: city with 16 in-	
	tersections	120
6.14	Velocity results with "Biased" density distribution: city with 4	
	intersections	121
6.15	Velocity results with "Biased" density distribution: city with 16	
	intersections	122
6.16	Waiting-Time results with "Biased" density distribution: city with	
	4 intersections	123
6.17	Waiting-Time results with "Biased" density distribution: city with	
	16 intersections	124
6.18	Flow results with "Random" density distribution: city with 4 in-	
	tersections	125
6.19	Flow results with "Random" density distribution: city with 16	
	intersections	125
6.20	Velocity results with "Random" density distribution: city with 4	
	intersections	126
6.21	Velocity results with "Random" density distribution: city with 16	
	intersections	127
6.22	Results with "Random" density distribution. City with 4 inter-	
	sections	128
6.23	Results with "Random" density distribution. Cities with 16 inter-	
	sections	128

## List of Tables

5.1	Queue lengths and halted vehicles in cities with 200 meters be-	
	tween intersections	97
5.2	Queue lengths and halted vehicles in cities with 500 meters be-	
	tween intersections	97
5.3	Queue lengths and halted vehicles in cities with 700 meters be-	
	tween intersections	97