IV CONGRESO INTERNACIONAL DE DISEÑO E INGENIERÍA NAVAL

11 - 13 DE MARZO DE 2015

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

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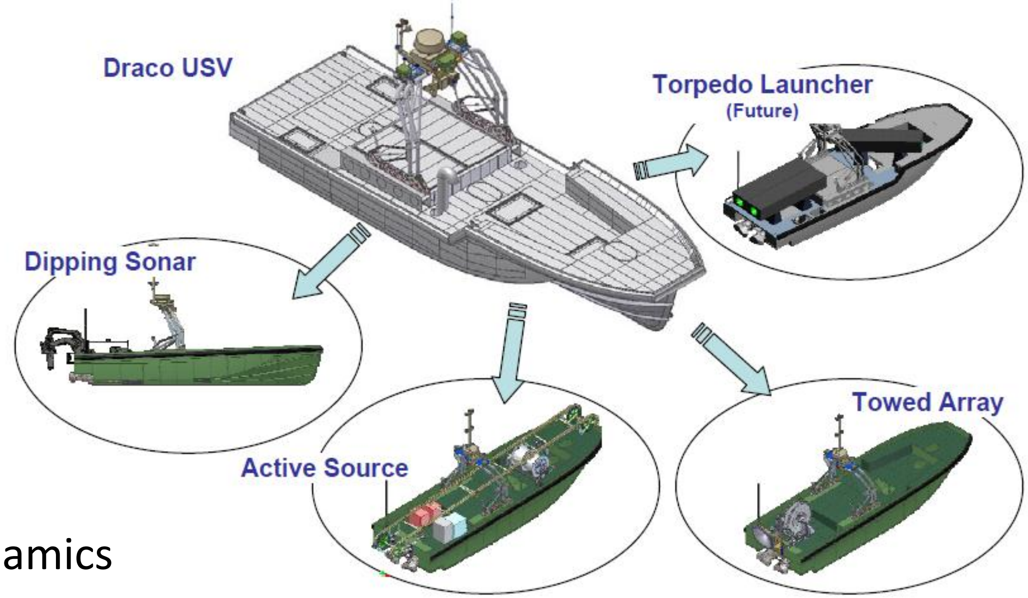
1. INTRODUCTION - USVs

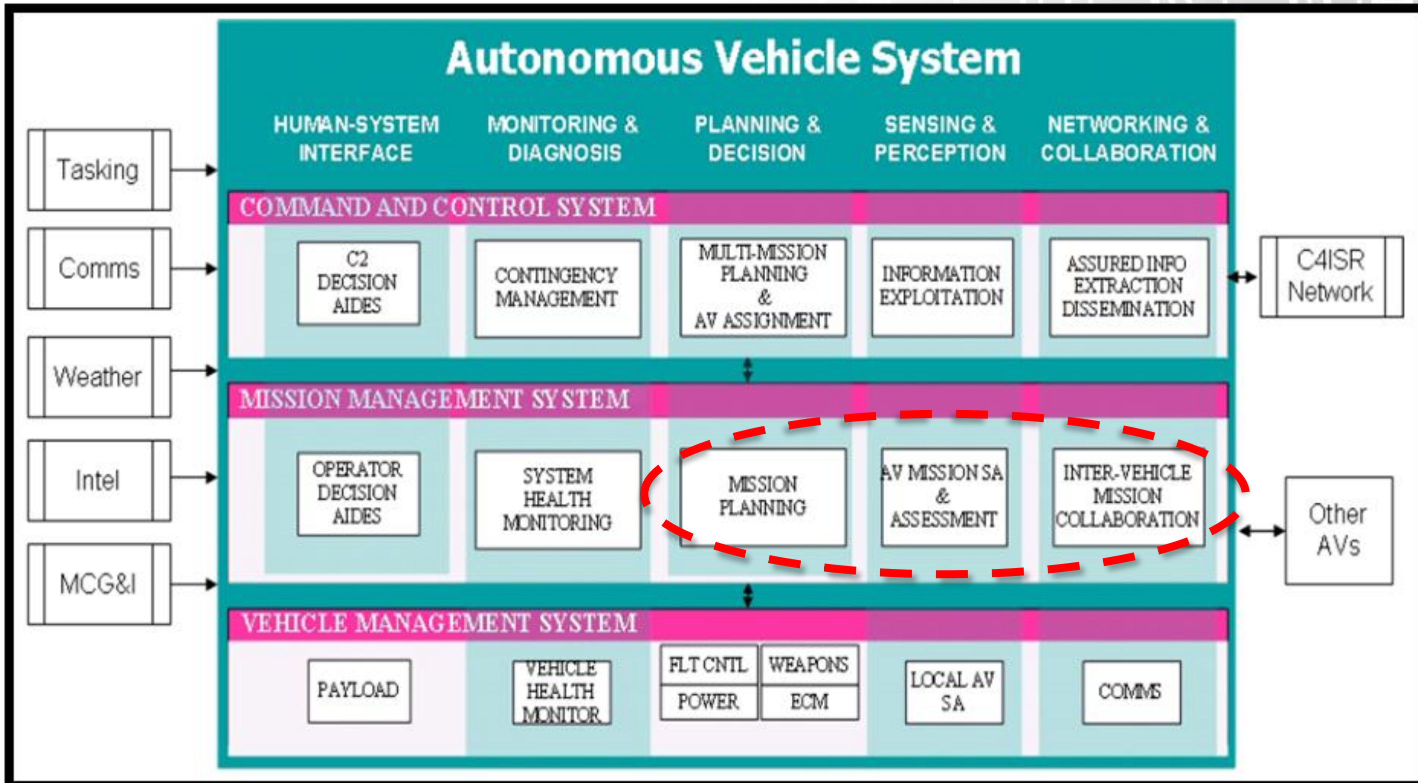
Spartar Scout USV – U.S.

Inspector USV – ECA Robotics



Draco USV – General Dynamics

1. INTRODUCTION



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

Mission Simulation Tools

Route | Operating Time | Performance | Effectiveness

1. INTRODUCTION

1. Mine Countermeasures (MCM)
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

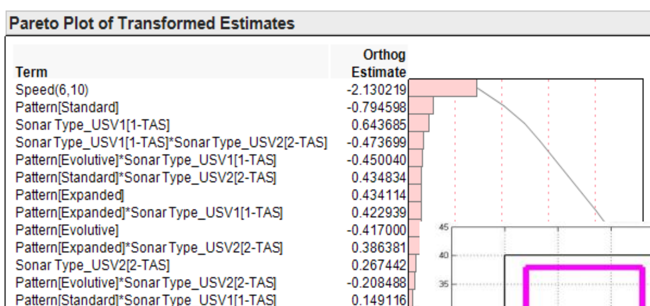
Missions selected by U.S. Navy in Master Plan 2007

Operational Situation - OPSIT
Scenario ASW

MATLAB LabVIEW

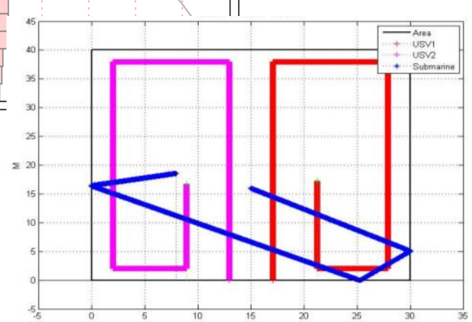
- Search Pattern
- Sonar Type
- Search Speed
- Search Direction
- Search Starting Point
- Amount of USVs

Effectiveness Assessment



Pareto Plot of Transformed Estimates

Term	Orthog 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]*Sonar Type_USV1[1-TAS]	-0.450040
Pattern[Standard]*Sonar Type_USV2[2-TAS]	0.434834
Pattern[Expanded]	0.434114
Pattern[Expanded]*Sonar Type_USV1[1-TAS]	0.422939
Pattern[Evolutive]	-0.417000
Pattern[Expanded]*Sonar Type_USV2[2-TAS]	0.386381
Sonar Type_USV2[2-TAS]	0.267442
Pattern[Evolutive]*Sonar Type_USV2[2-TAS]	-0.208488
Pattern[Standard]*Sonar Type_USV1[1-TAS]	0.149116



Design Of Experiments
DOE

2. DESIGN OF MODEL - Scenario

Premises

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

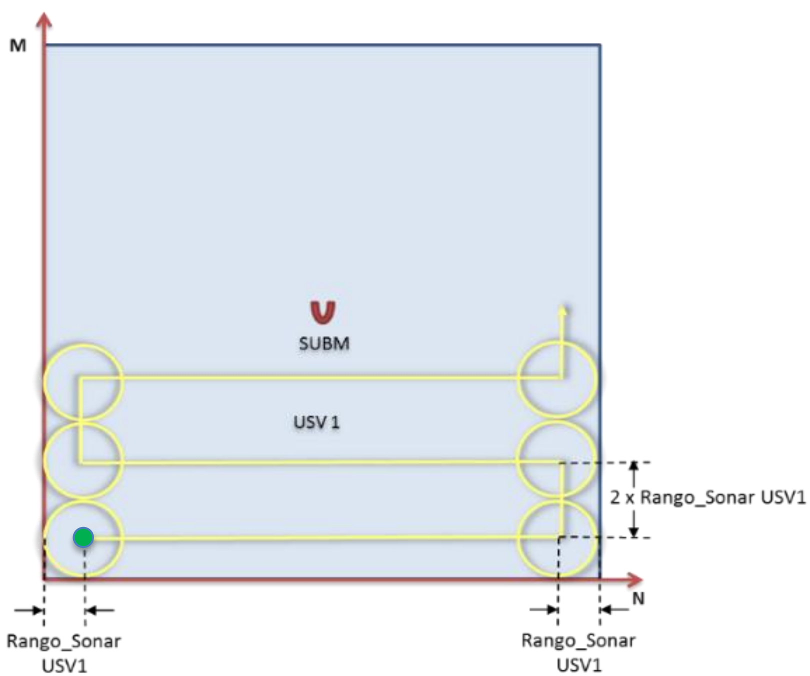
- Units involved:
    - USVs with ASW payload
    - Diesel Electric Submarine (threat)
        - Random position and course, constant speed

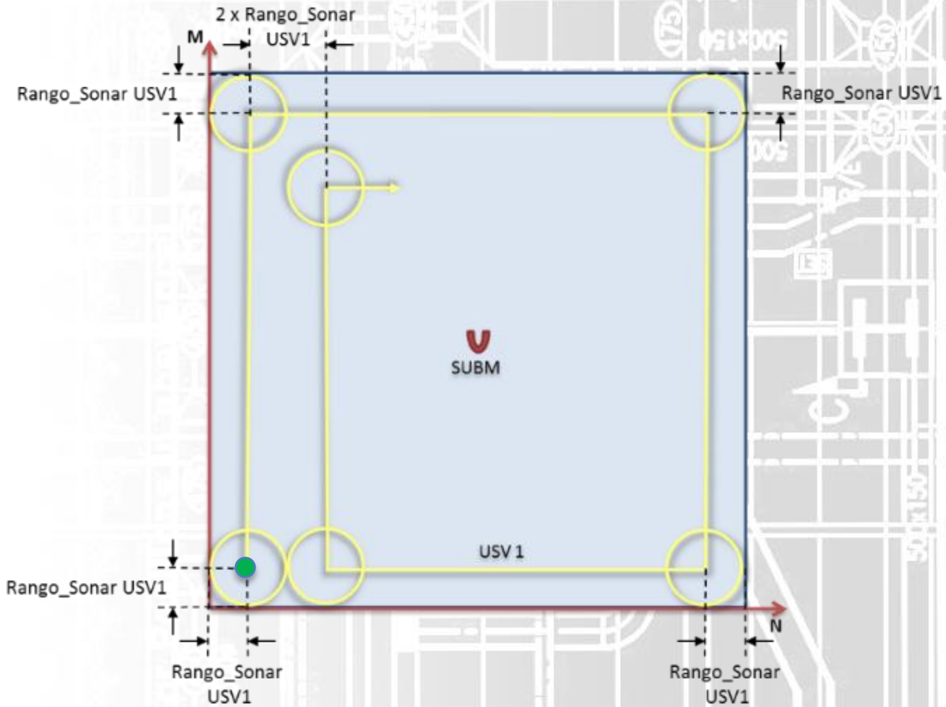
- Searching Area	30 NM x 40 NM
- Sea State	2
- Range	24 Hr @ 10 Kt
- Primary Mission	Submarine detection

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

2. DESIGN OF MODEL - Factors

Search Pattern | Sonar Type | Search Speed | Search Direction | Search Starting Point | Amount of USVs

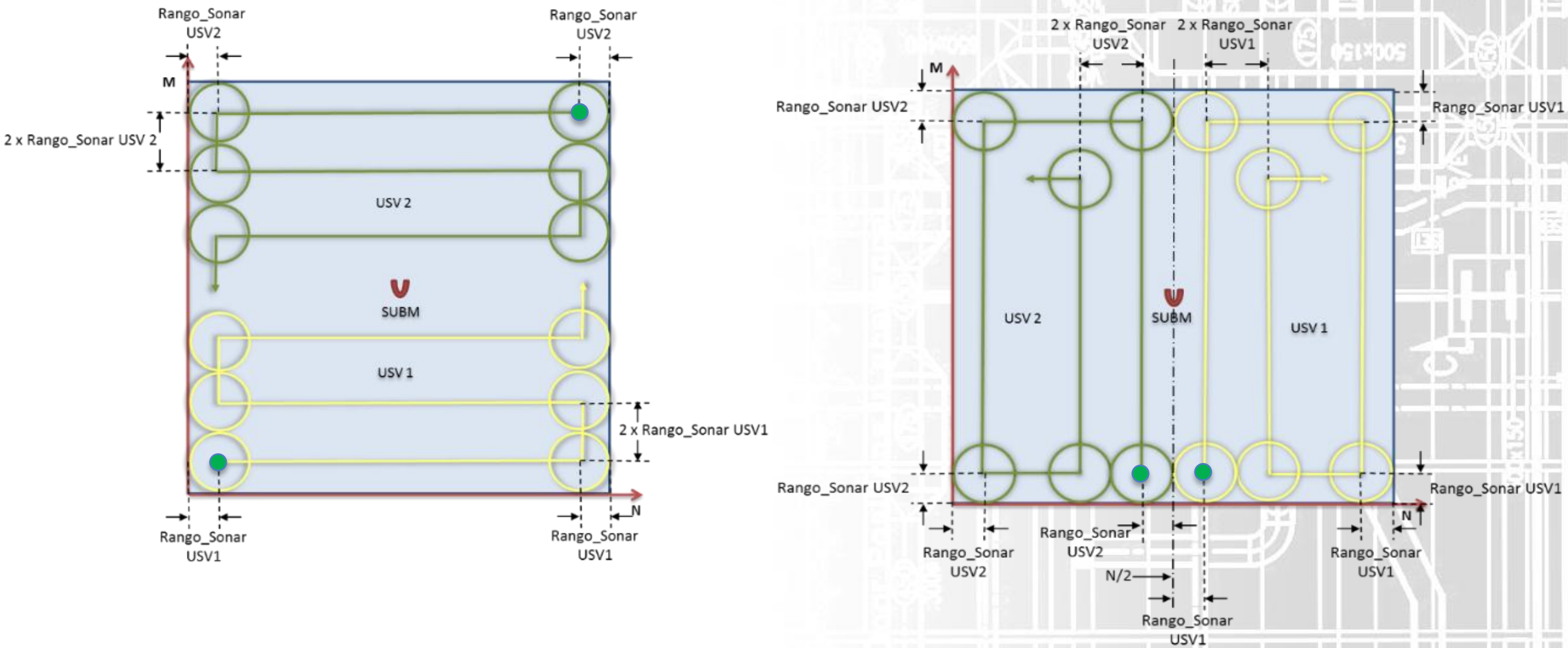




Standard & Evolutive - 1 USV

2. DESIGN OF MODEL - Factors

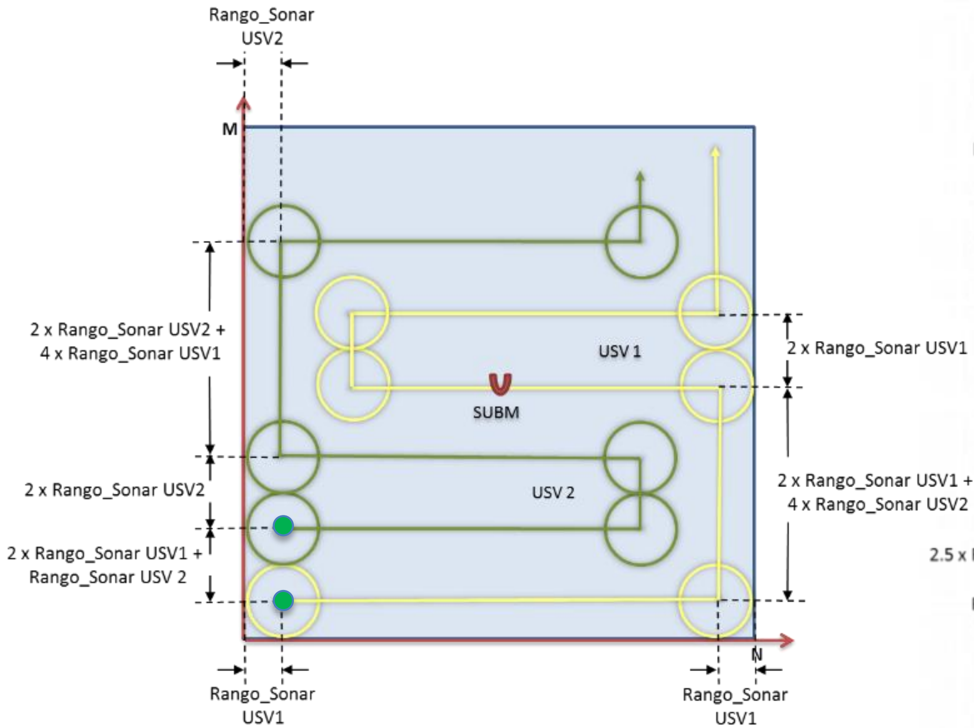
Search Pattern | Sonar Type | Search Speed | Search Direction | Search Starting Point | Amount of USVs

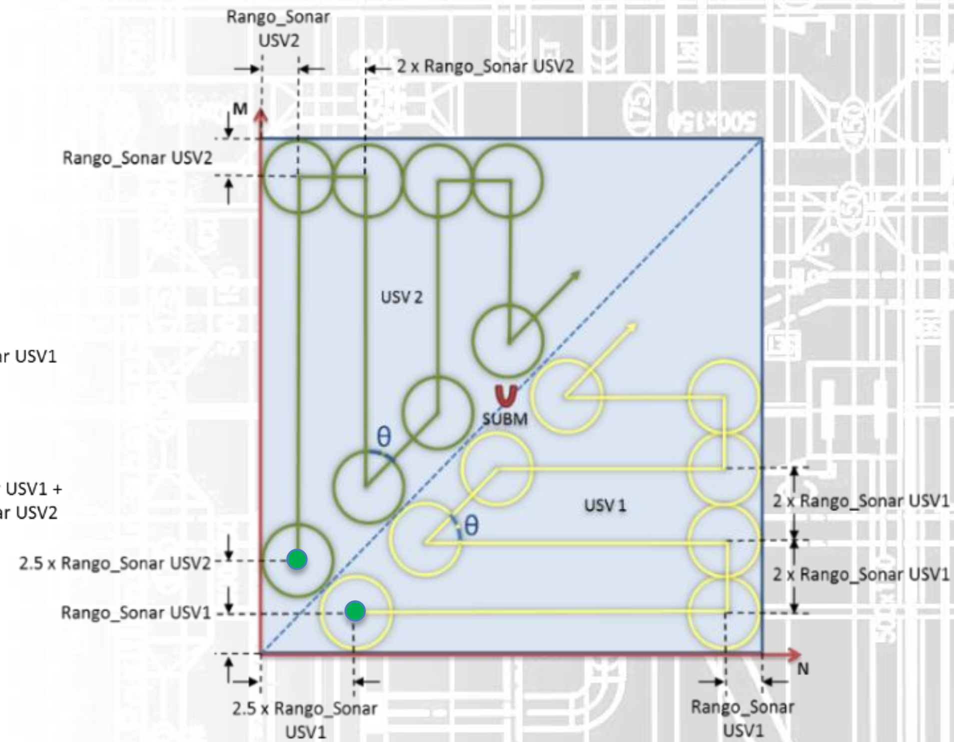


Standard & Evolutive - 2 USV

2. DESIGN OF MODEL - Factors

Search Pattern	Sonar Type	Search Speed	Search Direction	Search Starting Point	Amount of USVs





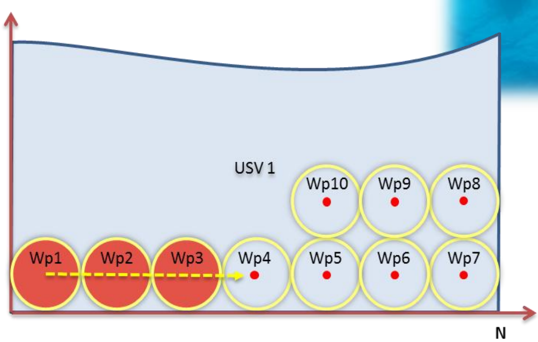
Expanded & Diagonal - 2 USV

2. DESIGN OF MODEL - Factors

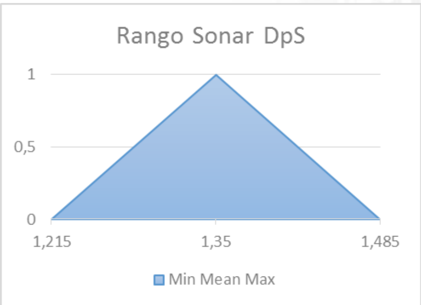
Search Pattern | Sonar Type | Search Speed | Search Direction | Search Starting Point | Amount of USVs

Sprint & Dip

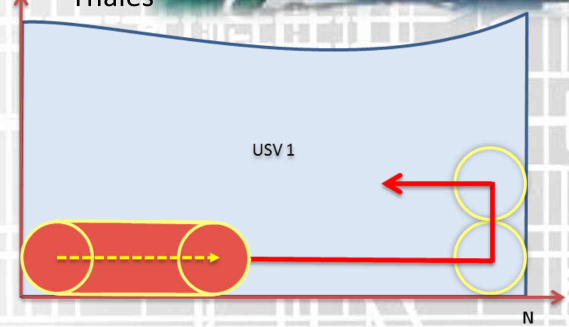
Thales



Dipping Sonar



Thales



Towed Array Sonar

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	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

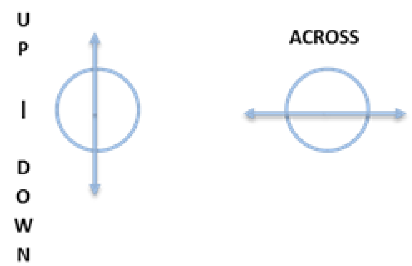
- 6 Kt
- 8 Kt
- 10 Kt

Goal:

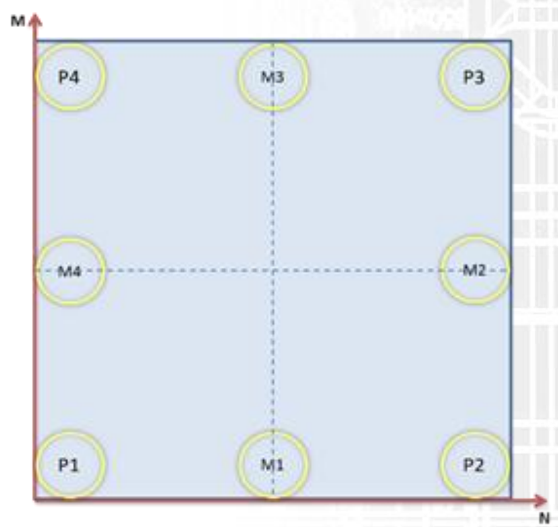
- Detection time of threat
- Enough range for success of mission

2. DESIGN OF MODEL - Factors

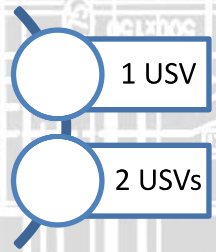
Search Pattern | Sonar Type | Search Speed | Search Direction | Search Starting Point | Amount of USVs



Search Direction



Starting Point



Amount of USVs

Detection Time of Threat

Effectiveness Difference

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.

$$\mathbf{MOE_{ASW} = w_1 {*} MOP_1 + w_2 {*} MOP_2} \qquad w_1 = 0.4 \qquad w_2 = 0.6$$

2. DESIGN OF MODEL - Restrictions

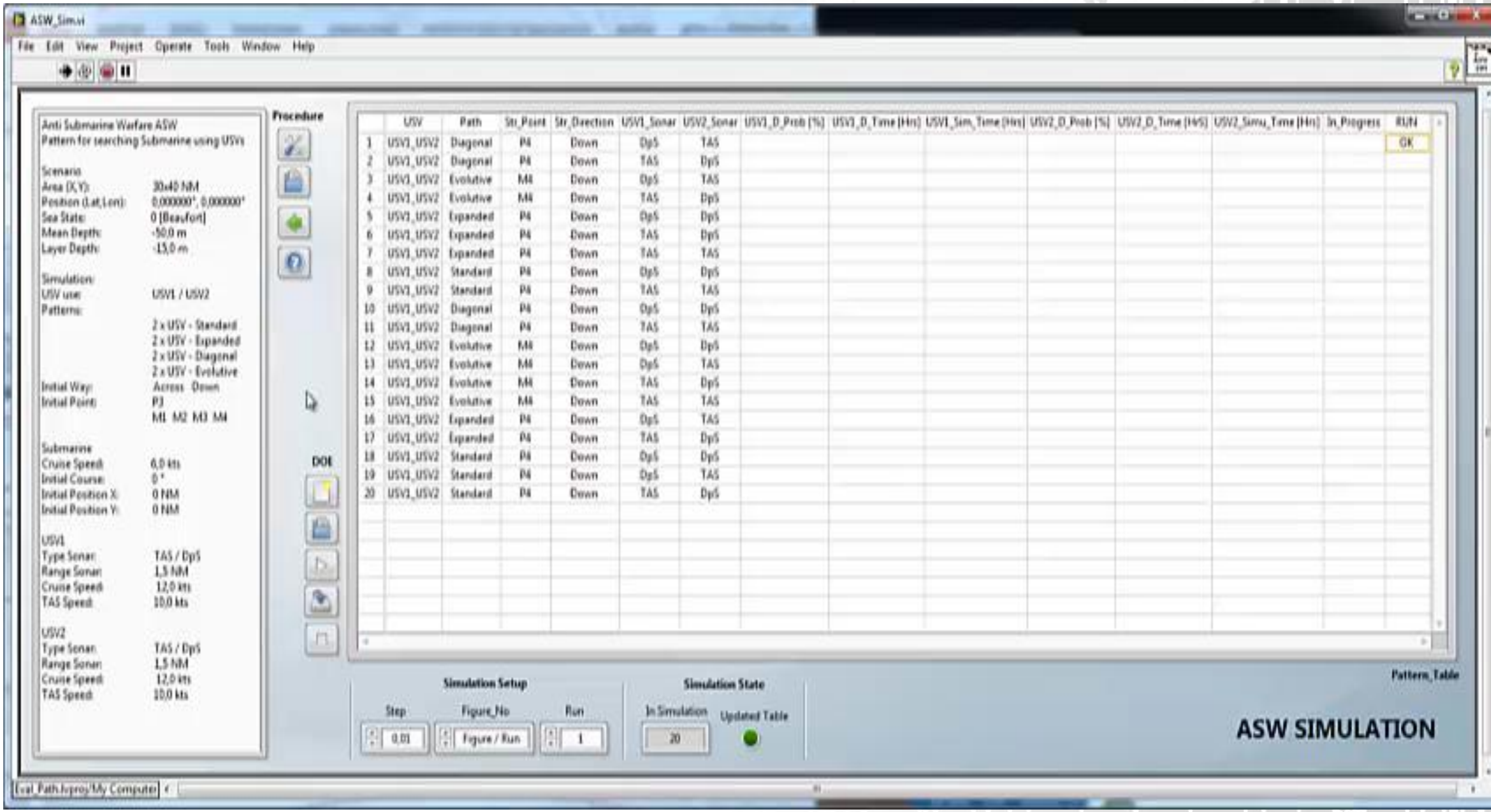
Summary

Factor	Type	Levels			
		Level 1	Level 2	Level 3	Level 4
USVs Speed	Continuous	6 Kt	8 Kt	10 Kt	-
Sonar Type	Discrete	DpS	TAS	-	-
Amount of USVs	Discrete	1 USV	2 USVs	-	-
Search Pattern	Discrete	Standard	Expanded	Evolutive	Diagonal
Search Starting Point	Discrete	P1	P2	P3	P4
Search Direction	Discrete	Up/Down	Across	-	-

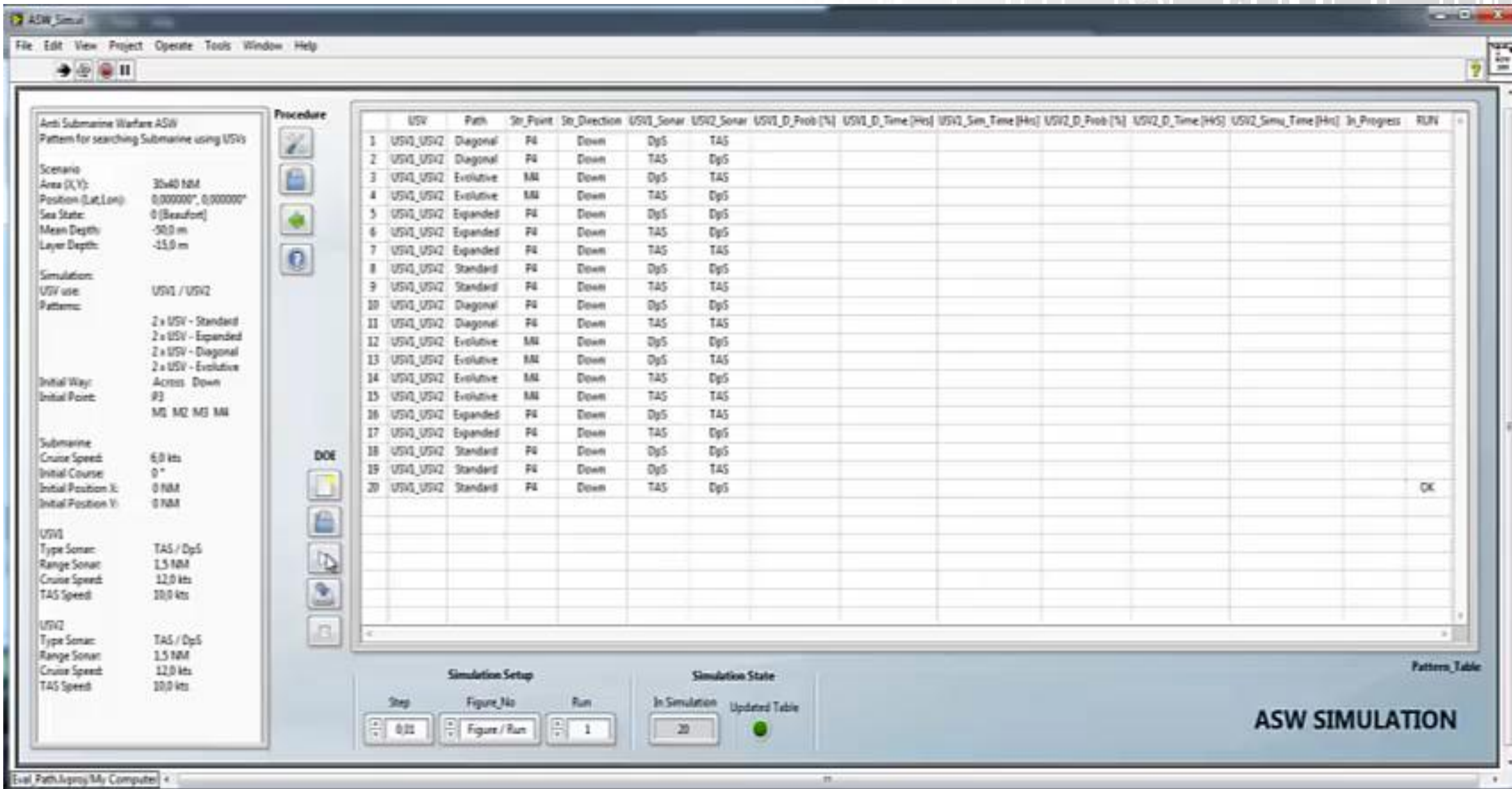
Restrictions

Factors		USVs Speed			Sonar Type		Amount USVs		Search Pattern				Search Starting Point				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
USVs Speed	6 Kts	-	-	-														
	8 Kts	-	-	-														
	10 Kts	-	-	-														
Sonar Type	DpS				-	-												
	TAS				-	-												
Amount USVs	1 USV						-	-		X		X						
	2 USVs						-	-										
Search Pattern	Std.								-	-	-	-						
	Expd.						X		-	-	-	-						
	Evol.								-	-	-	-	M1	M2	M3	M4		
	Diag.						X		-	-	-	-					X	X
Search Starting Point	P1										M1		-	-	-	-		
	P2										M2		-	-	-	-		
	P3										M3		-	-	-	-		
	P4										M4		-	-	-	-		
Search Direction	Up/Do											X					-	-
	Across											X					-	-

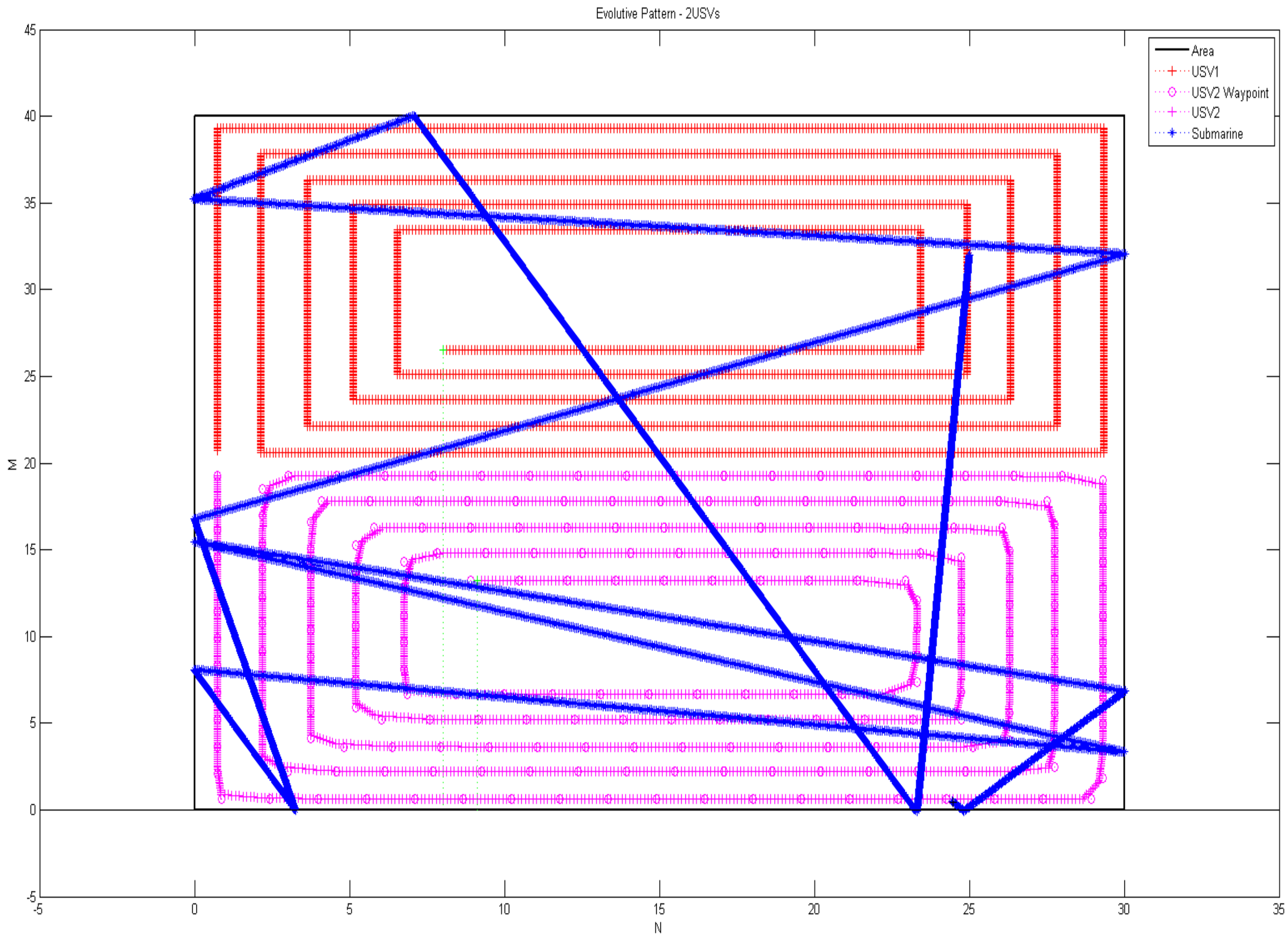
3. ROUTE PLANNER - Software



3. ROUTE PLANNER - Software

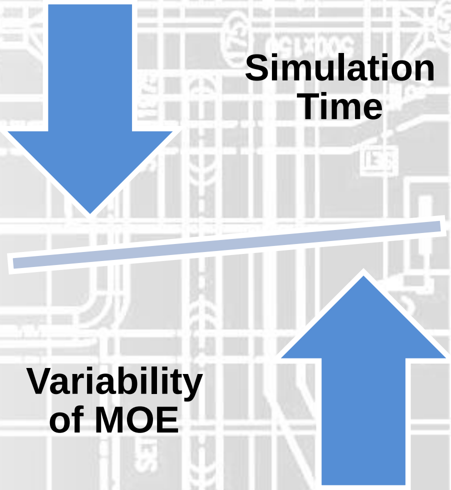


3. ROUTE PLANNER - Software



3. ROUTE PLANNER - Variability

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

4. RESULTS

Sensitivity Analysis Results

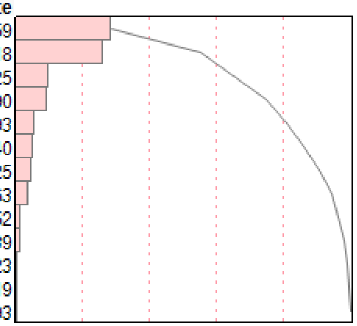
- Use two (2) USVs in the scenario, increase the effectiveness by 20% in compare with a USV.
- The search starting point depend of search pattern. However P2 y M1 have more effectiveness than other.
- The starting direction also differs on the search pattern. The starting direction “Down” is the best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

Pareto Plot of Transformed Estimates

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
Pattern[Evolutive]*Sonar Type_USV2[2-TAS]	-0.0010223
Pattern[Expanded]*Sonar Type_USV2[2-TAS]	-0.0009319
Sonar Type_USV1[1-TAS]*Sonar Type_USV2[2-TAS]	-0.0009193



Pareto chart – Response of Probability of Detection

4. RESULTS

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

Term	Orthog 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]*Sonar Type_USV1[1-TAS]	-0.450040
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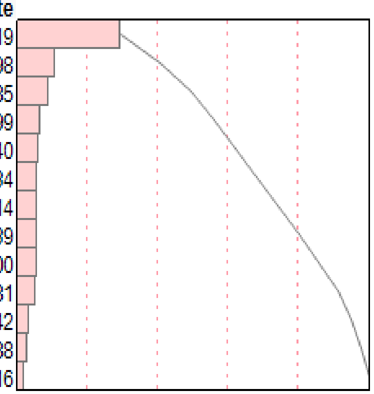


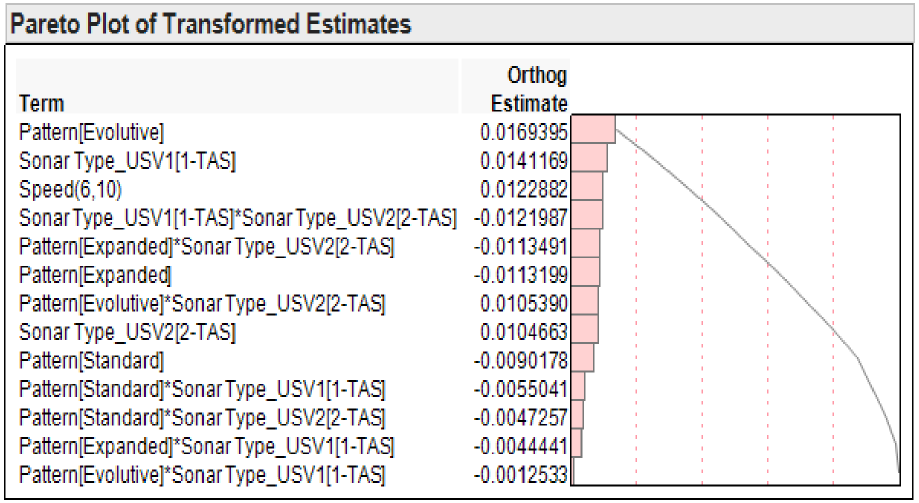
Pareto plot- Response of Submarine time detection

4. RESULTS

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.



Pareto Plot of Transformed Estimates

Term	Orthog 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]*Sonar Type_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]*Sonar Type_USV2[2-TAS]	-0.0047257
Pattern[Expanded]*Sonar Type_USV1[1-TAS]	-0.0044441
Pattern[Evolutive]*Sonar Type_USV1[1-TAS]	-0.0012533

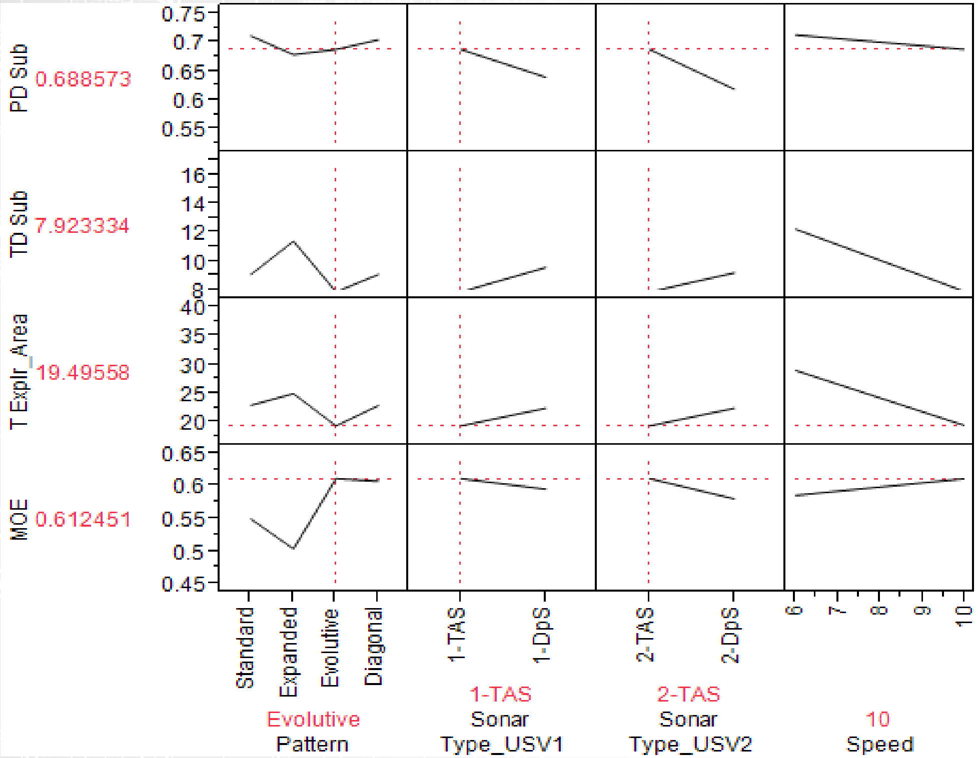
Pareto Plot – Response of Measure of Effectiveness - MOE

4. RESULTS

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!!

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11 - 13 DE MARZO DE 2015