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Adapted FMECA for Supporting Maintenance Actions

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Abstract: In a Navy ship the knowledge of the equipment’s and systems state are a pillar and a necessity for operation success. Nowadays equipment’s are monitored with multiple sensors, and data are storage and processed through automatic systems. However, the data is not always useful, and most of the times it is never putted into useful data. The maintenance management in the organization understudy are made based in the maintenance management system and based in the opportunity and attributed missions considering good sense decision of the responsible engineers. The actual systems allow decision based on registered data. With this study, we intend to develop a FMECA risk analysis considering a selection of a navy ship equipment’s. The FMECA methodology will be adapted to include various severity parameters and data from equipment’s condition control. The result of adapted FMECA will give the risk of the equipment operation. For that, considering some maintenance action doesn´t occurred in time, it would be defined some strategies of mitigating the risk. With this methodology, we intend to build a support decision making system for the maintenance management based on risk.

Keywords: FMECA, Maintenance, Decision, Condition control

Introduction

Maintenance is a necessity of current equipment´s and systems in various industrial contexts. In the Portuguese Navy ships represent complex systems with amounts of installed sensors and data produced by the modern mechanical and electronic systems.

To maintained equipment and systems operationality many preventives and sometimes corrective actions may be taken. In the organization there is a strong and well stablished maintenance plan that allows the ships good performance. But there are some procedures that can be enhanced with the objective of optimizing maintenance performance and well cost management.

The motivation of this study is centered on the:

- Environment of scarce resources, human and material for ships maintenance.
- Need to implement a leaner maintenance system.
- Develop a dynamic maintenance support system based in a decision-making software.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

This work are divided in chapters where at first it was made a state of the art in the area of ship maintenance and the methodologies that may be applied to treat data, then it was focus on the Failure Mode, Effects and Critically Analysis, it is also exposed actual organization in surface ships in the Portuguese Navy, then the methodology of monitoring and treat data it is present, follow by the case study with FMECA applied to propulsion diesel engines, and then the results are present and some mitigating strategies are exposed.

Maintenance Management Based on Data

There are some environments, because of timing, economic context, localization of the ships, that does not allow performing some maintenance actions, in that case prioritize maintenance, assuming that not all maintenance can be performed (US Navy, 2015) can be one logic strategy to concretize only what must essentially be do it to maintain a ship navigating with a good level of operationality.

The maintenance that is not performed should be reallocated also according to future prioritization. To implement these strategies, decision trees were used by US Navy (2015), so it is believed that is possible to implement some techniques that it will enhance maintenance management also in Portuguese Navy.

In the naval industry, the Fragility and Criticality (FaC) methodology is used to study the probability of any maintenance being discontinued (Button, 2015; Martin et al., 2017). The criteria from condition monitoring maintenance should be detailed, for example: in flight hours of a helicopter, it should be discriminated the time it flies over sea in a saline environment and the time it flies over land (Tinda et al, 2021). The condition based maintenance should be used in substitution of the maintenance based in functioning time (Tinda et al, 2021).

The factors that influence decisions about maintenance on warships are the need of reduce costs and the difficulties on scheduling maintenance given the availability of shipyards (Blanton, 1997). A qualitative analysis of the life cycle status of surface ships of the United Kingdom Royal Navy (RN) was made to reducing costs in the military (Ford et al., 2015). US Navy surface ships was being modernized considering that it was intended to be implemented a fault prediction system (Lee, 2020). The ship maintenance strategies should be integrated and planned when project and construction is made, if it is so, may be the process of future maintenance intervention will be agile and adaptive (Eckstein, 2020).

To carry out a maintenance planned system on ships three steps were proposed by Cullum et al. (2018): “Risk Assessment-Condition Monitoring and Machine Learning”, “Maintenance Scheduling-Decision Theory” and “Quantify Availability and Overall Maintenance Cost”. Some methodology regarding these three steps may be implemented in the Portuguese Navy. A computerized maintenance management system (CMMS) was proposed to be applied in military ships, considering automation and respective sensors (Dragos et al., 2020). The actions before its implementation:

- ✓ Planning.
- ✓ Software preparation vs control attributes.
- ✓ Process for obtaining the data.

If ships maintain a record of anomalies to prevent the occurrence of similar damages, it will be possible to measure performance of the implemented maintenance and make proposals for improvement (Alhouli, 2011). Certain statistical methodologies can effectively contribute to the implementation of condition based maintenance. Lampreia et al. and Vairinhos et al. (2015) had applied respectively modified control charts and biplots for data analysis.

The Implemented System in the Organization

The Portuguese Navy (Marinha, 1984) has implemented a data collection and processing system since the 1980s, computerized in the 1990s, with software, SICALN, first in an MS-DOS environment, and later in an ORACLE environment. This system is now also being evaluated for possible enhancement and substitution.

In the Data Collection and Treatment System (SRTD), there is no systematic statistical treatment of the collected data, it is only available for consulting. “The life cycle of a ship is defined as the period of time elapsed from its conception to its alienation. (Marinha, 2020) To keep the ships operational, during their life cycle there may be maintenance interventions that can have three stages of maintenance (Marinha, 2020) :

- The 1st stage;
- The 2nd stage;
- The 3rd stage;
- These processes of maintenance and recovery of the operationally of the means are possible through the technical coordination of the various organization members involved.

The Portuguese Navy Maintenance organization inspired in the current normative but adapted to its reality consists in the preventive maintenance and corrective maintenance, the first it is subdivided in the systematic and the conditioned, and the second: the current, eventual, urgent, and very urgent. Sometimes in the corrective maintenance another maintenance “figure” appears, the contingency maintenance, where only the essential corrections are made do accomplished some ship mission.

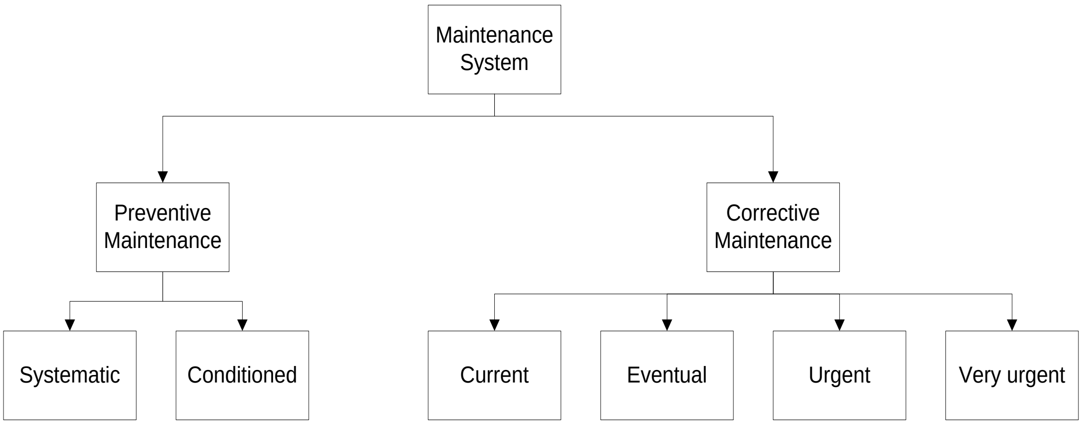

Figure 1. Maintenance organization

The current model maintenance management is considered to have the following general characteristics:

- It is a strong model in Normative and organizational basis.
- It is inflexible.
- The crossing of data is done based on the common sense of the maintenance project managers.

It was a very strong and good maintenance management plan when ship´s Navy came in the seventies and eighties, but nowadays need some upgrade to treat data from equipment´s. It is believed that the actual work may contribute for enhance the maintenance management in surface ships.

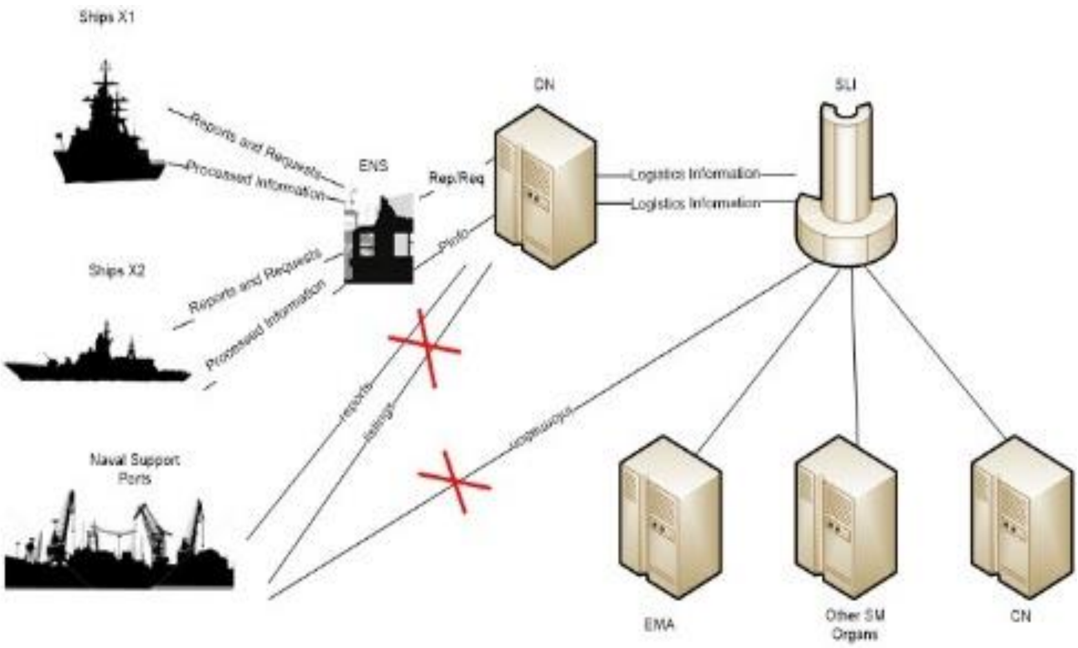

Figure 2. SRTD flux

In the actual SRTD flux, a request or report it is generated in the ships which represents the first level for maintenance in the ship, this procedure is made in the SICALN, then the Administrative Command with its specialist made the first triage and decide if it is a work for the operational workshop or for the Shipyard. If it is not for the operational workshop the work it is forwarded to the Technical Direction, after evaluation the request is sent to the Shipyard.

Methodology

The methodology to proceed to the study begin with the equipment selection for the study, then the sensors selection, the data selection, then the FMEA is applied, then define the levels of FMECA parameters, then decide which control condition parameters will contribute for the results, then calculate the FMECA-CC and if the results are not acceptable it should return to the beginning of the process, if it are the results should be crossed with the results of others equipment's, and then it is decided if we should proceed to a maintenance action or not, if not, the we should monitor the equipment state by continuously observing the results of FMECA-CC, if yes we procced to a maintenance action.

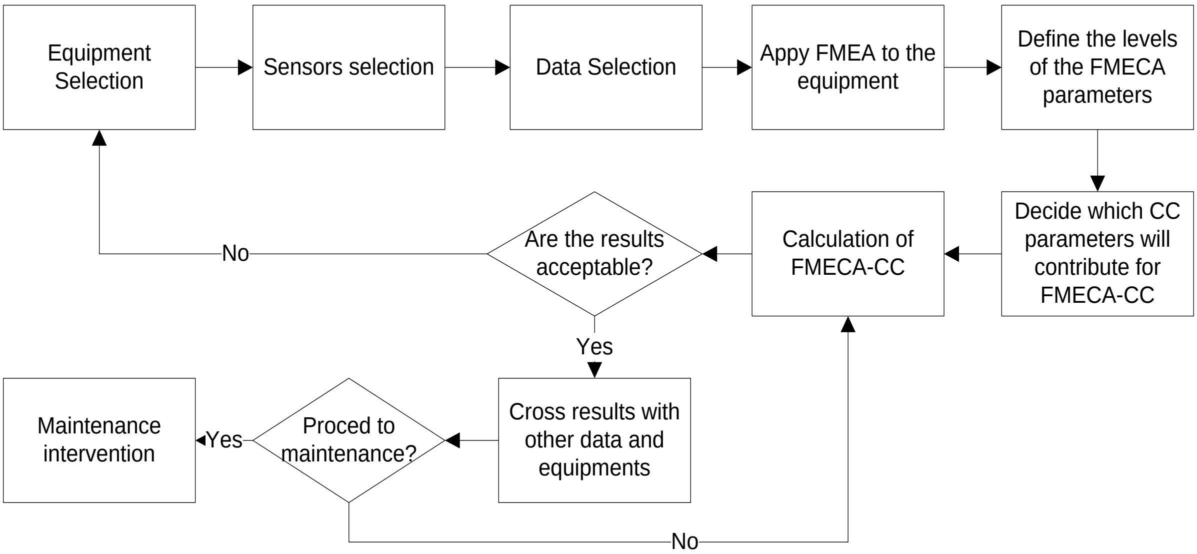

Figure 3. FMECA-CC methodology

Case Study

The maintenance life cycle is defined as the "time elapsed between entry into service and the end of the first interim overhaul, or between the completion dates between two consecutive interim overhauls." (Marinha[i], 2020). The maintenance plan for Portuguese Navy ship under study, is a 5-year cycle, where the first 23 month correspond to an operational state, then a small revision with the duration of 2 months, then another 23 months on an operational state, and finally a period of intermediate revision of 12 months considering docking of 5 months.

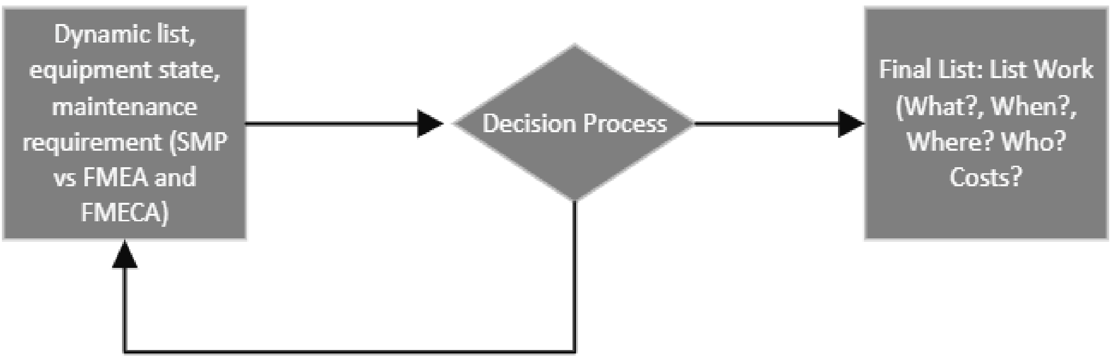

Figure 4. Basis decision process

Basis decision process starts with the equipment and its sensors, Fig. 4, where it should exist a dynamic list which is fed by the equipment's sensors and by the registering of some maintenance action in the SRTD and maybe another systems, based on what the FMEA and FMECA are built.

The equipment´s selected to be exposed in this study are two diesel engines from ship with combined propulsion. The characteristics of the selected diesel engines (Diesel engines 1163 TB83) are:

- 12 cylinders in V;
- 1163 - Engine series, 100 strokes from a cylinders in litters;
- T – Turbocharger engine;
- B – Air cooler, with cooled pistons;
- 8 – Maritime propulsion engine;
- 3 – Project digit;

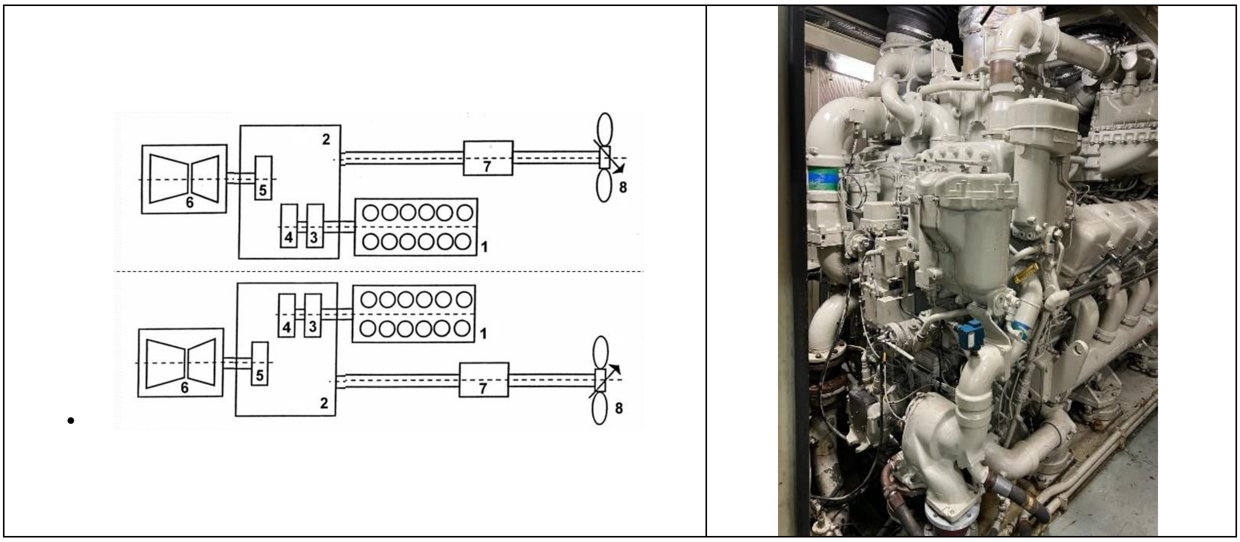

Figure 5. Propulsion system and engines understudy

For risk assessment various methodologies may be used. In the maintenance area Failure Mode and Effect Analysis (FMEA) and Failure Mode, Effects and Critically Analysis (FMECA) may be one of the applicable methodologies. First and before the risk evaluation it was applied a FMEA, Table 1. It was used the data from the existing maintenance plan system, and the aspect, impact and how to detect was developed according to the perception of the authors.

Table 1 – Applying FMEA for risk analysis on propulsion diesel engines.

Man.Act. Motors	Aspect	Impact	How detect
Verify evacuation gas colors, condensations, obstructions, etc	Inadequate gas color	Inadequate fuel mixture/Valves out of tune	Observing gas outsider methodology
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inadequate gas color	Out of calibration injectors/Excessive fuel consumption	Observing gas outsider methodology

Then to calculate the FMECA results it was used equation nr 1. Where the O it's the probability of occurrence, S the severity and D de detection facility.

$$RPN_{DM}=O*S_m*D* \qquad (1)$$

It was considered 5 Severities: Safety, Environmental, Equipment, Personnel, Operational; and for FMECA overhaul calculus the mean of it St=mean(S_S;S_E;S_{eq};S_P;S_O).

Results

On Table 2 we observe the results of FMEA and FMECA. It is to be referred that although the results, the FMEA, data and even the risk evaluation, should be, in the future work, verified using the opinion of other specialist that can attribute some other leve

Table 2. Applying FMECA for risk analysis

Man.Act. Motors	Aspect	Impact	How detect	S_S	S_E	S_{Eq}	S_P	S_O	O	D	FMECA	CCV	CCT	CCP	CCTex	FMECA_CC
Verify evacuation gas colors, condensations, obstructions, etc	Inadequate gas color	Inadequate fuel mixture/Valves out of tune	Observing gas outsider methodology	1	4	5	3	1	1	1	2,8	1	1	3	1	5
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inadequate gas color	Out of calibration injectors/Excessive fuel consumption	Observing gas outsider methodology	1	5	5	5	4	1	1	4	3	2	3	3	10

The scales of St are stated in table 3, where it was considered five levels of severity, security severity, environment severity, equipment severity, severity on people and operational severity.

Table 3. Applying FMEA for risk analysis

Value Atribution	Security Severity (SS)	Environment Severity (SE)	Equipment Severity (SEq)	Severity on People (SP)	Operational Severity (SO)
0,1	No impact	No impact	No impact	No impact	No impact
1	Light impact	Light impact	Light impact	Light impact	Light impact
2	Impact medium severity	Impact medium severity	Equipment operating without security systems	Impact on health	Severe impact
3	Severe impact	Severe impact	Equipment operating in general degraded mode	Impact on health with absence from service	Ship limited
4	Inoperative Ship	Impact on the interior of the ship	Equipment operating in general degraded mode	Permanent health damage	Limop ship at risk of imminent failure
5	Impact on ship safety	Aggravated internal and external impact	Ship INOP_Equipment inoperative without redundancy	Life risk	Inoperative Ship

For the parameterization of the occurrence and detection it was defined 6 levels of value attribution, Table 4.

Table 4. Levels of occurrence and detection

Value Atribution	Ocurrence (O)	Detection (D)
0,1	Occurred more than 10 years ago	Easy detection
1	It occurred between 5 and 10 years ago	Detection difficulty medium low
2	Occurred less than 5 years ago	Medium difficulty detection
3	Occurred less than 1 year ago	Detection difficulty medium high
4	Occurred less than 6 months ago	Deteção dificuldade extremamente alta
5	Permanently	Not detectable (Till something goes wrong)

For the FMECA-CC it was considered various scales for condition control: CC-CCV for vibration (Root mean Square (RMS) values; CCT for thermography and CCTex where the text from SRTD is considered for respective equipment, Table 5.

Table 5. CC cathegorization

Value Atribution	Vibration (CCV)	Termography (CCT)	Operating Parameters (Temperatures or Pressures) (CCP)	Detection Text about engine and corrective maintenance
1	Low level	Low level (no difference)	Low level	No occurrence in the last 5 years
2	Low medium level	Low medium level (1º - 4ºC difference from normal)	Low medium level	Occurred once in the last 5 years
3	Middle level	Average level (4º - 15ºC difference from normal)	Middle level	Occurred between 2 and 5 times in the last 5 years
4	High middle level	Medium high level (difference 15ºC and maintains)	High middle level	Occurred 5 to 10 times in the last 5 years
5	High level	High level (difference >15ºC from normal) star_border	High level	Occurred more than 10 times in the last 5 years

FMECA vs FMECA-CC

Comparing the results of traditional FMECA and FMECA-CC it was verified a higher sensibility of FMECA-CC, Table 6, where the data from equipment condition control are used. So condition control data will allow an adjustment of the results of the originally FMECA.

Table 6. Comparing traditional FMECA and FMECA-CC

Diesel Propulsion Engines – Maintenance activity	Aspect	Impact	How detect	FMECA	FMECA_CC
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inappropri ate gas color	Inadequate fuel mixture/Valves out of tune	Method of observing gases abroad	2,8	5
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inappropri ate gas color	Out of calibration injectors/Excessiv e fuel consumption	Method of observing gases abroad	4	10
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inappropri ate gas color	Fuel carryover/fire risk	Method of observing gases abroad	4	7
While sailing, check the color of the exhaust gases, condensation, obstructions, etc.	Inappropri ate gas color	Lack of rim seal/lubrication oil carryover/fire risk	Method of observing gases abroad	4	6

Also, the study in others equipment´s may be considered for implementing FMECA-CC, equipment´s like Air Compressor & Oil and Marine Gasoil Centrifugal purifier. If the knowledge of overall equipment´s is a reality, may the decision be to proceed to parallel maintenance during maintenance to main engines. If decision is to proceed to an intervention in the diesel engine, and if the risk in the compressor is high and it can be done during the engine maintenance. The same for centrifugal purifier or other equipment´s.

Although the obtained results, not only the equipment's state, but also the opportunity to proceed to a maintenance in the operational period of the ship and the material and personal resources are important and to be accounted in the maintenance process. Strategies for mitigating the calculated risk may be when some anomaly is detected and there is no possibility of intervention, the equipment's monitor should be more frequent and some minor maintenance intervention (contingency), without put the equipment out of service, may be made.

Conclusions and Future Work

In an environment of scarce material and human resources a dynamic maintenance management may be a solution for optimize the resources. Before implementing a dynamic maintenance management system, the previous data and implemented processes were analyzed. FMEA and FMECA may be a base for a maintenance decision support system applied to equipment system plan.

The registered information considered for the decision support system applying an FMECA-CC are: equipment´s maintenance system plan, the condition control data (Vibrations/thermography/parameters/data-text registered-DSM58). Application of dynamic work lists may lead to maintenance optimization and consequently reducing cost in material and personnel.

For future work the FMECA must be validated on job, Finish the data analysis using the risk analysis methodology, finish the FMECA analysis and integrate other related equipment´s and choose the best methodology for the presented data.

Scientific Ethics Declaration

* The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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