Spatio-Temporal Process Approach for Multi-Hazard Risk Analysis

Dr. A. Harinda Lakmal, Senior Lecturer, Department of Civil Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Ratmalana

Abstract

The term Risk is always followed by the term of Hazard. Risk might be interpreted as damage either to the human life or physical assets. On the other hand, risk depends on the hazard event occurring probability and the effect to the society by the event. This paper addresses to discuss possibilities to overcome the aleatory uncertainty through spatio – temporal data. It is necessary to develop new techniques to accommodate the peculiarities of the combined spatial and temporal information that take their outset in existing techniques and minimally extend them. On this platform, the current status of the risk analysis, the limitations and proposed solutions for the applicable methodology due to uncertainties of the risk analysis models, are discussed.

Introduction

Any threat, which occurs again to the innocent human life is called a hazard that can be measured by risk. Hazards may be either natural or manmade. Any hazard, which can happen directly due to the natural phenomena is called natural hazard like flood, landslide, storms, or tsunami etc. The concept of risk is invoked as a central issue across a wide range of policy debates. How can risks be reliably identified, how can they be managed, under what circumstances should they be accepted or rejected and, especially, how are they likely to be interpreted or 'perceived' by different people? These questions arise in areas as diverse as health and lifestyle, hazardous industries, pensions and investments, transport, climate change and environmental protection.

In risk analysis, the extent to which potential undesirable consequences threaten the performance of a given activity is quantified by constructing and analyzing a model. The model constitutes a simplified representation of the real system, reflecting the causal relations that produce the events focused on by the decision-makers. The complexity of the model is governed by several factors, such as the complexity of the system, the knowledge about the system that is available to the risk analysis team, the amount of information the decision-makers consider a sufficient basis for making the decision in question and the resources available to the analysis team.

Risk analysis aims to use available information to estimate the risk to individuals or populations, property, or the environment, from hazards by qualitatively & quantitatively. Among them, the qualitative risk analysis deals with the description of the magnitude of potential consequences and the likelihood that those consequences will occur.

Status of Risk Analysis

Risk, because of natural hazards, depends on two factors named, the probability of a certain event occurring and the effects of that event. The effects depend on the characteristics of hazard and on the exposure and vulnerability of people and the built environment. The effects of natural hazards can generally be classified as building and infrastructure damage, direct and indirect economic losses; and societal losses (injuries, fatalities, social dislocation). For the calculation of these effects, it is necessary to model those hazards / scenarios on mathematical base.

Initially, in the model of natural hazard events is the development of a mathematical model to represent the physics of the phenomenon. Broadly speaking, two kinds of mathematical representations can be developed called, deterministic and probabilistic.

Deterministic models provide results for a specific scenario, usually the worst-case scenario, but they do not provide information about the effect of uncertainties on the results. Probabilistic models, on the other hand, can account for uncertainties by using random variables. The effects of each of these events and their probability of occurrence can then be determined. To ensure that the model includes a probable population of events likely to affect the region of interest, values for the random variables used to model the hazard can be obtained from historical records. By working with a range of possibilities and modelling uncertainty in a rigorous manner, probabilistic models provide a more complete picture of the risk. For this reason, probabilistic models are becoming the preferred methodology for risk analysis [4].

Limitations of the Current approaches

The most difficult part of probabilistic model development is the identification and inclusion of uncertainty in the model. In particular, it is important to distinguish and represent two kinds of uncertainty: aleatory and epistemic.

Aleatory uncertainty includes natural variability and the inherent randomness of complex physical phenomena. This kind of uncertainty can be estimated but it cannot be reduced.

As an example of aleatory uncertainty, never predict the location, time and intensity of the next hazard will affect. In other words, uncertainty emerges due to the information gather from input data.

Epistemic uncertainty is the result of inadequate data and incomplete model development due to limitations in knowledge of the phenomenon's physics. This kind of uncertainty can be reduced with better data collection, advances in knowledge of the physics of a phenomenon and refinement in models to represent it. For example, in a cyclone model epistemic uncertainty exists in the model itself and the values of model parameters such as central pressure, radius to maximum winds, translation speed, and location and characteristics of buildings affected by the phenomenon [3].

Among those uncertainties, aleatory uncertainty is the most considerable limitation in this research.

Brief EXPLANATION OF the Limitation

At present, there is no correlation between the input data with time. I.e. its only concern the static condition, instead the dynamic. If it is possible to use the time dependent spatial data instead of the present input, it is not quite impossible to predict those hazards to violate the aleatory uncertainty. Input data, i.e. the causing factors may have different steady periods, which can maintain its statues constantly. Within this steady period it is almost act as ideal to the modelling criteria. If it is so, final predicted result and the ground truth or final incidence ideally, match together. However, unfortunately it will not happen, as nothing factors have infinite length of steady period. Length may vary up to hundreds or thousands million years from the mille – second. Due to this variation, the steady period may classified as long term & short term. Generally, if any factor has the steady period of more than ten years it may classified into long term steady factor, while the rest as short term. Example of long-term steady factors is soil condition, geological factors, bedrock etc. In hazard modelling, less number of long-term steady factors associates with recognized models. Unlike, long-term factors, short-term steady factors have inconsistent behaviours in considerable period. Due to this inconsistency, final incidence may vary from the prediction. Ignoring the short-term factors is impossible, as the quantity take much higher value than long term. Ground water condition, Land use, Land cover, tidal level, etc. are examples of short-term steady factors.

Solution to the Limitation

Perfect solution will be the use of time dependent spatial data (i.e. Spatio-temporal data) instead, the present input data. What will be the separation between current & Spatio-temporal data? There is not much significant change between them. Only consider the time due to the spatial changes. As a result, the whole modelling system will change in to 4D from 3D, by using the Time variable as the fourth axis. However, the most important thing should keep in mind, that the Independent variable will be Time in this 4D system, while the rests are dependent since nothing will steady due to the time. Then is it necessary to use Spatio-temporal data for all kind of causing factors in the model? No. The Spatio-temporal data for Long-term steady factors will not effective on cost benefit basis for short-term period. Therefore, it is sufficient to use Spatio-temporal data for short-term factors, while remaining long-term factors as constant basis, which can easily be use to current input data. The next question will be is it possible to automate Spatio-temporal data. Answer is "Yes." Therefore, above discussed limitations may overcome with the appropriate spatio – temporal data automation model.

Spatio-temporal data automation models

It is necessary to have a better support for both spatial and temporal changes by a spatio – temporal model. Spatial changes can be classified as static or transitional, as well as the temporal changes can be classified as mutation or movement. When considering the uncertainty point of view, the most important fact is the temporal changes.

Mutation refers to changes to the internal mechanism of an event or a process or to the interaction between event or process and their environment. Movement concerns the travel of an event or an entity from one place to another and the event or entity may or may not involve changes in spatial properties other than location [5].

The ideal example for this type of modelling is Cyclone. Thunderstorm and tornado as subsets of cyclone may develop in a place and progress to other place. A practice of artificial rainfall in a region may mutate the patterns of precipitation and water resources in its surrounding area. Type V changes, i.e. for a given area where attributes may change site to site and from time to time, analysis is done by fixing location, controlling time, and measuring attributes (Yuan, 1996), describe the mutation of a type of processes or events (semantically objects) by two sets of temporal objects;

each of them is linked to a set of spatial objects. Comparisons are made between the two sets of spatial and temporal objects to show how a process mutates its attributes, temporal properties, and spatial characteristics in the two sets of time series. Therefore, a comparison of frequency, period, and severity of an event in an area at different periods may suggest Type V temporal changes in the area.

Figure 1 expresses the spatio – temporal representation of the mutation of Cyclone as follows.

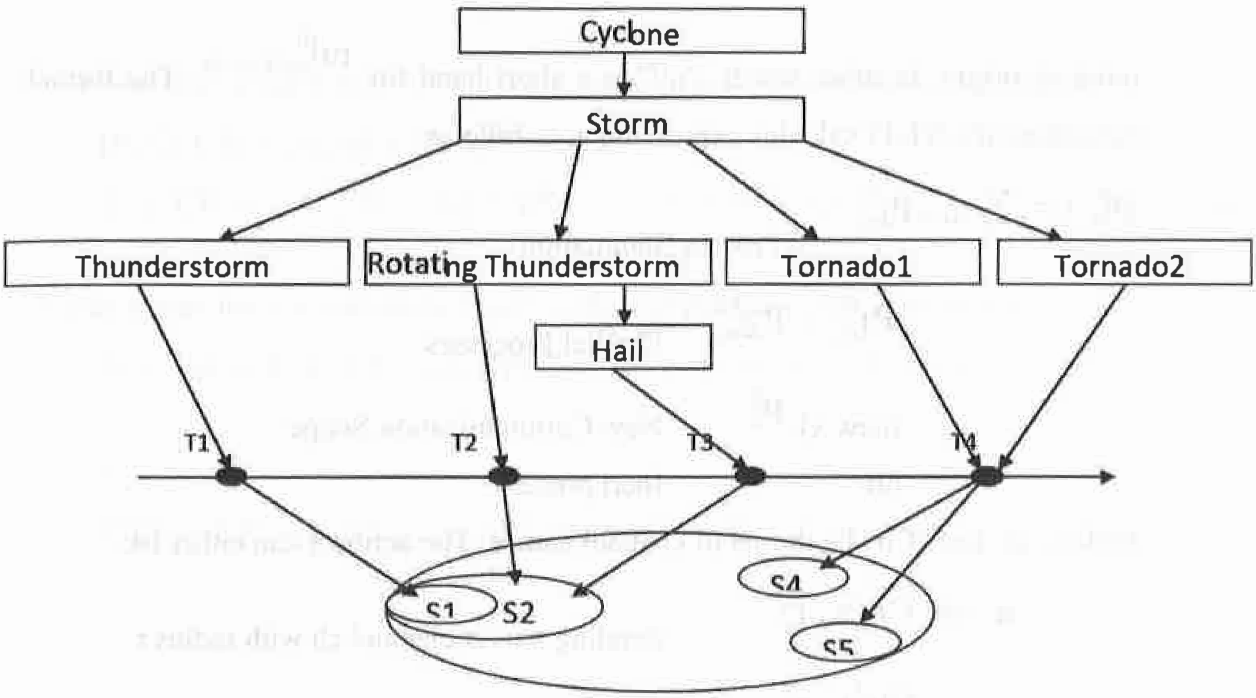

Figure 1: An example of mutation of Cyclone

Modelling of mutation can be done by using the following syntax and semantics of ST-Pi calculus, which is the spatio temporal extension of pi calculus [2].

ST-Pi calculus [1] is the spatio temporal extended π – Calculus to allow a free movement of parallel π processes. Adding a spatial notion to a process definition is straightforward, as each process P can be associated with a certain position $\vec{p} \in V, V = \Re^d$ being a vector space with a norm || ||V.

As each process P is now associated with its current position $\vec{p}$ and a movement function m, it can be written as $P^{\vec{p}}_m$. The position vector is superscripted and, since it is a vector, marked with an arrow. The movement function of the process is subscripted.

ST-Pi calculus [1] expressions use the same operators as π processes, so it can be presupposed that a normal form (or standard form) can be found for each expression. A normal form is an expression (new $\tilde{a}$) (M1| . . . |Mn), with $\tilde{a}$ being a set of restricted names five (5) and each process Mi is a sum.

Syntax: The set of all ST-Pi calculus expressions are rather similarly to the π – calculus, except that the replication, i.e. it is not part of the basic definition. An empty process, "nil", is introduced, which does not move and has its position at V's point of origin. In other words, "nil" is a short hand for $\mathrm{nil}^{\vec{0}}_{m(\bar{0},\chi)=\bar{0}}$. The formal definition of a ST-Pi calculus expression is as follows:

$$P^{\bar{p}}_{m} ::= \sum_{i \in I} \pi_i \cdot Pi^{\vec{p}_i}_{1_{m_i}}$$

Process Summation

$$P1^{\vec{p}_1}_{m_1} \mid P2^{\vec{p}_2}_{m_2}$$

Parallel Processes

$$(\text{new } x)\ P^{\vec{p}}_{m}$$

New Communication Scope

nil Inert process

Prefix – π: Let "Ch" be the set of channel names. The action π can either be:

$$\pi ::= \overline{Ch}\langle x, r\rangle$$

Sending x over channel ch with radius r

$$Ch\langle x, r\rangle$$

Receiving x over channel ch with radius r

$$wait\langle t\rangle$$

Waiting until time t

Semantics: The operational semantics have defined as rules on a tuple, but with the help of some predicates. Two predicates are defined on this configuration: COMM is true if a communication is possible and WAIT is true if the end time of a wait action has been reached. If neither is true, no parallel process may act or interact at any remaining moment of the current time interval. This results in the transition from one interval to another. The predicates are used to express the conditions of the two rules that constitute the semantics of a ST-Pi calculus execution.

The predicate COMM defines under which circumstances process $P1^{\vec{p}_1}_{m_1}$ is able to send "y" over channel "Ch" to is able $P2^{\vec{p}_2}_{m_2}$, where "y" then substitutes "x":

$$\left(P_1, P_2, Q_1, Q_2, Ch, x, y, CP, T, o\right) \in COMM \Leftrightarrow$$
$$P1_{m_1}^{\vec{p}_1}, P2_{m_2}^{\vec{p}_2} \in \vec{t}_1, \vec{t}_2 \in T \wedge Ch, x, y \in Ch \wedge o \in [0,1-\lambda] \wedge$$
$$(P_1 = \ldots.. + \overline{Ch}\langle y, r_1\rangle.Q_1 + \ldots\ldots) \wedge (P_2 = \ldots.. + Ch\langle x, r_2\rangle.Q_2 + \ldots..) \wedge$$
$$\| \left(\vec{p}_1 + o.(\vec{t}_1 - \vec{p}_1)\right) - \left(\vec{p}_2 + o.(\vec{t}_2 - \vec{p}_2)\right) \|_v \leq r_1 + r_2$$

The predicate Wait is true if there is a process P that acts time-triggered due to a wait action:

$$\left(P, Q, CP, t_i, \lambda, o\right) \in WAIT \Leftrightarrow$$
$$P \in CP \wedge o \in [0,1-\lambda] \wedge (P = \ldots.. + wait\langle t\rangle.Q) + \ldots.. \wedge t = (t_i + \lambda + o).\delta_t$$

In addition to that, the NIL rule can be used to reduce nil processes. NIL rule declared as:

$$P = nil \wedge P \in CP : \langle \tilde{a}, CP, T, t_i, \lambda, \delta_t\rangle \rightarrow \langle \tilde{a}', CP', T', t_i, \lambda, \delta_t\rangle \text{with} :$$

if

$$CP' = CP - P, \tilde{a}' = clear(\tilde{a}, CP'), T' = T - \vec{t}_{ind(P)}$$

Conclusion and Future work

In risk analysis, we are concerned with uncertainty related to the outcomes of carrying out some activity that is considered important in a decision-making setting. Examples of outcomes considered are observable quantities such as the number of fatalities, the extent of environmental damage or performance measures of purely economic interest, such as the degree of fulfilment of technical objectives or time consumption. Typical decision processes where risk analyses are used are the overall selection of conceptual layout in a project, comparison of alternative system configurations, and operational strategies. Risk analyses may improve the decision basis by quantifying the overall risk level associated with the decision alternatives, identifying main contributors to risk, and the most effective measures for reducing it. Finally, further research still needs to incorporate spatiotemporal constructs from natural phenomena into the modelling of temporal information to fully analyse the risk of natural hazards through uncertainties.

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