Enhanced Ships Operation using Integrated Automation Systems

Ioannis Dagkinis[1]*

Panagiotis M. Psomas[2]

Agapios N. Platis[2]

[1]Department of Shipping Trade and Transport,
University of the Aegean, Korai 2a,
Chios, Greece
[2]Department of Financial and Management Engineering,
University of the Aegean, Kountouriotou 41,
Chios, Greece

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Abstract

Global shipping for becoming sustainable will have to organize the ships and each field of shipping industry, in accordance efficient management and operation principles. This will require the adoption of new techniques and the transformation of companies, their ships, systems, and management practices. A modern automation and control system is a fully integrated system covering many aspects of the ship operation. Whether for cargo, passenger or special-purpose ships, Integrated Automation Systems meets every requirement in shipping and offers decisive advantages over the entire "life" of a ship. The adaptation can suit perfectly to the special requirements in shipping and creates the prerequisites for maximum economy, reliability, and safety on board. Integrated Automation includes the propulsion plant operation, power management operation on the auxiliary engines, auxiliary machinery operation, cargo loading and unloading operation, navigation and administration of maintenance and purchasing of spares. The study focuses on implementation of IAS and its contribution in ship's performance and safety. The proposed model incorporates different failure rates for the different sensors of the Integrated Automation system as well as repair actions that need to be performed. The system can experience various levels of deterioration and when a failure occurs, a repair procedure is carried out and the system is restored to its initial fully operational state. A numerical example based on the empirical data is used to illustrate the proposed model.

Keywords: *Integrated Systems, vessel monitoring, Ship automation, Markov Chains, Availability, Safety*

1. Introduction

The composition of a comprehensive shipping lane of the future includes ambitious plans to develop, fine-tune and implement progressive policies in core areas of sustainable performance such as environmental, social, and economic.

Global shipping for becoming sustainable will have to organize the ships and each field of shipping industry, in respect with efficient management and operation principles (Kågeson, 2011) (Kagkarakis, et al., 2016). This will require the adoption of new techniques and the transformation of companies, their ships, systems, and management practices. In total, the qualitative operation of ships will simultaneously focus on wide and deep developments as:

- Effectiveness, which represents Logistics and networks, by optimize networks, capacity, and speed.

- Efficiency, with optimization of vessels operation (e.g., performance monitoring, economical speed, etc)
- Competence and awareness
- Technologies, in components and systems
- Contracts and collaborations, which represent Newbuilding contracts, charter parties, innovation with suppliers etc.

For operational optimization the selection of marine equipment and enhance of marine systems should focus on factors as low energy consumption, low pollution, and high efficiency. For example, in evaluation of technical index of ships, a strong emphasis should be laid on the rationality of load factor of main engine, generator, boiler and air condition system, etc. and effective control of harmful emissions, vibration and noise. Also, the full ship control can be accessed from the bridge location for propulsion as well as for auxiliary plants, giving the master the full picture. Another benefit is the increased safety, especially regarding fire / smoke / heat detection due to the use of sensor units and the provision of displays with access to full ship data on the bridge.

Hence, in a ship many parameters should be controlled or monitored (Aiello et al., 2020). These parameters include the navigation control equipment on bridge, the speed and position of vessel, the cargo equipment, and the cargo spaces at loading, unloading or in transfer period. Furthermore, in the engine room various temperatures, pressures, levels in tanks, viscosity of fuels, flow control, speed, torque control, voltage, current, machinery status, and equipment status.

On the other hand, as the market is driving ship owners to become more efficient, as well as the reduced staff on board, create the need for monitoring systems and automated control on the ship (Miller et al., 2021). These automation systems enable the ship operation capability to be carried out with minimal involvement of crew members and the opportunity of unattended operation of machinery spaces.

The International Maritime Organization (IMO), responsible for standardized regulations covering all aspects of marine safety, has special classifications for providing information on whether the hull and technical equipment of a ship are perfectly seaworthy in all respects. These strict international guidelines refer to the construction and running of a ship – but also to its maintenance and the conditions that must be met. Against this background the reliability of all systems onboard is gaining in importance and makes it easy to see why intelligent automation solutions, are indispensable aboard modern ships.

A modern automation and control system is a fully integrated system covering many aspects of the ship operation. Whether for cargo, passenger or special-purpose ships, Integrated Automation Systems meet every requirement in shipping and offer decisive advantages over the entire life of a ship. The adaptation can suit perfectly to the special requirements in shipping and creates the prerequisites for maximum economy, reliability, and safety on board. Integrated Automation includes the monitoring and control; propulsion plant operation, power management operation on the auxiliary engines, auxiliary machinery operation, cargo loading and unloading operation, navigation and administration of maintenance and purchasing of spares.

Another reason to adopt the Integrated Automation System (IAS) is based in the cost-effectiveness of a ship and is the top priority for ship-owners to the enormous pressure of global competition. Therefore, it is necessary to consider not only the net cost of acquisition, but the total cost of ownership in overall operational lifetime. Thus, the benefits for ship-owners from the Integrated Automation system must form the basis for the following:

- Space-saving and cost-effective automation solutions from a single source perfectly tailored to their individual requirements
- Uniform and reliable automation solutions for whole ship
- Products and systems with low intrinsic weight and modest space requirements
- Efficient remote diagnostics system with which downtimes can be minimized and maintenance work properly planned
- Low training costs

Generally, automation systems of ships allow in individual and remotely diverse components to integrate and automatically interact and be implemented so that minor equipment and plants such fuel, seawater cooling system and HAVC, can be monitored and controlled remotely.

This paper presents the evaluation of the availability through the implementation of IAS by using different deterioration levels. The study refers to the different engine sensors such as exhaust gas temperature, engine pickup, and fuel supply. These sensors are critical components of monitoring system, and their operational condition is examined.

The reminder of the paper is organized as follows: in section 2 the IACS is described in detail. In section 3 the asymptotic availability for the IACS is defined. An illustrative case is presented in section 4 and conclusions are presented in section 5.

2. Description of the Proposed Model for the Integrated Automation System

The operating conditions of the machinery on a ship should be constantly monitored (Kandemir & Celik 2020). This should be done not only to present the operating conditions to the crew, but also to inform them for machinery condition and the occurrence of abnormalities. The correct monitoring maintains the safety of the equipment's and prevents an unexpected interruption of ship operations (Logan, 2003).

For this reason, sensors are installed, measure parameters and transmit the values to IAS, in order to control the operating condition of each machine. These indications when exceeds predefined values, an alarm is activated or even interrupted the machine operation.

In this category, of control sensors, are the sensors of the main engine, which must be maintained in order to maintain their efficiency (Carlucci et al., 2008) (Basurko & Uriondo, 2015).

In accordance the criticality of some functions such as that of main engine and the specificity of the operating conditions in the engine room where the sensors installed, this article examines the exhaust temperature control sensor, the speed sensor, and the fuel supply sensor where of the main engine. The malfunction of each one of those sensors may lead to operating system degradation conditions or even be the cause many hours downtime interruption due failures in major engine parts.

An Integrated Automation System is considered, consisting of three different sensors. It is assumed that the condition of the system can be classified in one of the following categories such as: perfect operational state, three different deterioration levels D_1, D_2, D_3 and complete failure, as can be seen in Figure 1. At the failure state, a repair procedure is carried out and the system returns to the perfect operational state. Apart from the perfect operational state and the failure state, the IAS can be in one of the abovementioned degraded conditions due to deterioration. By assuming that the sojourn time in any state follows an exponential distribution, the system's evolution in time can be modelled by a continuous time Markov process $\{X(t), t\geq 0\}$ [Ross, 1996].

The proposed model is based on the following assumptions. As we assumed above the states of the model that the Integrated Automation System can experience three different deterioration levels (D_1, D_2, D_3) can be seen in Fig. 1. Initially, the system is in its fully operational state *O*. We assume that the system can transit in the first deteriorating state D_1 with rate λ_1. However, due to the fact that the sensors of the system can degrade more than one at the same time the Integrated Automation System can transit from the perfect functioning state to the second degraded state D_2 with rate λ_2, or even more the system reaches the third deterioration state D_3 with rate λ_3. Finally, the system can transit from the states *O*, D_1, D_2, D_3 to the failure state *F*, with rates λ_{F1}, λ_{F2}, λ_{F3} and λ_{F4} respectively, where in this case the system can experience a total failure while being either in the perfect functioning state, or in any other degraded state.

On the other hand, a repair action can be carried out when is in state D_1 and the system is restored to the previous operational state *O*, with rate μ_1. The same happens for the other two degraded state D_2, and D_3, where the system can be repaired and returns to the previous operational state *O* with rates μ_2 and μ_3 respectively. Furthermore, a repair action is performed, when the system is in the failure state *F*, and the Integrated Automation System is restored to the fully operational state *O* with rate μ_F.

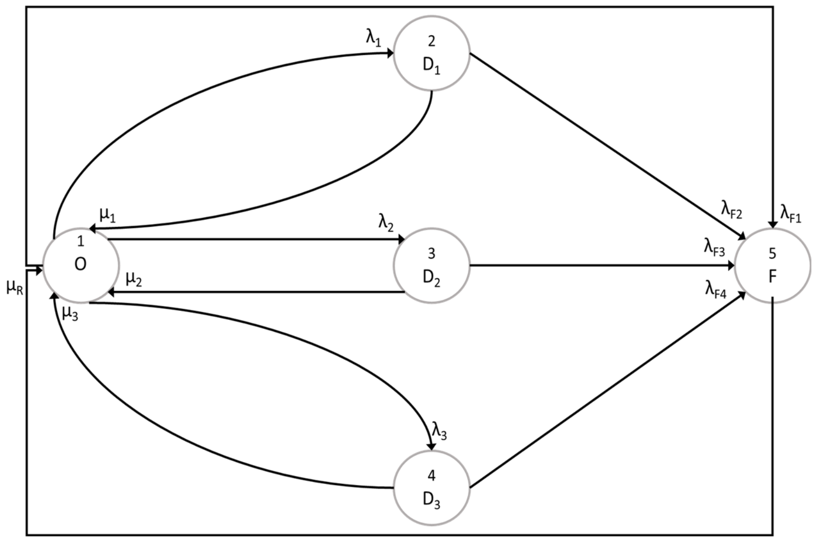

Figure 1: State transition diagram for the deterioration Integrated Automation System

3. Asymptotic Availability

Availability is considered as a dependability measure which provides the probability of the system to be in an operational state at time t: *Av*(*t*)=Pr(system is functioning at instant *t*) (Trivedi et al. 2017).

Let *E* be the state space of the Markov process $\{X(t),\ t \geq 0\}$. The state space of the proposed model can be partitioned into two subsets: subset *U* containing the operational states and subset *D* containing the non-operational ones with $E = U \cup D$, $U \cap D = \emptyset$, $U \neq \emptyset$, $D \neq \emptyset$. Note that the subset *D* contains the states where both systems are failed, the maintenance states and the states with low wind intensity. The rest of the two systems states are considered as operational. Therefore, the availability of the each of the systems at time t can be defined by the following Eq. 1:

$$Av(t) = \Pr(X(t) \in U) = \sum_{i \in U} P_i(t) \quad (1)$$

where $P_i(t)$ is the probability of the system to be in state (*i*) at time *t*.

The asymptotic availability can be computed by the following Eq. (2):

$$Av(\infty) = \lim_{t \to \infty} \sum_{i \in U} p_i(t) = \sum_{i \in U} \pi_i \quad (2)$$

where π_i, is the asymptotic probabilities of the system in state *i*.

According, to Fig. 1, subset *U* can be written as *U* = {1, 2, 3, 4}. Integrated automation system's availability can be then computed by the above Eq. (3) as follows:

$$Av = \pi_1 + \pi_2 + \pi_3 + \pi_4 \quad (3)$$

4. Case Study: Experimental Results and Analysis

In order to numerically illustrated the theoretical results presented analytically in the previous sections, given the appropriate deterioration, failure and repair parameters for the above-mentioned system, the introduced model can be used to evaluate the availability. Table 1 summarizes the values of the model parameters.

Table 1. Summary of the model parameters [y^{-1}]

λ_1 =8.13	λ_{F3} =12.048	μ_R=876.42
λ_2 =4	λ_{F4}=185.185	
λ_3 =6	μ_1=11682	
λ_{F1}=0.33	μ_2 =2923	
λ_{F2} =37.03	μ_3 =8760	

According to the above parameters used in our model and the method described in Section 2, the availability (*Av*) of the Integrated Automation System is 0.9994. It is also interesting how the choice of input parameters can affect the availability of the system. An interesting observation from the numerical evaluation of the proposed model is that when no repair action will be applied to the degraded states detected by sensors or the degraded of the sensor itself. In this case, the alarm can be set out of scan by the engineer of the ship and the engine can continue its operation under degraded state till the total failure state. This operational status could lead to large-scale and costly repairs, since the operating process continues and may endanger a major component of the machine. Thus, the repair rates are set equal to zero and the availability in this case is 0.9869.

Having computed the availability for the studied system for the two different cases, it would be better for the Integrated Automation System, a repair action to be performed in order to be more reliable.

5. Conclusions

The extensive Integrated Automation Systems (IAS) as produced from giant electronic companies include functionalities for advanced automatic monitoring and control of both efficiency and operational performance. The systems integrate all vessel monitoring parameters and control all processes onboard, as to operate the vessel at the lowest cost and best fuel performance. The requirements for factors such as maximum economy with exploitation of any possible potential for optimization, reliability based on availability of all on-board systems which is of crucial importance, and safety on board as a paramount importance on the open sea, permit to the crew through IAS to be fully aware of what is happening on the ship at all times. Thus, the administration by integrated monitoring, alarm and control system provides protection to passengers, the environment, the ship's equipment and its cargo, and sustainable benefits to ship owners, and shipping operators.

In this paper, an Integrated Automation System consisting of different sensors is studied. In terms of modelling, we introduced a scenario of performing repair or not on the different sensors. Furthermore, the methodology of how to evaluate the availability under the aforementioned assumptions is studied.

For the proposed model, we provided the appropriate theoretical framework to calculate the availability of the two cases. The corresponding solutions can be used for planning a repair strategy on the three sensors that would improve the Integrated Automation System's availability. The innovation of this work consists in providing a model for degrading automation systems with repair and sudden failures.

In the future, we intend to extend our work by developing an Integrated Automation System with more sensors where each state experiencing deterioration in more levels. Furthermore, for the proposed model additional actions can be performed such as maintenance actions that would improve even more the reliability of the system.

References

Aiello, G., Giallanza, A., Vacante, S., Fasoli, S., & Mascarella, G. (2020). Propulsion monitoring system for digitized ship management: Preliminary results from a case study. *Procedia manufacturing*, 42, 16-23.

Basurko, O. C., & Uriondo, Z. (2015). Condition-based maintenance for medium speed diesel engines used in vessels in operation. *Applied Thermal Engineering*, 80, 404-412.

Carlucci, A. P., de Risi, A. D., Laforgia, D., & Naccarato, F. (2008). Experimental investigation and combustion analysis of a direct injection dual-fuel diesel–natural gas engine. *Energy*, 33(2), 256-263.

Kågeson, P. (2011). Applying the principle of common but differentiated responsibility to the mitigation of greenhouse gases from international shipping.

Kagkarakis, N. D., Merikas, A. G., & Merika, A. (2016). Modelling and forecasting the demolition market in shipping. *Maritime Policy & Management*, 43(8), 1021-1035.

Kandemir, C., & Celik, M. (2020). A human reliability assessment of marine auxiliary machinery maintenance operations under ship PMS and maintenance 4.0 concepts. *Cognition, Technology & Work*, 22(3), 473-487.

Logan, K. P. (2003, March). Prognostic software agents for machinery health monitoring. *In Proceedings of the IEEE Aerospace Conference* (Vol. 7, pp. 3213-3225).

Miller, A., Rybczak, M., & Rak, A. (2021). Towards the autonomy: Control systems for the ship in confined and open waters. *Sensors*, 21(7), 2286.

S. M. Ross: Stochastic Processes, 2nd ed. Hoboken, NJ:Wiley, (1996).

Trivedi, Kishor S., Andrea Bobbio. 2017. *Reliability and Availability Engineering: Modeling, Analysis, and Applications*. Cambridge: Cambridge University Press.