ON USING INTUITIONISTIC-FUZZY NUMBERS in RISK MANAGEMENT

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Abstract

- **This paper considers the evaluation of the Risk Priority Number (RPN) for FMEA (Failure Mode and Effects Analysis) approaches, and Software Risk Management (SRM).**
- **There are presented: the traditional RPN method and existing fuzzy logic based methods.**
- **Intuitionistic-fuzzy numbers and computational methods involving IFNs are described, and a new methodology for RPN estimation is presented.**
- **Finally, the new IFN-FMEA risk assessment is explained (over specific defuzzyfication methods) and its usage is shown for software project management**

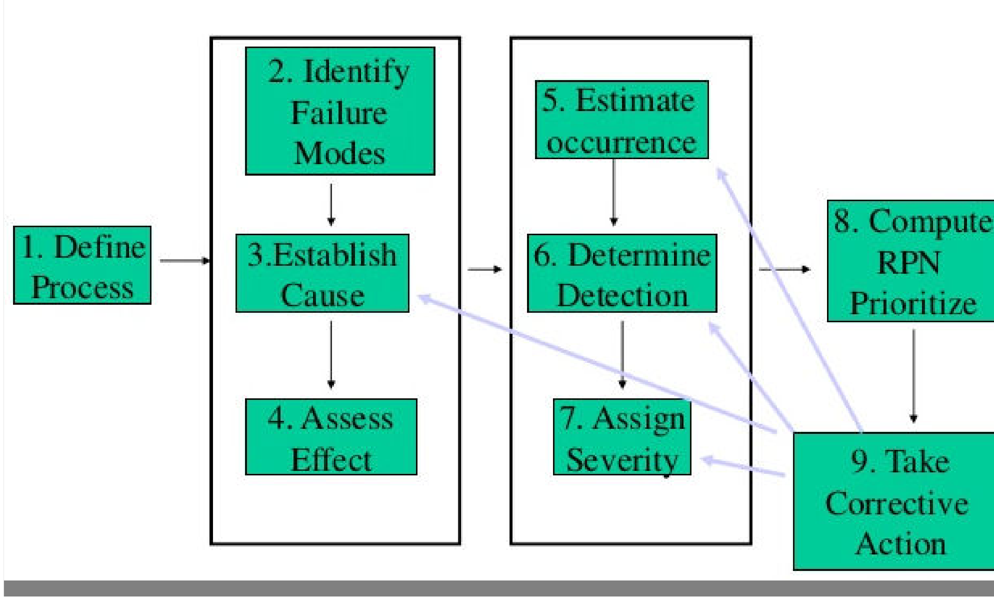
RPN (Risk Priority Number)

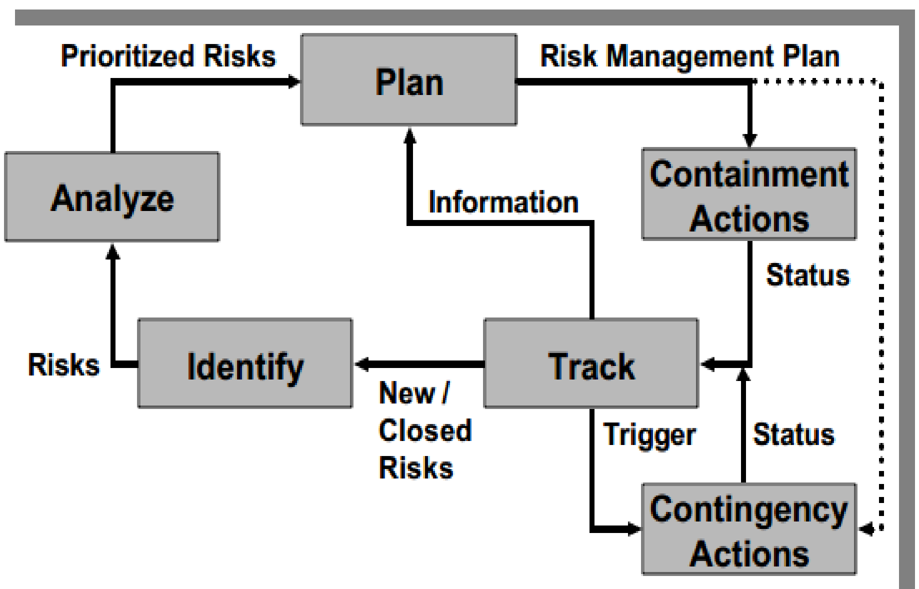
- The RPN (Risk Priority Number) is computed by the multiplication of the following parameters: ***severity*** (impact) – a measure indicating the gravity of the effects of a failure/hazard which affect the whole system or a vital component, ***occurrence*** – a measure indicating the probability of occuring a failure or a hazard, and ***detection*** – a measure indicating the detectability of the failure/hazard by adequate methods of control or inspections: RPN = **S***everity* x **O***ccurrence* x **D***etection*.

RPN Calculation, and FMEA Flow diagram/Risk Management

- In the RPN calculation, **the assigned values on the three index qualitative scales are interpreted as being numbers**.
- The RPN defines **the priority of the failure**. It is used to rank the potential deficiencies.
- A goal of FMEA is to **reduce the RPN** or Criticality/ Severity categories.

FMEA Flow Diagram





Risk Management Process

Qualitative scale for the severity index (S) (Stamatis 1995)

	Level	Criteria
No	1	No effect.
Very slight	2	Customer not annoyed. Very slight effect on product or system performance.
Slight	3	Customer slightly annoyed. Slight effect on product or system performance.
Minor	4	Customer experiences minor nuisance. Minor effect on product or system performance.
Moderate	5	Customer experiences some dissatisfaction. Moderate effect on product or system performance.
Significant	6	Customer experiences discomfort. Product performance degraded, but operable and safe. Partial failure, but operable.
Major	7	Customer dissatisfied. Product performance severely affected bu functionable and safe. System impaired.
Extreme	8	Customer very dissatisfied. Product inoperable but safe. System inoperable.
Serious	9	Potential hazardous effect. Able to stop product without mishap—time dependent failure. Compliance with government regulation is in jeopardy.
Hazardous	10	Hazardous effect. Safety related—sudden failure. Non-compliance with government regulation.

"Wouldn't it be great to be able to prioritize all risk items in an easy way?"

S	x O	x D	= RPN
2	10	10	200
10	10	2	200
10	2	10	200

Qualitative scale for the occurrence index (O) (Stamatis 1995)

Effect	Level	Criteria
Almost never	1	Failure unlikely. History shows no failure.
Remote	2	Rare number of failures likely.
Vert slight	3	Very few failures likely.
Slight	4	Few failures likely.
Low	5	Occasional number of failures likely.
Medium	6	Medium number of failures likely.
Moderately high	7	Moderately high number of failures likely.
High	8	High number of failures likely.
Very high	9	Very high number of failures likely.
Almost certain	10	Failure almost certain. History of failures exists from previous or similar designs.

Qualitative scale for the detectability index (D) (Stamatis 1995)

Effect	Level	Criteria
Almost certain	1	Proven detection methods available in concept stage.
Very high	2	Proven computer analysis available in early design stage.
High	3	Simulation and/or modelling in early stage.
Moderately high	4	Tests on early prototype system elements.
Medium	5	Tests on preproduction system components.
Low	6	Tests on similar system components.
Slight	7	Tests on product with prototypes with system components installed.
Very slight	8	Proving durability tests on products with system components installed.
Remote	9	Only unproven or unreliable technique(s) available.
Almost imposible	10	No known techniques available.

Problems in the RPN interpretation

- The assumption that the three failure mode indexes are all equally important.
- The assumption that the scales of the three S , O and D indexes have the same metric and that the same danger level correspond s to the same values on different index scales
- The possibility of identifying, with the same RPN, situations characterized by different danger index levels. For example , the condition assigning to (S, O, D) indexes the values (8, 1, 1) is considered at the same level as (2 , 2, 2). Both situations determine an RPN = 8. Other cases:

S	x	O	x	D	=	RPN
2		10		10		200
10		10		2		200
10		2		10		200

Proposals

- Severity: IFN
- Occurrence: Subjective probabilities or Frequency (when available)
- Detectability: IFN (cases: TIFN, TrIFN)
- A new multiplication operator
- The SOD Result is an IFN
- Order relation (comparison) for IFN
- Defuzzyfication
- IFN-FMEA formulation
- Compare against known approaches and applications

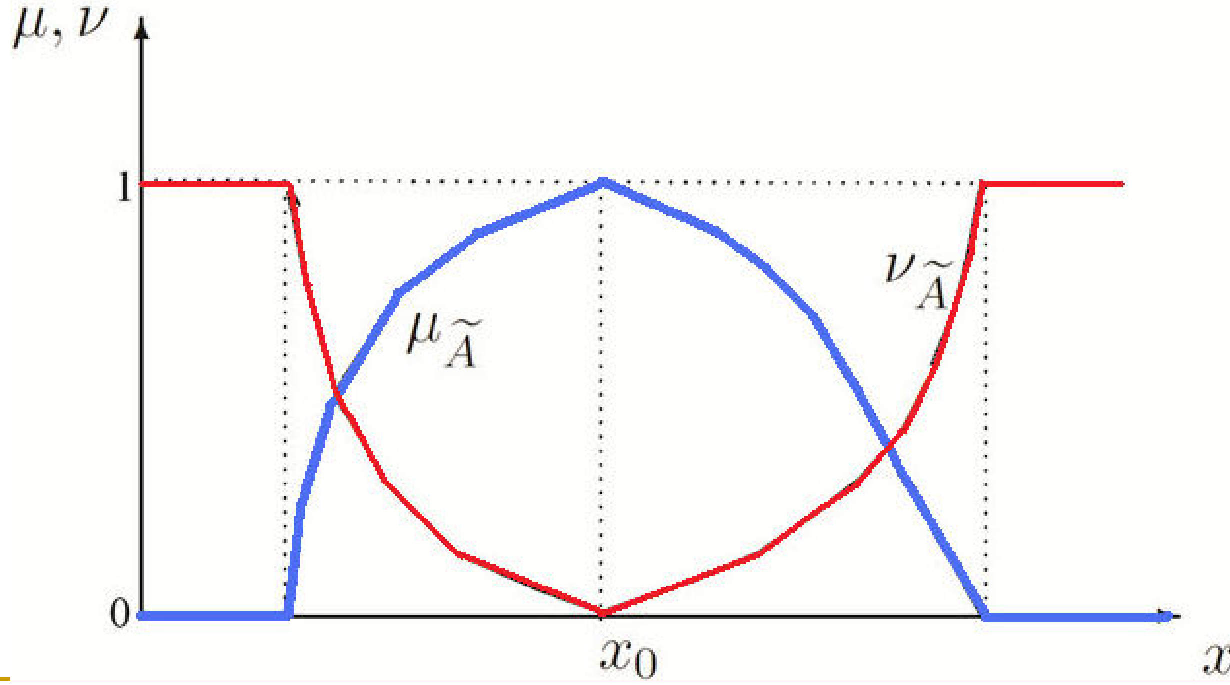
Subjective probabilities

- A probability derived from an expert/individual's personal judgment about whether a specific outcome is likely to occur.
- Subjective probabilities contain no formal calculations and only reflect the subject's opinions and past experience.
- Uses for RARE* events, otherwise the frequency of event can be used as an estimation for the probability of appearance.
- Problem: Subjective probabilities differ from person to person. Because the probability is subjective, it contains a high degree of personal bias.
- A multi-expert approach is necessary.

* *Rare events are events that occur with low frequency. Rare events encompass* ***natural phenomena*** *(major earthquakes, tsunamis, hurricanes, floods, asteroid impacts, solar flares, etc.),* ***anthropogenic hazards*** *(warfare and related forms of violent conflict, acts of terrorism, industrial accidents, financial and commodity market crashes, etc.), as well as* ***phenomena for which natural and anthropogenic factors interact in complex*** *ways (epidemic disease spread, global warming-related changes in climate and weather, etc.).*

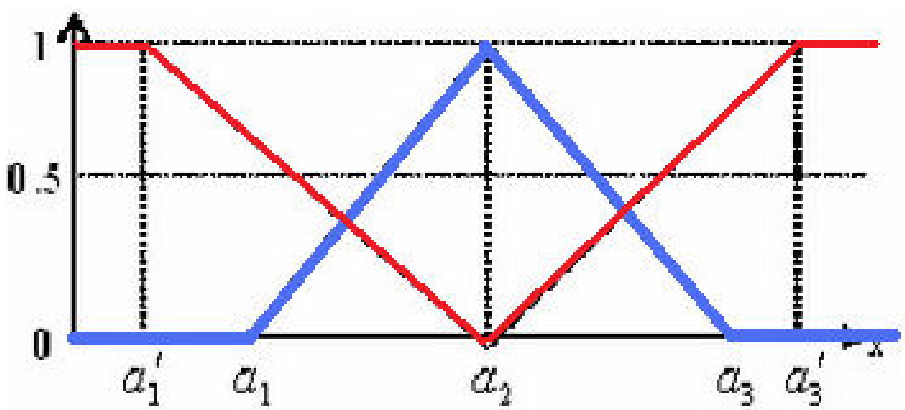
Intuitionistic-Fuzzy (Atanassov) numbers (IFN)

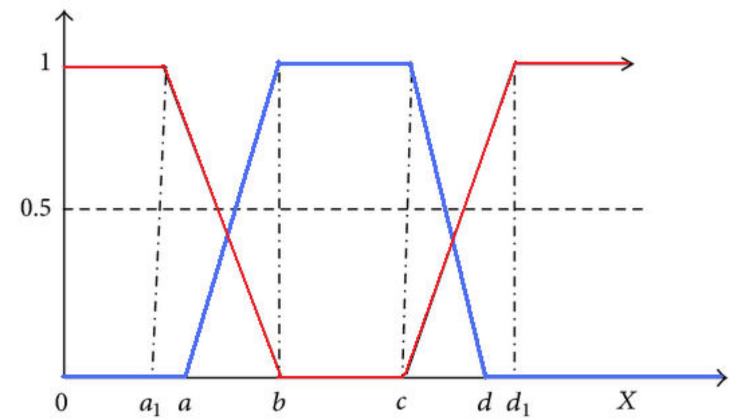
- Defined on the Real set of numbers
- By two functions: a *membership* function (μ - in blue), and a *non-membership* (ν - in red) function.



TIFN & TrIFN

- The most used IFNs: Triangular, Trapezoidal (red – the *non-membership* function; blue – the *membership* function)





TIFN(a'_1, a_1, a_2, a_3, a'_3)

TrIFN(a_1, a, b, c, d, d_1)

TIFN – Analytic expression (another way to describe TIFN)

- TIFN (m-a’, m-a, m, m+b, m+b’), a, b, a’ & b’ are distances around m;
- Alternative notation: TIFN (m; a, b, a’, b’)

$$\mu_A(x) = \begin{cases} \frac{x-m+a}{a}, \text{ for m-a} \le x \le m \\ \frac{b+m-x}{b}, \text{ for m} \le x \le m+b \\ 0, \text{ otherwise,} \end{cases} \qquad \nu_A(x) = \begin{cases} \frac{m-x}{a'}, \text{ for m-}a' \le x \le m \\ \frac{x-m}{b'}, \text{ for m} \le x \le m+b' \\ 1, \text{ otherwise.} \end{cases}$$

a' > a and b' > b

Computing with TIFN (defined as previously shown)

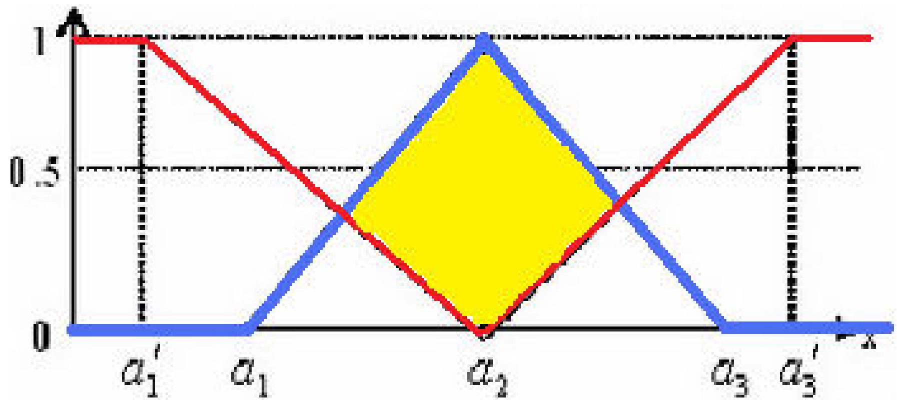
- If TIFN α = (m; a, b; a', b') and k > 0, then the TIFN kα is given by (km; ka, kb; ka', kb').
- If TIFN α = (m; a, b; a', b') and k < 0, then the TIFN kα is given by (km; kb, ka; kb', ka').
- If α = (m1; a1, b1; x1, y1) and β = (m2; a2, b2; x2, y2) are TIFNs, then the sequence defined by (m1+m2; a1+a2, b1+b2; x1+x2, y1+y2) describes the TIFN $\alpha \oplus \beta$.
- If α = (m1; a1, b1; x1, y1) and β = (m2; a2, b2; x2, y2) are TIFNs, then the sequence defined by (m1m2; m1a2+m2a1-a1a2, m1b2+m2b1+b1b2; m1x2+m2x1-x1x2, m1y2+m2y1+y1y2) describes the TIFN $\alpha \otimes \beta$.

Computing TIFN-RPN

- Given $S(s; s_1, s_2, s'_1, s'_2)$ the Severity model as TIFN
- Given p in [0, 1], the (subjective) occurrence probability of the failure
- Given $D(d; d_1, d_2, d'_1, d'_2)$ the Detectability index, as TIFN
- Then the TIFN-RPN result is: $pS \otimes D \rightarrow T$

Ordering TIFNs

- In order to rank the failures (F_1, F_2, …, F_n) based on TIFN-RPN, T_1, T_2, …, T_n, an order relation should be defined
- Proposal: For every T_i, let t_i be the abscise of the gravitation centre of the **Yellow** region (the centroid approach); **T_i LE T_j if and only if $t_i \leq t_j$.**



LE – Less or Equal

Advantaje over Fuzzy approaches (Zadeh's numbers)

- The Region is a 4-point polygon in the case of TIFN, while for Fuzzy numbers, the region is a triangle, and the centroid of TIFN depends also on the non-membership function.
- The model (TIFN-RPN, **LE**) can solve the case when same RPN is obtained for situations characterized by different danger index levels.

TIFN-FMEA approach

- For every Failure F_i (i=1, 2, …, n) establish (S_i, p_i, D_i).
- Compute $T_i = p_i S_i \otimes D_i$ (i = 1, 2, …, n)
- Rank the Failures according to the LE relation applied on the T_i sequence of TIFN-RPNs.
- Take corrective measures/actions as for usual FMEA.

TIFN-FMEA applications

- Industrial applications
- Economical field (risk management)
- Health (risk management)
- Any field where the standard FMEA can be used
- Better behaviour of TIFN-FMEA due to the existence of both a membership and a non-membership function.
- Extension: The Occurrence index can be modelled as TIFN. Then $T_i = S_i \otimes p_i \otimes D_i$.

Software Risk Management (SQAS21.01.00)

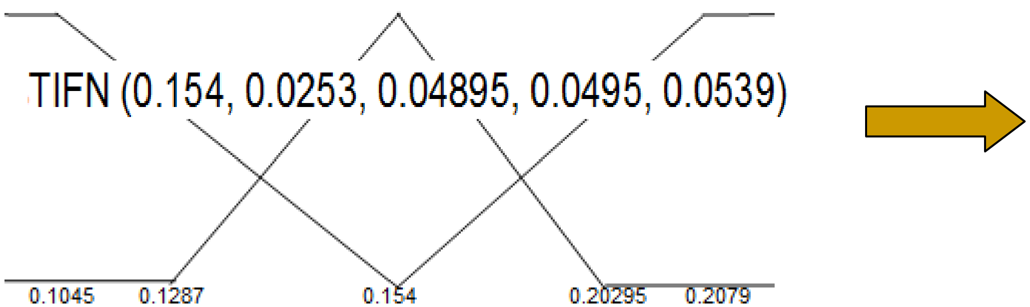
Communicate

SRM Model Functions	Process Activity Steps	Task	Outputs
Identify	(1) Identify Risks	The SRE Team analyzes a taxonomy of potential risk areas to identify a candidate list specific to the project.	Initial Risk Form
Analyze	(2) Analyze Risks	The SRE Team completes Risk Management Forms noting impact on cost, schedule, product quality, and probability and reaches a consensus on each risk.	Updated Risk Form
	(3) Prioritize Risks	A Risk Level is calculated for each risk serving as the means to rank the project risks.	List of prioritized risks
Plan	(4) Identify Risk Aversion Methods	The SRE Team performs an analysis to determine what risk aversion actions could be taken - risk avoidance, control, assumption, or transfer.	Risk Management Plan
	(5) Identify Risk Mitigation Methods	The SRE Team analyzes each remaining risk and develops a mitigation action to reduce the probability and/or severity of impact of each risk event.	Risk Management Plan
	(6) Identify Risk Recovery Methods	For each of the top N risks, the SRE Team documents the contingency actions and determines the trigger for invocation of a contingency action.	Risk Management Plan
	(7) Define Risk Metrics	The SRE Team identifies and documents the metrics necessary to determine if a risk is being averted or mitigated.	Risk Tracking Metrics
	(8) Implement Mitigation Actions	Management proactively proceeds to implement the identified risk aversion and mitigation actions.	Updated Project Plan
Track	(9) Track Risk	Project leads collect, analyze, and report metrics on both a periodic and event driven basis to concerned management.	Active risk metrics program
Control	(10) Implement Contingency Actions	Activate appropriate contingency action on identification of flagged risk metric value.	Updated Project Plan

Software Risk Management Process Overview

Computing example (one Rule from an IFN-Base Rule System)

- If Severity is Marginal, the Failure appears Occasionally, and Detectability is Low then TIFN-RPN = ?
- Details: S=TIFN(4; 0.1, 0.1, 0.2, 0.2), the Occurrence rate p = 0.0055 (or p = TIFN(0.007; 0.006, 0.003, 0.007, 0.003), when TIFN-FMEA is used), and D = TIFN (7; 1, 2, 2, 2) then TIFN-RPN = (0.154, 0.0253, 0.04895, 0.0495, 0.0539)



$t_{COG} = 0.156228$

Conclusions

- Using TIFN-FMEA approach, the ambiguity problem can be solved easily.
- Commuting from the discrete scale to intuitionistic-fuzzy modelling offers to the specialist/expert more the freedom to appreciate the required level (of severity, occurrence, and detectability)
- The proposal is a general one and may be applied to many fields of activity (mainly for risk management department).

Future developments

- Development of an Expert System for FMEA/FMECA approaches (depending on resources)

Supporting:

- Classical RPN
- Fuzzy RPN
- IFN RPN
- Multi expert and multi failure approaches

Discussions