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DATA REPRESENTATION OF RISK IN CONSTRUCTION

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Abstract: Risk is a major factor in construction. Few of the information systems commonly used in construction address risk explicitly, yet risk is complex, and the analysis and management that requires deep analysis of all aspects of the project that calls upon many—perhaps most—of the project's information systems. As an initial component of risk management information systems, this paper discusses the representation of construction risk information. Definitions of risk are provided. Alternative approaches include the representation of specific versus generic risks, and the implicit versus explicit representation of risks. A basic explicit, generic risk model is presented, consisting of risks, likelihoods, impacts, and magnitudes. An extended model is then presented that adds threats, assets, vulnerabilities, and other concepts.

Keywords: Risk, Construction Risk, Risk Management, Risk Representation

1 Introduction

Risk is a major factor in construction management, underlying decisions such as project delivery forms, construction methods, budgeting, and even the decision of whether to undertake a project in the first place. Of the information systems commonly used in construction—CAD, scheduling software, estimating systems, etc.—few address risk explicitly. Yet risk is very complex. The analysis and management of risk must identify potential risks facing the project, assess their potential likelihood and impacts, predict how risk events could propagate through different aspects of the project, and develop effective mitigation plans. This requires deep analysis of all aspects of the project that calls upon many—perhaps most—of the project's information systems.

Within the general field of information systems to support construction management, one area of interest is the treatment of risks and the development of systems to better support risk management—risk management information systems (RMIS). As a preliminary task, this paper explores a broad range of ways in which risks are or could be modeled and represented explicitly or implicitly in information systems within the construction industry. Later work will discuss the range of system functionality that can be associated with these risk representations to carry out RMIS tasks, and the application of portions of this framework in the development of specific information systems. The paper addresses the elements that make up the concept of risk and approaches for modeling and representing this information.

This paper draws from work done in conjunction with the Mefisto Project, a research and development project, and from collaboration with the project's principal investigator, Prof. Dr.-Ing. R. J. Scherer, Institute of Construction Informatics, Dresden, Germany. The work also drew from several researcher's previous work on construction risk, including De Zoysa (2000 and 2006), Omidvar (2008), Yaworsky (1994), and Abdelgawad and Fayek (2010)

2 Definitions of Risk

There is no widespread agreement about the exact definition of risk, but the alternative definitions offered generally include the same basic set of concepts. For example, Hubbard (2010) defines risk as “a state of uncertainty where some of the possibilities involve a loss”, or, in a simpler form, *the possibility that*

something bad will happen, or even, *loss exposure*. These definitions point to two broad concepts at the heart of risk:

- A loss/something bad happening: This concept *identifies* the negative thing that could happen. This concept is at the core of the first major risk management process, *risk identification*.
- A state of uncertainty/possibility/exposure: This concept provides some measure of the level or magnitude of a risk. It highlights that risk inherently relates to uncertain information—certainty about future events removes all concept of risk. This concept is central to the second major risk management process, *risk quantification*.

The factor analysis of information risk (FAIR), which provides a taxonomy of risk concepts in an attempt to bring some consistency to the treatment of risk (developed for the information security field, but quite generic in its approach), defines risk as “the probable frequency and probable magnitude of future loss” (Jones, 2005, p. 5). This definition deals with the identity of a risk as a future loss and extends the uncertainty-based quantification of risk in terms of two components that are generally used in risk measurement: frequency (likelihood) and magnitude (impact).

ISO, in its standards relating to risk management, defines risk as the “effect of uncertainty on objectives” (ISO Guide 73:2009(E/F), p. 1). This defines risk at a more abstract level, but it still centres on the concept of uncertainty and it generalizes the concept of loss to “impact on objectives”. The notes provided by ISO with this definition further clarify that this definition is intended to convey similar concepts to those described previously:

“NOTE 3 Risk is often characterized by reference to potential events ... and consequences ...NOTE 4 Risk is often expressed in terms of a combination of the consequences of an event ... and the associated likelihood ... of occurrence. NOTE 5 Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood.” (ISO Guide 73:2009(E/F), p. 1)

3 Alternative Approaches for Representing a Risk

Although the central defining concepts of risk are fairly universal, many approaches exist to model risks and represent them in information systems. A comprehensive framework for risk management information systems should accommodate multiple representations of risks, just as a physical component of a construction project (e.g., a concrete column) may have several different representations within a comprehensive project data model (e.g., a tabular item in a bill of quantities, a 2D line drawing, a 3D model, an item in a construction schedule, etc.). This section outlines these basic alternatives representations.

3.1 Specific Risks vs. Generic Risks

Many types of risks exist on construction projects. For example, Perry and Hayes (1985) classified construction risks into the following categories:

- Physical, e.g., earthquake.
- Environmental, e.g., ecological damage
- Design, e.g., design changes
- Logistics, e.g., availability of specialized resources
- Financial, e.g., adequate cash flow
- Legal, e.g., liability for acts of others,
- Political, e.g., changes in law,
- Construction, e.g., industrial relations,
- Operational, e.g., maintenance needs.

Many other researchers have similarly attempted to enumerate both types of construction risks and specific risks that might befall construction works. Different construction risks can be very different in nature from each other, and any risk management information system that supported detailed decision

support for specific risks would necessarily need to be tailored to those specific types of risks (e.g., analyzing the impact of an under-strength batch of concrete on the on a building's structure, or analyzing the impact of delayed progress payments on the project's cash flow). Any system that provides deep analysis of specific types of risks will necessarily address a specific, narrow scope, and cannot support a comprehensive range of all project risks. A contrasting approach is to treat risks generically, e.g., as any type of uncertain event with the potential to impact the project. Since our interests lay in comprehensive approaches to risk management, we will focus primarily on the later of these—approaches that represent risks in general.

3.2 Implicit Representations: Risk as an Outcome Probability

If risk implies the probability of a negative outcome, some approaches focus on representing and analyzing the outcome probability, without explicitly representing a loss event. An example of an approach that models risk as the probability of some project parameter having an undesirable outcome is a system that calculates stochastic project cost estimates as a probability distribution over a range of total project costs (and, in particular, calculates the probability that costs will exceed revenues, resulting in a financial loss). In this way, any system can be said to deal with project risks if it represents and analyzes uncertainty in any project parameter that can have a negative outcome on the project. The following examples of project outcomes may be addressed by specific software systems that analyze uncertain outcome values (and therefore, analyze the associated risks):

- The cost of the project or of its components,
- Prices (labour, materials, equipment, etc.),
- Project revenues, inflation rates, and other financial elements,
- Productivity,
- Quantities,
- Durations (construction durations, delays, procurement/delivery times, etc.),
- Quality,
- Material properties (soil strength),
- Structural strength, or other technical parameters.

Such systems would provide explicit representation of the uncertain quantities of certain risks, without providing any explicit representation that identifies and describes the loss event itself. Some such systems may provide excellent and very valuable treatment of specific types of risks, but without explicit representation of the identity of various risks, this type of representation is unlikely to form the basis of a general risk treatment approach.

3.3 Explicit Representations: Basic Model of Risk Events

In contrast to the previous section, systems can explicitly represent the loss events corresponding to various project risks—e.g., represent a list of the different risks that a project team should evaluate.

The previous section described systems that explicitly represent the uncertain risk quantities without explicitly representing risk identities. In contrast, explicit approaches could represent risk events without any representation of the uncertain risk quantities. For example, a risk register system could provide an extensive checklist of possible risks that a project team should review in order to identify the specific risks that are relevant to a given construction project (and it could include complex reasoning to help identify the appropriate risks), all without any treatment of the uncertain quantities. However, this would be unusual. More commonly, explicit approaches would represent both the identification of risk events and their associated quantities.

A basic model for representing risks, then, includes the identification and quantification of risk events. The essential quantity of a risk event is some type of measure of the magnitude of the risk (risk magnitude, risk score), which is almost always comprised of a combination of two essential factors: the probability that the risk event will occur (risk probability, likelihood) and the impact if the risk event does

occur (risk impact, cost, severity, ...). In terms of a formal data model, this could include a single class, as shown in Figure 1.

The data models shown in this report are conceptual, they establish the essential ideas, but are not fully developed for implementation in software. Relationships between classes are sketched in the figures, but are not shown in the class listings. Alternative names for classes and attributes are given, and names corresponding to the FAIR or ISO standards are indicated in superscript.

Class: Risk (a.k.a. Risk Event, Loss Event^{FAIR})

Definition: A future occurrence that would cause some loss. Generally refers to a potential future occurrence that is recognized as possible, but is not anticipated (if the occurrence is expected, then it would typically be recognized as part of the expected plan, and not considered as a risk). Implies some level of uncertain knowledge regarding the occurrence (negative future events that were known to be forthcoming with certainty would not generally be considered risks). May be used describe positive outcomes as well as losses.

Attribute Definitions:

Name: A label that identifies and describes an individual risk.

Likelihood (a.k.a. Loss Event Frequency^{FAIR}) The probability of the risk occurring.

Impact (a.k.a. Probable Loss Magnitude^{FAIR}, Consequence^{ISO}, severity, cost) The loss that is expected to arise if the risk event does occur. Generally expressed as a monetary value.

Magnitude: (a.k.a. Risk^{FAIR}, Risk Score^{ISO}) A measure of the overall amount of risk. In most cases, the risk score is a function of the risk likelihood and the risk impact. Can be a unitless ranking or score, a linguistic value (e.g., high, medium, low), a monetary value obtained by multiplying the impact by the likelihood, a probability distribution over a range of costs, or some other measure. This value seems to be equivalent to the FAIR definition of risk of “the probable frequency and probable magnitude of future loss” (Jones, 2005, p. 5).

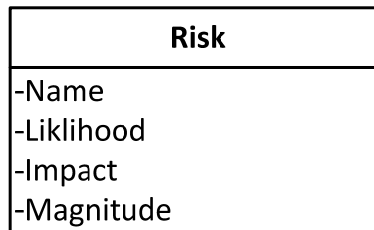


Figure 1. A Basic Risk Model

3.4 Explicit Representations: Extended Model of Risk Events

The basic risk model presented in the previous section, though simple, is sufficient to support extensive risk management practices. Yet, there are many more risk-related concepts that can be added to the model to support much richer and more advanced RMIS's. This section—which draws heavily from the FAIR taxonomy (Jones, 2005), recast as a data model—develops threats as the potential sources of risks, assets as the objects incurring the loss, and the sequence of events that must occur to actually cause the loss. The names and concepts are drawn from FAIR (sometimes directly, although quotations will not be used here), unless otherwise noted. The classes, attributes, and relations of an extended risk model are described below and shown in Figure 2. Several examples are provided later in Section 3.5.

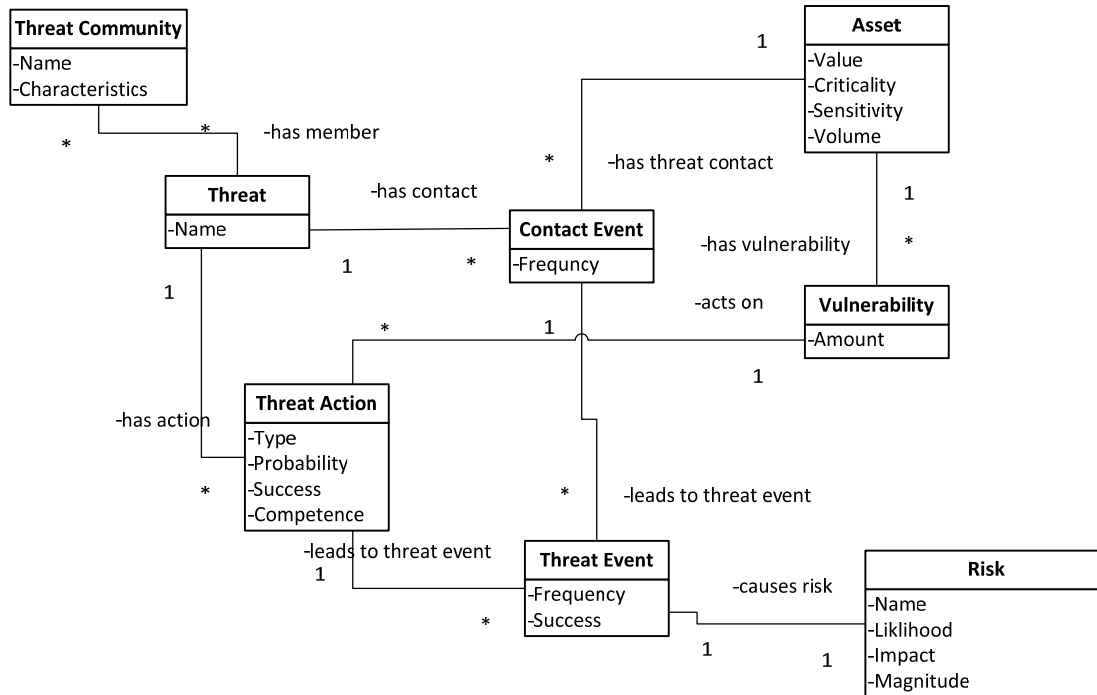


Figure 2. Extended model of risk-related threats, assets, and events

Class: Threat (a.k.a. Threat Agent, Risk Source^{ISO}, Hazard^{ISO})

Definition: Anything (e.g., object, substance, human, etc.) that is capable of acting against an asset in a manner that can result in harm. (FAIR distinguishes a threat agent as an individual within a threat population, but this model will not make that distinction).

Attribute Definitions:

Name: Description of the threat.

Class: Threat Community

Definition: A group of threats that share common characteristics.

Attribute Definitions:

Name: Description of the threat community.

Characteristics: The threat characteristics that are shared by the members of the threat community.

Class: Asset

Definition: Anything that is capable of incurring a loss of value, or gaining a liability value, as a result of a loss action by a threat. For construction projects, this may often be a physical part of the constructed facility, a work process that is negatively impacted to incur a loss, or the project as a whole. ISO uses a more general concept of “objective” as the thing that is damaged by the loss.

Attribute Definitions:

Cost: (a.k.a. Value) The value of the asset, generally expressed as a replacement cost.

Criticality: Describes the impact of the asset on the organization.

Volume: The amount of asset that is at risk (e.g., for a risk of damage by weather affecting interior finishings that are stock-piled on site, how many units could be affected?).

Class: Vulnerability

Definition: A way that an asset can suffer a loss of value.

Attribute Definitions:

Name: Describes the vulnerability.

Amount: (a.k.a. Exposure^{ISO}) The amount of loss that could be caused by this vulnerability.

Class: Threat Action (a.k.a. Capability^{FAIR})

Definition: A loss-causing action that a threat can cause to an asset, corresponding to the asset's vulnerabilities. A single threat can cause multiple threat actions since it can cause different types of losses to different types of assets.

Attribute Definitions:

Name: Describes the type of loss-causing action that the threat is capable of imparting.

Probability: The probability that the threat will act against an asset when it comes into contact with the asset. In cases where the threat is a human acting intentionally against the asset, the threat action probability will depend upon the value of the asset, the level of effort required, and the risk *to the threat agent*.

Success: The probability that the threats action against the asset will be successful in causing a loss.

Class: Contact Event

Definition: An occurrence where a threat comes into contact with an asset, creating the potential for a loss event to occur.

Attribute Definitions:

Frequency: The frequency with which the threat comes into contact with the asset.

Class: Threat Event

Definition: An occurrence where a threat acts against an asset.

Attribute Definitions:

Frequency: (a.k.a. Threat Event Frequency^{FAIR}) The frequency with which the threat event occurs. A function of the contact event frequency and the threat action probability.

Success: The probability that the threats event against the asset is successful in overcoming controls and causing a loss.

3.5 Example

The following figure illustrates how some typical risks facing a construction project may be modeled using the classes defined in the previous section. The figure shows instances of the defined class (attribute values are not provided) that could be used to model examples of risks facing a construction project. Figure 3 illustrates an example of three risks arising from storms. Two risks arise from two different vulnerabilities of the work site: the risk of being forced to provide unanticipated water protection equipment, materials, and labour because of heavy precipitation hitting the site, and the risk of general productivity reductions caused by severe weather. The third risk relates to delays in the material supply network arising from severe weather hitting the region. The benefit of individually modeling contact events, vulnerabilities, threat actions, threat events, and risks (as opposed to rolling all of these into a single risk object) stems from the ability to individual estimate the frequencies, probabilities, costs, etc. of these different risk elements.

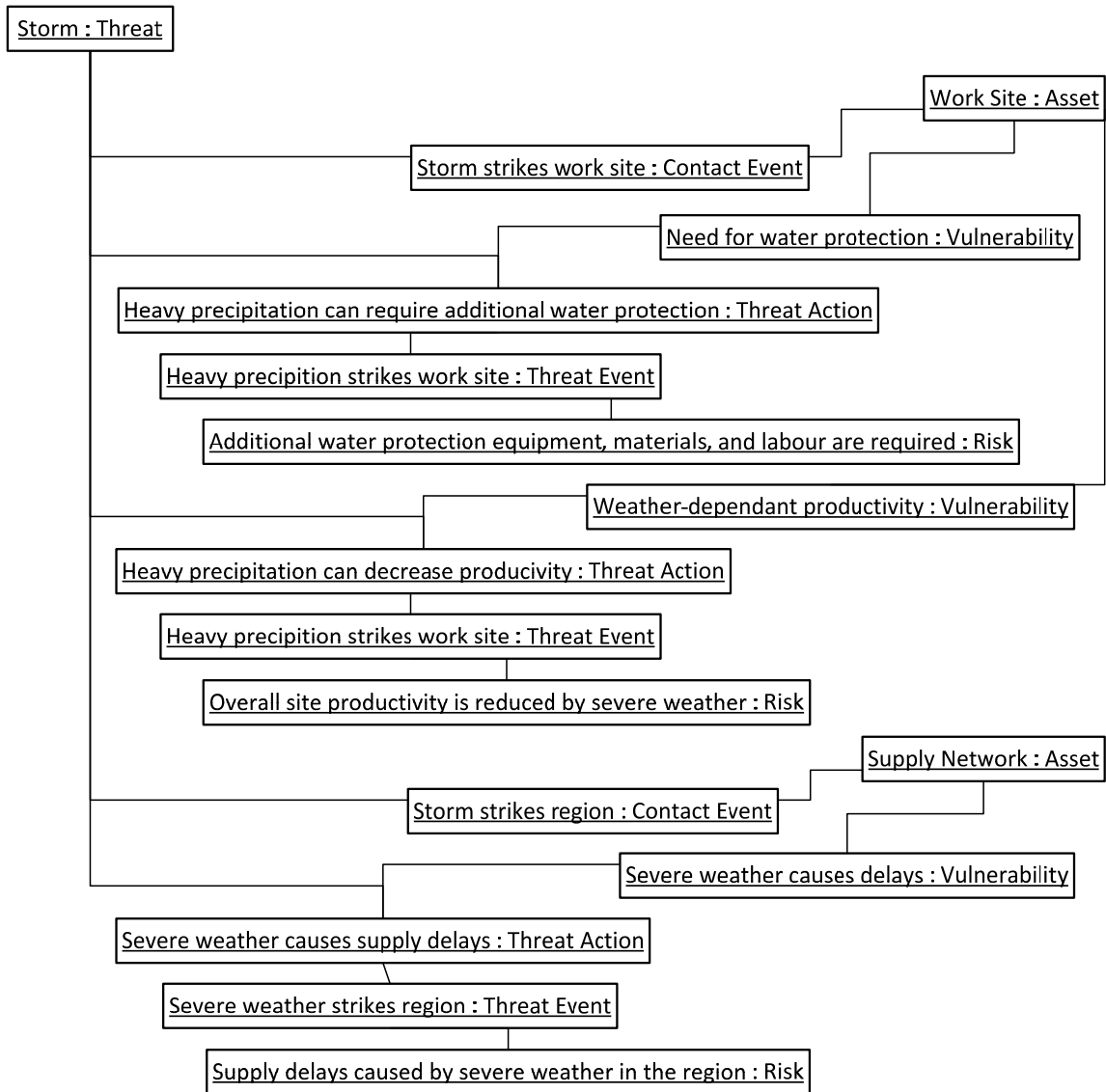


Figure 3. Instances to model construction risks associated with a storm.

4 Representation of Other Risk-Related Concepts

In addition to the concepts of risk, threats, assets, etc. that are represented in the model presented previously, there are a number of other concepts related to the risk that could be incorporated into a comprehensive risk model. These will not be fully modelled here, but will be mentioned briefly:

- *Controls, mitigation, risk responses:* controls are things (e.g., processes, devices, features of the assets that are at risk) that are put into place to reduce or eliminate risks. Controls can be primarily preventative, detective, or responsive in nature. Many of the attributes described in the previous risk model will be influenced by the presence and effectiveness of controls (e.g., frequency of threat events, probability of success of a threat event, impact of risks, etc.). Mitigations or risk responses are responsive controls—measures put into place to respond to risks. Representing risk responses could include representation of entire work plans developed as contingencies to be carried out in the event that certain risks are encountered.
- *Risk owner, stakeholders and their risk perceptions:* the actors associated with risks (aside from people or organizations acting as threats) can include a risk owner, who is a party that is likely to bear

the loss arising from a risk and is generally given responsibility for managing the risk. Different parties involved in the risk scenarios can also be modeled as individual stakeholders, particularly if any values or choices relating the risks are modelled (e.g., risk aversion, risk tolerance, risk perception, etc.), since these are subjective and values will be different for different individuals.

- *Risk context, organizational context, and external environment context:* Risk scenarios are influenced by a wide range of factors in the internal and external context. A risk model may try to represent these relationships, but because they can include a broad range of heterogeneous factors, they could only be represented in a comprehensive risk model in a very generic way (e.g., some type of general “context factor” representation).
- *Classifications:* There are many ways that risks can be grouped and classified into risk categories.
- *Risks without consequences:* ISO defines the concept that a risk event that takes place without causing the expected losses can be described as “near miss”, “near hit”, incident, or close call. A record of near miss risk events can be valuable in assessing future risk likelihoods and impacts.
- *Associations with other project model objects:* Risks are generally associated with other project information—such as the objects or processes that are negatively impacted by the risks, the actors that cause or respond to the risks, the resources and plans used to respond to risks, etc. Much of this information could already be represented in a comprehensive project or building information model (BIM). Models used to represent risks, then, should include association links to this other relevant information within a comprehensive project model.
- *Risk triggers, risk event chains, related risks:* The extended risk model given above represents a risk situation as a string of specific types of events: a contact event between a threat and an asset, leading to a threat event, leading to a risk (a loss event). An alternative to this approach of describing specific types of sequential events is to model the idea that risks are triggered by external factors: risk triggers. This can be represented by explicitly modeling risk triggers, which can be anything that causes or triggers a risk. This approach can be extended to represent chains of events that eventually lead to risks. For example, the event “election” could trigger the event “loss of project’s political sponsor”, which could trigger the event “project cancelled”. It may be that long event chains could be modelled in this way, with only the final link representing an actual risk to the project. Alternatively, a model could capture the idea that risks are inter-related, and any one risk on a project could influence other risks (or they could both be influenced by common factors). For example, if a project is impacted by the risk “foundation excavation delayed by severe weather”, then the project has a much higher likelihood of also experiencing the risk “foundation concrete work delayed by severe weather”. A model could represent such influence associations between risks. The modeling of risk event chains may involve influence diagrams, semantic nets, or similar techniques.
- *Risk management artifacts:* Risk management functionality will be discussed in Section 6, but if systems are created to support risk management, then a risk model may need to represent some artifacts of the risk management process itself. These could include risk management processes (e.g., the representation of a plan that includes risk management activities), risk management plans, risk criteria, risk reporting, etc.

5 Other Representation Issues

The previous sections outlined risk-related concepts that can be represented within a comprehensive risk framework. This section discusses a few additional issues relating to how risks can be represented.

5.1 Modeling of Risks within BIM and IFCs

The previous discussion described that risks are associated with a wide range of types of project information: physical components, work processes, actors, etc. As such, risks can be positioned appropriately within a comprehensive building information model (BIM). However, few, instances of comprehensive BIM models that incorporate risk have been found (Ye 2009). In particular, the international open standard for BIM models, the Industry Foundation Classes (IFC), does not include a representation for risks. It also does not support probability distribution values for key project parameters such as costs and durations, which would be useful in developing risk-related project data. It does

include the representation of events, from which many of the risk-related classes could be derived, and this class would be able to be associated with a wide range of other project information.

5.2 Visual Representations of Risks

To this point, risk representation has been discussed in terms of data representation and data structures. Another type of representation that could be a part of a comprehensive risk framework is a visual representation. A construction project could include a very large number of risks, and it will be difficult for humans to keep track of these risks, identify the risks relevant to specific situations, and recognize significant risks and patterns. Visualization can help with this. Figure 4 provides an example of a visualization of impact risks for the international space station, where risks associated with different locations of the space station are visualized using the geometry of the space station itself, and using a colour coding scheme to identify the magnitude of risk. Colours are often used to illustrate risk magnitude (e.g., using red, yellow, and green to indicate risk magnitude).

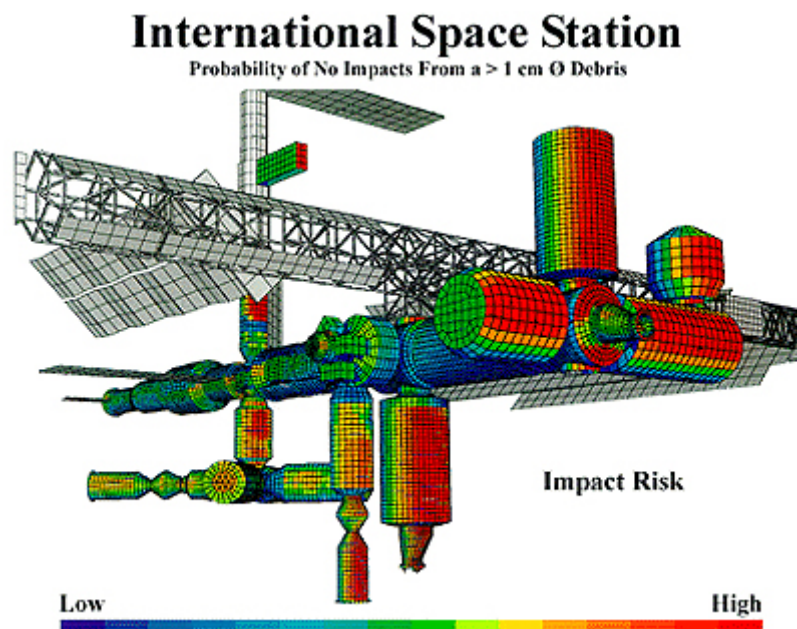


Figure 4. A visualization of impact risks for the international space station (source: http://en.wikipedia.org/wiki/File:ISS_impact_risk.jpg)

6 Functionality of Risk Management Information Systems and Conclusions

This paper has presented models to the representation of risks within RMIS's. Froese (2012) goes on to outline a collection of functionality that could be supported by RMIS's, ranging from core risk management processes (including risk planning and analysis tasks of risk identification, risk quantification, risk mitigation; risk control) to fairly "blue sky" ideas for future systems.

To summarize, risk is a critical issue in the construction industry. At present, computer tools are used to support very specific risk management processes, such as checklists for risk identification or spreadsheets for risk assessment calculations. However, with the emergence of integrated project information models (e.g., BIM and IFC's), and advanced computing techniques such as data mining, the potential exists for much more advanced support of risk management and analysis. This paper outlines an approach to the representation of risk in Risk Management Information Systems (RMIS), as one early step on a long path towards the development of advanced computer systems to support the risk management process in the construction industry.

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