

The Systems Integration Technical Risk Assessment Model based on a Bayesian Belief Networks

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Keywords: *Systems integration risks, Systems integration risks modelling, Bayesian networks, Risk assessment, Expert knowledge elicitation*

ABSTRACT

This paper presents an approach for modelling Systems Integration Technical Risks (SITR) assessment using Bayesian Belief Networks (BBN). SITR represent significant part of project risks associated with development of large software intensive systems in Defence and Civilian Industry. We propose conceptual modelling framework to address the problem of SITR assessment at early stages of a system life cycle. This framework includes a set of BBN

models, representing the risk contributing factors, and complementing Parametric Models (PM), used for providing input data to the BBN models.

We present rationale and modelling objectives, describes details of BBN models, including their topology and point out the use of idioms. In conclusion we summarise BBN model benefits and constraints for SITR assessment, and provide suggestions for further research direction for model improvement..

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1. INTRODUCTION

The main purpose of this paper is a description of Bayesian Beliefs Network application framework for a new application domain: Systems Integration Technical Risk (SITR) assessment. We propose a novel framework, which combines BBNs and complimentary risk assessment Parametric Models, used as source of quantitative input data for BBNs.

Modern computer systems are becoming more powerful and complex. Modern embedded systems capabilities and functionalities are growing rapidly. This growth of systems complexity results in corresponding increase in Systems Integration (SI) process complexity. SI phase of System Development Life Cycle has one

of the highest levels of risks in system development.

Despite the large investments that are made in SI improvement, integration efforts are still failing for a number of technical, organizational, managerial, and planning reasons.

2. BBN REAL WORLD APPLICATIONS

There are a number of papers describing successful application of BBN for risk related management purposes. It was shown by Fenton *et al.* (2004) that a classic risk assessment produces a quantified result combining evidence of different types. He pointed out that BBNs provide effective decision support for problems involving uncertainty and probabilistic reasoning. In addition, a BBN model

implemented as a graphical tool can be used for various types of 'what-if' and sensitivity analysis. These problems are being successfully addressed in a wide range of application domains using BBNs.

Fenton *et al.* (2007) presented a good selection of examples on how to apply BBN for solving real problems:

- Microsoft has used BBNs for user-support and automated fault diagnostics.
- QinetiQ developed a BBN-based model to predict vehicle reliability accurately based on information about the architecture and design process.
- BBN model provides Radical Improvements for Software Fault Prediction developed for Philips Consumer Electronics

Software project estimation model based on BBN has been presented by Wang *et al.* (2007). Software estimation models should support managerial decision making in software projects. However, the most current models do not achieve this goal to the extent managers are looking for as the authors witnessed. .

Literature review provides evidence of BBN applicability for a wide spectrum of problems, including risk assessment and therefore BBN can be selected for SITR evaluation.

These are the key benefits of BBN's which make them very suitable for SITR evaluation:

- BBN provides a formal mechanism for recording and testing subjective information.
- BBN is able to explicitly quantify the uncertainty.
- BBN provides a mechanism for sensitivity analysis by reasoning from cause to effect and backwards.
- BBN provides a mechanism for updating the beliefs about unknown factors known as the posterior probability distribution based on the observed evidence.
- BN makes possible the prediction with incomplete data.

3. SITR IDENTIFICATION

The systems integration is a process when the first time fully engineered components and subsystems are linked to each other and made to perform as a unified functional entity.

As practice shows, the engineering of a new complex system with many interacting components, there always remains unforeseen incompatibilities that do not reveal themselves until the system elements are brought together, no matter how thoroughly the individual components have been tested

At SI phase a resolution of such incompatibilities becomes a very costly exercise.

The current trend is to consider SI as an iterative and continuous process embedded into a spiral type of life cycle model, and does not represent a separate phase following the development phase.

Chitister and.Haimes (1996) define SI is a process of amalgamation and coordination among all the coupling and interactions of the system's components so that entire system can perform its intended functions as a unit.

The source of risks is introduced and spread across the system life-cycle development stages: requirements definition, specification, architecture, development, integration and verification. Clearly, the cost of late risk mitigation should be much higher than the cost of risk prevention at early stages. One of the helpful strategies for alleviating the SI risks is to increase attention to potential integration issues throughout the development life cycle – beginning in early stages rather focusing on them late in the development process. Therefore, timely assessment of sources of risks affecting SI is likely to be essential for success of SI phase.

Systems technical risk is defined as a measure of the probability and severity of adverse effects inherent in the system technical development. Systems integration is a large-scale and complex process. Factors which contribute to SI complexity can be of different nature: technical, managerial, organizational or planning. SI has such nature where coupling and interconnectedness among all parts and functions of the system as well as influence of the process, people and environment must be accounted for.

In modeling of large-scale and complex system with one-sided limited view it is impossible to clarify multiple components objectives, constraints of a system and such limited model cannot cover all relevant and critical system aspects.

Hall (1989) developed a theoretical framework to capture multiple dimensions and perspectives of a system. He proposed the Hierarchical Holographic Modeling (HHM) concept for system modelling. The result of HHM process is the creation of a very large number of risk scenarios, hierarchically organized into sets and subsets.

Chitister and Haimes (1996) adopted HHM approach to build a comprehensive framework for the identification and management of risk associated with the systems integration. The HHM framework includes most, if not all, categories of risk from multiple visions and gives a comprehensive coverage of the sources of risk in SI. HHM framework provides multidimensional presentation of the sources of risk in systems integration. The proposed HHM framework consists of seven visions (views) or decompositions: such as system, temporal sequence, leadership, environment, acquisition, quality, technology.

We focus on the technical aspects of risk factors in systems integration. Therefore, we have to consider a technical category of the quality vision as our primary concern. In other words, we will consider technical risks arising from the functional, temporal, development and technology perspectives.

This approach for identifying systems integration technical risk and for creating a taxonomy of these risk factors has been described by Loutchkina *et al.* (2010). The authors recommended strategies for alleviating the SI risks relates to potential integration issues throughout the development life cycle. The paper explores cause-and-effect relationships of the specific system's quality attributes and SI process complexity. The paper focuses primarily on technical aspects of systems integration. Process Hierarchical Holographic modeling methodology has been adopted to capture diverse characteristics of systems integration process.

Table below summaries identified sources of risk related to systems integration process and artifacts.

Table 1. Technical Sources of Risks in Systems Integration

Sources of Risks	Quality attributes	Input for Risk assessment
Requirements	Completeness Feasibility Testability Traceability	Requirements Specification Tree Traceability Matrix
System Architecture	Architectural design completeness & sufficiency Abstraction in system architecture Integrability Commonality Modularity Modifiability Testability Standards based Interoperability	System Design Documents
Low level software design and development	Integrability Commonality Modularity Modifiability Testability Standards based Interoperability	Software Detailed Design Documents
Systems Integration Design	Integration architecture Integration strategy Integration mechanism	Integration plan
Verification Design	Traceability Feasibility of the Verification Cost-effective Verification Completeness	Verification Plan
Systems Support for Integration	Quality of CASE Tools and Testing Equipment Readiness	Config. And management Plan
Technology aspect	Compatibility Level of Novelty Complexity	

The systematic assessment of these attributes at the design phase provides the foundation for SITR

analysis and identified relations determine a basic topology of the required model BBNs.

4. BBN MODEL DESIGN

Modelling objectives for SIRT model are to:

- develop modular and extendable approach for systems integration risk assessment modelling,
- acquire domain knowledge and expertise available in Australian Defence and Industry, and
- develop executable prototype (tool) to demonstrate applicability of the suggested approach.

Neil (2000) stated that BBNs have number of benefits, but there are fundamental barriers that significantly restrict their use in dealing with large-scale problems. The challenge is how the power of BBNs can be made easily accessible to practitioners and be practically applied to real-world problems.

For example, BBN models have certain constraints and limitations that reduce models usability. Radlinski (2008) pointed out difficulties when some variables needing adjustment are not observable. In other words generic BBN model has to be modified to represent a particular case of interest. It practically means that repetitive expert knowledge acquisition is required and new conditional probabilities values have to be populated into BBN.

To overcome this issue we propose having a hybrid model consisting of two linked sub-models: generic BBNs, representing relations between conceptual risks (nodes), and Parametric Models, representing evaluation of risks related to a particular case. It is worth noting that parametric models are commonly used in risk analysis and assessment. Figure 1 shows models hierarchy and interface.

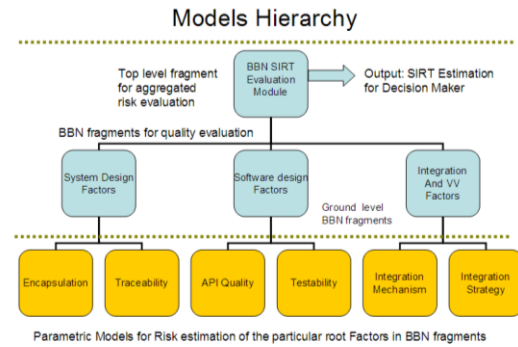


Figure 1. Model Hierarchy and Interfaces

The top level BBN module is shown on figure 2. It contains 10 nodes. The top node SIRT Index contains distribution of probabilities for aggregated risk states. Six parent nodes represent connectors to the other six BBNs, called fragments or modules. These fragments are used in risk evaluation for following factors: technological risks, project context generic risks, requirements and specifications risks, system support related risks, system design risks and software design risks. Two intermediate nodes: system architecture risks and development related risks are definitional nodes, which aggregate parents' nodes risks, forming definitional relationship.

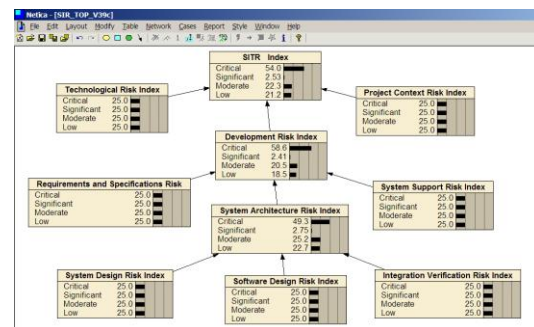


Figure 2. Top level BBN for SIRT evaluation

The second level fragments are complex BBN models used for evaluation of aggregated risks, represented by conditional relations between conceptual nodes. These nodes and relations form BBN fragment topology. The second level fragments accept input quantitative data provided by supporting parametric models. An example of such fragment is shown below:

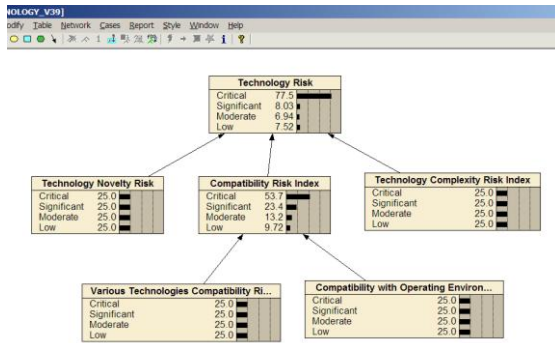


Figure 3. The second level BBN fragment for Technological Risks evaluation

Building a BBN usually requires a careful trade-off between the desire for a rich model on one side and required efforts for construction, probabilistic inference in the network on the other side. The major sources of SIR have been identified and become our core foundation for the iterative process of building the BBN model of systems integration risks assessment. During development of our BBN we always keep in mind that nodes (and links) must be easily modified and added without significant modifications in the rest of the model.

The BBN model design and development process involves three main steps:

- 1) Identification of the variables (particular risk SISR factors) that are of importance, along with their possible state values.
- 2) Identification of the relationships between the variables and expression of them in a graphical structure.
- 3) Definition and elicitation of the probabilities required for its quantitative part.

After determining a set of relevant variables, the first step is to construct the graphical structure of the Bayesian network. Our aim is to produce the 'right' graph to be a sensible model of the types of reasoning being applied as recommended by Neil (2000).

The second step involves the identification of quantitative probabilistic dependency between the represented variables (nodes), which have to be captured into directed arcs. The main guideline was chosen for our BBN model to select the arc (link) direction reflecting causality relation (cause to effects) or parent/child relation. This decision has an advantage, because domain-experts, who do not have a background of probability theory,

understand this relation as the most logical way and that helps avoid unnecessary complications.

To simplify BBN model construction we use modular technique. Our complete SIR BBN model will initially consist of smaller individual fragments built independently which form a set of nodes linked together by associated semantic. Under Laskey (1997) scheme a fragment is a set of related variables that could be constructed and reasoned about separately from other fragments. Ideally fragments must make sense to the expert who must be able to supply some underlying motive or reason for them belonging together.

At step 3 we define and assess the probabilities required for its quantitative part. BBNs may represent either qualitative or quantitative variables. Qualitative variables are used to model real-world variables whose values are typically measured on a discrete subjective scale, for example: low, medium, high. In the absence of hard data, we must rely on domain experts to provide, often subjective, judgments to inform the values used in CPTs as recommended by Neil (2005).

Figure below shows a diagram of the selected BBN development process, proposed by Niel *et al.* (2000).

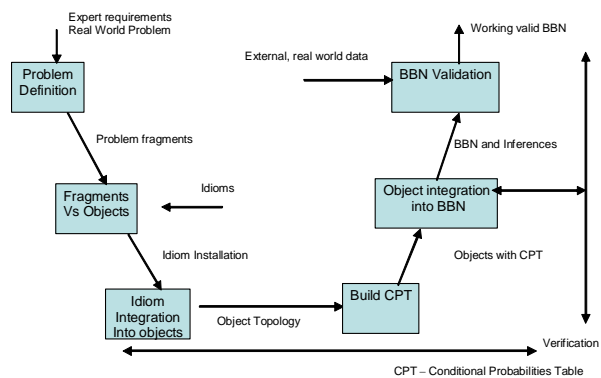


Figure 4. Model development process

Currently we are at the phase of building Conditional Probability Tables (CPT). This phase includes expert knowledge elicitation processes and tables population with credible probability values.

5. PARAMETRIC MODEL DESIGN

We accepted the approach suggested by Boehm *et al.* (2008, 2009) for parametric risk models. Boehm described a lean framework and toolset for early identification of program risks. He also stated importance and needs for Defence program

managers in early warnings of any risks for achieving effective project management.

Excel spreadsheets are used for PM implementation. An individual spreadsheet aggregates set of risk sources associated with the particular conceptual parent node in BBN and consists of a list of statements, where each statement describes positive indicator or meaning of a particular source of risk. Each statement has to be assessed and rated in two dimensions by domain experts and then value of risk exposure would be evaluated by PM and linked to a particular source of risk. All ratings have to be done by experts based on the assessment of the all available and relevant design documents in a particular project context.

Let consider one example, assume that we have conceptual parent node in BBN called "Quality of Design for Testability Risk Index". Then it may be a set of sources of risk, related to quality of design. Let consider only two of them: quality of integration plan and stability of test design team.

Domain experts rate statements in two dimensions: (1) strength of evidence supporting statement and (2) criticality of consequences in the case of lack of evidence.

Strength of evidence may be rated as: strong, partial, weak or low. Criticality of consequences on the project outcome may be assessed and rated as: critical, significant, moderate or little. The calculated by PM risk exposure is the product of evidence strength and level of consequences. The stronger the evidence means the less risk probability.

In our example experts rated strength of evidence as strong for quality of integration plan and they rated criticality of consequences in case of lack of integrated plan as critical. PM automatically calculates risk exposure as moderate in this particular case.

In fact, PM includes risk assessment method based on evidence, and that sort of risk assessment has to be done in early phases of any large projects. Quantitative outcomes of these risk assessments provide input values for the upper level models in BBN.

There is an underlying assumption for PM:

- All statements for a single conceptual entity have to be independent for risk evaluation consistency.

However the same statement can be reused for different conceptual entities.

PM limitations are a disintegrated and independent treatment of risks on individual basis. However, top level BBN models can mitigate this limitation in natural way on conceptual level using conditional dependency in CPT approved by experts.

6. DOMAIN KNOWLEDGE ELICITATION ISSUES

Quality of knowledge elicitation processes, collected data and data processing routines is a paramount concern of SITR assessment and subsequent validation of a suggested model. Nature of conceptual entities and their relations forming BBNs and experts rating of PM statements requires clear and correct expert judgment at every step.

Expert knowledge elicitation process is a very important step, usually extended in time. At this step we have to deal with people (experts) and face all communication issues: delays, misunderstanding, and even resistance.

As we discussed earlier there are two different formats for knowledge representation in the suggested SITR model:

- BBN nodes' Conditional Probabilities Tables. They represent expert knowledge in term of generic relations between abstract constructs and do not depend on a particular project.
- Expert statements ratings. They reflect expert knowledge in terms of evaluation of values in particular project context.

Wiegmann *et al.* (2005) provides good introduction to the elicitation practice. BBN networks represent knowledge both qualitatively and quantitatively. The qualitative component consists of a directed graph of the variables are represented by nodes, and their influences on other variables are represented by arcs connecting the nodes. The quantitative part consists of the probabilities that directly influence the variable of interest. The probabilities represent the magnitudes of each variable's influence.

The qualitative structure of the network and many of the conditional probabilities required to quantify a BBN must be elicited from domain experts, based on their knowledge and experience.

The development of BBN's also involves a major psychological component, including experts' subjective beliefs that can be biased by a variety of factors. Of interest to the present project, therefore, is the process of eliciting expert judgments for use in the development and subsequent validation of BBN's.

Weigmann also classified methods for improving probability elicitation:

- **Frequency Estimation Method** uses probability scales allowing experts to mark probabilities on a graphic scale, which are fast and easy to understand; however, they tend to be inaccurate and prone to scaling biases.
- **Gamble methods** allow probabilities determination using gamble-like methods.
- **Hierarchical methods** were developed as a method to allow experts to provide either qualitative or quantitative information, whichever they were most comfortable providing.
- **Multiple Experts methods** can be considered more accurate in the final probabilities by balancing multiple viewpoints and drawing from a larger pool of knowledge.

At this stage we consider using hierarchical methods for BBN CPT values elicitation and direct expert rating for parametric models.

Important insights on the use of expert judgment in the qualification of risk assessment have been discussed by Rosqvist (2003). In particular we are interested in applying, with adaptation, his elicitation method for expert judgments in the form of triangular probability distribution functions related to achievement levels of software quality attributes. That adaptation will allow more accurate estimation of probability values provided by experts in the form of triangular distributions.

7. CONCLUSIONS AND FURTHER RESEARCH RECOMMENDATIONS

In this paper we propose a novel approach to address challenging problems in systems integration technical risk assessment from systems engineering perspective.

We described an approach for identification of systems integration technical risk and risk factors taxonomy.

We propose a novel solution for SITR evaluation using hybrid model, which combines Bayesian Belief Networks (BBN) and Parametric Models. Rationale and modelling objectives have been presented in both models which have been described and illustrated by examples.

Knowledge elicitation issues have been discussed and suggestions made.

Finally, we recommend continuing this research by:

- completing questionnaires for expert knowledge elicitation,
- finalizing elicitation process and procedures,
- conducting actual elicitation process, and
- processing acquired data for CPT population

Model validation has to be done after extensive model testing and sensitivity analysis with subsequent expert evaluation of model usability.

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