The next step in the rise of maritime human factors simulation models : Optimising vessel layout using human factors simulation

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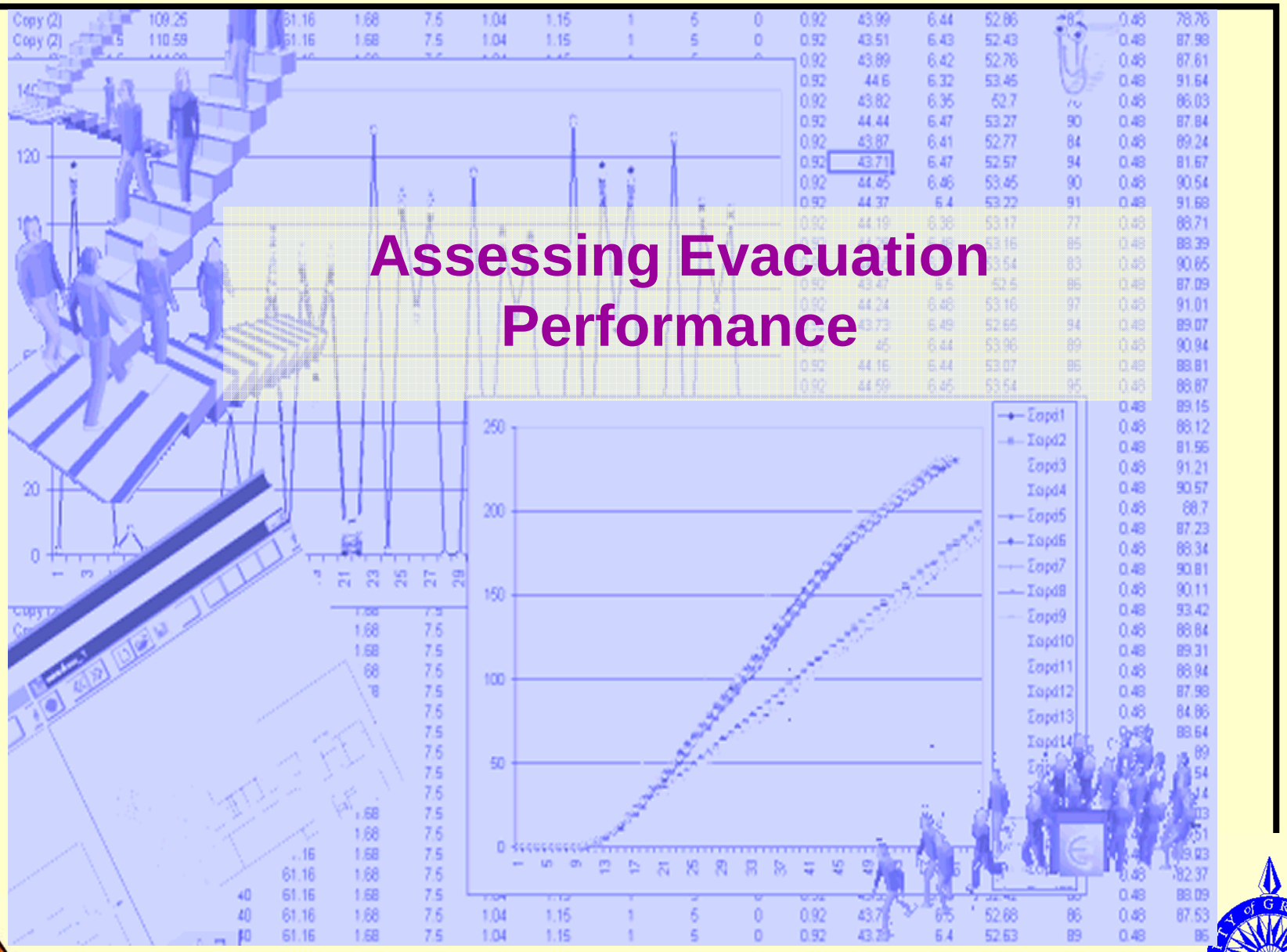
Presentation Outline

- Introduction – assessing HF performance
- Assessing Evacuation Performance
- How to Assess Normal Operations Performance
- Introducing the HPM
- Example application – Surface Combatant
- Conclusions

Introduction

- Modifying the internal layout/operating procedures of a ship has HF implications for crew/paxs and hence overall levels of safety and efficiency.
- How do we assess HF benefits or disbenefits that result from vessel internal layout and configuration?
  - **Evacuation:** Changing location of cabins, public facilities, corridor systems, stairs, assembly locations etc will have a direct impact on evacuation capabilities.
  - **NOP, PAX Vessels:** Size, location and configuration of restaurants, cinemas, bars, etc will influence the ease with which they can be accessed, filled and emptied.
    - This will impact operational characteristics and profitability of the vessel.
  - **NOP, Naval Vessels:** Compartment size, location and configuration will have an impact on the time required to change state and/or the minimum number of crew required to efficiently operate the vessel.
    - This will impact overall operating efficiency, ability to fulfil the assigned mission and lifetime costs of crewing.



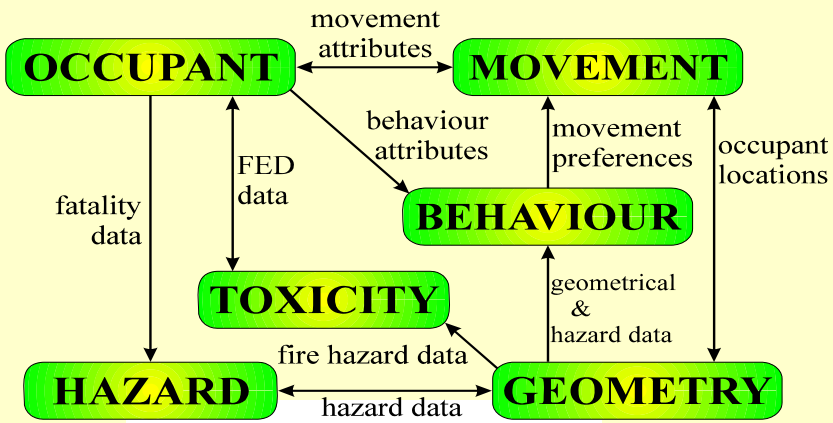
Assessing Evacuation Performance

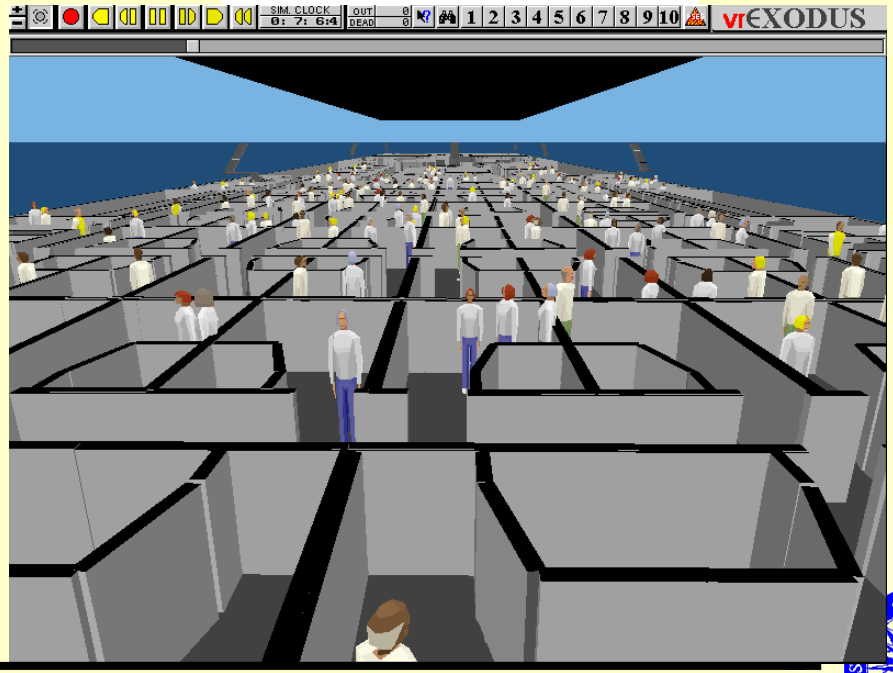
Assessing Evacuation Performance

- Evacuation issues assessed using ship evacuation simulation software to demonstrate compliance with appropriate regulations:
  - **Passenger ships:** MSc Circ 1033
    - 2 core scenarios (day and night) + a variation for each core scenario
  - **Naval Ships:** 'Naval Ship Code' currently under development for NATO navies
    - Chapter 7 of the code involves 3 core scenarios + variations for each core scenario.
      - Normal Day Cruising
      - Normal Night Cruising
      - Action Stations

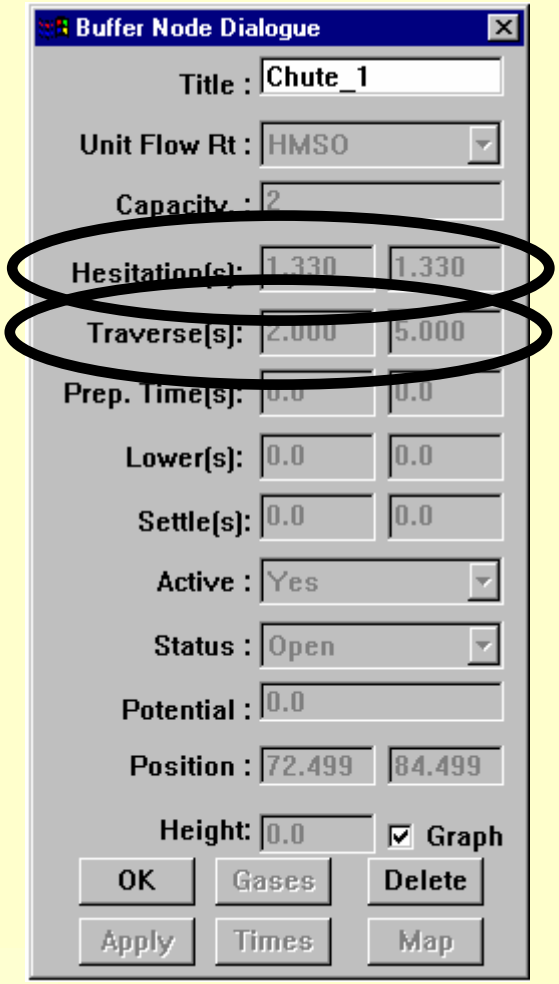
maritimeEXODUS Software

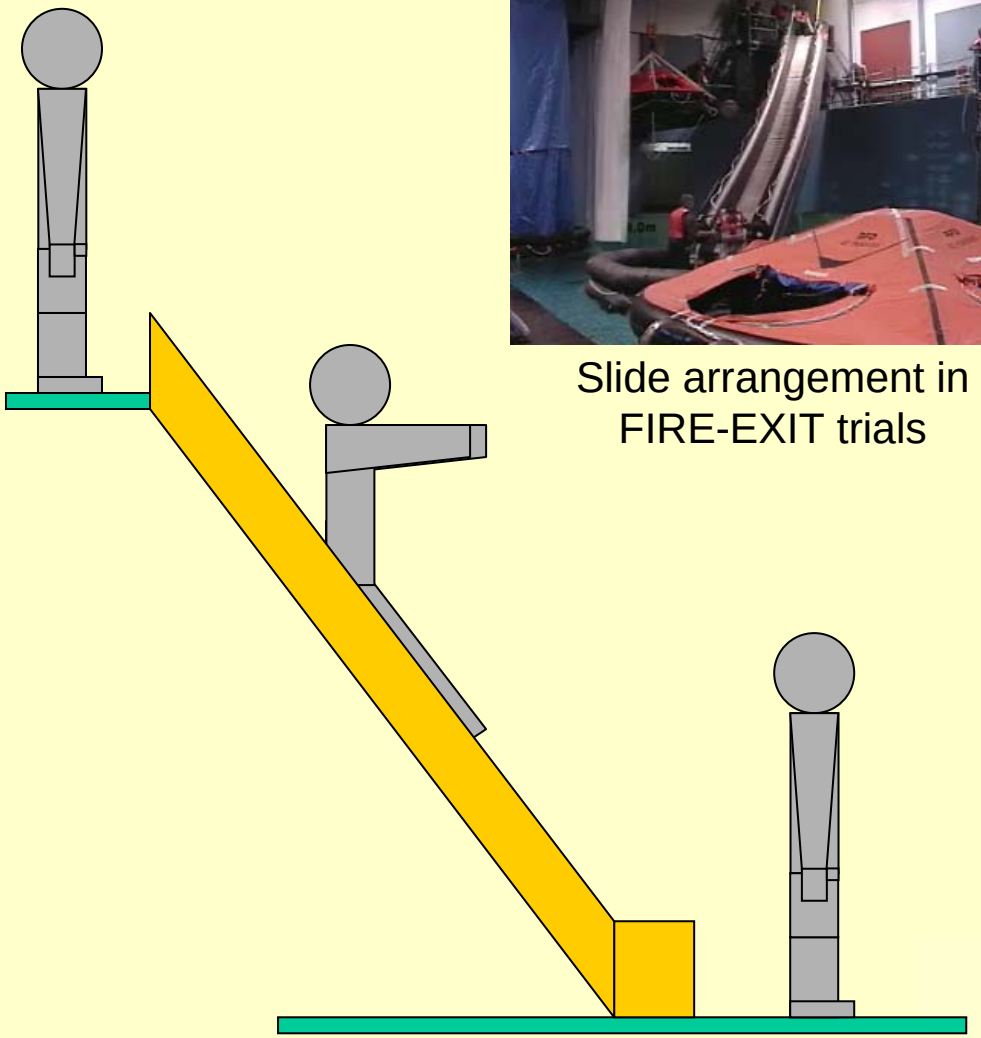
- **EXODUS:** *software tools used to simulate behaviour and movement in large complex spaces.*
- EXODUS R&D started 1989
- Users in 30 countries.
- mEX fully compliant with MSC Circ 1033 and in addition has capabilities for:
  - Impact of fire, heel, trim and dynamic motion,
  - Abandonment system,
  - HF data specific to naval applications
  - Licensed to 3 NATO navies:
    - UK, Spain, Netherlands





maritimeEXODUS: Representation of Slide

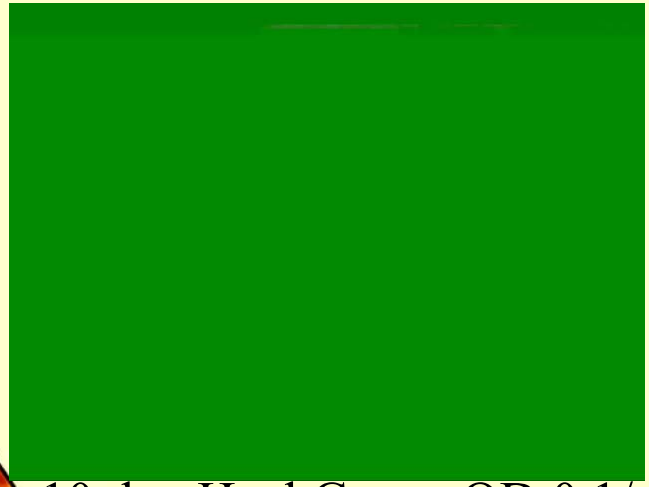




Slide arrangement in FIRE-EXIT trials

SHEBA Fire-Exit: Static Heel and Smoke, Dynamic Motion Trials with BMT Fleet Technology

10-20 deg motion, 5 sec period



10 deg Heel Group OD 0.1/m

20 deg Heel Group OD 0.5/m

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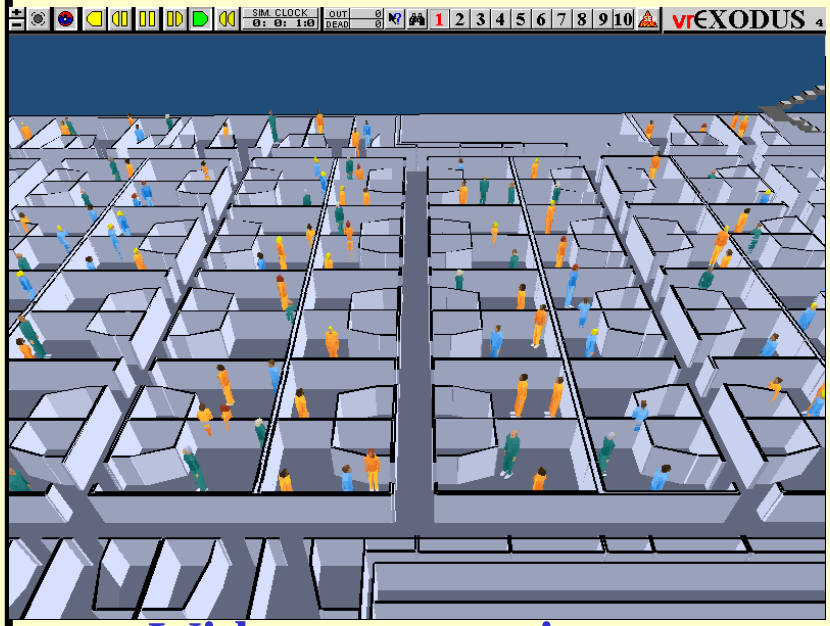
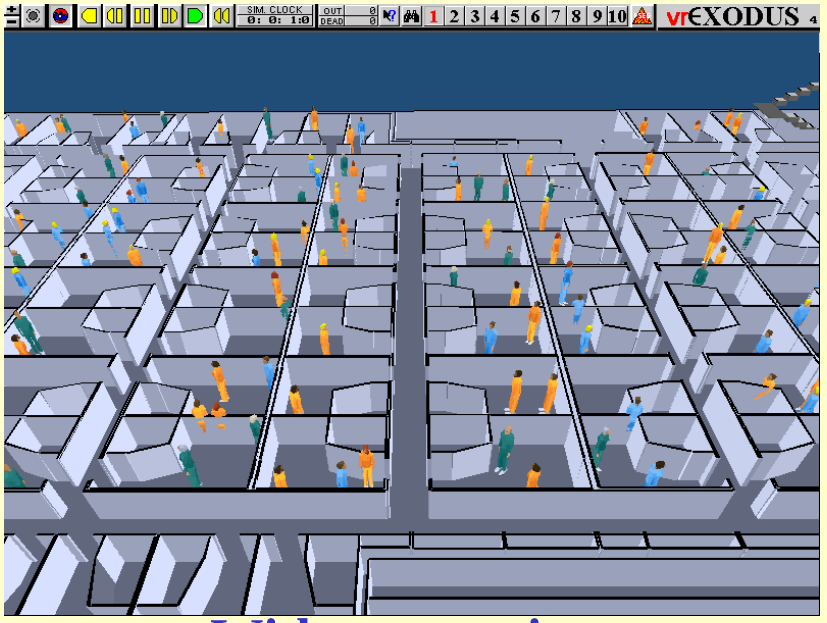
maritimeEXODUS simulation involving fire+suppression



Without water mist



With water mist

	No fire	fire	fire+mist
—Time to muster (no safety factor):	**15 m 57 s**	**28 m 13 s**	**31m 4 s**
—Average # fatalities:	**0**	**26**	**3**
—Fatalities occur between:	-	**7-15 min**	**7-11 min**
—All fatalities occur on:	-	**Deck 6**	**Deck 6**
—Average travel distance of victim:	-	**6 m**	**4.5m**

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Naval HF data incorporated within mEX

- Warship configuration is inherently more complex than that of a passenger vessel: e.g. different fixtures and fittings.
- NOP and emergency procedures more complex.
- Require additional HF data and software capabilities to accommodate

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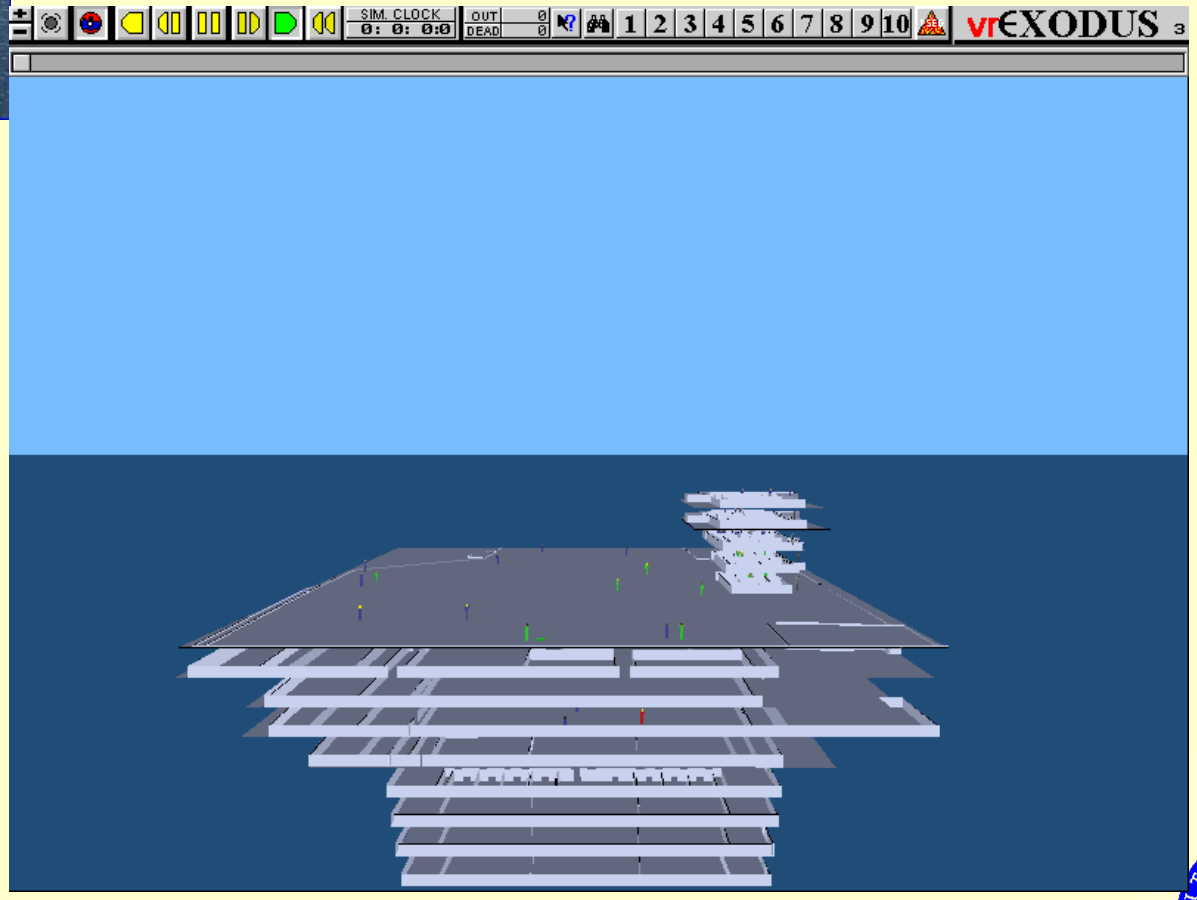
Naval Applications: CVF



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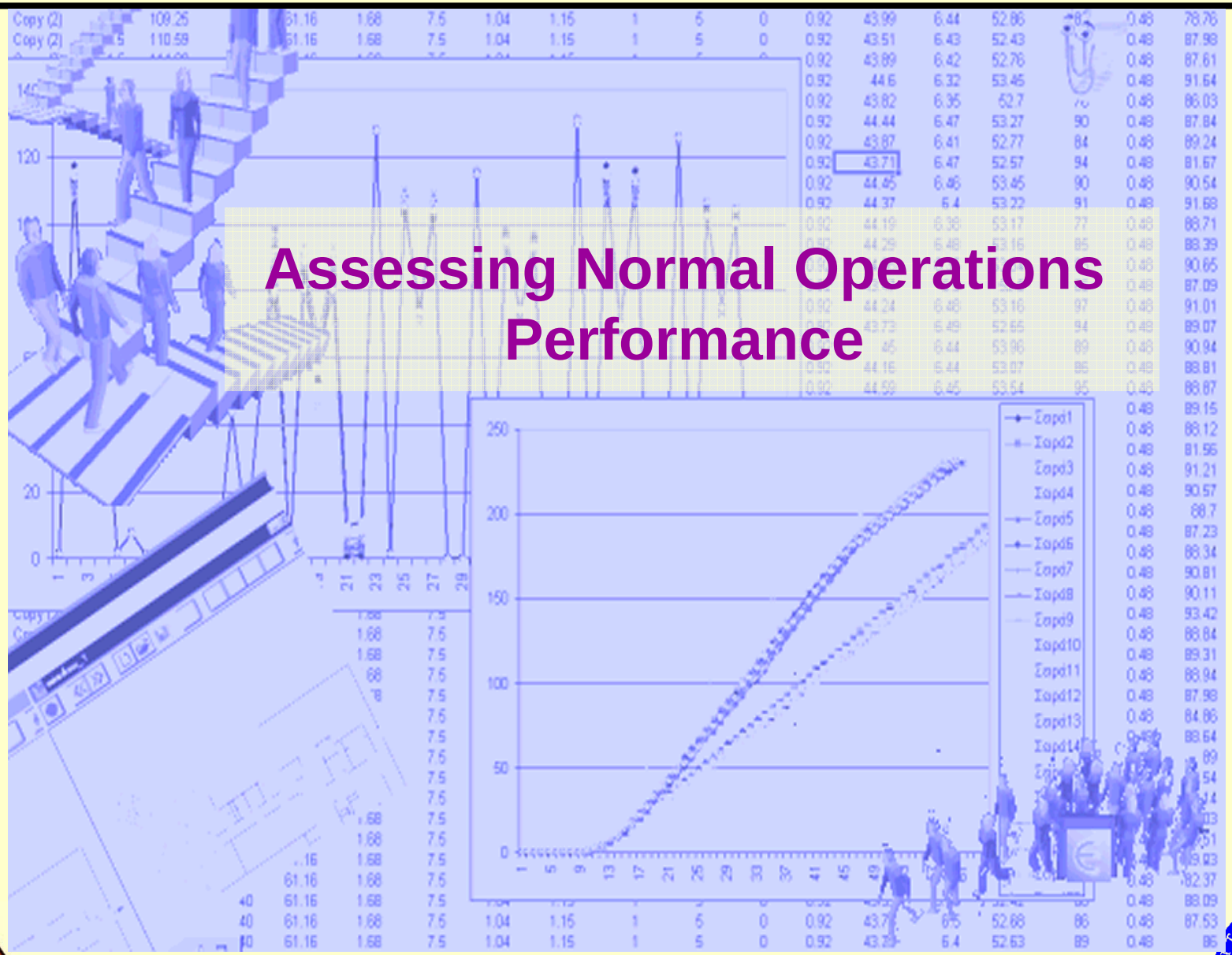
Assessing Normal Operations Performance



Assessing Normal Operations Performance

- How do we assess HF performance of vessel in NOP?
- How do we determine overall HF performance of vessel?
  - No standarised guidelines exist.

- Conclusions drawn concerning overall suitability of ship design by one naval architect can be quite different from those of another.

- Extremely difficult for fleet operators to set consistent and verifiable HF design objectives for new vessel concepts.

HF Assessment : Requirements

- To address these issues FSEG have developed the Human Performance Metric (HPM).

- HPM methodology enables the assessment of HF issues associated with vessel layout and crew operating procedures for a given vessel design.

- HPM methodology is:
  - SYSTEMATIC: routinely and rapidly applied to a given design
  - TRANSPARENT: logic process by which decision is made is clear
  - REPEATABLE: other engineers should be able to do the same analysis and arrive at the same conclusion
  - DISCRIMINATING: identifies best performing vessel
  - DIAGNOSTIC: identifies areas of HF performance which can be improved


Human Performance Metric

HPM Assessment : Methodology

- HPM methodology described using a surface combatant as an example
  - However, methodology can be applied to any vessel type.

- HPM requires:
  - Identification of relevant Evaluation Scenarios
  - Specification of relevant Performance Measures
  - Identification of relevant sub-groups of crew/passengers
  - Simulation and evaluation of relevant scenarios

HPM : Evaluation Scenarios (ES)

- Define a range of relevant ES to test the vessel.
  - Intended to define scope of challenges vessel will be subjected to.
  - Defined in conjunction with client.
  - Made up of both evacuation and NOP scenarios.
  - Dependent on the nature and class of vessel.
    - ES for cruise ship will be different to those for a naval vessel
    - ES for aircraft carrier may be different to those for a submarine.
- For the surface combatant example we will use the following 7 scenarios:
  - Normal Day Cruising A (Evacuation Scenario)
  - Normal Day Cruising B (Evacuation Scenario)
  - Action Station Evacuation (Evacuation Scenario)
  - State 1 Preps (NOP scenario)
  - Blanket Search (NOP scenario)
  - Family Day A (NOP scenario)
  - Family Day B (NOP scenario)

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HPM: Function Groups (FG)

- Ships crew undertake different tasks.
- Therefore crew is divided into logical subgroups based on crew roles known as FG.
- FG allow analysis to focus on performance of important crew subgroups whose contribution may swamp that of other FGs or be swamped by other FGs when considering the overall performance of the vessel.
- Examples of FG for a surface combatant are:
  - Entire ships company
  - Fire and repair party
  - Warfare
  - Electrical
  - First Aid

HPM : Performance Measures (PM)

- Performance of each FG in each ES is assessed through a set of PM. e.g.:
  - Number of WTDs used in the scenario.
  - Time required to close all WTDs.

- Each PM returns a value determined from computer simulation of each ES.
  - At present 32 different PM have been defined.

- High PM values indicate poor performance.

HPM : Vessel Performance (VP)

- VP determined as follows:
  - Perform all ES, determine PM values for each relevant FG in each ES.
  - Normalise PM values (based on largest PM score across each variant)
  - For each ES, take weighted sum of PM to determine ES score.
  - Take weighted sum of ES scores to determine VP.
  - All weights defined in consultation with client and are based on perceived importance of PM and ES

- Vessel with lowest VP has best performance according to the ES, PM and weights defined.
  - Examination of Scenario scores and PM scores indicates if performance of winning vessel can be further improved.

HPM Example

- VP for Variant 1.
  - •Seven scenarios, three function groups, weight distributions and normalised scores.

Variant 1 Design								
Evaluative scenario	Functional Groups						Scenario Score	Scenario Weight
	FG_1		FG_2		FG_3			
	weight	score	weight	score	weight	score		
Normal Day Cruising A	1	44.90	0	0	0	0	44.90	1
Normal Day Cruising B	1	49.86	0	0	0	0	49.86	1
Action Stations Evacuation	1	49.43	0	0	0	0	49.43	1
State 1 Preps	0.5	60.79	0.5	62.05	0	0	61.42	1.5
Blanket Search	0	0	1	78.59	0	0	78.59	1.5
Family Day A	0.5	50.37	0	0	0.5	40.52	45.44	1.5
Family Day B	1	56.63	0	0	0	0	56.63	1.5
Overall Performance of Functionality Groups	312.50		164.42		30.39			
						Overall Performance of design		507.3

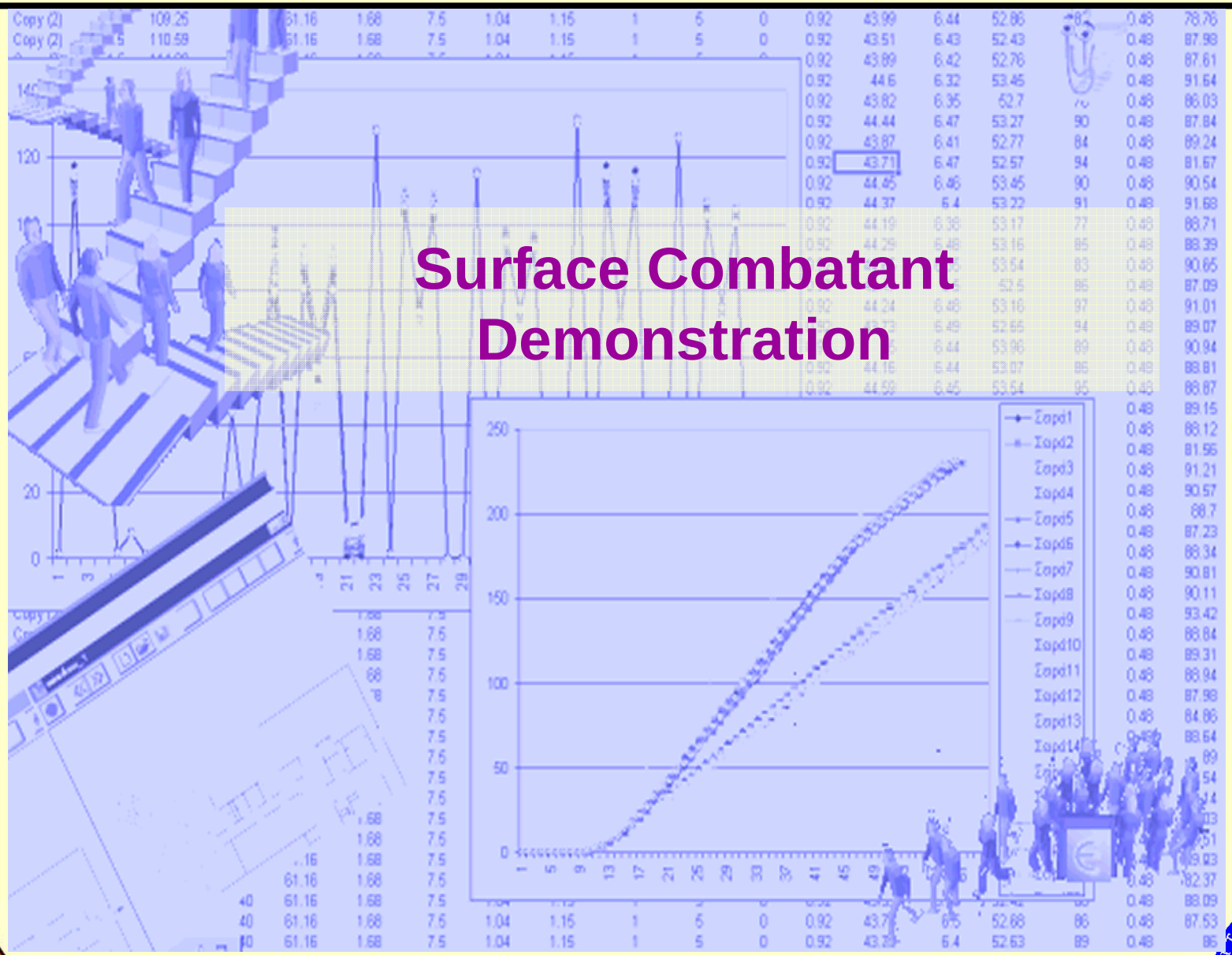
PM for FG1 for the State 1 Prep NOP Scenario

FG_1 – Entire Population		Variant 1	
	Weight	raw	norm
CONGESTION CRITERIA			
C1 – the number of locations in which the population density exceeds 4 p/m² for more than 10% of the overall scenario time'	3	0	0
C2 – the maximum time that the population density exceeded the regulatory maximum of 4 p/m² for 10% of the simulation time	3	0	0
GENERAL CRITERIA			
G1 – average time required to complete all operations;	6	146.2	0.77
G2 – average time spent in transition	5	68.28	0.87
G3 – time to reach final state	8	958.0	0.70
G4 – Average time spent in congestion	6	10.17	0.22
G5 – average distance travelled	2	43.69	0.81
PROCEDURAL CRITERIA			
p1 - the total number of operations completed by function group	3	588	0.98
GEOMETRIC CRITERIA:			
M1 – the number of WTD used during the scenario.	4	56	0.84
M2 – the number of Hatches used during the scenario.	4	39	1
M3 – the number of ladders used during the scenario.	2	43	1
M5 – the number of doors used during the scenario.	1	142	0.97
M6 – Longest time that a WTD was open during scenario.	4	742.9	0.65
M7 – Longest time that a Hatch was open during scenario.	4	664.4	0.62
M8 – the number of times the FG moved between decks	4	337	0.99
M13 – Average number of components used per member of FG during the scenario	3	4.90	1
M14 – Most times a WT door was operated	3	17	0.85
M15 – Most times a hatch was operated	3	9	1
M16 - Average number of doors used per person	3	1.41	1
M17 - Average number of WT doors per person	3	2.20	0.94
M18 - Average number of hatches used	3	0.65	0.89
		Functional Group Score for FG1	60.79

PM for FG2 for the State 1 Prep NOP Scenario

FG_2 – Damage Control and Fire Fighting		Variant 1	
	Weight	raw	norm
GENERAL CRITERIA			
G1 – average time required to complete all operations;	6	262.2	0.74
G2 – average time spent in transition	5	186.3	0.89
G3 – time to reach final state	8	958.0	0.70
G4 – Average time spent in congestion	6	10.34	0.15
G5 – average distance travelled	2	77.25	0.82
PROCEDURAL CRITERIA			
P1 - the total number of operations completed by function group	3	170	0.94
P2 – average time spent performing actions	4	20.42	1
GEOMETRIC CRITERIA:			
M1 – the number of WTD used during the scenario.	4	56	0.84
M2 – the number of Hatches used during the scenario.	4	39	1
M3 – the number of ladders used during the scenario.	2	43	1
M4 – the number of doors used during the scenario.	2	102	0.94
M5 – the number of times the FG moved between decks	4	71	0.95
M6 – Average number of components used per member of FG during the scenario	3	8.42	0.89
M7 – Most times a WT door was operated	3	8	0.67
M8 – Most times a hatch was operated	3	5	1
M9 - Average number of doors used per person	2	1.52	1
M10 - Average number of WT doors per person	3	4.96	0.85
M11 - Average number of hatches used	3	1.52	0.92
M12 – Time to close all WT doors (i.e. time to achieve WT integrity Z)	6	781.3	0.67
M13 – Time to report back that vessel has upheld WT integrity Z	6	958.0	0.70
		Functional Group Score for FG2	62.05

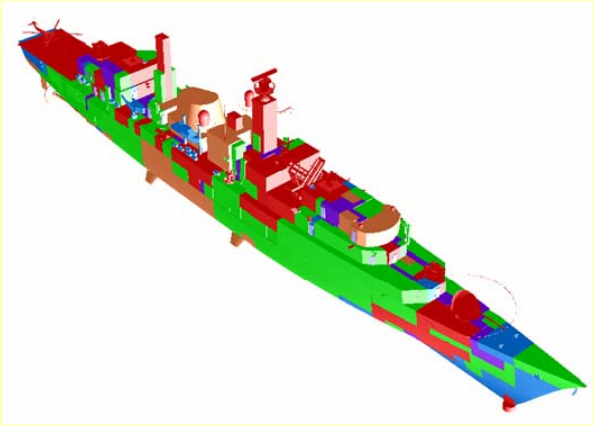
Surface Combatant Demonstration



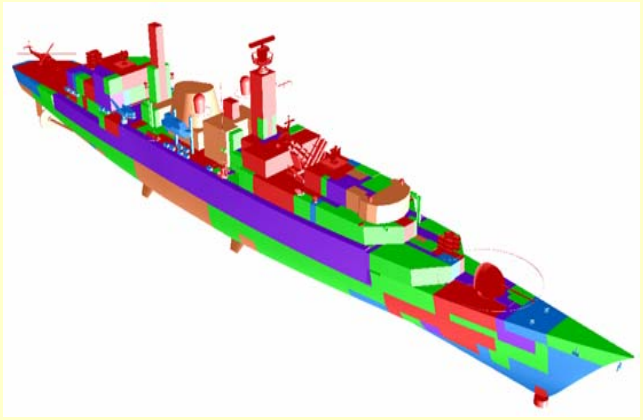
HPM Demonstration

- Two design variants of a Type 22 Batch III Frigate.
  - Variant 1 has two ***single*** passageway passing decks
  - Variant 2 has two ***double*** passageway passing decks
- Each variant has a crew of 262 with the same OP and the same FGs (Full crew, Damage Control Fire Fighting Party).
- Each variant has the same number of vertical access points.
- In total 18 PMs are used in the analysis.
- 7 ES investigated
  - 3 evacuation
  - 4 NOPs

Hypothetical Example involving Type 22 BIII and double passage variant



T22 BIII single passageway



Double passageway variant

- Paramarine models developed by Prof David Andrews and his team from UCL
  - RED: fight, GREEN: crew spaces, PURPLE: passageways,
  - BLUE: stores
- **Models are hypothetical designs and so results should not be considered to be indicative of actual performance.**

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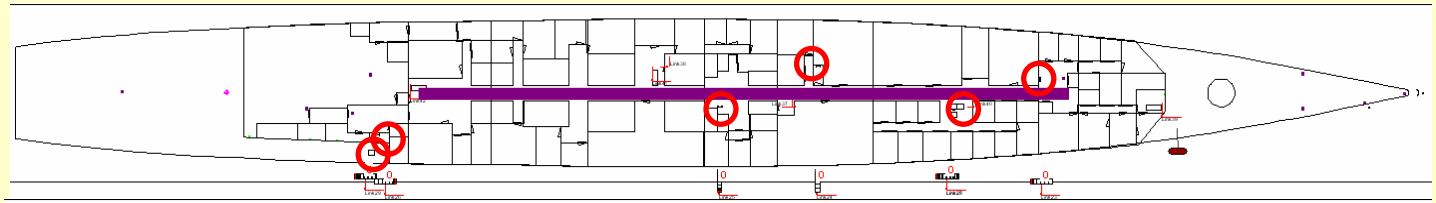
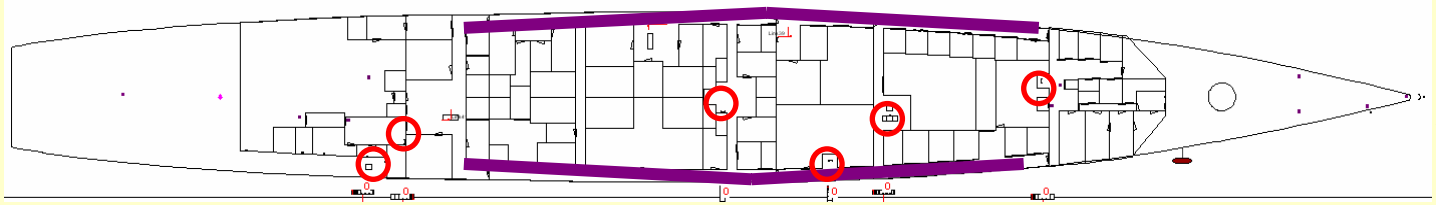
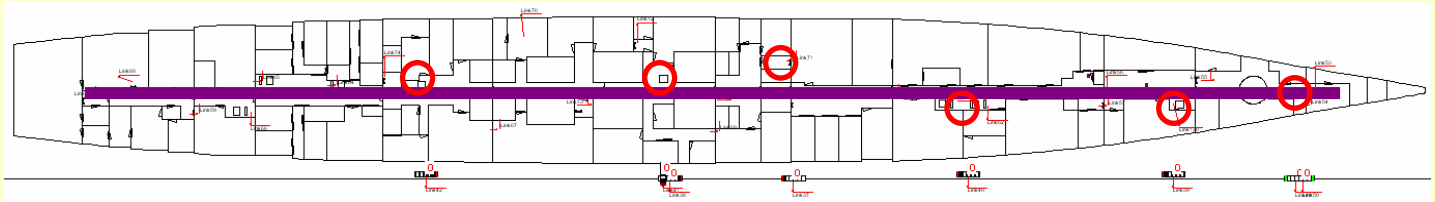
Single and double passageway vessels



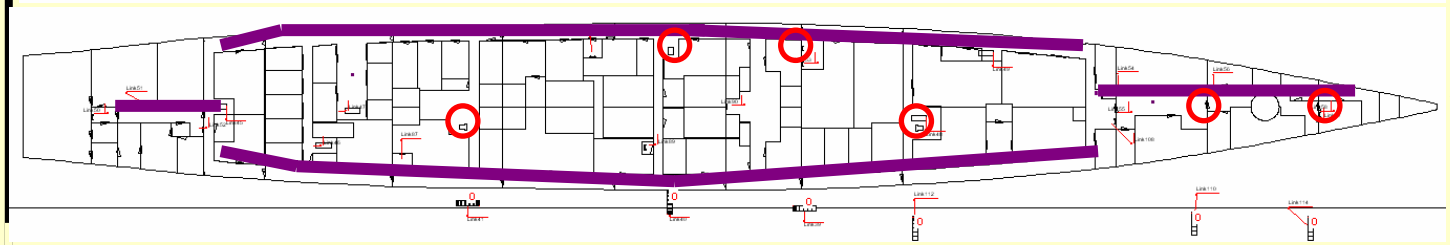
No 1 Deck Variant 1



No 1 Deck Variant 2



No 2 Deck Variant 1



No 2 Deck Variant 2

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Overall performance of Variant 1 and Variant 2

- Overall, Variant 1 outperforms Variant 2 by 3%.

Variant 1 Design								
Evaluative scenario	Functional Groups						Scenario Score	Scenario Weight
	FG_1		FG_2		FG_3			
	weight	score	weight	score	weight	score		
Normal Day Cruising A	1	46.14	0	0	0	0	46.14	1
Normal Day Cruising B	1	50.81	0	0	0	0	50.81	1
Action Stations Evacuation	1	51.45	0	0	0	0	51.45	1
State 1 Preps	0.5	67.01	0.5	67.91	0	0	67.46	1.5
Blanket Search	0	0	1	81.90	0	0	81.89	1.5
Family Day A	0.5	54.76	0	0	0.5	37.48	46.12	1.5
Family Day B	1	55.88	0	0	0	0	55.88	1.5
Overall Performance of Functionality Groups	323.56		173.77		28.11			
						Overall Performance of design		525.4

Variant 2 Design								
Evaluative scenario	Functional Groups						Scenario Score	Scenario Weight
	FG_1		FG_2		FG_3			
	weight	score	weight	Score	weight	score		
Normal Day Cruising A	1	44.33	0	0	0	0	44.33	1
Normal Day Cruising B	1	48.39	0	0	0	0	48.39	1
Action Stations Evacuation	1	46.70	0	0	0	0	46.70	1
State 1 Preps	0.5	75.92	0.5	75.74	0	0	75.83	1.5
Blanket Search	0	0	1	84.16	0	0	84.16	1.5
Family Day A	0.5	51.37	0	0	0.5	47.57	49.47	1.5
Family Day B	1	57.30	0	0	0	0	57.30	1.5
Overall Performance of Functionality Groups	320.84		183.05		35.68			
						Overall Performance of design		539.6

Comparison of HPMs for Variant 1 and Variant 2

Evaluation scenario	Scenario Weight	Variant 1	Variant 2	% difference
Normal Day Cruising A	1	46.14	44.33	3.93%
Normal Day Cruising B	1	50.81	48.39	4.77%
Action Stations Evacuation	1	51.45	46.70	9.23%
State 1 Preps	1.5	67.46	75.83	-12.40%
Blanket Search	1.5	81.89	84.16	-2.77%
Family Day A	1.5	46.12	49.47	-7.27%
Family Day B	1.5	55.88	57.30	-2.53%

- Overall, Variant 1 outperforms Variant 2 by 3%. However:
  - In Evacuation scenarios, Variant 2 is 6% more efficient than Variant 1
  - In NoP Scenarios, Variant 1 is 6% more efficient than Variant 2
- Worst performing scenario for Variant 1 is Action Stations Evacuation
- Best performing NoP scenario for Variant 1 is State 1 Preps.

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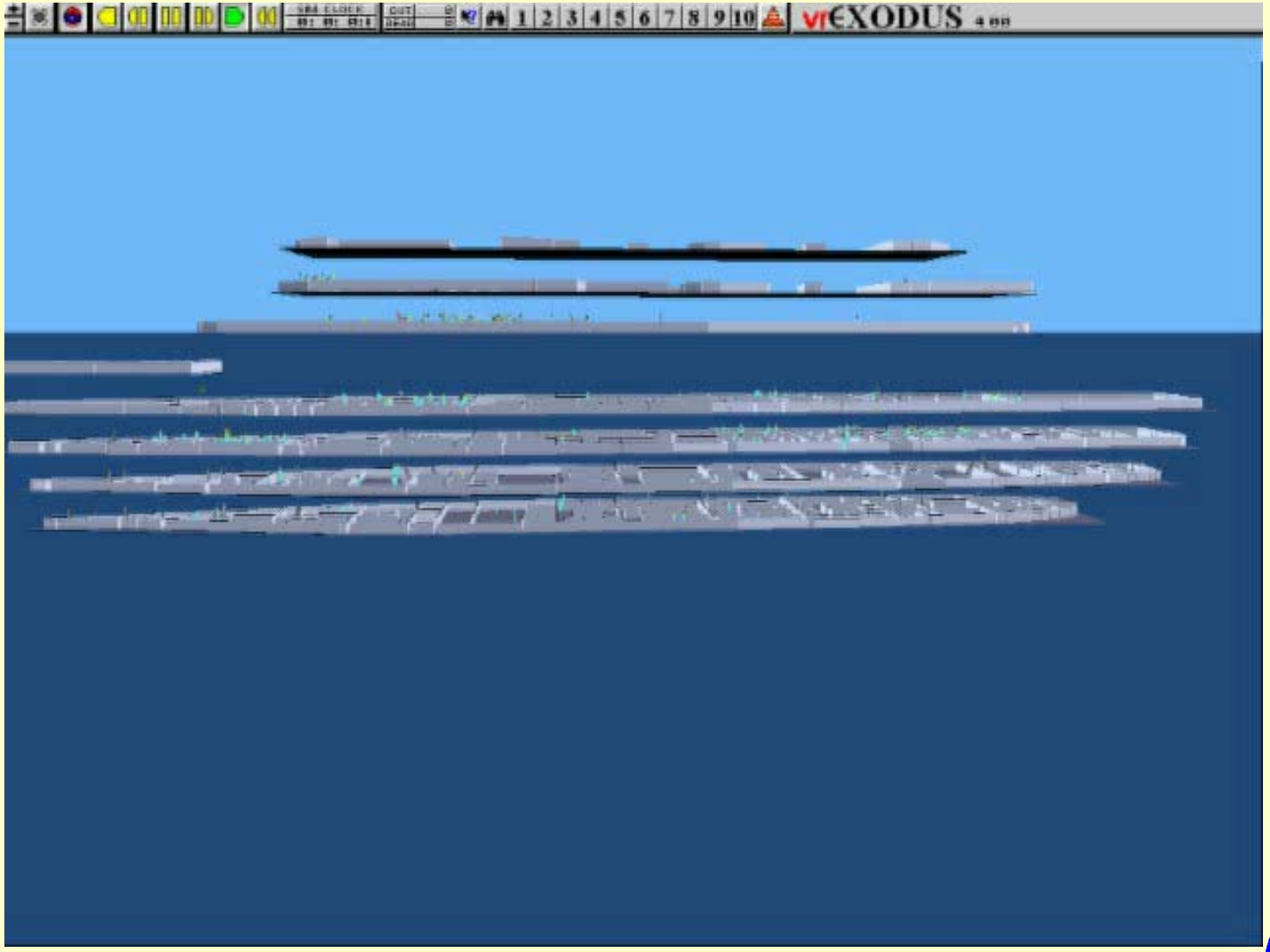
Action Stations Evacuation Variant 1



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PM for FG1 for the Action Station Evacuation Scenario

FG_1 – Entire Population		Variant 1		Variant 2	
	Weight	raw	norm	raw	norm
CONGESTION CRITERIA					
C1 – the number of locations in which the population density exceeds 4 p/m² for more than 10% of the overall scenario time'	8	4	1	4	1
C2 – the maximum time that the population density exceeded the regulatory maximum of 4 p/m² for 10% of the simulation time	3	75.4	1	42.14	0.56
GENERAL CRITERIA					
G1 – average time required to complete all operations;	4	256.7	1	193.5	0.75
G2 – average time spent in transition	3	36.61	0.80	45.76	1
G3 – time to reach final state (has to be within 3000 seconds)	8	666.[illegible]	0.22	534.5	0.20
G4 – Average time spent in congestion	3	150.[illegible]	1	74.93	0.50
G5 – average distance travelled	4	47.1[illegible]	0.94	50.11	1
GEOMETRIC CRITERIA:					
M1 – the number of WTD used during the scenario.	2	24	0.89	27	1
M2 – the number of Hatches used during the scenario.	2	31	1	25	0.81
M3 – the number of ladders used during the scenario.	2	31	1	25	0.81
M5 – the number of doors used during the scenario.	1	78	1	76	0.97
M8 – the number of times the FG moved between decks	2	373	1	322	0.86
M13 – Average number of components used per member of FG during the scenario	2	4.47	1	4.36	0.98
M14 – Most times a WT door was operated	4	9	0.82	11	1
M15 – Most times a hatch was operated	3	10	1	7	0.70
M16 - Average number of doors used per person	3	1.59	0.62	1.94	1
M17 - Average number of WT doors used per person	3	1.46	1	1.19	0.82
M18 - Average number of hatches used per person	3	0.27	1	0.23	0.83

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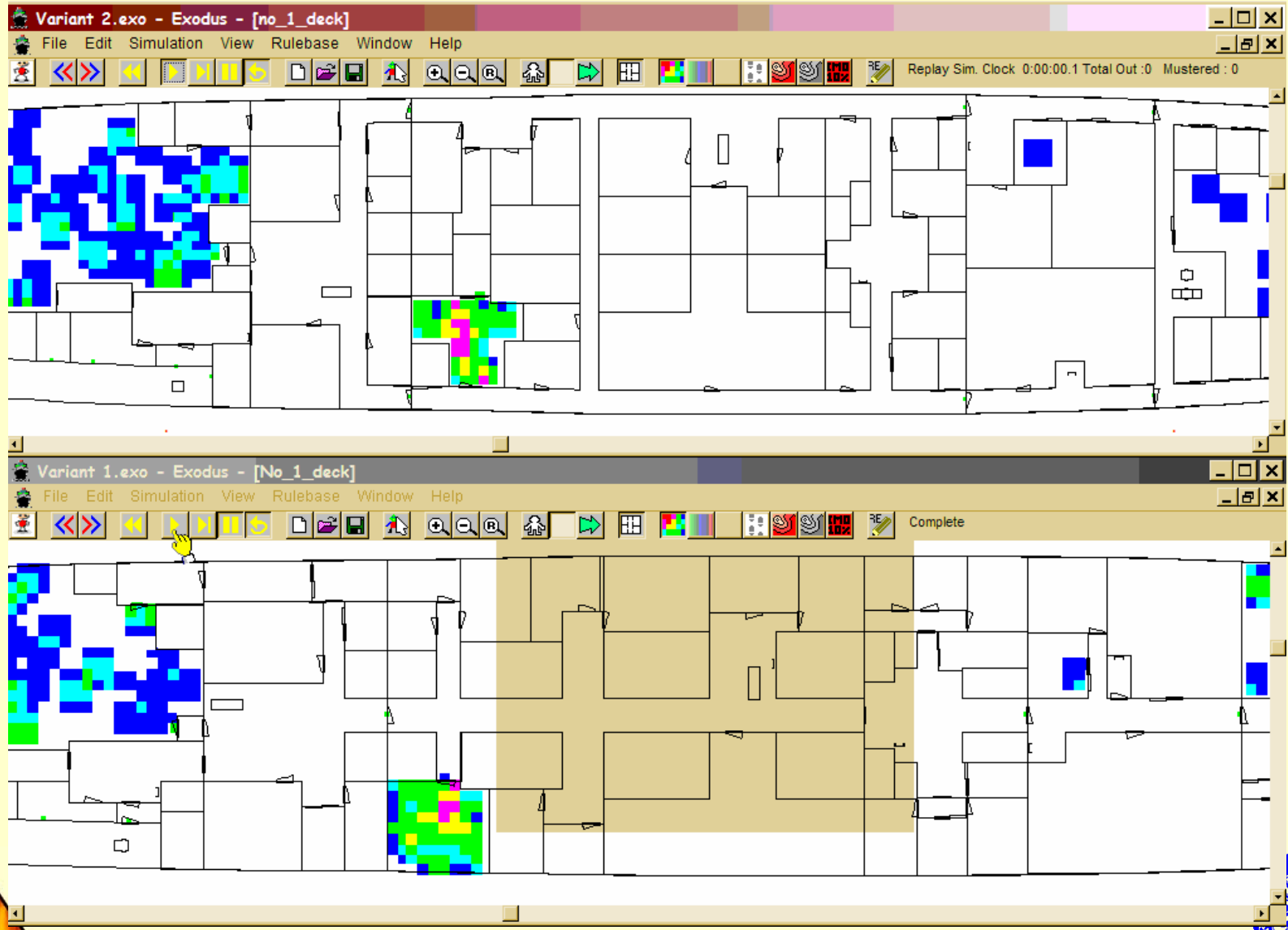
Action Stations Evacuation Variant 2 and Variant 1 (No 1 Deck)



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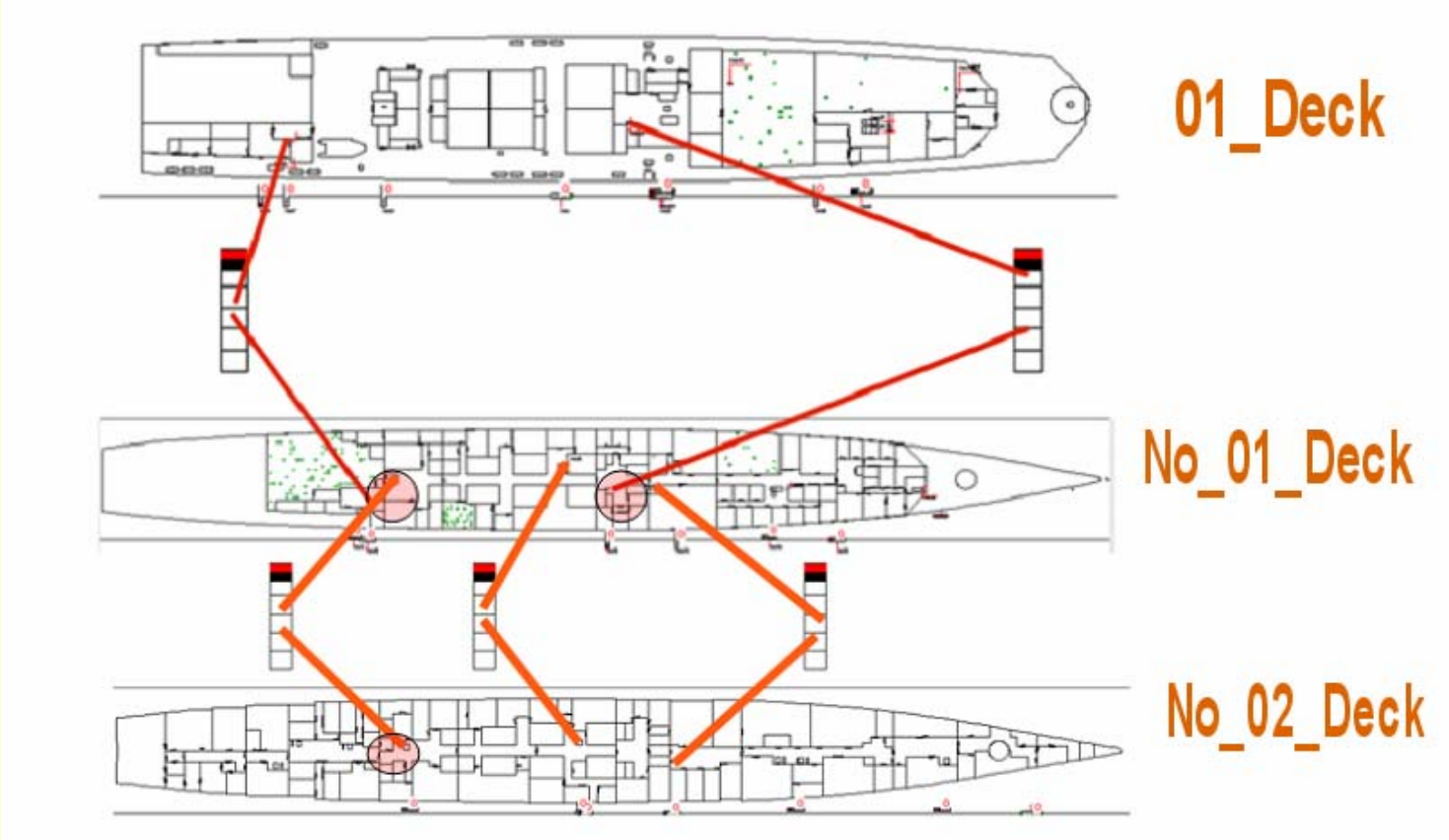
Improving the 'Best' Design

- HPM can be utilised to improve performance of winning design.
  - For the winning design, identify the worst ES
  - Use PM scores to identify source of poor performance.
    - Variant 1 identified as marginally better design.
    - Action Stations Evacuation identified as Variant 1's poorest performing ES.
    - Primarily due to number of high congestion regions.

Variant 1: Three Primary Congestion Regions in Actions Stations Evacuation



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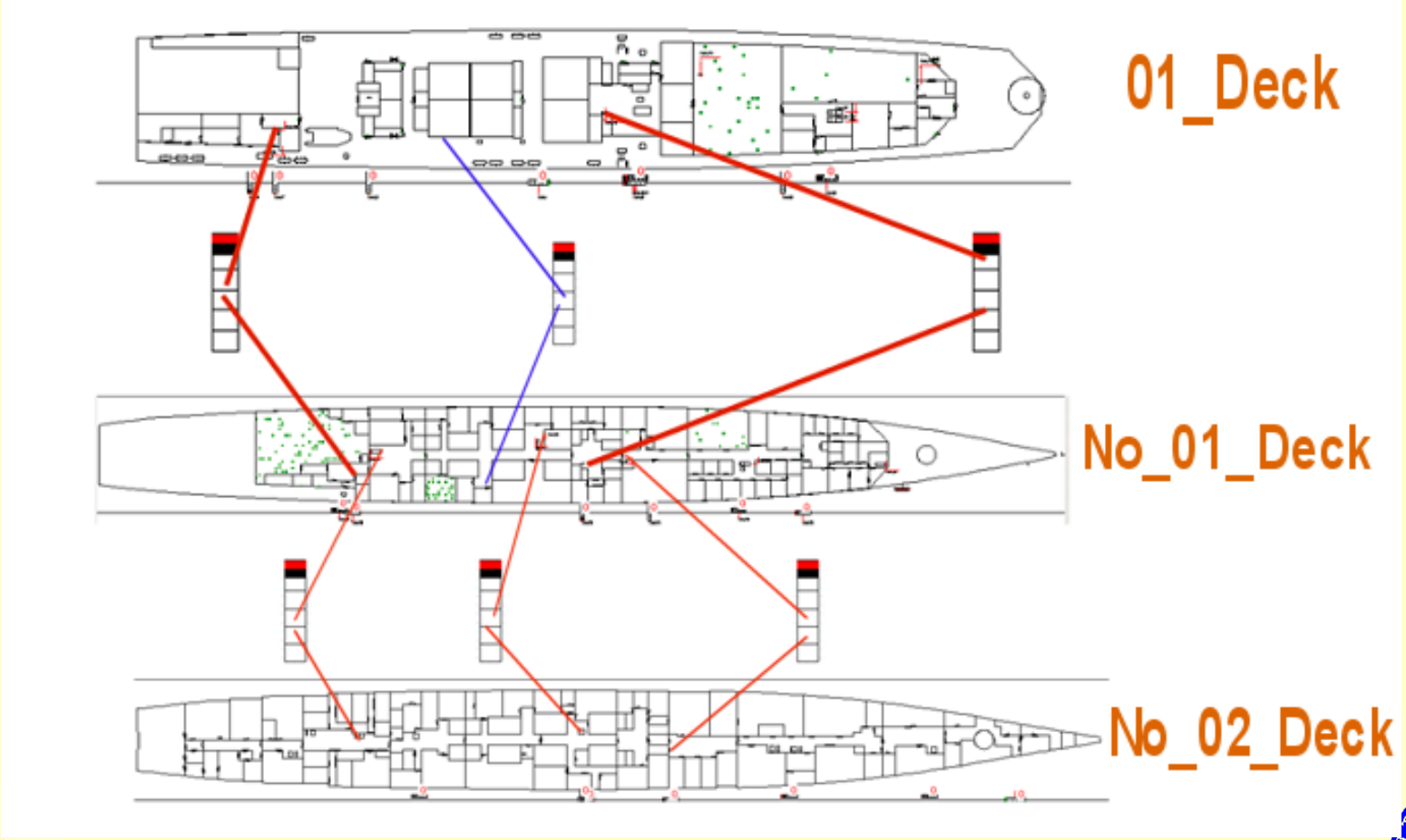
Suggested Improvement: Variant 3

- Suggested solution place additional ladder between 01_Deck and No_01_Deck.



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Overall performance of Variant 1 and Variant 3

- Overall, Variant 3 outperforms Variant 1 by 5%.

Variant 1 Design								
Evaluative scenario	Functional Groups						Scenario Score	Scenario Weight
	FG_1		FG_2		FG_3			
	weight	score	weight	score	weight	score		
Normal Day Cruising A	1	47.81	0	0	0	0	47.81	1
Normal Day Cruising B	1	51.62	0	0	0	0	51.62	1
Action Stations Evacuation	1	52.78	0	0	0	0	52.78	1
State 1 Preps	0.5	74.30	0.5	77.22	0	0	75.76	1.5
Blanket Search	0	0	1	86.25	0	0	86.25	1.5
Family Day A	0.5	56.40	0	0	0.5	48.17	52.28	1.5
Family Day B	1	57.57	0	0	0	0	57.57	1.5
Overall Performance of Functionality Groups	336.58		187.30		36.13			
						Overall Performance of design	560.0	

Variant 3 Design								
Evaluative scenario	Functional Groups						Scenario Score	Scenario Weight
	FG_1		FG_2		FG_3			
	weight	score	weight	score	weight	Score		
Normal Day Cruising A	1	46.59	0	0	0	0	46.59	1
Normal Day Cruising B	1	44.99	0	0	0	0	44.99	1
Action Stations Evacuation	1	46.68	0	0	0	0	46.68	1
State 1 Preps	0.5	70.10	0.5	76.90	0	0	73.50	1.5
Blanket Search	0	0	1	85.36	0	0	85.36	1.5
Family Day A	0.5	55.73	0	0	0.5	43.37	49.55	1.5
Family Day B	1	53.57	0	0	0	0	53.57	1.5
Overall Performance of Functionality Groups	312.99		185.71		32.52			
						Overall Performance of design	531.2	

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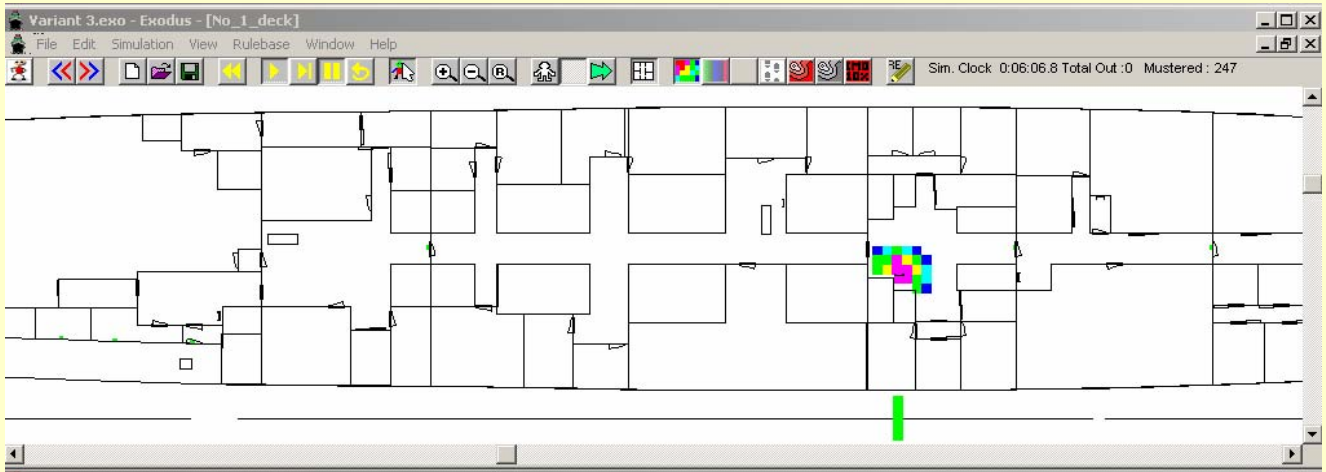
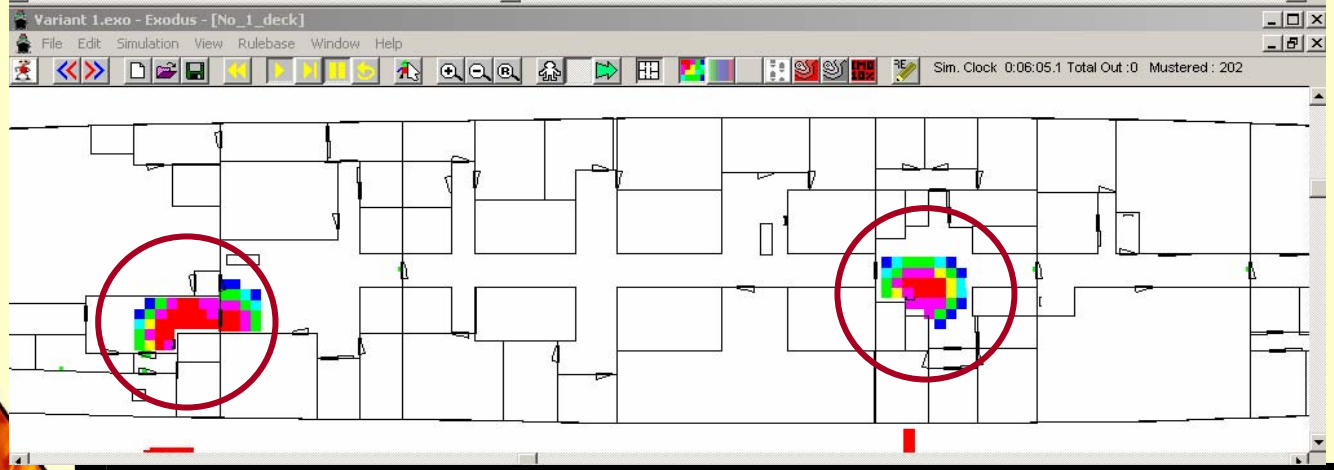
Action Stations Evacuation Variant 3 and Variant 1

• Two of the three main congestion areas in Variant 3 have been removed and third congestion region significantly improved by addition of single ladder



Variant 3
No 1 Deck



Variant 1
No 1 Deck

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Comparison of HPMs for Variant 1 and Variant 3

Evaluation scenario	Scenario Weight	Variant 1	Variant 3	% difference
Normal Day Cruising A	1	47.81	46.59	-2.61%
Normal Day Cruising B	1	51.62	44.99	-14.72%
Action Stations Evacuation	1	52.78	46.68	-13.05%
State 1 Preps	1.5	75.76	73.50	-3.08%
Blanket Search	1.5	86.25	85.36	-1.05%
Family Day A	1.5	52.28	49.55	-5.52%
Family Day B	1.5	57.57	53.57	-7.48%

- With proposed modifications, Variant 3 outperforms Variant 1 by 5%.
  - In Evacuation scenarios, Variant 3 is **9.2%** more efficient than Variant 1
  - In NoP Scenario Variant 3 is **3.6%** more efficient than Variant 1
  - Variant 3 Action Stations Evacuation has improved by **13.1%**
  - Variant 3 State 1 Preps has improved by a further **3.1%**

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Comparison of HPMs for Variant 3 and Variant 2

Evaluation scenario	Scenario Weight	Variant 3	Variant 2	% diff V3 and V2	% diff V1 and V2
Normal Day Cruising A	1	46.15	44.94	2.63%	3.93%
Normal Day Cruising B	1	47.74	48.78	-2.18%	4.77%
Action Stations Evacuation	1	48.69	49.78	-2.26%	9.23%
State 1 Preps	1.5	66.63	76.60	-14.96%	-12.40%
Blanket Search	1.5	80.33	84.74	-5.49%	-2.77%
Family Day A	1.5	44.80	49.81	-11.21%	-7.27%
Family Day B	1.5	53.04	57.89	-9.14%	-2.53%

- Adding a ladder to single passageway variant improves overall performance by 4% making it 7.3% more efficient than double passageway variant.
- In evacuation scenarios, single passageway variant is 0.7% more efficient than double passageway variant.
- In NoP Scenarios, single passageway variant is 10% more efficient than double passageway variant
- Single passageway variant now outperforms double passageway variant in almost all scenarios

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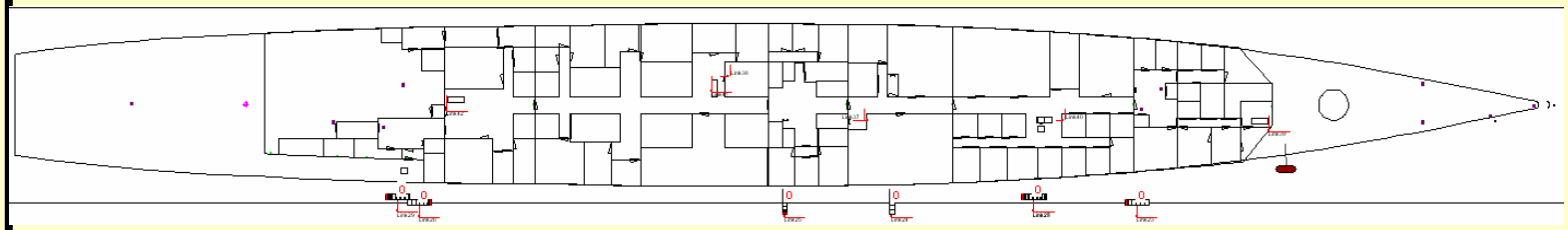
Low Resolution Design

- To improve versatility of HPM technique apply to early stage design.
- Early stage design does not contain the detail found in GA.
  - Compartments are not all clearly defined.
  - Connectivity between compartments not considered
  - Early design stage designs consist primarily of:
    - Water tight compartments
    - Water tight doors
    - Connections between decks.

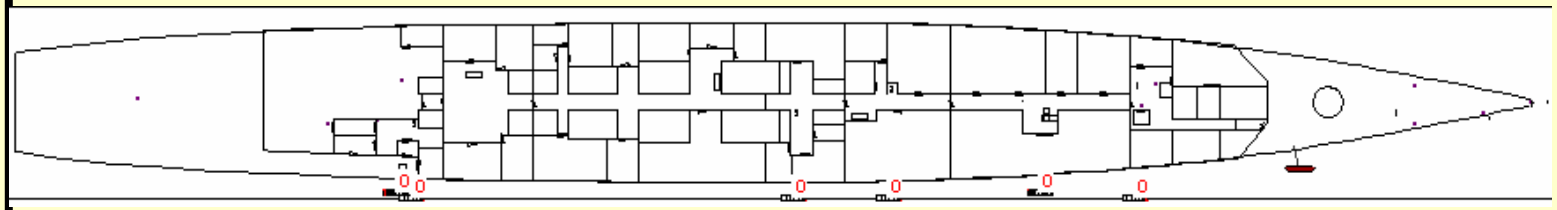
- Clearly this will have an impact on PM.
- Analysis may involve modifying PM and ES
  - e.g. PM involving non-water tight doors not relevant
  - e.g. ES blanket search not relevant.

- While useful for discriminating between competing designs, at this level of design resolution, there is limited potential for diagnostic analysis.
- However, can link mEX directly to Ship design software PARAMARINE

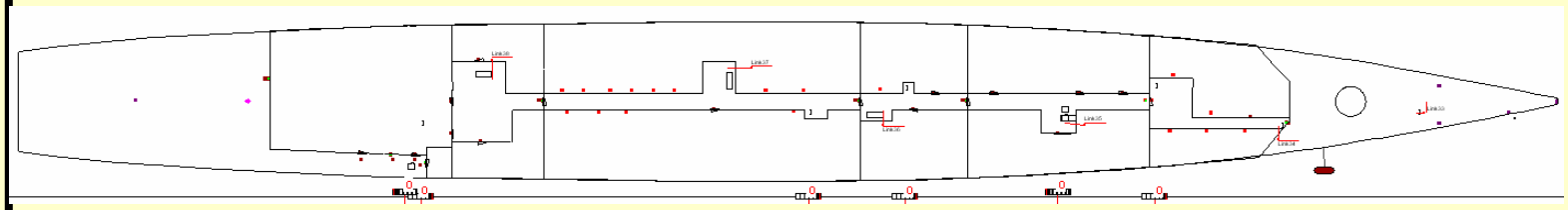
Comparison of Variant 1 No 1 Deck, High, Low and Very Low resolutions



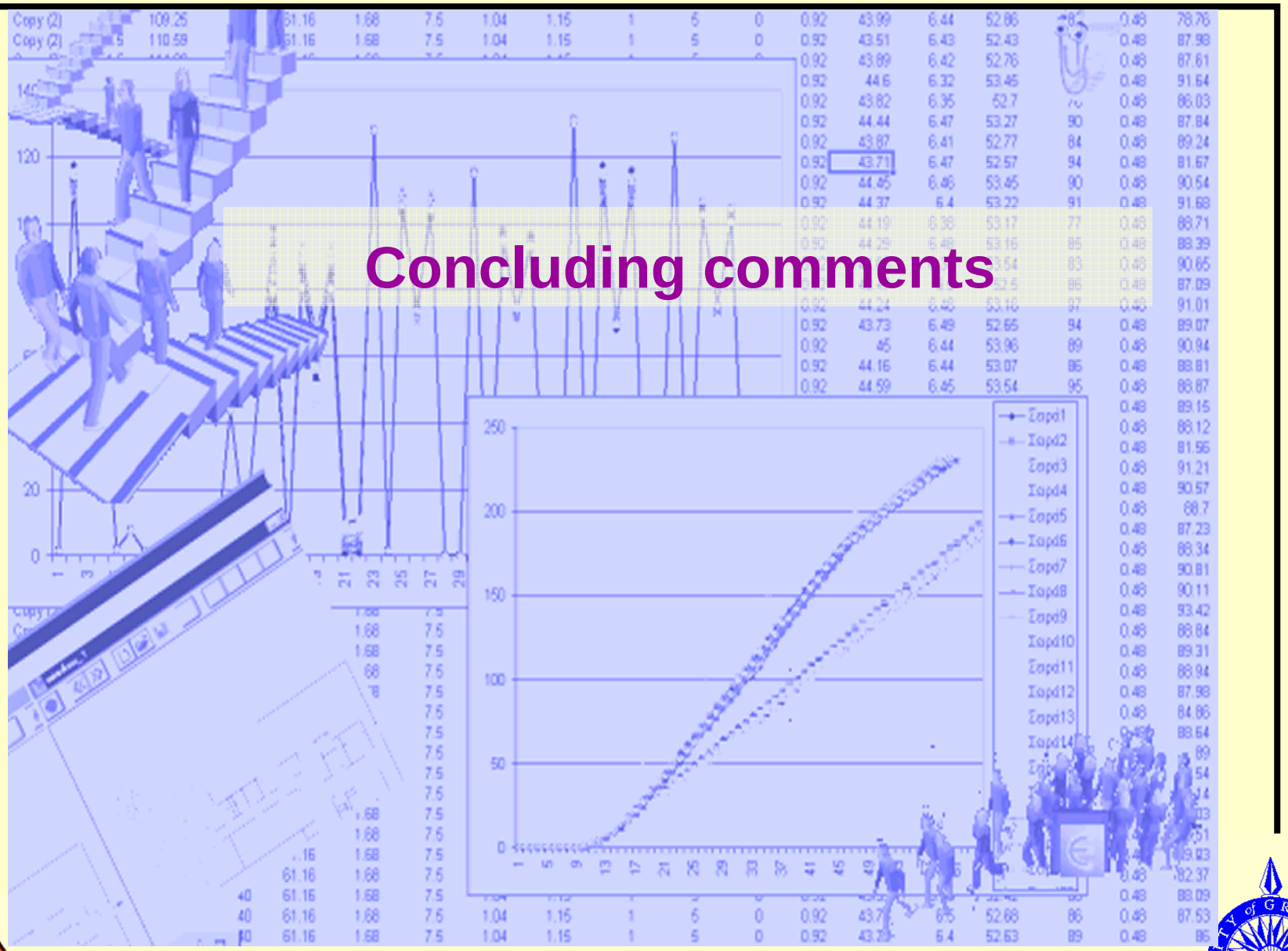
HR



LR



VLR



Concluding comments

Conclusions

- Human Performance Metrics:
  - A comparative tool
  - Use in evaluating vessel performance
  - Use in discriminating between designs
  - Diagnostic for performance improvement
  - Systematic and transparent to user priorities

- HPM can be used by Fleet operators to set design criteria for contractors.

- Fleet operators could define their own “Gold Standard” based on performance of existing front line vessels.
  - Performance of existing vessels would become a defacto standard
  - New build could then be evaluated against the “Gold Standard”
  - Evaluation criteria can be set and measured.
  - E.G.
    - Contractor could be set the task of designing a future surface combatant that outperformed the current Gold Standard by X%.
    - HPM provides a means of:
      - specifying required target performance
      - measuring performance of candidate designs

Conclusions

- HPM will have a direct impact on through life costs
  - Saving for ship operators
  - Improve efficiency of the ship design process
  - Reduce design and build time and cost
  - Achieve safer ship operations
  - Achieve more efficient personnel operations onboard

- Technique is applicable to passenger vessels