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Towards Dynamic Criticality-Based Maintenance Strategy for Industrial Assets

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Abstract: An asset's risk is a useful indicator for determining optimal time of repair/replacement for assets in order to yield minimal operational cost of maintenance. For a successful asset management practice, asset-intensive organisations must understand the risk profile associated with their asset portfolio and how this will change over time. Unfortunately, in many risk-based asset management approaches, the only thing that is known to change in the risk profile of the asset is the likelihood (or probability) of failure. The criticality (or consequences of failure) of asset is assumed to be fixed and has considered as more or less a static quantity that is not updated with sufficient frequency as the operating environment changes. This paper proposes a dynamic criticality-based maintenance approach where asset criticality is modeled as a dynamic quantity and changes in asset's criticality is used to optimize maintenance plans (e.g. determining the optimal repair time/replacement age for an asset over it life cycle period) to have a better risk management and cost savings. An illustrative example is used to demonstrate the effect of implementing dynamic criticality in determining the optimal time of repair for a bridge infrastructure. It is shown that capturing changes in the criticality of the bridge over time and using this understanding in the risk analysis of the bridge provided the opportunity for better maintenance planning resulting to reduction of the total risk.

Keywords: Dynamic criticality; asset management; asset risk profile; replacement age; maintenance plan.

1. INTRODUCTION

Many European and North American countries undertook an enormous investment in construction of infrastructures such as highway networks in the second half of the 20th century, most of which are either completed or near completion. As a result, the need in funding changed from building new structures to repair, rehabilitation, and replacement of the existing ones (Neves & Frangopol 2005). Given that funds and maintenance resources are scarce and ever decreasing, there is need for appropriate techniques to maintain adequate level of safety and serviceability in infrastructure assets while minimising the total expected life-cycle cost. Decision makers are faced with the challenge to decide when and how to repair, rehabilitate, replace and/or shutdown the deteriorating facilities (Kong & Frangopol 2003).

Infrastructure assets will require effective cost evaluation methods to assess reasonable expenditures allocated for their life-cycle cost management. It is very important to optimise investment for management of any such infrastructure asset over its lifetime. In order to achieve this, it is crucial for the organisation to have good knowledge and understanding of the risk profile associated with their asset portfolio and how this changes over time. Unfortunately, traditional methods of modelling and simulating lifecycle performance for infrastructure management, including bridge management systems, commonly do not account for risk associated with potentially failure scenarios (Ayyub, B. and Popescu 2003).

There are two types of maintenance interventions for infrastructure assets; preventive maintenance and essential maintenance (rehabilitation) (Robertson & Weligamage 2003). While essential or rehabilitation is carried out to make infrastructure safer for users, preventive maintenance is conducted to avoid costly unplanned maintenance. For an optimum maintenance plan, an assessment of the asset's life-cycle cost is first carried out to justify both short and long-term strategy. Several methods based on probabilistic theories have been used for life cycle models which are mostly based on a deterministic approach. However, the condition of most infrastructures is mostly stochastic and the factors that determine their criticality are dynamic in nature. A comparison between static and dynamic methods for life cycle cost analysis in (Zayed et al. 2002) show conflicting results. There is need for dynamic models and tools to quantify risk, and benefit associated with infrastructure asset.

1.1 Objective

The methodology proposed in this paper considers a risk-informed decision approach to maintenance planning (e.g. timing of interventions in a capital program) for infrastructure assets such as bridges. The risk analysis takes into account the dynamic nature of an asset's criticality and uses the changes in criticality to optimise the timing of interventions for an asset. The methodology gives a true picture of the criticality of the bridge as it takes into account social, environmental, and political impacts. A systems

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dynamic approach is used to model the criticality of the asset as a dynamic function which changes over time due to factors such as population growth, urban growth, and new developments (e.g. industries).

The objective of this study is to develop and demonstrate a methodology for assessing dynamic criticality of assets which changes over time and to use this understanding to optimise timing of intervention in order to achieve better risk management and better cost savings.

2. A BRIEF REVIEW OF LITERATURE

One of the main uses of criticality analysis for maintenance purpose is that it is used to provide input into the capital program so that "high criticality" equipment is given a higher priority for upgrade or replacement (Assetivity - Asset Management Consultants 2015). But also, the timing of intervention is very crucial to an optimal capital investment decision. Many risk-based approaches, in asset management, uses criticality as part of it risk analysis procedure for improving capital investment decisions. In (Pschierer-barnfather et al. 2011), the underlying methodology used in Condition-Based Risk Management (CBRM) to determine asset criticality was described. This methodology has been designed to be highly practical, enabling network operators to rapidly determine the criticality of many tens of thousands of assets, particularly when the available data is limited or incomplete. This methodology enables network owners and operators to target network investment towards the most beneficial parts of the network, providing a powerful tool for resource allocation and prioritisation. Condition-based risk management (CBRM) (Barnfather et al. 2014) was presented as a methodology that brings together asset information, engineering knowledge and practical experience of assets to define and quantify current and future asset condition, performance and risk. CBRM provides a means to express and communicate engineering information for large numbers of assets in a form that enables asset managers to define and justify future investment. The CBRM methodology was first created by EA Technology Limited (EATL) and Electricity North West Limited (ENWL) in 2002/3.

In (CHESTERTON et al. 2014)(IAN n.d.), Severn Trent Water (STW) strived to achieve a high degree of confidence in the serviceability of its reservoirs. The Portfolio Risk Assessment (PRA) is used to recommend programme for capital works schemes that further improved reservoir safety. Capital works were reviewed, ranked and initiated between the assessment periods. While the reservoir risk ranking was informative, the prioritisation of the works was more heavily led by works programming to effect construction cost efficiencies. As a result of the dynamic nature of the criticality of the reservoirs, the PRA also recommended that the assessment process be a live one and periodically revisited.

In the last decade, there have been fruitful research efforts worldwide on maintenance planning optimisation for deteriorating highway bridge structure systems in order to obtain a rational allocation of resources under financial constraints. Many of them focused on minimising cumulative life-cycle maintenance cost while enforcing permissible limits on relevant performance measures in order to keep bridges safe and serviceable (Liu & Frangopol 2004). However, the application of dynamic criticality (using system dynamic approach) is a new concept.

3. DYNAMIC CRITICALITY

One crucial question that must be answered by asset-intensive organisations is: "Do we understand the risk profile associated with our asset portfolio and how this will change over time?" a clear understanding of this is necessary to achieve strategy objectives and optimise maintenance investments for infrastructural assets.

3.1 Scenario description

In many risk-based asset management approaches, the only thing that is known to change in the risk profile of the asset is the likelihood (or probability) of failure. The criticality (or consequences of failure) of asset is assumed to be fixed and has considered as more or less a static quantity that is not updated with sufficient frequency as the operating environment changes (Adams et al. 2016). As seen in Figure 1(a), risk is defined as the combination of failure probability and the consequences of failure (criticality). The figures below describe what an asset risk profile (incorporating maintenance interventions) will look like when criticality is considered to be static versus when it is considered to be dynamic.

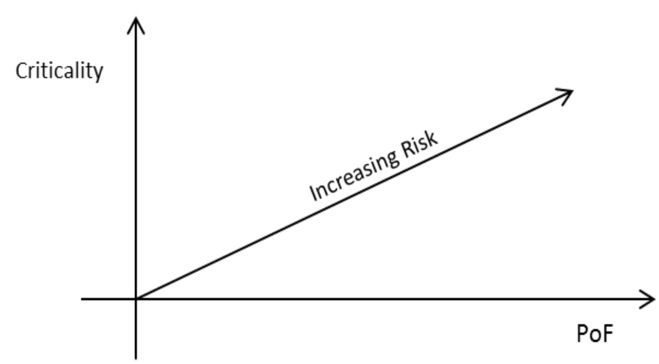

Figure 1(a): **Definition of Risk**

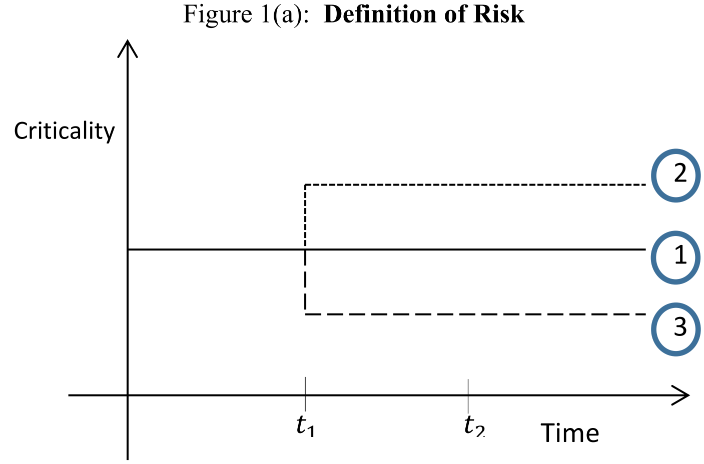

Figure 1(b): **Scenarios showing changes in criticality**