Risk Based Reasoning in Decision-Making for Emergency Management

An Introduction

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Presentation outline

- Problem Definitions
- Methodological Assumptions
  - Abstract Intelligent Agent
- Multi-Context
  - Decision-Making
  - Emergency Management
  - Risk
- Temporal Decision - Making Model
- Conclusions

"Make everything as simple as possible, but not simpler." [Albert Einstein]
Problem Definition

**RBR** is **not** a reasoning about risk,

it is **not** a part of risk analysis or risk management,

It is a reasoning process which starts from just recognized risk and leads to a decision.

… but **RBR can be applied** in different hazard situations by human managers and by computer Decision Support Systems.
Why Risk Based Reasoning?

**TARGET:**
**Active/Intelligent Decision Support Systems** for Emergency Management

**METHOD:**
Systemic approach, Qualitative Reasoning/Physics [Winograd, 1994],
**TOGA** (Top-down Object-based Goal-oriented Approach) meta-methodology [Gadomski, 1990/3]

**META-PROBLEM:** We need to identify rather what is possible to support than how to do it. -- Needed:
- a model of **Computer-Human-Environment aggregate**
- its specification to the level where current tools of information technology are applicable.

**SOLUTION:** RBR in frame of **Decision-Making model** under Emergency Management constrains

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Methodological Assumptions: TOGA Concepts

RDR requires the modeling of: intelligence, decision making, risk

Basic paradigms:
- Top-down
- Object-based
- Goal-oriented Approach

Basic conceptualization couple:
- Intelligent Agent
- Environment
  interaction

Basic concepts:
- Object
- Relation
- Change
- Action
- Message
- Communication
- Information
- Preferences
- Knowledge

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Abstract Intelligent Agent representation: Basic concepts of IPK architecture

- **Information**: how a particular situation looks (before, now, in the future)?
  - facts, measurements, observations

- **Knowledge**: how situation may be classified and modeled, and what is to do in” this type of situation “?
  - descriptive frames, rules, procedures, methods

- **Preferences**: what is more important? what is more efficient?

- **Goal**: what should be achieved?

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Set of preferences

- Reasoning about preferences

Set of knowledge

- Reasoning about knowledge

(Risk?)

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Abstract Intelligent Agent: Multi-level Architecture

Real Domain

Activity Domain System

Preferences System

Knowledge System

Possible domain-independent reasoning mechanisms:
deductive, inductive, abductive, case based ... + different logics
Multi-Context

Emergency-Management context

Decision-Making context

Risk analysis context

Methods

Formal Mechanical RBR in IDSS for EM

Systemic & AI approach based on Abstract Intelligent Agent and AI technologies

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Definitions

**Decision-making** (d-m) is a mental activity implied by the necessity of a **choice** either
- without known **criteria**
- or
- without known **alternatives**.

**Decision** - a result of the choice.
Reasoning in IPK model

Knowledge and Information

\[ I_y = K_i (I_x); \quad \text{or} \quad K_i: I_x \rightarrow I_y \]
\[ A_y = K_o (I_x); \]

I - information representing state/situation/change of a decision domain, DD

K\(_i\) - knowledge operator representing an inference association on DD

K\(_o\) - knowledge operator representing an available operation on DD

A\(_y\) - represents an action on DD executable by agent.

K can be a result of: algorithmic calculation, rule, or expert advise.
Reasoning in IPK model

Preferences

\[ I_{in'} = P( I_{in}, I; I_M); \]

- \( P \) represents a preference operator on DD
- \( I_{in} \) denotes an initial preferred state of DD, called intention
- \( I_{in'} \) denotes a final preferred state of DD, called intention
- \( I \) denotes current state of DD.

\[ Y = P( X , I; I_M) \]

If intention_is \( X \) and \( I \in I_M \) then better intention_is \( Y \), what is equivalent to:

**For every state from the class \( I_M \), \( Y \) is better then \( X \).**
Reasoning in IPK model

An example of the knowledge-based interference path

Here, we may demonstrate that for the decision-making we need or new information or new preferences or new knowledge.
Reasoning in IPK model

First type of Decision-Making rules (preferences about knowledge):

\[ m_{PK}: \left( \text{if } A_1 \in AX \text{ and } A_2 \in AY \text{ and } Ix \in IM \text{ then } A_2 \right) \]

where \( AX, AY \) are classes of possible actions of the decision-maker,

\( IM \) is a class of the states of \( DD \).

Second type of Decision-Making rules (preferences about preferences):

\[ m_{Pp}: \left( \text{if } P_1 \in PX \text{ and } P_2 \in PY \text{ and } Ix \in IM \text{ then } P_2 \right) \]
Emergency Management (E-M) Contexts

Emergency
A state where risk and/or losses generation are higher than level accepted by the Decision-Maker (local administration) and which activate an adequate response of human organization (it starts from the mobilization of an emergency-management organization).

Emergency management goal
Reduce risk and losses to an accepted level.

Emergency management decision

Knowledge Base

No action (emergency end)

Preferences Base

Decision-Making

New Information

Action adequate to E-M’er role and E-domain situation
Definitions

Risk

It exists only in the context of decision-making.

It is an integrated factor related to an event/situation/object/product/action indicating whether it can cause harm, injury for human or another losses for D-M’er World [Gad].

Risk can be expressed in different scales which a choice dependent on
- D-M’er information about considered entity,
- D-M’er current situation (possibilities of actions)
- D-M’er’s criteria (role = competencies, responsibility and duties).

RBR requires operations on risk, as on the attributes of other ED-entities.
(ED-entity - event/situation/object/product/action related to Emergency Domain).

Different conceptualizations of risk require different reasoning methods.
Risk is dependent on IPK of D-M'er

Humans tend to
- sustainability,
- betterment/improvement of their life conditions and to
- maintenance of their properties.

Therefore risk factor value is determined according to their belief about their situation, possibilities and desires of D-M'er in concrete circumstances.

- Risk is a key criterion in the d-m choice.

- Risk is considered proportional to the probability of loss generation event and to the importance of this loss for the decision-maker.
Risk Contexts

Risk is an attribute of emergency domain elements:

- objects, \( O(R,.) \)
- relations (propagation), \( r (R,. ) \)
- changes (caused by D-M’er), \( ch(R,. ) \)

**Risk object.** an object with can be sources of losses or an object which [in situation X] may generate losses, and risk related to this object is not neglected from the point of view of a criteria assumed as a qualitative risk reference level.

In other words, if the risk value related to the object influences D-M’er decisions then this object is considered as a risk object.

RBR integrates reasoning and risk features.

There are many methods which can lead to the adding value to the **risk factor.**

**Problem:** what people does when the risk value is highly uncertain.

*Reasoning and D-M under uncertainty of risk assessment.*
Risk in D-M

Risk can be expressed in different modes:

- **quantitative**: calculated (related to engineering equipments).
- **qualitative**: assessed (economic, political).
- **comparative**: described (social, cultural).

Descriptive RAss produces a comparison among few different events considerable risky by domain experts.

Choice of a proper risk expression depends on our goals/preferences, knowledge and information.
Evaluation of losses can be defined in a few scales of values. The choice depends on human expert. For example we can accept 3D space, $3D = L_1 \times L_2 \times L_3$.

**L1. Human Losses** with the 5-th values domain: 
*not_exist*, *not_expected*, *low* (for example: cars incident), *high* (aircraft, airport, local industrial explosion with toxic gas emission), *very_high* (epidemy, city-size,..).

**L2. Material (Economical) Losses**; their scale is numerical and depends on the preferences of human D-M'er. Their normalization to the interval $(0,1)$ may be useful.

**L3. Cultural & Environmental Losses**; they are not retrieval, or are recoverable after more than 15 years, possible values scale: 
*neglected*, *low*, *significant*, *high*, *very_high*, *unforeseeable_high*. 
Risk evaluation can be based on the estimation of qualitative losses and probability of event. Risk is estimated in a moment $t$ and it refers to an event $E (t, \Delta t, \cdot)$:

$$ R (E, t) = P (E,t) I \times L (E, \cdot) \times, $$

$P (E,t) I$ - a diagonal matrix of estimated by experts (or calculated) probability of an event $E$ in the moment $t$.

$L$ - $D3$ vector of losses, $R = [r1, r2, r3]^T$.

$\Delta t$ - the time of duration of event $E$.

The expression (*) can be quantitative or qualitative. An example of Risk 5-values scale: $n$ (no_risk), $l$ (low), $m$ (middle), $h$ (high), $vh$ (very_high).

Total risk $R_T (t) = \sum_{\text{qualit}} R (E_i, t). = \max r_i (E_i, t)$.

General initial criterion could be the following:

if $R_T (t) > \text{low\_risk}$ then the emergency organization should be active.
Risk assessment

From the perspective of D-M’er and for RBR, exists only a D-M’er belief about objectivity of risk.

Qualitative Risk assessment

<table>
<thead>
<tr>
<th>Probability: L1(\text{losses})</th>
<th>n (=0)</th>
<th>low</th>
<th>middle</th>
<th>high</th>
<th>very high</th>
</tr>
</thead>
<tbody>
<tr>
<td>not exist</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
<td>n</td>
</tr>
<tr>
<td>not-expected</td>
<td>n</td>
<td>n</td>
<td>l</td>
<td>l-m</td>
<td>m</td>
</tr>
<tr>
<td>low</td>
<td>n</td>
<td>l</td>
<td>m</td>
<td>m</td>
<td>h</td>
</tr>
<tr>
<td>high</td>
<td>n</td>
<td>m</td>
<td>m-h</td>
<td>h-vh</td>
<td>vh</td>
</tr>
<tr>
<td>very high</td>
<td>n</td>
<td>m</td>
<td>h</td>
<td>vh</td>
<td>vh</td>
</tr>
</tbody>
</table>

Table - An example of the Qualitative Multiplication Matrix for Risk Assessment (ri).
• Temporal Decision - Making Model

Risk, Danger, Chance and Hope Model

Integration of the concepts of losses, risk, profits and hope in time scale of D-M’er.

Assessment Models

Losses - Risk - Danger

Profits - Chance - Hope

D-M Model

Danger - Hope

D-M Criterion
Danger assessment

**Assumption:** Risk can appear in deterministic or probabilistic way after a time $t$.

*Danger* extends hazard and emergency state on situations where risk is yet considered neglected.

*Danger* take under consideration the time when a particular risk may appears.

Danger in a moment $t_o$ exists if a risky event can appear after the time $t$. 

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Danger

If $P_o(s_0 \rightarrow s)$ is the probability of the passing of E-domain from a state $s_0$ to the state $s$, i.e. which leads to the event $E$ with not neglected risk $r(E,.)$, then:

$$d(E, t) = \frac{P_o(s_0 \rightarrow s)}{t + \tau}$$

where: $d$ is danger in an arbitrary moment $t_0$ related to an event $E$ which will appear in the moment $t_0 + t$.

$t - s$ called waiting time

$\tau$ - is a time interval recognized by experts as necessary for the elimination of $r(E,.)$.

Example: Let us assume: $P_o(s_0 \rightarrow s) = 1$ then

<table>
<thead>
<tr>
<th>$t$</th>
<th>$d(E, t)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt; 1$</td>
<td>$r(E,)$</td>
</tr>
<tr>
<td>$1$</td>
<td>$1/2 \ r(E,)$</td>
</tr>
<tr>
<td>$2$</td>
<td>$1/3 \ r(E,)$</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>$100$</td>
<td>$1/101 \ r(E,)$</td>
</tr>
</tbody>
</table>

The same risk if related to remote future events has very low danger because D-M’er has many time to decide when he/she should intervene.
 Chance and hope

In the cases of not very-high risk and insufficient data, human decisions depend very strongly on the individual psychological profile and temporal preferences.

These aspects represent S-M'er point of view. In routine tasks, humans tend to minimize their own danger (risks) and to maximize possible profits.

The analog to the risk factor, but related to profits is here chance factor. The chance factor may be expressed in the same way as risk. The analog to danger may be hope factor estimated as follows:

\[
\tau
h (E, t) = \frac{P_o (s0-> s)}{Ch (E, \tau)} - \frac{t + \tau}{t + \tau}
\]

where \(\tau\) is a minimal time necessary for the modification (to increase) either \(P_o (s0-> s)\) or \(Ch (E, \tau)\).

In real situations, human agent decision depends on the confrontation of his/her dangers and hopes.
Consequences of incomplete expert knowledge

Event (d-objects, changes, ∆t)

d-object - an object from emergency domain ED
change - is describable as a process
d-object is risk object if during ∆t it can cause losses.

Event (losses, risk, ∆t)

Event is possible

We have introduced possibility operator ◊.

◊ e1(O1) and ∃P (E1(Oa) -> E2(Ob)) and (e1 ∈ E1 and O1 ∈ Oa) and (∃ O2 ∈ ED and O2 ∈ Ob) ----> ◊ e2 (O2) and e2 ∈ E1
Emergency propagation

In this way we have defined the emergency propagation operator of possible events.

This is the Risk (risky Event) propagation operator from O1 to O2 object which satisfy the condition of emergency management activation:

Risk (O1, O2)

Example:

\[ \diamond e_1(O1) \text{ and } ( \exists \Rightarrow (O1 \rightarrow O2) ) \Rightarrow \diamond e_2 (O2) \]

It means

If event e1 related to the object 1 is possible, and exists an emergency propagation from 01 to O2 then event 2 related to the object 2 is possible.
Reasoning

Natural vs. technological source of the risk - is a false problem in RBR.

The Example of a Basic Reasoning string:

Let $X$ be event/object/action,

If $X$ may cause losses (L) then $X$ is risky. - Unconditioned

If $\Diamond X$ and $L(X)$ are unaccepted$_{(i)}$ and $\text{Prob}[X]_{(j)}$ is unneglected

then $X$ is risky. - Conditional

Context dependent variables: $L_i = 0$ or $1$, $\text{Prob}[X]_{(j)} = 0$ or $1$

$i, j$ - are indexes of different points of view.
Risk and Losses Propagation - Events model

Emergency propagation map

- primary event
- registred event
- cause searching model
- consequence searching model
- Domain - risk model
- Domain model

Active events
Expected/possible events

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Emergency propagation - Objects model
(losses and risk propagation between domain objects)

LEGEND
Dynamic states of nodes:
- active
- no more active
- not activated (yet)
- disactivated

- not vulnerable node (no losses)
- vulnerable node (with losses)
- cause-consequence relation
- primary source
- transmitter
- secondary sources
- barrier
- output node (emergency escalation)

Decisions are based on the assessment of danger.
Illustration of Multi-level reasoning and D-M

Observation activity

Action execution
Intelligent Decision Support System - Its domains of intervention

- Suggested intervention
- Suggested executors
- Suggested cooperation
- Suggested request of information

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ACTIVITY DOMAINS OF
EMERGENCY MANAGER

different roles

Emergency manager

cooperation

Experts

tasks

action

Executor 1 (afu)

tasks

Emergency manager

Executor 1 (afu)

tasks

Emergency manager

Executors N (afu)

tasks

Emergency Supervisor

tasks

cooperation

cooperation

cooperation

EMERGENCY DOMAIN
IDSS: Human-Computer Cooperation

[Gadomski at al, 1995]

EMERGENCY DOMAIN

- Information: em. domain current data
- Knowledge: rules, models, plans, strategies
- Preferences: risk, roles and resources criteria

EMERGENCY MANAGER

Cooperation
- dialogue
- suggestions
- explanations

Active DECISION SUPPORT SYSTEM

Intervention decisions
- Continuous monitoring
- Images, Measured Data

(Intelligent Agent)

cooperation

Human Organization

Experts

Intranet/Internet

data acquisition
Annex: Emergency Management Context

**Characteristics of emergency/crisis domains:** cover high-risk industrial plants accidents, transport accidents, territorial disasters and calamites. In general, it is referred to a **high risk**, complex domains not formally structured, such as ports, territory with population, airport infrastructure, railways node, oil pipes systems, chemical industry, etc. and to adequate **human organizations** which contribute as executors and partners in emergency management. Especially important are **multi-events emergencies** where previously prepared plans have to be changed or realized under unexpected conditions.

**Characteristics of emergency managers**
- They have qualitative weakly structured knowledge about emergency domain, their own competencies, their own organization possibilities, and other potential partners of emergency managing.
- They have a strong managerial skill, direct human assistants, an access to different experts and to information about the emergency and resources state.
- They need to cooperate with other emergency managers.
- They work under stress and in the presence of **many risks**.
- They are not computer specialists.
Annex: Top Emergency Activities - Domain Independent

1. Hazard Recognition and Risk Assessment

2. Danger Management
   Intervention Planning
   Resource Management: Control and Coordination
   Intervention Control and Coordination
   Warning and Communications

3. Risk Management
   - Instructions and Procedures dissemination
   - Logistic and Facilities
   - Training and Exercises
   - Public instruction and Information about risk
   - Finance and Administration Infrastructure Management
Hazard Recognition, Risk Assessment and Danger Management

RBR method must be adequate to the precision obtained from Risk and Danger Assessment.

Two Support Strategies in IDSSs
- Top-down support -- suggestion what to do.
- Bottom-up support -- suggestion how to do
1. IDSS for Emergency management needs a domain-independent model of Emergency Domain and role-independent model of Decision Maker.

2. Abstract Intelligent Agent model seems to be useful framework for the conceptualization of Decision Maker and RBR.

3. Risk Based Reasoning seems to be implementable on computer.

4. RBR should work for quantitative and qualitative assessment of risk and danger.

5. Reasoning rules should be either acquired from experts or calculated from domain-dependent models.

6. RBR can employ different logics.

7. RBR requires an experimental validation and research effort yet.