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ANALYSIS OF TECHNICAL AND ECONOMIC FEASIBILITY TO IMPLEMENT ELECTRIC PROPULSION IN PASSENGER TRANSPORT VESSELS OF THE BRAZILIAN NAVY: AN APPROACH BY THE AHP METHOD

Sérgio Mitihiro do Nascimento Maêda

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Summary

- Access for students, civil and military servants from the pier of the 1st Naval District to Ilha das Enxadas.
- Numerous daily travel routine = High fuel consumption.
- Technical and economic feasibility of implementing electric propulsion by lithium-ion batteries in new vessels.
- Technical and operational data were collected from these vessels, and commercial proposals were requested from companies in the sector.
- Using the AHP Method
- The feasibility of the project was verified and may serve as a basis in order to promote this technology in other vessels in the different districts of the Brazilian Navy.

Relevance

OPERATIONAL RELIABILITY
Power by cables;
Engine connected directly to the propeller.

COMFORT
Noise level reduction;
Vibrations from the engine.

SOCIO-ENVIRONMENTAL
Emission of gases resulting from burning;
Reduction of lubricant consumption; and

ECONOMIC
Operational cost reduction;
Optimization of public resources.

Introduction

- Economic development of emerging countries – Increased consumption of fossil fuels;
- Social and Environmental Development;
- Investments in new technologies: Increased efficiency in transport logistics;
- Adoption of new practices to replace existing and existing ones;

  - Impact Analysis in the environment where it will be inserted;

  - Attribution of PO in process optimization; and

  - Use of AMD tools to solve complex problems.

Methodological Procedures

- Analysis of vessel design data:

  Structure, Length, Capacity, Installed power, Autonomy...

- Operational data analysis:

  Number of trips made, Service speeds, Average consumption...

- Interview with military personnel responsible for the operation and maintenance of the vessels;
- Evaluation of the technical and economic aspects of the propulsive systems under analysis: Diesel and Electric; and
- Use of the AHP tool in the evaluation of the criteria and alternatives involved.

The CIAW 07 Conopus II and 08 Sirius II vessels, were built in 1981 and have a wooden and fiberglass structure. Daily they make the itinerary of the 1st Naval District x Ilha das Enxadas at a speed that varies between 6 to 7 knots, with an average crossing time of twenty minutes.

- Average consumption of 15 liters of diesel oil - trip;

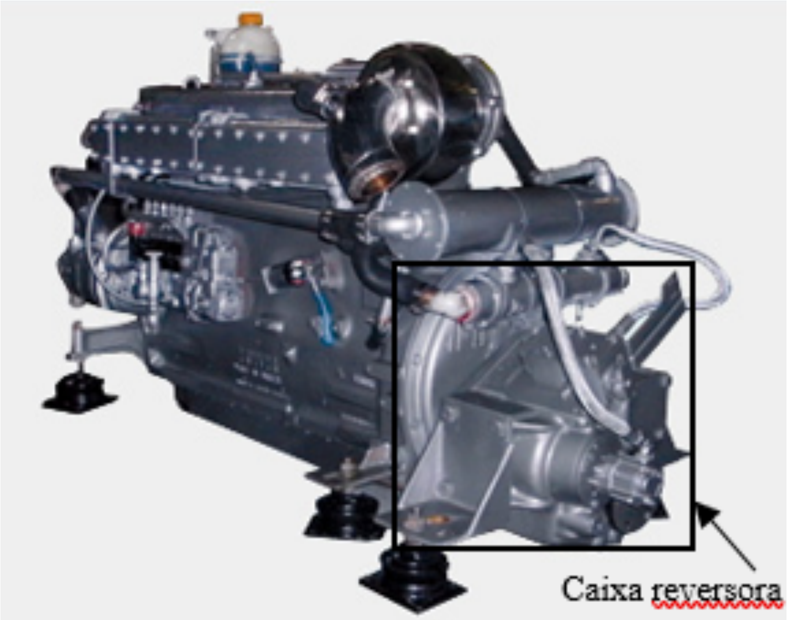
- Dependence on sea, wind, capacity and general conditions of the vessel, such as the availability of engines…

	January	February	March	April	May
03 (RIGEL)	400	*	800	*	867
06 (ORION II)	856	*	544	944	1042
07 (CONOPUS II)	608	1160	951	580	1111
08 (SIRIUS II)	1768	1916	1527	1983	1808
14 (CHUI).	230	811	1119	1338	*
Monthly consumption	3862	3887	4941	4845	4828
Average monthly consumption	4473 liters				

Analysis of installed power capacity:

Conventional diesel propulsion:

2 X MWM 229 6 TD + Twin Disc MG5050 V-Drive acoplada (194 kW @ 2500 rpm).

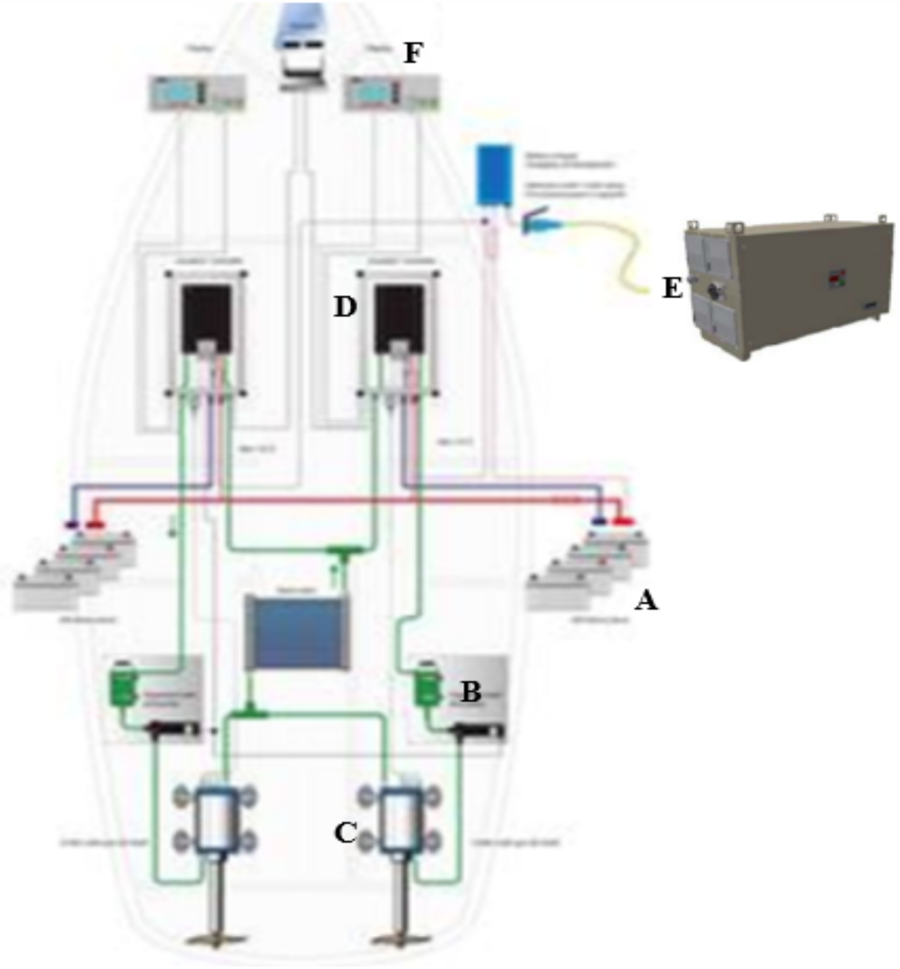


Estimated gross mass of the diesel propulsion system:

- 800 liters of diesel oil. Considering the density of 876.8 kg/m³ @20°C, this volume results in a mass of 701.44 kg
- 1 X MWM 229 6 TD engine = 545kg, which together with the 70kg reversing unit generates a total of 615kg. As each vessel has two units, the set yields a total mass of 1230kg.
- Based on the data presented, it initially has a mass of 1931kg.

The Electric Propulsion System

- Battery bank (A):
- Two converters (CC-AC) (B);
- Two three-phase synchronous motors with coupled reversers (C);
- An engine and battery bank monitoring and management system (D);
- A battery charger for installation on land (E); and
- A display for the operator interface (F).



Estimation of the gross mass of the Electric propulsion system: 1st Law of Thermodynamics

- Average volume of ODM spent on the trip: 15l
- Average ODM density: 876.8kg / m³ @20°C
- Average mass of ODM spent on the trip: 13,152 kg
- ODM calorific value: 12 kWh / kg
- Energy used: 157.8kWh
- Thermal efficiency of the 4-stroke diesel engine: 44%
- Efficiency of three-phase permanent magnet electric motor: 95-98%
- Battery bank energy used per trip: (157.8x0.44) / 0.98 = 70.8kWh
- Considering the energy density of 160Wh / kg, we have: 70.8 / 0.16 = 442.8 kg of battery, this to provide the necessary energy for each trip.
- Each vessel must have 1770kg in its battery banks. Considering that the mass of each electric motor is 195 kg, for this system we would have an estimated mass of 2160 kg.

Economic analysis of the propulsion systems:

In order to measure the base acquisition cost of the propulsion systems, budgets were requested from companies in the sector, taking into account the construction characteristics of the current vessels.

Estimated cost of the diesel propulsion system: R$ 268.500,00

Electric propulsion system cost estimate: R$ 1.135.845,00

* Quote on 06/20/2019: R$ 3.87 for each U $ 1.00

Economic analysis of the propulsion systems:

Average cost / trip:

- Conventional diesel propulsion system:
  15 liters x R$ 4,00* = R$ 60,00

- Electric propulsion system: The estimated cost of kWh / trip is:
  (69.3 kWh for four trips x R$ 1.00**) / 4 = R$ 17,32

* Considering the value of R $ 4.00 for the ODM

** Considering the average value between peak and off-peak hours.

Application of AHP method

Criteria	Diesel Propulsion	Eletric Propulsion
C1 - Cost of Implementation	Low	High
C2 - Cost of Operation	Medium	Low
C3 - Social and Environmental Aspect	Bad	Great
C4 - Gross Mass	Average	High

Preference between criteria					Normalization					Average
	C1	C2	C3	C4		C1	C2	C3	C4	
C1	1	1/3	1/7	5	C1	1/(56/5)	(1/3)/(40/9)	(1/7)/100/63)	5/24	0,11565476
C2	3	1	1/3	9	C2	3/(56/5)	1/(40/9)	(1/3)/ (100/63)	9/24	0,26946429
C3	7	3	1	9	C3	7/(56/5)	3/(40/9)	1/(100/63)	9/24	0,57625
C4	1/5	1/9	1/9	1	C4	(1/5)/(56/5)	(1/9)/(40/9)	(1/9)/(100/63)	1/24	0,03863095
Σ	56/5	40/9	100/63	24	Σ	1	1	1	1	

Application of AHP method

Calculation of the Consistency															
	C_1	C_2	C_3	C_4		Averg (Σ)		Total		Total		Averg (Σ)			$\lambda_{máx}$
C_1	1,00	0,33	0,14	5,00		0,1156		0,481		0,481		0,116		4,159	4,223
C_2	3,00	1,00	0,33	9,00	X	0,2694	=	1,156		1,156	/	0,269	=	4,291	
C3	7,00	3,00	1,00	9,00		0,5762		2,542		2,542		0,576		4,411	
C_4	0,20	0,11	0,11	1,00		0,0386		0,156		0,156		0,039		4,031	

Calculation of the Consistency Index (CI) and the Consistency Ratio (RC)	
$IC = (\lambda_{máx} - n) / (n-1)$	0,074
RC = IC/IA	0,083

For n (number of elements compared) equal to four, the Consistency Ratio (RC) must be less than 0.09

Application of AHP method

Performance of alternatives in the criteria					Criteria Averages				Result
	C_1	C_2	C_3	C_4	C_1	C_2	C_3	C_4	
Diesel	0,8333	0,1666	0,1000	0,7500	0,11565476	0,26946429	0,57625	0,03863095	0,204065
Elétrica	0,1666	0,8333	0,9000	0,2500					0,795935

Final Result:

Diesel propulsion system: **0,204**

Electric propulsion system: **0,796**

Discussion of Results and Conclusion:

- **Base acquisition costs for propulsion systems:**

- Conventional diesel propulsion system: R$ 268.500.00
- Electric propulsion system: R$ 1.135.845.00.

- **Operational costs of propulsion systems (per trip):**

- Conventional diesel propulsion system: R$ 60,00
- Electric propulsion system: R$ 17,32

- **Analysis of the gross mass of the systems (considering the ODM mass for four trips)**

- Conventional diesel propulsion system: 1931 kg
- Electric propulsion system: 2160 kg

- **The total cost of purchasing the electric propulsion system represents about 4 times the cost of the conventional diesel propulsion system**
- **The energy cost of the electric propulsion system represents 0.28% of conventional diesel**
- **The mass of the electric propulsion system is 10% greater than conventional diesel**

sergiomnmaeda@gmail.com

https://www.researchgate.net/
profile/Sergio_Maeda2