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Reducing fatigue damage for ships in transit through structured decision making

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ABSTRACT

Research in structural monitoring has focused primarily on drawing inference about the health of a structure from the structure's response to ambient or applied excitation. Knowledge of the current state can then be used to predict structural integrity at a future time and, in principle, allows one to take action to improve safety, minimize ownership costs, and/or increase the operating envelope. While much time and effort has been devoted toward data collection and system identification, research to-date has largely avoided the question of how to choose an optimal maintenance plan. This work describes a structured decision making (SDM) process for taking available information (loading data, model output, etc.) and producing a plan of action for maintaining the structure. SDM allows the practitioner to specify his/her objectives and then solves for the decision that is optimal in the sense that it maximizes those objectives. To demonstrate, we consider the problem of a Naval vessel transiting a fixed distance in varying sea-state conditions. The physics of this problem are such that minimizing transit time increases the probability of fatigue failure in the structural supports. It is shown how SDM produces the optimal trip plan in the sense that it minimizes both

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transit time and probability of failure in the manner of our choosing (i.e., through a user-defined cost function). The example illustrates the benefit of SDM over heuristic approaches to maintaining the vessel.

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1. Introduction

Research in the structural health monitoring (SHM) field has focused primarily on the identification of the state of the structure using ambient or applied vibrations. While estimates of structural integrity are necessary, they do not by themselves achieve the goals of SHM. Consider, for a moment, three classes of objective for which one may want an automated SHM system:

1. Improve safety
2. Reduce maintenance costs
3. Increase operational envelope

In all three the desired system output is a decision. A system designed to improve safety is required to decide whether or not a given structure is considered safe. Reducing maintenance costs requires decisions be made on the part of the maintainer on how to balance usage with the inevitable degradation. Increasing the envelope of operation (e.g., telling a vessel operator he/she can go faster) involves a decision about how much risk one is willing to accept vs. the performance gains associated with pushing the bounds of safe usage. A prospective SHM system should be capable of using available information to produce optimal decisions about maintenance and usage.

In this work, we consider structured decision making (SDM) in the context of a ship transit problem. The goal will be to balance timely completion of the journey with the associated structural degradation. This particular problem has received attention in both military and commercial shipping. To-date, researchers have largely defined their role as to provide information about the current damage state, and perhaps projections of the future damage state, to a decision-maker. A recent paper by Clauss et al. nicely integrates the components required of "decision support" for a ship transit problem [1]. Specifically they predict both wave and corresponding ship motion and present the information to an operator. Other works are similarly devoted to decision support whereby the information relevant to ship transit decision making is provided the end user ([2–5]). In some cases, the system may even provide the decision-maker a set of possible actions he/she might take (see e.g., [6] in the context of "fire control").

The role of the system currently ends here and it is implicitly assumed that the decision-maker has access to the relevant information and then uses his/her intuition to make smart decisions. Presumably this intuition includes the rough outlines of a cost–benefit analysis. This "heuristic" approach is unsatisfying for at least two reasons. First, there is no objective algorithm by which structural models and associated parameter estimates are translated into decisions. Instead decisions are made subjectively and are neither repeatable nor transparent. Second, such decisions are extremely unlikely to be optimal for any but the simplest problems.

Our goal here is therefore to take the problem one step further and use all available information to produce the optimal course of action for the operator to take. As we will show, the mathematics of decision making can be formalized using many of the tools and algorithms developed already for other purposes. All that is required is a conceptual framework for (1) describing our space of possible decisions mathematically; (2) providing a formal definition of what we want in a "good" decision; and (3) providing a means of optimizing over our space of possibilities to find the best decision. Approaches that produce an actual decision or maintenance plan as the output are few. A notable exception is the recent work of Huynh et al. [7] where the authors developed an approach that produces an optimal maintenance plan for monitoring a system degraded by fatigue cracks. An important feature of [7] is that it is dynamic in the sense that it incorporates newly available information in the decision-making process. We too view this as an essential