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Context- and bias-free probabilistic mission impact assessment

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ABSTRACT

Assessing and understanding the impact of scattered and widespread events onto a mission is a pertinacious problem. Current approaches attempting to solve mission impact assessment employ score-based algorithms leading to spurious results. We identify a fourfold problem with score-based algorithms: (1) score-based algorithms enforce deep training of experts to employed frameworks for specification (non-context-free), (2) require reference results for interpreting obtained results (non-bias-free), (3) require assessments outside of an experts' expertise (non-local), and (4) require validation of end-results against ground truth. This paper provides a formal, mathematical model for bias- and context-free mission impact assessment. Based on a probabilistic model we reduce mission impact assessment to a well-understood mathematical problem based on definitions from local expertise and allow for a validation at data level. This is useful for areas and applications where qualitative assessments are required, such as assessments in critical infrastructures or military contexts.

1. Introduction

Modeling dependencies of missions on various involved resources is a novel field of research, which pursues the goal of assessing the influences of local impacts on some resources onto a higher goal, i.e., a mission. Assessments somehow require an approach to "spread" locally created impacts onto higher goals, such as missions or processes. Early approaches attempting to solve a problem of mission impact assessment use ad-hoc methods involving newly established algorithms. We argue that such newly created algorithms suffer from multiple discrepancies, which we categorize into four different groups: (1) An expert must first fully understand and be trained in a system before he can assess configurations and parameters. We say, such systems do not provide a context-free assessment. (2) Obtained results from a system require a steep learning curve for interpretation and easily lead to overfitting by a dulling due to learned reference values. This means, results are not bias-free and require knowledge about a system. (3) During configurations, experts are forced outside their expertise, leading to potentially inaccurate specifications. We argue that it is favorable to accept disagreement from multiple knowledge sources instead of enforcing the definition of one allegedly congruent knowledge base. Finally, configurations (compare Problems 1 and 3) were assessed by a possibly overtrained expert and might be inaccurate, but parameters are not verifiable nor can be validated by an independent third party. This means, (4) obtained results from a newly created algorithm must be validated against a ground truth. Ground truths for occurred events and their exact impact on a mission are often not available in large quantities or are confidential.

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To put things into perspective, a non-context-free system requires an expert to understand how an evaluation reacts to a parameter of "5" and how to a parameter of "3"—without the context of the complete framework, such values do not have any meaning and are neither verifiable, validatable, nor are understandable. Further, an end-user becomes biased from interpretation of received results: With an unclear, non-mathematical definition of an end-result, e.g., "yellow," "3," or "severe," an end-user intrinsically adapts over time to "normal" results and becomes biased, i.e., a reported "severe" "red" error of category "5" is first taken seriously, if it persists for an hour.

In this work, we take a view from different perspectives toward mission impact assessment. We consider three views from three experts from different expertise and combine them inside a well-defined probabilistic graphical model. We provide a context-free assessment of defined parameters and models, which are assessable and can be validated by themselves without knowing their later use. Based on this probabilistic model one finds a well-understood problem: In a complex network multiple events possibly occur, whose local effects must be assessed toward a global effect. Using a probabilistic approach, one can benefit from existing, well-defined and well-understood algorithms to solve this problem and obtain probabilistically sound results that are understandable without the knowledge of our approach. Obtained results are understandable using commonsense and do not suffer from biased interpretations. Furthermore, we present results of two real world use cases on real data using our approach.

The contribution of this article can be summarized as follows: By introducing a well-defined probabilistic graphical model for mission impact assessment, we are able to reduce impact assessment on a well-defined mathematical problem, which allows for a validation of results at data level and does not require deep training of experts. By resorting to local conditional probability distributions one is able to integrate widespread knowledge from different expertise into one sound model. This is useful for applications, where qualitative assessments are required and perpendicular views from multiple experts onto a problem must be brought inline. As a long-term goal, this provides the basis for an automated response system based on a mathematical well-defined model for risk and impact assessments in a predictive and retrospect analysis over time in changing and dynamic environments.

1.1. *Scope and structure of this article*

The remainder of this article is structured as follows: In Section 2 we discuss related work and identify common discrepancies and benefits of existing approaches. Based on a well-defined probabilistic graphical model, we develop in Section 3 a mathematical model for mission impact modeling based on views from different experts. We introduce a notion of temporal aspects to cover dynamic environments to a certain degree and propose an independent-timeslice model assessing impacts at independent points in time, e.g., at independent short-, mid- and long-term time points. Based on this model, we discuss mission impact assessment as a formalized problem and its theoretical complexity in Section 4, and evaluate the scalability and accuracy of a proposed algorithm in largely scaled domains. In Section 5 we apply the introduced independent-timeslice mission impact assessment in two real world use cases involving business-, IT-, and security experts from different domains and show that the approach delivers satisfying and greatly accepted results.

Based on recent advantages in artificial intelligence and probabilistic graphical models, we dedicate Section 6 to an outlook of future work on an extension of the presented independent-timeslice model toward completely dynamic probabilistic mission impact assessments for rapidly changing environments and time-dependent analyses at a, if intended, nearly continuous time granularity. We discuss and propose various approaches for such an extension and show how derived independent-timeslice models can be reused directly in future work. We conclude in Section 7.

2. Related work

Mission modeling and mission impact assessment is an emerging field of research. While existing approaches deliver early results and claim to solve mission impact assessment, a formal definition of an underlying problem is yet missing, which leads to the mentioned problems of biased interpretation of results and a non-context free parametrization. Employed fudge factors in newly established algorithms lead to untraceable and spurious results demanding data driven validations. Unfortunately, large, standardized datasets for validation are yet missing for mission impact assessment and in the following presented work. de Barros Barreto et al. (2013) introduce a well-understood modeling technique and use BPMN models to acquire knowledge. An impact assessment is based on various indexes and numerical scores, such as exploit index, impact factor, infrastructure capacity index, and graph distances. Various numerical factors are arbitrarily combined, without a mathematical foundation and cannot provide a transparent, understandable and verifiable assessment to an expert. Further, an assessment is solely based on direct impacts, leaving aside transitive impacts and/or defining a manual description of all dependencies between individual devices inside one organization, which is, in most of the cases, an unfeasible process.

Albanese et al. (2013) present a well-modeled formalism for complex inter-dependencies of missions as a set of tasks. Using numerical scores and tolerances in a holistic approach Albanese et al. focus on cost minimization. Their approach can solely be validated holistically, as involved parameters do not bear local semantics and do not provide bias-free and context-free understandable results. Buckshaw et al. (2005) propose a quantitative risk management by involving various experts and present a score-based assessment based on individual values and a standardization using a weighted sum. Unfortunately, a mathematical foundation is missing and obtained results are only interpretable after deep training of experts in the characteristics of this approach. Buckshaw et al. themselves note that a validation of the proposed model requires large amounts of actual data and ground truth, which both are not available.

Jakobson (2011) presents a well-understood conceptual framework using interdependencies based on operational capacity at different abstraction layers. In this dependency model, impacts are propagated and reduce the operational capacity, which has a similar intention to our approach. However