Optimal Maintenance Strategies for an Industrial Scrubber System

Industrial scrubber systems are used on large ships to clean their exhaust gas from sulfur oxide. Scrubber maintenance can be optimized to reduce its costs. Due to the complexity of the system and its maintenance, a model is made to help determine the optimal maintenance strategy regarding the costs. The model checking tools PRISM and Storm were used to analyze the model. Insights were gained on the construction and behavior of such a model and thereby on the optimal maintenance strategy regarding the costs.

Introduction

This project was performed within the Automation Development team at Alfa Laval Nijmegen B.V. This company develops the scrubber systems for large seagoing vessels and strives to improve their Data Driven services available for their scrubber systems.

The international maritime organization (IMO) has set limits for the sulfur oxide levels of the exhaust gas emitted from ships. As also shown in Figure 1, to comply with these regulations, ships must either use compliant fuel or use a scrubber system that cleans the exhaust gas. When using the latter, it may occur that the system fails and either maintenance needs to be performed or the vessel needs to switch to compliant fuel. When neither of these can be done, the vessel is charged with a fine for being out of compliance. Each of these options is very expensive, so it is important to know which course of action is least expensive.

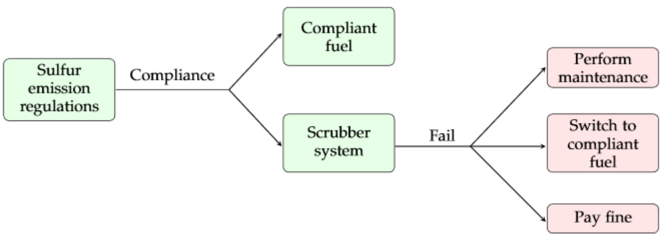

Figure 1. Options for compliance to the sulfur emission regulations.

To minimize maintenance costs of a scrubber system, it is helpful to have a mathematical model that computes the optimal maintenance strategy. To support Alfa Laval with constructing such a model, the following question was answered:

How can a mathematical model be used to determine the optimal maintenance strategy for a scrubber system with respect to the costs if fed with complete data?

The data required to model realistic situations was not available. Therefore, this project focused on the structure of the model and obtaining insights from it on the optimal maintenance strategy by considering varying situations.

The scrubber system

The components of the scrubber system that were considered in this project are pumps and sprayer layers. The pumps pump water through the system towards the sprayer layers in the jet and absorber section. These layers spray the water onto the exhaust gas to clean it. The cleaned gas is then let out into the air and the water is let back into the sea or reused in the system. Sensors measure the gas and water to check if values such as pH and turbidity are within the permitted ranges.

Construction of the model

Scrubber maintenance is closely related to the degradation of its components. A stochastic model is required to model this. Furthermore, actions such as performing maintenance, sailing, switching to compliant fuel and paying a fine must be modeled. Moreover, every action is associated with a certain cost. Based on these requirements, a Markov decision process was chosen to model the scrubber maintenance. States in the model represent the possible health conditions of the system.

The conditions of the components are indicated by *good*, *faulty* and *failed* (in Figure 2 indicated by resp. 0, 1 and 2). A schematic view of the model for one pump is shown in Figure 2 with transition probabilities q_0, q_1, q_2. Each arrow represents an action taken from a state. Choosing action Sail has a probability of moving to a worse condition, which models that a component can break down over time. The models for the separate components are combined into a model for the whole system.

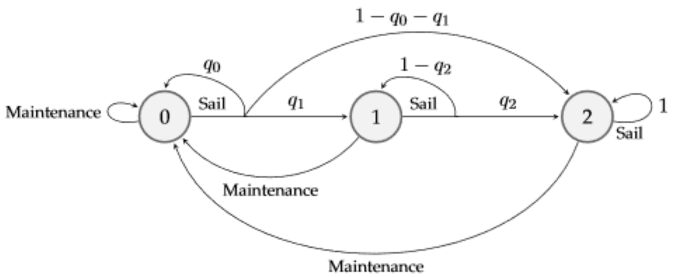

Figure 2. Model for one pump of the scrubber system.

Due to the complexity of the scrubber system, the model can have millions of states and transitions. Therefore, the model checking tools PRISM and Storm were used to compute the minimum expected costs and optimal maintenance strategy for various situations.

Results and observations

The results presented here are for a ship halfway on its trip. Both look at the two sprayer layers of the jet section and show which action(s) to take according to the optimal maintenance strategy. The first key result was that maintenance on sprayer layers is only performed when a layer has failed. This can be seen from the results in Table 1. Two situations were considered: 1) both sprayer layers are in faulty condition with a probability of 0.99 of moving to the failed condition, and 2) one of the sprayer layers is in the faulty condition and the other is in the failed condition. Maintenance during the trip on layer 2 of the jet section (MDT_{j2}) is only performed in situation (2).

Table 1. Optimal action(s) during a trip for the jet section.

Jet layer1		Jet layer2		Action(s)
cond. jet1	*Prob*$(1 \to 2)$	cond. jet2	*Prob*$(1 \to 2)$	
1	0.99	1	0.99	Sail
1	0.99	2		$MDT_{j2} \to$ Sail

A second key result is that when maintenance during the trip is not possible, for example if the necessary components are not in stock, switching to compliant fuel is chosen over paying a fine. This is shown in Table 2. Just as in the previous result, this only occurs when at least one component has failed. The action *FailSail* indicates that the ship is sailing to the next port with a broken scrubber.

Table 2. Optimal action(s) during a trip for the jet section when maintenance during the trip is not possible.

Jet layer1		Jet layer2		Action(s)
cond. jet1	*Prob*$(1 \to 2)$	cond. jet2	*Prob*$(1 \to 2)$	
1	0.99	1	0.99	Sail
1	0.99	2		FS $\to$ FailSail $\to$ MNP_{j2}

Conclusion

The main conclusions of this project are summarized as follows:

- Maintenance on sprayer layers is only optimal when the layers are broken,
- Switching to compliant fuel is chosen over paying a fine,
- For the pump section it was shown for which probabilities the optimal maintenance strategy changes,
- Costs are significantly lower when maintenance is performed at the right moment as indicated by the optimal maintenance strategy.

Overall, this project showed an approach to building a model for scrubber maintenance. Furthermore, even without data, it showed interesting results regarding the optimal maintenance strategy with respect to the costs.

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