



DESIGN AND DEVELOPMENT OF ROUTE PLANNER FOR UNMANNED SURFACE VEHICLES (USVs)

DISEÑO Y DESARROLLO DE UN PLANIFICADOR DE RUTAS PARA VEHÍCULOS DE SUPERFICIE NO TRIPULADOS

Vladimir Díaz Charris





CONTENTS



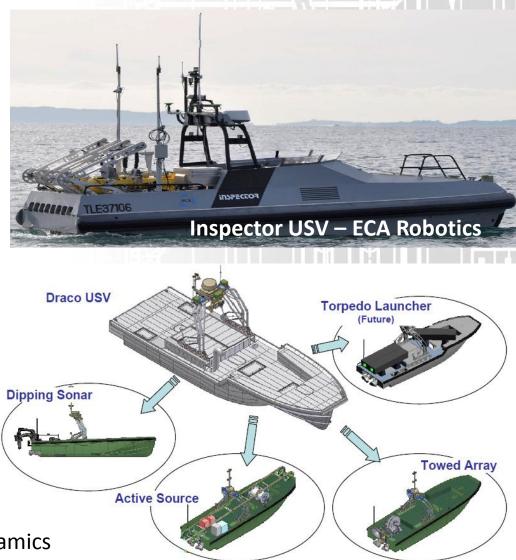
- 1. INTRODUCTION
- 2. DESIGN OF MODEL
- 3. ROUTE PLANNER
- 4. RESULTS
- 5. CONCLUSION

1. INTRODUCTION - USVs





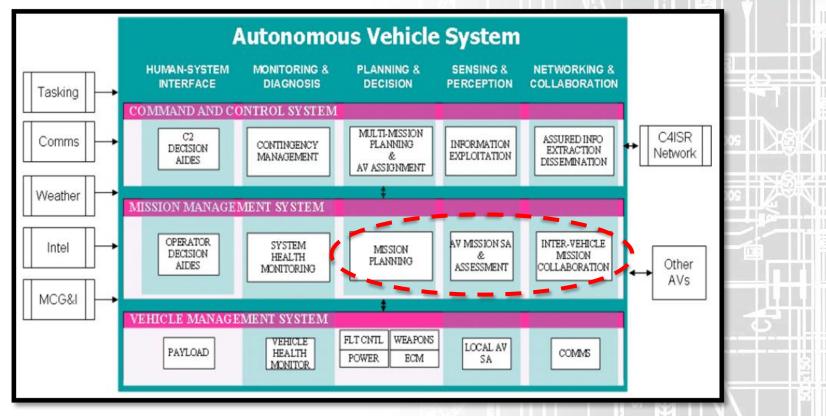
Spartar Scout USV – U.S.



Draco USV – General Dynamics

1. INTRODUCTION



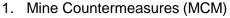


Autonomous Vehicle in Support of Naval Operations, The National Academies Press - 2005



1. INTRODUCTION

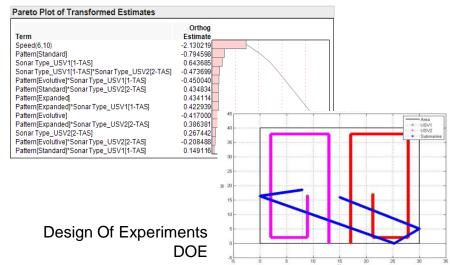




- 2. Anti-Submarine Warfare (ASW)
- 3. Maritime Security
- 4. Surface Warfare (SUW)
- 5. Special Operations Forces (SOF) Support
- 6. Electronic Warfare (EW)
- 7. Maritime Interdiction Operations (MIO) Support

Missions selected by U.S. Navy in Master Plan 2007

Effectiveness Assessment



Operational Situation - OPSIT Scenario ASW



Sonar Type

Search Pattern

Search Speed

Search Direction

Search Starting Point

Amount of USVs

2. DESIGN OF MODEL - Scenario



Premises

- Operational Situation – ASW Mission: Departing port with submarine threat

- Units involved:

USVs with ASW payload **Diesel Electric Submarine (threat)** Random position and course, constant speed

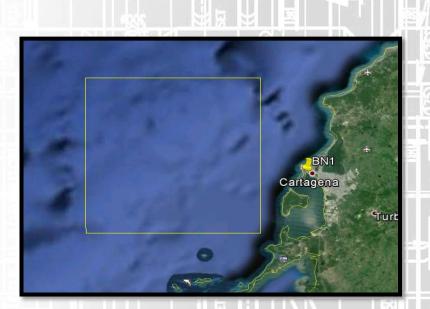
- Searching Area

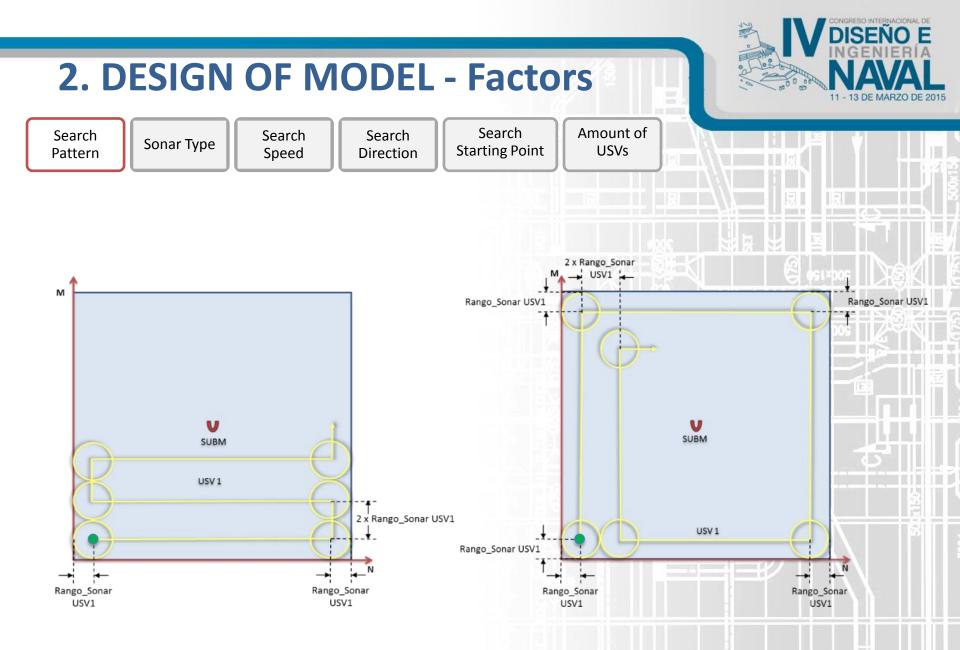
30 NM x 40 NM 2

- Sea State
- Range

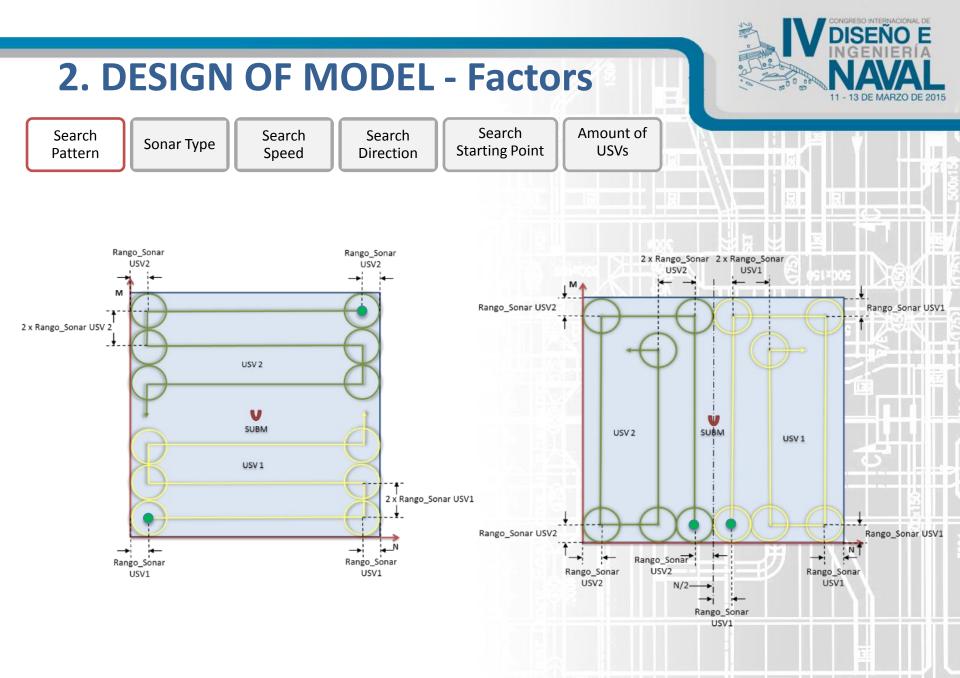
24 Hr @ 10 Kt - Primary Mission Submarine detection

- End Simulation:
 - Submarine detected
 - Search area is covered without detections

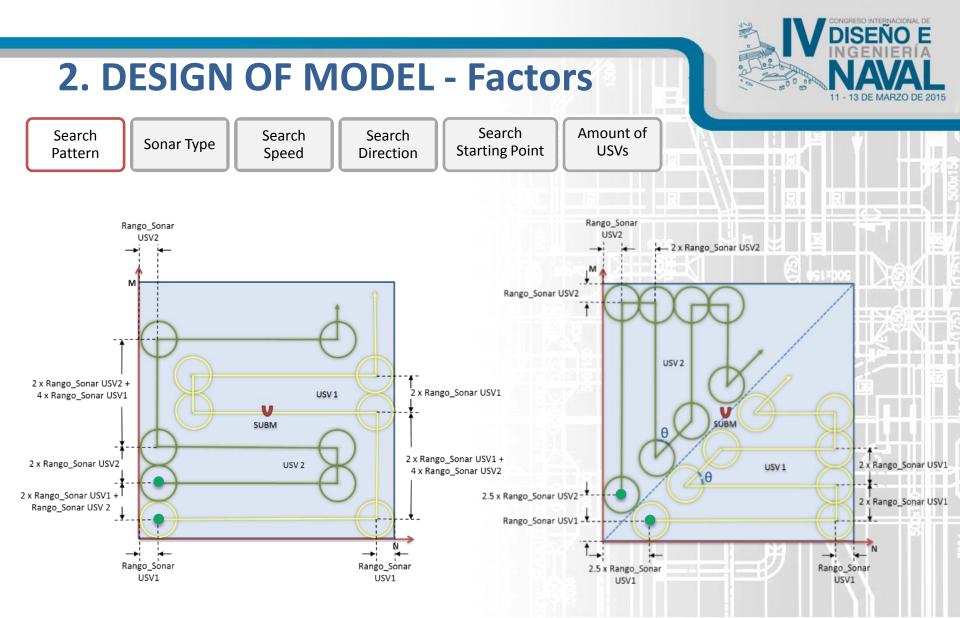




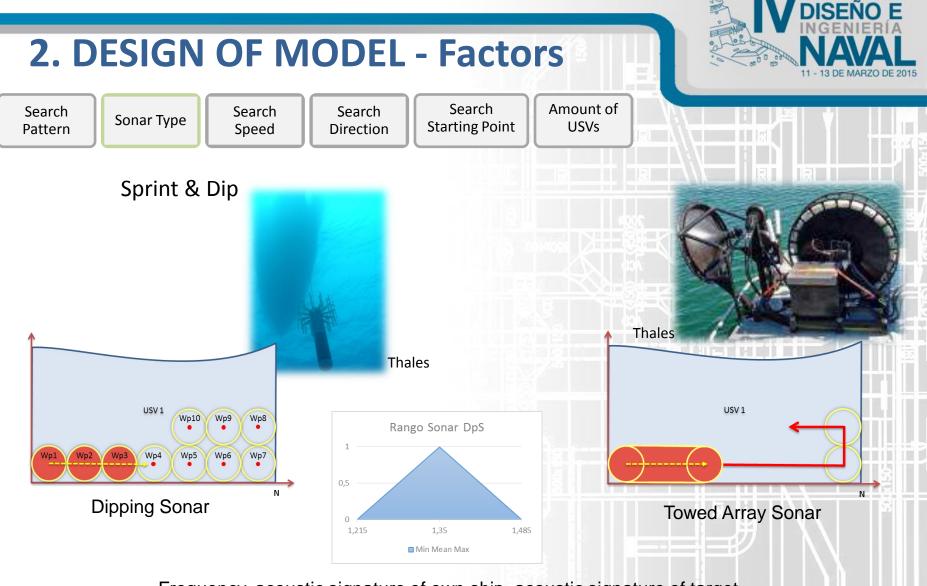
Standard & Evolutive - 1 USV



Standard & Evolutive - 2 USV



Expanded & Diagonal - 2 USV



Frequency, acoustic signature of own ship, acoustic signature of target, salinity/temperature of water, etc.

Results of research conducted at COTECMAR to determine the best combination of weapons and sensors to be installed on future Platforms Strategic Surface - PES ARC.

2. DESIGN OF MODEL - Factors



Search Pattern

Sonar Type Sea

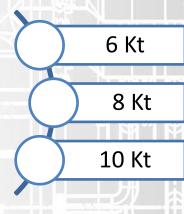
Search Speed Search Direction Search Starting Point Amount of USVs

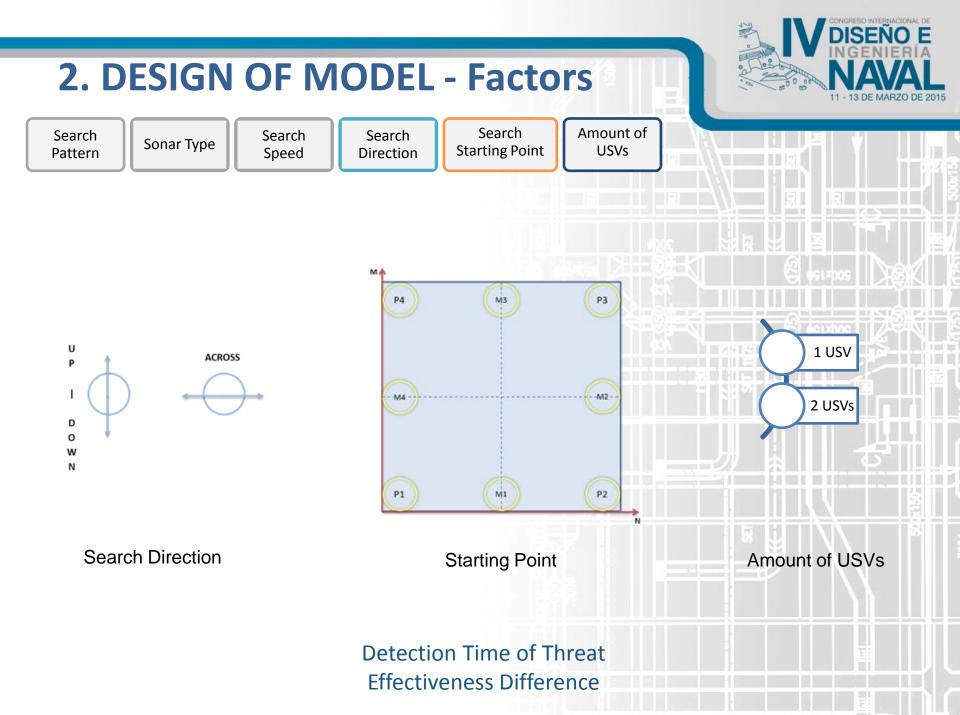
Maximum Speed:

- Impact in USV Range
- Impact in Probability of detection using TAS
 - Self & environment noise

Goal:

- Detection time of threat
- Enough range for success of mission





2. DESIGN OF MODEL - Response



Mission Assessment

According to operational situation, two Measure Of Performance - MOPs are defined to determine success of mission

 MOP_1 = Time to detect the threat MOP_2 = Probability of detection of the threat

The Measure Of Effectiveness – MOE of the mission, is define by weighted sum of the MOPs established.

 $MOE_{ASW} = w_1^*MOP_1 + w_2^*MOP_2$

$$W_1 = 0.4$$
 $W_2 = 0.6$

2. DESIGN OF MODEL - Restrictions



Footor	Turne		Lev	els	
Factor	Туре	Level 1	Level 2	Level 3	Level 4
USVs Speed	Continuous	6 Kt	8 Kt	10 Kt	
Sonar Type	Discrete	DpS	TAS	-	- 3
Amount of USVs	Discrete	1 USV	2 USVs	NH 33	- 1542. S.
Search Pattern	Discrete	Standard	Expanded	Evolutive	Diagonal
Search Starting Point	Discrete	P1	P2	P3	P4
Search Direction	Discrete	Up/Down	Across		

Restrictions

Factor	s	US	SVs Spee	ed	Sonar	Туре	Amour	nt USVs		Search	Pattern		Se	earch Sta	arting Po	int	Search	Direction
	Levels	6 Kts	8 Kts	10 Kts	DpS	TAS	1 USV	2 USVs	Std	Expd.	Evol.	Diag.	P1	P2	P3	P4	Up/Do	Across
	6 Kts	-	-	-														
USVs Speed	8 Kts	-	-	-														
	10 Kts	-	-	-														
Sonar Type	DpS				-	-												
Solial Type	TAS				-	-												
Amount	1 USV						-	-		Х		Х						
USVs	2 USVs						-	-										
	Std.								-	-	-	-						
Search	Expd.						Х		-	-	-	-						
Pattern	Evol.								-	-	-	-	M1	M2	M3	M4		
	Diag.						Х		-	-	-	-					Х	Х
	P1										M1		-	-	-	-		
Search	P2										M2		-	-	-	-		
Starting Point	P3										M3		-	-	-	-		
	P4										M4		-	-	-	-		
Search	Up/Do											Х					-	-
Direction	Across											Х					-	-





3. ROUTE PLANNER - Software

		NALO KATA	1	00500					arrent St.								and the second
inti Submarine Warfa	re ASW	Freedure		USV	Path	Sti,Paint	Str, Direction	USV1_Sonar	USV2_Sonar	USV1_D_Prob (%)	USV1_D_Time(Hin)	USV1_Sim_Time (Hirs)	USV2,0,Peeb [5]	UW2_D_Time (H45)	USV2_Simu_Time(Hn)	In Piegress	81/14 =
attern for searching	Submarine using USVs	12	1	05V1_05V2	Diagonal	P4	Down	Dy5	145							Tana and Tana	GK
cenario		Concession of the local division of the loca	12.	05V1_05V2	Diagonal	P4	Down	TAS	0pS								
rea (X,Y):	30x40 NM		12	USV3_USV2		MI	Down	OpS	TAS								
estion (Lat, Lon):	0,000000*, 0,000000*		1.5	05V1,05V2		MI	Down	TAS	DpS								
na State:	0 (Beaufort) -50.0 m		12.	05V1_05V2		P4	Down	Op5	DpS								
fean Depth: ever Depth:	-50.0 m -13.0 m	Summer of Street	1.	05V1_05V2	- 10 C - 10 C - 1	P4	Down	145	DpS								
de salar		0	114	05V1,05V2		P4	Down	845	145								
imulation		Construction of the local distribution of th		USV1_USV2		P4 P4	Down	0p5	DpS TAS								
SV user	USV1 / USV2		10	USV1_USV2 USV1_USV2	Standard	På	Down	0#5	DpS								
atternic	2 x USV - Standard		11	USV1_USV2	Diagenal Diagenal	Pá	Down	745	TAS								
	2 x USV - Expanded		12	USV1_USV2	Include a second	M	Down	Dp5	DpS								
	2 x USV - Diagonal		1 CO-	USV1_USV2		Mi	Dewn	Des	TAS								-17
and the second	2 x USV - Evolutive		10.00	USV1_05V2		1.44	Down	TAS	DpS								
vitial Ways vitial Points	Acress Desen P3	D.		USV1_USV2		1.44	Down	TAS	TAS								-17
attain a darah	ML M2 M3 M4	.46		USV1_USV2		P4	Down	Op5	TAS								
			10 C C C C	USV1_USV2		64	Cown	745	DpS								
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nuse speen	0,0 en	100	19	USV1_USV2	Standard	P4	Down	Dat	TAS								
vitial Position X	0 NM		20	USV1_USV2	Standard	P4	Down	TAS	DpS								
sitial Position VI	0 NM	1000		(Decourse)													
6/4																	
VD4 Senar	TAS / Dp5	and the second se															
ange Sonari	1.5 NM	De															
ruise Speed AS Speed	12,0 km 10,0 km	(a)						-	_							_	
vo staatt	10,0 Mb		-				_		-								
/SV2		n.	-			_										1 I	1.
ype Sonan	TAS / DpS		1														
ange Sonan ruise Speed	1,5 NM 12,0 km																Pattern Tal
AS Speed	10,0 kts		1		Simulation 5	etup		Dime	Simulation	State							No.
			a second	Step	Figure N	0	Run	In Sm	ulation Up	ated Table							
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3. ROUTE PLANNER - Software



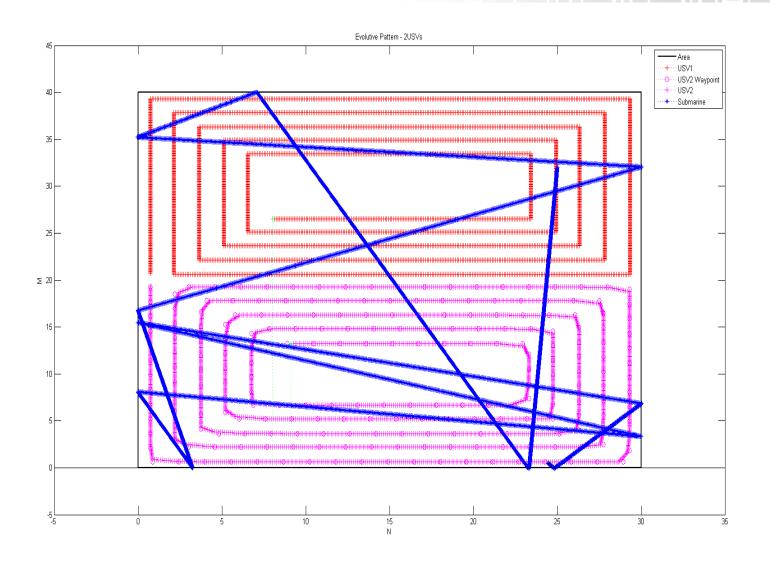
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ASW Smul

ti Submarine Warts	W24 +++	Procedure	-	1/54	Path	Str. Point	Str Direction	USVI Server	USIZ Sonar	USVI D Prob (%)	USVI D. Time (His	USV2 Sen Tene H	Asl USV2 D Probil	51 3/5/2 D. Time (H	6] USV2.Simu.Time.[Hn] In.Progr	EIS RUN -
	Submarine using USVs	1921	1	1911,0517	Dagonal	P4	Down	Dus	T45			and the second se	and the second second		de la facella de la facella de la facella	Annanasana
a na serie a serie se		1		1001,0007		P4	Down	TAS	DeS				-			
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State	0(Beaufort)			0541,0542		P4	Down	DyS	DyS							
sen Depthy	-500 m			USV1_USV2		74	Down	745	DeS							
er Depth:	-15,0 m	6	7	19942, 19942	Epanded	P4	Down	745	TAS			-				
nulition		0		10541,0542		PI	Down	Dy5	DyS							
Vule	054 / 0542		9	454,4547	Standard	P4	Down	745	T45							
Dentus			10	094,097	Dagonal	P6	Down	045	DyS							
	2 x VSV - Standard			10541,10542		P6	Down	745	TAS							
	2 s USV - Expanded		12	19545, 0542	Evolutive	ML	Down	095	095							
	2 x USV - Diagonal 2 x USV - Evolution		13	USV1_USV7	Evolutive	8.82	Down	DyS	TAS							_
al Way:	Acres Down		14	0541,0542	Evolutive	1.61	Down	745	DpS							
ul Port	P3		15	1990, 1997	Evolutive	5.64	Down	145	TAS							
	MD M2 M3 M4		26	1/5/0_0/5/2	Expanded	PE	Down	D#5	TA5							
11223			17	0541,0542	Expanded	PE	Down	TAS	095							
interine ice Speed	60 km	DOE	18	4514,0517	Standard	P4	Down	045	DøS							
ial Course	0.		19	1/541_1/542	Standard	PE	Down	045	145							
tal Position X:	0 104	1.101	27	1/515_1/512	Standard	PE	Down	745	Dp5							OK .
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5 Speed	10/0 km			340	Figure.)	2	Run	40-	199							
			100					1.30	ulation Upd	eterd Table					A CIAL CTRALL	MOITA
			1	6,22	Figure	Run	1	2	2						ASW SIMUL	ATION





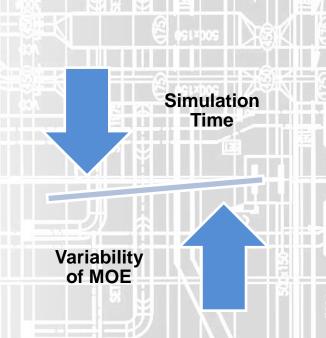




3. ROUTE PLANNER - Variability



	MOE			1.LÚ
Experiment	100	500	1000	5000
1	0.3679	0.3276	0.2989	0.2812
2	0.3809	0.3299	0.3253	0.2903
3	0.2730	0.3244	0.2696	0.2775
4	0.3464	0.3265	0.2968	0.2739
5	0.3263	0.3231	0.3011	0.2724
6	0.3718	0.2720	0.2839	0.2801
7	0.3854	0.2840	0.3315	0.2868
8	0.3520	0.2977	0.3225	0.2777
9	0.2920	0.2959	0.2997	0.2731
10	0.3712	0.3260	0.2995	0.2903
Simulation Time	0.5 [min]	2 [min]	5 [min]	21 [min]
Mean	0.3466	0.3107	0.3028	0.2803
Std Dev	0.0383	0.0212	0.0190	0.0067



3. ROUTE PLANNER - DOE



Design of Experiments

Factor	Value
Amount of USVs	2 USVs
Search Starting Point	P3
Search Direction	Up/Down

Element	Entrada	Тіро	Valor
Scenario	Área [X Y]	Constant	[30 40] NM
	TAS Sonar Range	Average	1.5 NM
USV 1	DpS Sonar Range	Average	1.35 NM
	DpS Searching Time	Constant	5 min
	TAS Sonar Range	Average	1.5 NM
USV2	DpS Sonar Range	Average	1.35 NM
	DpS Searching Time	Constant	5 min
	Starter X point	Random	[0 – Área X]
Submorine	Starter Y point	Random	[0 – Área Y]
Submarine	Starter Detection	Random	[0 – 359.9]
	Speed	Constant	6 Kts



Sensitivity Analysis Results

- Use two (2) USVs in the scenario, increase the effectiveness by 20% in compare with a USV.
- The search starting point depend of search pattern. However P2 y M1 have more effectiveness than other.
- The starting direction also differs on the search pattern. The starting direction "Down" is the best based on the effectiveness.

DOE Analysis Results - Pd

It shows on the response of probability of detection, the most influent factors in the response are the sonar type TAS for USV1 and USV2. Exactly the sonar type influence more than the 20% of the variation in the response, through the Pareto plot is not possible to identify another variable that has a strong incidence in the response.

Term	Orthog Estimate
Sonar Type_USV2[2-TAS]	0.0382459
Sonar Type USV1[1-TAS]	0.0352018
Speed(6.10)	-0.0132425
Pattern[Standard]	-0.0129090
Pattern[Evolutive]*Sonar Type_USV1[1-TAS]	-0.0079393
Pattern[Expanded]	-0.0068540
Pattern[Standard]*Sonar Type_USV1[1-TAS]	0.0062425
Pattern[Evolutive]	0.0052063
Pattern[Standard]*Sonar Type_USV2[2-TAS]	0.0023952
Pattern[Expanded]*Sonar Type_USV1[1-TAS]	0.0022939

Pareto chart – Response of Probability of Detection



DOE Analysis Results - Td

Continuing the response of Submarine time detection, appears the unique factor that actually influence the variation is the speed on 30%. The Pareto plot shows the other factors influence in a lower way in the variability of the Submarine detection.

Pareto Plot of Transformed Estimates	
	Orthog
Term	Estimate
Speed(6,10)	-2.130219
Pattern[Standard]	-0.794598
Sonar Type_USV1[1-TAS]	0.643685
Sonar Type_USV1[1-TAS]*Sonar Type_USV2[2-TAS]	-0.473699
Pattern[Evolutive]*SonarType_USV1[1-TAS]	-0.450040
Pattern[Standard]*SonarType_USV2[2-TAS]	0.434834
Pattern[Expanded]	0.434114
Pattern[Expanded]*SonarType_USV1[1-TAS]	0.422939
Pattern[Evolutive]	-0.417000
Pattern[Expanded]*SonarType_USV2[2-TAS]	0.386381
Sonar Type_USV2[2-TAS]	0.267442
Pattern[Evolutive]*SonarType_USV2[2-TAS]	-0.208488
Pattern[Standard]*Sonar Type_USV1[1-TAS]	0.149116

Pareto plot- Response of Submarine time detection



DOE Analysis Results - MOE

Finally is analyzed the Measure of Effectiveness – MOE, which includes the tow first responses into a single metric. It is analyzed by the Pareto chart, where there is not a factor that dominates the variability of the model, however the Evolutive pattern of search, the use of TAS sonar and the speed of search are the most influential variables in effectiveness increasing.

By the other hand, the Expanded and Standard patterns of search, have a lower influence in the model and could be analyzed subsequently in a different analysis. An important detail on the graphic, is the relationship between the sonar type and the search pattern, representing less variation but necessarily to be consider in a further analysis.

	Orthog
Term	Estimate
Pattern[Evolutive]	0.0169395
Sonar Type_USV1[1-TAS]	0.0141169
Speed(6,10)	0.0122882
Sonar Type_USV1[1-TAS]*Sonar Type_USV2[2-TAS]	-0.0121987
Pattern[Expanded]*Sonar Type_USV2[2-TAS]	-0.0113491
Pattern[Expanded]	-0.0113199
Pattern[Evolutive]*SonarType_USV2[2-TAS]	0.0105390
Sonar Type_USV2[2-TAS]	0.0104663
Pattern[Standard]	-0.0090178
Pattern[Standard]*Sonar Type_USV1[1-TAS]	-0.0055041
Pattern[Standard]*SonarType_USV2[2-TAS]	-0.0047257
Pattern[Expanded]*Sonar Type_USV1[1-TAS]	-0.0044441
Pattern[Evolutive]*Sonar Type_USV1[1-TAS]	-0.0012533

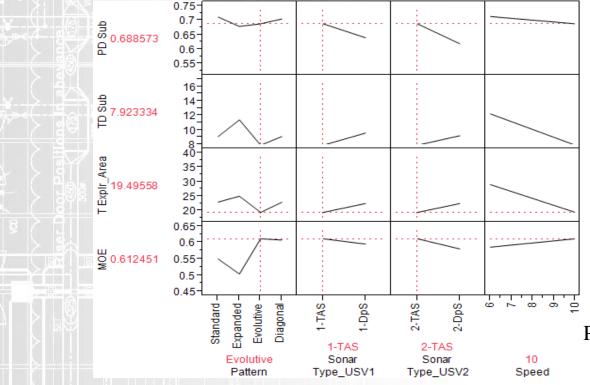
Pareto Plot – Response of Measure of Effectiveness - MOE



MOE Analysis Results - Prediction Profiler

The prediction profiler shows that the Dipping Sonar (DpS) does not generate any positive contribution in the effectiveness, this could be due to the stationary time of the USV while the search and also by the DpS has less range than the sonar TAS.

In addition shows a comparison for the factors of the model and the measure of effectiveness, based as best pattern of search the Evolutive pattern, the best type of sonar TAS and the behavior of the speed influence significantly on the improvement of the MOE to a maximum value of 10kts.



Prediction Profiler for MOE

5. CONCLUSION



The research get the best settings for the different factors that have incidence on the ASW using USVs, having as the best response using two unmanned vehicles to search for a threat in an area near from coast. Also, it determined the best effectiveness is achieved using an Evolutive search pattern, a TAS sonar type and go as fast as possible without performance degradation sonar.

It was determined that using the DpS dipping sonar is less effective than using TAS sonar. This could be by the DpS operation mode, because it is not continue and is necessary to move to different parts of the area to search, stop in each point of the area of search, considerably affects the detection time of the threat.



Thanks!!

