A Survey of Autonomous Driving Testing Practices and Challenges

Part 1 - Background	d Investigation		
*What type of organizati	ion are you working for?		
Technology companies Governments Other (Please specify)	Automobile manufacturing companies	Research Institutes	
*What is your role in the	e organization?		
Software Engineer	Software Architect / Tech Lead	Quality Assurance / Software Tester	
Research Scientist	Oirector / Manager	Safety Engineer	
Self-employed			
Other (Please specify)			
0/9 0/0	9/0 5		
976	9,6		
*Which gender identity o	do you most identify with	n? Prefer not to say	
Other (Please specify)			
0)60	9)60		
*How long have you bee	en conducting research ir	n the Autonomous Dr	iving
field?			
Less than 1 year	1 ~ 5 years	5 ~ 10 years	
More than 10 years			

Part 2 - Current Practice for Autonomous Driving System (ADS)

*What kind of ADS are you working on? (If your answer is multiple, please choose the field that is most familiar to you.)

Multi-me	odule Pipeline			
Sense Camera Lidar Lidar Lidar	Route Planning Behavior Planning T			
Radar Ultrasonic Sense Sense SLAM HD Maps Sense Perception & Localizati	Motion Planning Speed			
End-to-	End Pipeline			
Sense Cumera Lidar Radar Ultrasonic Sensor Input N	Steering Speed Control			
Multi-module s	tructure End-t	o-end (E2E) system		
Other (Please s	specify)			
100	100			
9	9/0			
Machine Learn	ing Doon	Loarning	Doinforcement I	oarning
Machine Learn Other (Please s	10,	Learning	Reinforcement L	earning
10, 1	10,	Learning	Reinforcement L	Learning
Other (Please s	10,		3/6/SUIT	Learning
Other (Please s	specify)	oed with? (check al	3/6/SUIT	Learning
Other (Please s	is your ADS equip	oed with? (check al	I that apply)	Learning
Other (Please solution) What sensors Camera	is your ADS equip	oed with? (check al	I that apply)	Learning
Other (Please s What sensors Camera GPS & IMU	is your ADS equip	oed with? (check al	I that apply)	Learning
Other (Please s What sensors Camera GPS & IMU	is your ADS equip	oed with? (check al	I that apply)	Learning
Other (Please s What sensors Camera GPS & IMU	is your ADS equip	oed with? (check al	I that apply)	Learning
Other (Please s What sensors Camera GPS & IMU	is your ADS equip	oed with? (check al	I that apply)	Learning

*Do you use Vehicle-to-everything (V2X) communication? Infrastructure Systen V2X Communication Ego-vehicle System Multi-module End-to-end System System Yes, I use V2X on E2E Yes, I use V2X on Multi-Yes, I use V2X on the module: Leveraging V2X (e.g., UniV2X): ADSs other than E2E communication for a Seamlessly integrating and multi-module. single task (e.g., object all key driving modules (e.g., perception, detection). planning) across diverse views (including other vehicles' views) into a unified network. No. *What kind of data do you use for V2X Transmission? (check all that apply) Raw data (e.g., LiDAR Intermediate-level data point clouds, RGB (e.g., BEV features) images) Other (Please specify) Have you ever conducted testing on the V2X system? Yes No

*What kind of systems l	have you tes	ted? (check all t	that <mark>ap</mark> ply)	
V2X perception systems	V2X plan	ning systems		
Other (Please specify)				
Other (Flease specify)	4			
10 10 T	0 10			
12 15				
[*] What sensors do you c	onduct V2X	testing on? (cl	neck all that apply)	
LiDAR (e.g., Point		e.g., RGB	Radar (e.g., Poi	nt
Clouds)	images)		Clouds)	
Other (Please specify)				
99 99	9			
Other (Please specify)	200			
John Committee of the C	110 12			
^k What testing methods	do you use d	on the V2X sy	stem? (check all tha	at appl <mark>y)</mark>
Knowledge-based	Search-b	ased	Data driven app	oroaches
approaches (e.g.,		es (e.g., driving	(scenarios are i	
metamorphic relation,	~ AVIII	classification	extracted, creat	
ontology, adversarial)	7	pecification)	clustered data)	
Unknown				
Other (Please specify)				
0,0	.07			

Public datas Other (Pleas	19	Private datasets		
6	5,6	3,60		
Public datasets	you have used:			
10,11	12/1	12/11		
	90	9/0		
Simulation to (testing on second scenarios in e.g., CARLA) Other (Please	virtual a simula <mark>tor,</mark>)	Real-world testing (testing on real-world scenarios)		
Other (Freds	Je speeny,			
- 0	4	101		
What cimula	ation platforms	are you use? (check al	I that apply)	
Wilat Silliule	acion piacionnis	are you use: (check ar	т спас арргу)	
BeamNG		CARLA	Baidu Apollo	
AWSIM (Aut	oware)			
Other (Pleas	se specify)			
1811	125	10011		
26	2/2	900		
For Testing A	ADS, which typ	e of testing do you us	se? (check all that ap	oly)
Online Testi	ng (conduct	Offline Testing (conduct testing in pre-		
time enviror	nment)	acquired/fixed		
	se specify)	scenarios)		

Multi-module Structure What level do you conduct testing in ADS? (check all that apply) System-level (conduct Module-level (conduct testing on the whole testing on each module separately, e.g., ADS) perception, prediction, planning, control)

This survey was created on Zoho Survey, an online survey tool. Create unlimited surveys for free on www.zoho.com/survey

Multi-module: Module-level Testing

*Which units ar	e you testing? (ch	eck all that apply)		
Perception Mod Other (Please s	<u> </u>	ning Module	Control Module	
20 TOTO SULVEY	ole Shiney			

Module-level Testing	g: Perception Module	e
*What is your Perception	module based on? (che	ck all that apply)
Machine Learning Other (Please specify)	Deep Learning	Reinforcement Learning
In the Perception modul	le, what specific tasks a	are you working on? (check a
that apply) Semantic Segmentation	Objective Detection	Objective Tracking
Environmental Understanding		
Other (Please specify)		
no wet	e vet	
that apply) LiDAR (e.g., Point Clouds)	Camera (e.g., RGB images)	Radar (e.g., Point Clouds)
Other (Please specify)	10,711	
	3,6	
*What testing technique	s do vou use for testing	Perception module? (check a
that apply)	o de de de	1 110,107
Black-box (query access to the model, i.e., only know inputs and outputs)	White-box (with full information, e.g., data, parameter, or model structure)	Grey-box (with partial information)
Unknown		
Other (Please specify)	They Touring	
96	3/0 2	

*What testing	g methods do	you use for testing	g Perception modu	ule? (check all
that apply)	4	4	4	
Knowledge- approaches metamorph ontology, ac	(e.g., ic relat <mark>ion</mark> ,	Search-based approaches (e.g., dripattern, classification) model, specification)	ving (scenarios n extracted,	n approaches are identified, created or data)
Unknown				
Other (Pleas	se specify)			
10 10	700	110°		
40	240 5	1201		
*The current	methods you	use for te <mark>sti</mark> ng the	Perception modu	le can meet
the testing i	requirements	. (Strong disagree to str	ong agree)	
				Jet Co
				100

Machine Learnir	าต	Deep Learning	Reinforcement Lear	nina
Other (Please sp	_	Deep Learning	Termoreement Lear	imig
Torright The same of the same	1970	1910, 1910, 1140		
0/05	0/05	0/6/27		
In the Planning	module,	what specific tasks are	e you working on? (che	eck al
that apply)				
Path Planning		Behavior Planning	Scenario Planning	
Other (Please sp	pecify)			
0	500	5.6		
Black-box (quer to the model, i.e	e., only	White-box (with full information, e.g., data, parameter, or model	Grey-box (with part information)	ial (
to the model, i.e know inputs and outputs)	e., only d	information, e.g., data,	information)	ial
Black-box (quer to the model, i.e know inputs and outputs)	e., only d	information, e.g., data,	information)	ial
Black-box (quer to the model, i.e know inputs and outputs)	e., only d	information, e.g., data,	information)	
Black-box (quer to the model, i.e know inputs and	e., only d	information, e.g., data,	information)	ial
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only d oecify)	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only d oecify)	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only d oecify)	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only d oecify)	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only d oecify)	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only	information, e.g., data, parameter, or model structure)	information)	
Black-box (quer to the model, i.e know inputs and outputs) Unknown Other (Please sp	e., only	information, e.g., data, parameter, or model structure)	information)	

*What testin	g methods do	you use for testing	Planning module?	check all that
apply)				
Knowledge- approaches metamorph ontology, a	s (e.g., nic relati <mark>on</mark> ,	Search-based approaches (e.g., drive pattern, classification model, specification)	_	re identified, reated or
Unknown				
Other (Plea	se specify)			
10 Je	7	767		
12/11	100	16,71		
		use for testing the		can meet the
testing requ	uirements. (Str	ong disagree to strong a	gree)	
	A ()			
	100			

Module-level Testing: Control Module

*What is your Control module based on? (check all that apply) Machine Learning Deep Learning Reinforcement Learn Other (Please specify) *In Control module, what specific tasks are you working on? (check all the apply) Steering Control Speed Control Stability Control	0/0
*In Control module, what specific tasks are you working on? (check all the apply)	0/0
*In Control module, what specific tasks are you working on? (check all the apply)	o/o
apply)	nat
apply)	nat
apply)	nat
Steering Control Sneed Control Stability Control	
Stability Collid	
Other (Please specify)	
to the model, i.e., only information, e.g., data, information) know inputs and parameter, or model outputs) structure)	
Unknown	
Unknown Other (Please specify)	
Unknown Other (Please specify)	

*What testing	g meth <mark>od</mark> s do	you use for tes	ting Control r	nodule? (chec	k all that
apply)					
Knowledge- approaches metamorph ontology, ac	(e.g., ic relati <mark>on</mark> ,	Search-based approaches (e.g. pattern, classific model, specificat	., driving ation	Data driven appro (scenarios are ide extracted, create clustered data)	entified,
Unknown					
Other (Pleas	se specify)				
		(e)			
	- 0 -	use for testing		nodule can m	ieet the
testing requ	iirements. (Str	ong disagree to stro	ing agree)		
	A (V) 100				(V)
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Module-level Testing: Other Module(s) *What module(s) are you testing? *What is your other module(s) based on? (check all that apply) Machine Learning Deep Learning Reinforcement Learning Other (Please specify) In other module(s), what specific tasks are you working on? What testing techniques do you use for testing other module(s)? (check all that apply) Black-box (query access White-box (with full Grey-box (with partial to the model, i.e., only information) information, e.g., data, know inputs and parameter, or mode outputs) structure) Unknown

Other (Please specify)

ງ meth <mark>od</mark> s do you	use fo <mark>r</mark> testing othe	er m <mark>odule(s)?</mark> (ch	neck all that
		Data driven ap	•
		extracted, crea clustered data)	
5,6	5.6	5 6	
e specify)			
è	4 64		
10/10/11/1	10/10/1/10		
		r module(s) can	meet the
rements. (Strong d	lisagree to strong agree)		
	, One Men		
	methods you used irements. (Strong do	sased (e.g., approaches (e.g., driving pattern, classification model, specification) methods you use for testing the othe frements. (Strong disagree to strong agree)	approaches (e.g., driving pattern, classification wersarial) methods you use for testing the other module(s) can irements. (Strong disagree to strong agree)

Multi-module Testing: LLMs/VFMs/Others Investigation

ADS Yes, I have	multi-module	Yes, I have used VFMs for testing multi-module ADS Other (I use other emerging models for multi-module ADS)	Yes, I have used based multi-mod None of the abov	ule ADS
*What other	emerging mo	odels do you use for A	DS?	

LLMs for Multi-module Testing *Which module(s) in ADS do you use the LLMs for testing? (check all that apply) Perception Module Planning Module Control Module Other (Please specify) *How do you use LLMs for testing? (check all that apply) Generate critical Retraining ADS scenarios Other (Please specify) st Compared with other testing methods, the introduction of LLMs into ADS testing improves the testing capability. (Strong disagree to strong agree)

VFMs for Multi-module Testing

Perception	Madula	Planning Module	Control Module	
		Flatilling Module	Control Module	
Other (Plea	se specify)			
	7	· · · · · · · · · · · · · · · · · · ·		
ow do you	use VFMs for	or testing? (check all tha	t apply)	
Generate c	ritical	Retraining ADS		
scenarios		4		
Other (Plea	se specify)			
100	. 10	1211		
9	9/9			
•		esting methods, the intesting capability. (Strong		to ADS
•		_ (to ADS
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	S
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	S
esting imp	roves the te	sting capability. (Strong	disagree to strong agree)	
•	roves the te	sting capability. (Strong	disagree to strong agree)	(A)

LLMs-based Multi-module ADS *Which module(s) in ADS do you use the LLMs? (check all that apply) Perception Module Planning Module Control Module Other (Please specify) *Compared with other ADS, the introduction of LLMs-based ADS improves the performance. (Strong disagree to strong agree)

VFMs-based Multi-module ADS

		do you use the VFM	IS? (check all that apply)	
Perception Other (Plea	Module ase specify)	Planning Module	Control Module	
aho "Je	<i>y</i>	· vey		
		OS, the introduction of disagree to strong agree)	of VFMs-based ADS imp	oroves
\bigcirc	A (V)	\bigcirc		\checkmark

Other Mode	el(s) for ADS			
*Please simply	specify the base	structure of the m	odel(s) you use.	
10hours	of Construct	S/C SURVEY		
*How do you t	use this emerging	model(s)? (check all	that apply)	
For ADS testin	ng For	emeging-model(s)- sed ADS	9/6/5/11	
Other (Please		076		
~ 1et		io det		
*Which modul	e(s) in ADS do you	u us <mark>e t</mark> he model(s)	? (check all that apply	100
Perception Mo		nning M <mark>o</mark> dule	Control Module	9700
Other (Please	e specify)			
12/11/10	12,1110	1011011VE		
	th other models, to nce. (Strong disagree	the introduction of to strong agree)	the emerging imp	oroves
900	969116		3/2/5	9/20

Multi-module: System-level Testing

*At system-level testing, apply)	what testing techniques	do you use? (check all that
Black-box (query access to the model, i.e., only know inputs and outputs)	White-box (with information, e.g., data, parameter, or model structure)	Grey-box (with partial information)
Unknown		
***	0)~/0	9)%
apply)	what testing methods d	O you use? (check all that
Knowledge-based approaches (e.g., metamorphic relation, ontology, adversarial)	Search-based approaches (e.g., driving pattern, classification model, specification)	Data driven approaches (scenarios are identified, extracted, created or clustered data)
Unknown		
Other (Please specify)		
12:01104	oney topoliney	
*The current methods your requirements. (Strong disa	•	esting can meet the testing
Sunday O		
		used Large Language on Models (VFMs: e.g., CLIP,
Yes, I have used LLMs for testing ADS	Yes, I have used VFMs for testing ADS	Yes, I have used LLM- based ADS
Yes, I have used VFM- based ADS	Other (I use other emerging models for ADS)	None of the above

50 NE	3	10 Jey	.,,0			
At system-l	evel testin	g, how do y	yo <mark>u u</mark> se LLI	Ms for testi	ng? (check al	I that apply
Generate co	ritical	Retra	ining ADS			
Other (Plea	se specify)					
100° 176	,	940 Mg				
010	0/.0	2				
At system-l	evel testin	g, how do y	you use VF	Ms for testi	ng? (check a	ll that apply
Generate conscious	riticai	Ketra	ining ADS			
Other (Plea	se specify)					
94	3/6					
0	0/0					
`Compared \	with other	tostina mo	thods the	introductio	n of LLMc in	nto ADS
testing imp						
agree)	01.0	30				0/10
5 6	5		5 6	- 5	(0	20
Compared v	with other	testina me	thods. the	introductio	n of VFMs i	nto ADS
testing imp						
ag <mark>r</mark> ee)			0)00	0)	6/0	0)%
	$A(\wedge)$	(\checkmark)	(\checkmark)		(\checkmark)	(\checkmark)
10 HO W		oho To	10h0	Ale C	10/10 11/6	

•	with other ADS, th nance. (Strong disagr	n of LLMs-based ADS	improves
~ · · · · · · · · · · · · · · · · · · ·	with other ADS, th nance. (Strong disagr	n of VFMs-based ADS e)	improves
		n of other emerging nong disagree to strong agr	

end-to-end (E2E) Sy	vstem		
your E2E system, wh	at are the output control	actions? (check all that a	ppl
Steering Location Other (Please specify)	Speed (e.g, Brake, Throttle)	Trajectory	
n the E2E system, wha	t sensors do you conduct	testing on? (check all th	nat
LiDAR (e.g., Point Clouds)	Camera (e.g., RGB images)	Radar (e.g., Point Clouds)	
Other (Please specify)	images,	Ciodas	
No Jet	tour on tour		
1500	15 JI		
Black-box (query access to the model, i.e., only know inputs and outputs) Unknown Other (Please specify)	White-box (with information, e.g., data, parameter, or model structure)	Ou use? (check all that a	
1000 100 100 100 100 100 100 100 100 10	Survey Sharet		

*In your E2E system, w	hat testing methods do yo	u use? (check all that apply)
Knowledge-based approaches (e.g., metamorphic relation, ontology, adversarial)	Search-based approaches (e.g., driving pattern, classification model, specification)	Data driven approaches (scenarios are identified, extracted, created or clustered data)
Unknown		
Other (Please specify)		
10110111111	miles 10th 10th 10th	
*In your E2E system, ha	ave you ever used Large Lander In Foundation Models (VFMs	anguage Models (LLMs:
Yes, I have used LLMs for testing ADS	Yes, I have used VFMs for testing ADS	Yes, I have used LLM- based ADS
Yes, I have used VFM- based ADS	Other (I use other emerging models for ADS)	None of the above
*What other emerging the base structure)	models do you use for ADS	? (Please simply specify
3/6 2011/1/ex	Survey 2010 Survey	

Generate of	9/9		use LLMS TO aining ADS	r testing? (c	heck all that	apply)
scenarios			0			
Other (Plea	ase specify)					
10 J	57	on Jet				
*In the E2E	system, <mark>h</mark> o	w do you	use VFMs fo	or testing? (heck all that	apply)
Generate of scenarios	critical	Retra	aining ADS			
Other (Plea	ase specify)					
0/95	0/0	5)				
5 6	5.70					
agree)	9 / 9			apability. (Str		
*Compared testing imp				introduction apability. (Str		
\bigcirc	\checkmark	\bigcirc	\checkmark	\checkmark	\checkmark	\checkmark
*Compared the perforn			ntr <mark>oduction</mark> to strong agre		sed ADS in	nproves
O TOWN HAVE	A V	₩	V 10th		\bigcirc	

based ADS improves the performance. (Strong disagree to strong agree)



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n	the other system	what are the output cont	eral actions of your sy	ıstam
	eck all that apply)	what are the output cont	ioi actions of your sy	Stell
CII	eck all that apply)			
	Steering	Speed (brake, throttle)	Trajectory	
	Location	Environment		
$\overline{}$	Other (Please specify)			
	, , , , , , , , , , , , , , , , , , ,			
	100 Jet	1000 Jet 1000 J		
	1º Survey	1º Lohoury		
	125 JULY 2/1	12 12 12 12 12 12 12 12 12 12 12 12 12 1	et seguret	01/0
ln:	125 JULY 2/1	at sensors do you conduct	t testing on? (check all	that a
n	other system, wh			
n	125 JULY 2/1	at sensors do you conduct Camera (e.g., RGB images)	t testing on? (check all Radar (e.g., Point Clouds)	
ln;	other system, who LiDAR (e.g., Point Clouds)	Camera (e.g., RGB	Radar (e.g., Point	
in	other system, wh	Camera (e.g., RGB	Radar (e.g., Point	
ln:	other system, who LiDAR (e.g., Point Clouds)	Camera (e.g., RGB	Radar (e.g., Point	

[*] In the other system, wh system? (check all that app	at testing methods do yo	ou use for testing the
Knowledge-based approaches (e.g., metamorphic relation, ontology, adversarial) Unknown	Search-based approaches (e.g., driving pattern, classification model, specification)	Data driven approaches (scenarios are identified, extracted, created or clustered data)
Other (Please specify)		
Carret (France Specify)	100	
10,10	1010 1010 110 110 110 110 110 110 110 1	
	ve you ever used Large L Foundation Models (VFM	
Yes, I have used LLMs for testing ADS	Yes, I have used VFMs for testing ADS	Yes, I have used LLM- based ADS
Yes, I have used VFM-based ADS	Other (I use other emerging models for ADS)	None of the above
1010 11 101		
0//	nodels do you use for ADS	S? (Please simply specify
the base structure)	5)_(0	

Generate scenarios	critical	Retr	aining ADS			
Other (Ple	ase specify)					
	K	4				
10h0 11		10/10/1/10				
n other sy	stem, how	v do you us	e VFMs for t	testing? (che	eck all that ap	ply)
Generate scenarios	critical	Retr	aining ADS			
Other (Ple	ase specify)					
10,713		10.71				
19	9/4	2				
esting im	with othe proves the	_	em testing			ee to stro
esting im		_				ee to stro
cesting impagree) Compared	with othe	e other syst	em testing ethods, the	capability. (Strong disagr	into ADS
cesting impagree) Compared cesting imp	with othe	e other syst	em testing	capability. (Strong disagr	into ADS
cesting impagree) Compared	with othe	e other syst	em testing ethods, the	capability. (Strong disagr	into ADS
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cesting impagree) Compared testing imp	with othe	e other syst	em testing ethods, the	capability. (Strong disagr	into ADS
Compared testing impagree)	with other	r testing me other syst	em testing ethods, the em testing	introductio	n of VFMs	into ADS
Compared Compared Compared Compared	with other	r testing me other syst	em testing ethods, the	introduction capability. (n of VFMs is Strong disagr	into ADS



Part 3 - Security Testing Investigation

Adversarial Attacks	Cyber Atta	membership infere attribute inference	Inference Attacks (e.g., membership inference, attribute inference, model stealing, model inversion attacks)	
Replay Attacks	Sensor Atta jamming, s		e.g.,	
Other (Please specify)			
	.0.184			
What defense met	nods have you use	ed? (check all that apply)		
Adversary training or model regularization		tion, or		
Timestamp and sequence number verification or dynamical key management and authentication			al ring	
Other (Please specify) 6			
1000111	101111111111111111111111111111111111111			
What defense tools	have you used? (check all that apply)		
CleverHans, Advbox, TF-Defense	or Wireshark, Snort	Metasploit, or Differential privacy	/	
TLS/SSL or CANsec	Anomaly de systems	etection Anti-jamming mate	erials	
Other (Please specify	6			

Adversarial Attacks		Cyber Attacks	membership attribute infer model stealin	Inference Attacks (e.g., membership inference, attribute inference, model stealing, model inversion attacks)		
Replay Attacks		Sensor Attacks (e.g., jamming, spoofing)		Physical Attacks (e.g., sensor damage)		
Other (Please s	specify)	iet so se				
9/6 9/6 10/1/4	105	3/6 2/1/2 3/6 2/1/2				

Part 4 - Follow Up

If you want to receive the study results, please enter your contact information (email address):					
The Med	1000	764]		
Can we cont	act you via th	is email <mark>ad</mark>	dress for clar	ifications?	
Yes		No			
- 0	\	F9.	· et	~	
Are you willing	ng to participa	ate in a foll	ow-up questic	onnaire?	
Yes	965	No 🥑			