Gaining a Better Understanding of How to Cope with Extreme Low Probability and High Impact Shock Events

And What About Sea Level Rise?

ARUP

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Paul Smith *

- Engineer
- Arup
- Concerned Human Being

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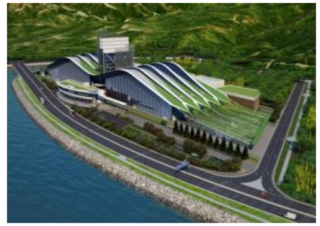
ARUP

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists offering a broad range of professional services.

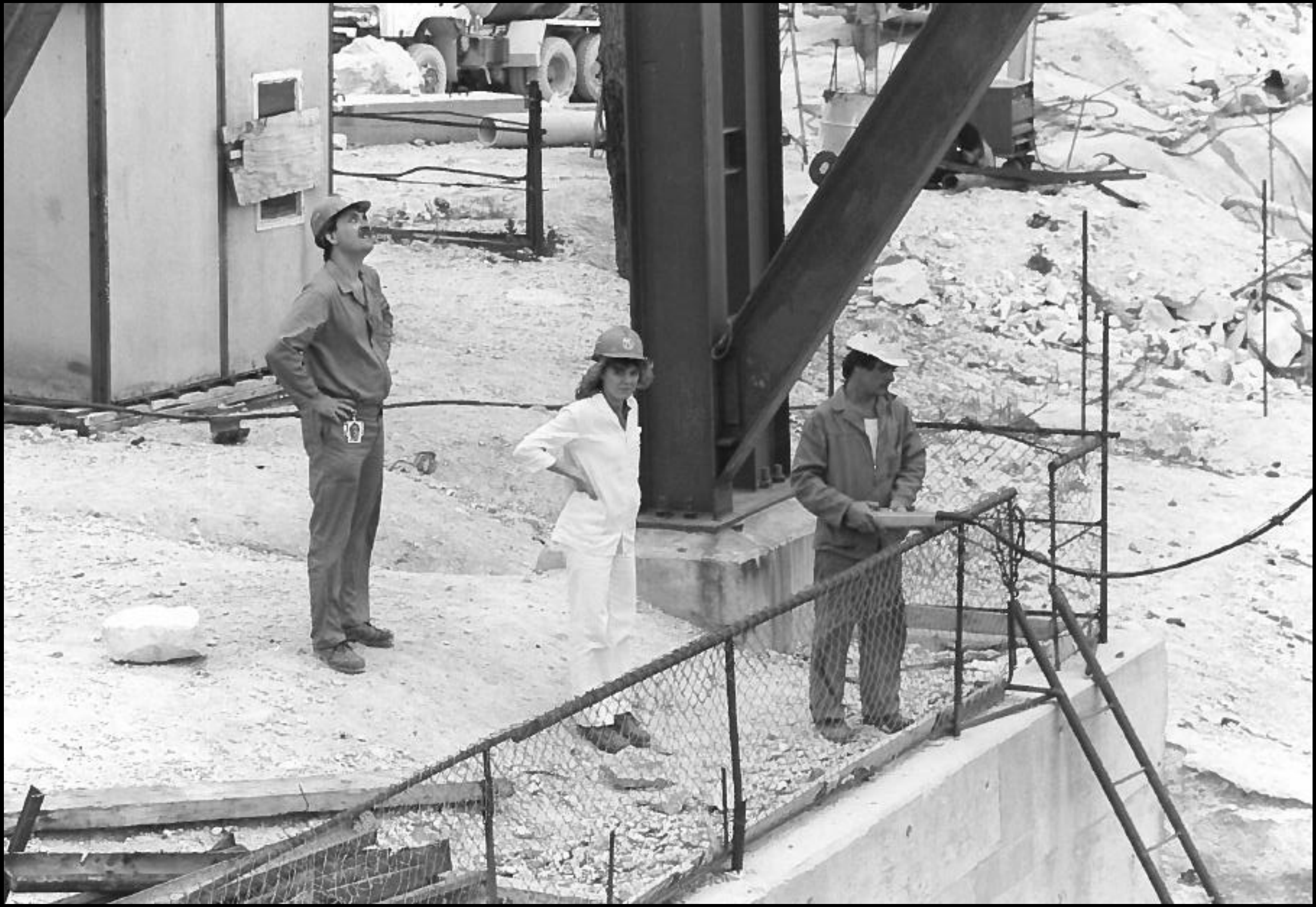





- Founded in 1946
- Named after Ove Arup
- 12,000 people
- 92 offices in 40 countries
- Projects have taken Arup us to over 160 countries
- Arup is a wholly independent organisation

- Independent
- Owned in trust for the benefit of its employees and their dependants
- No shareholders or external investors
- Able to determine our own priorities and direction as a business
- This Direction - Making the World a Better Place with Climate Change!

ESKOM Hydro-Electric Plant Build, Stellenbosch, South Africa **1986**



29 Years Ago : Principal Engineer with problems to solve - *but which problem first?*

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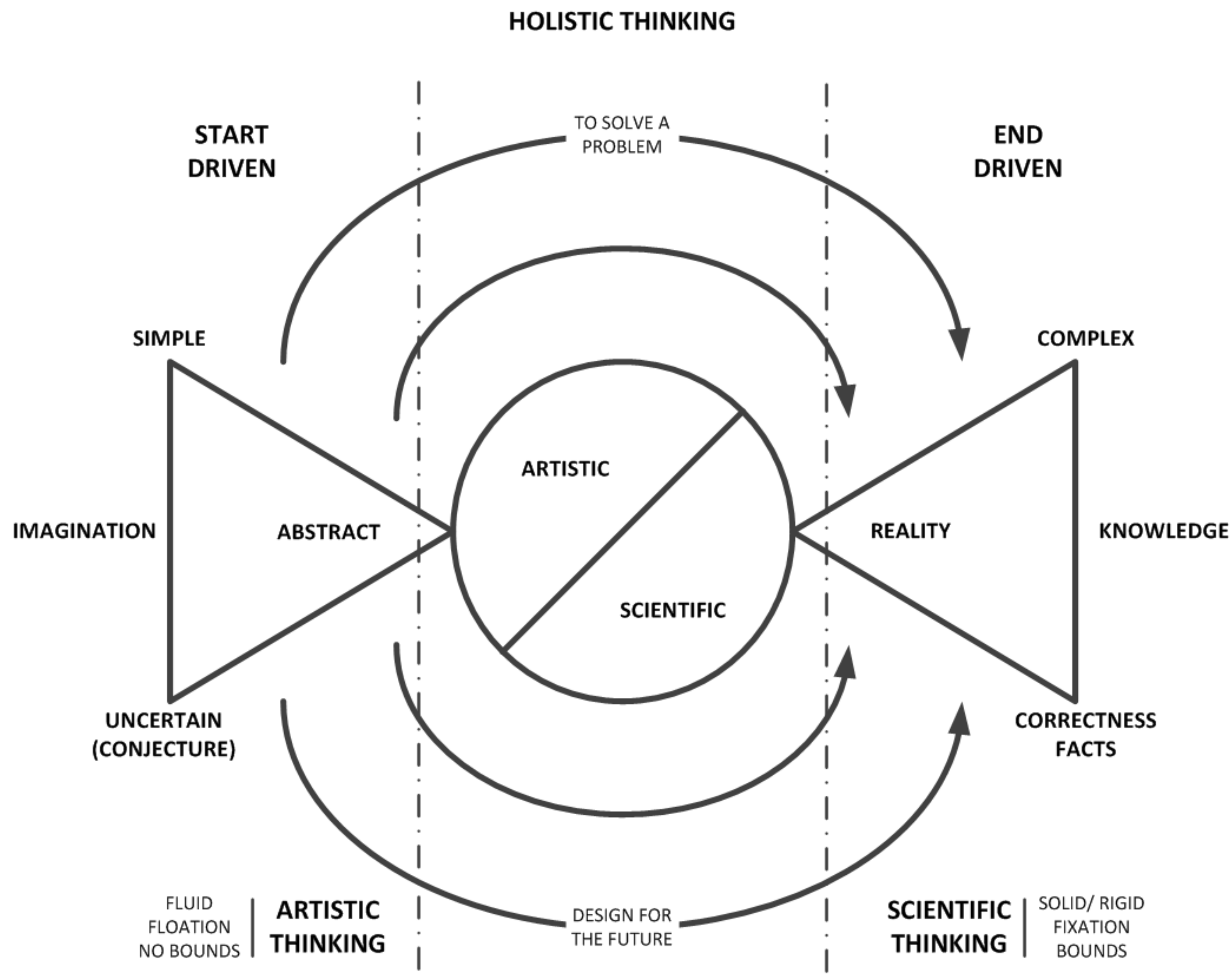


HOLISTIC THINKING
START DRIVEN
TO SOLVE A PROBLEM
END DRIVEN
SIMPLE
COMPLEX
ARTISTIC
IMAGINATION
ABSTRACT
REALITY
KNOWLEDGE
SCIENTIFIC
UNCERTAIN (CONJECTURE)
CORRECTNESS FACTS
FLUID
FLOATION
NO BOUNDS
ARTISTIC THINKING
DESIGN FOR THE FUTURE
SCIENTIFIC THINKING
SOLID/ RIGID
FIXATION
BOUNDS

Principal Objectives

for Disaster / Accident Risk Reduction and Resilience Improvement, in cooperation with ODU, Norfolk VA.

- To perform quantitative assessments of the risk and impact posed by possible extreme natural hazard shock events of low probability and high impact. This requires evaluation analyses using both deterministic and probabilistic symbolic modelling.

- To carry out the quantitative assessments with realistic modelling data and information of the specific vulnerable system or location being analysed, as opposed to a "conservatively- oriented" approach. *{Please note: This "realistic" modelling approach will utilise "real" system data and information as far as possible, yet also being aware and accounting for the degree of uncertainty that possible shock events of low probability and high impact represent}.*

- Develop the logic, methodology and actual evaluation technique with real pilot assessments, recognising the need to perform these assessments, while gaining a better understanding of the limitations and constraints that this new approach presents.

- To identify and define particular areas in which future research and development may be fruitfully directed, while at the same time establishing a comprehensive educational framework that may be used by educational and training institutions for the future.

- To include independent peer scrutiny that interrogates the effectiveness, useability and validity of analysis results, and how the results may be best applied for establishing (i) disaster (and accident) risk reduction, (ii) resilience improvement and (iii) well founded coping strategies for low probability and high impact shock events.

Significant Objectives

for Disaster / Accident Risk Reduction and Resilience Improvement, in cooperation with ODU, Norfolk VA.

- To actively coordinate and cooperate the support needed for development of research, development and training to establish a recognised and accepted means for quantitative assessment of the risk and impact posed by extreme natural hazard shock events of low probability and high impact.

- To produce specific Pilot Example Studies of priority localities that are potentially vulnerable to low probability and high impact shock events. The results from the quantitative assessments will provide (i) disaster (and accident) risk reduction, (ii) resilience improvement and (iii) well founded coping strategies.

- To establish a Round-Robin Benchmarking initiative that may confidently be applied world-wide, while also establishing the basis for a future International Standard and Code of Practice.

- To establish an international forum for lessons learned and a culture for continuous improvement of the International Standard and Code of Practice.

- To gain recognition of the International Standard and Code of Practice, thereby introducing a recognised basis for financial regulation political governance to have a fairly rigorous and consistent means of applying a systemic disaster risk reduction and resilience improvement evaluation technique that is able to address society's technical infrastructure, social well being and environmental impact from extreme natural hazard shock events of low probability and high impact.

Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

2014

Technical Innovation in Nuclear Civil Engineering – TINCE 2014
Paris (*France*), September 1st – 4th, 2014

The Holistic Integrity Test (HIT[1]) for Designers.

Concept of **Holistic Integrity Test** first introduced in 2014 is to **HIT** the Nuclear Facility, its plant, contained dangers and its specific / regional site to determine how it copes with a severe shock event, specifically addressing onerous threats and shocks – accounting for **Before, During and After** the Accident.

The **HIT** was explained at TINCE 2014 in terms of a Nuclear Facility, addressing three fundamental risk reduction goals, although the technique is universally applicable:

- The ability to tolerate and withstand shocks, while continuing to sustain key safety functions;
- The ability to wisely direct and manage the crisis situation, accounting for the diverse scenarios that could occur;
- To be able to quickly recovery and stabilise to a safe and secure state that is stable and sustainable in the long term.


Quantified Risk Analysis
The GAPS

Gaps	Holistic Disaster & Accident Risk Assessment Gap Issues:
Gap 1.	Understanding and knowledge by modeling of disasters and emergent accidents should be based on a standard quantitative risk analysis logic, methodology and process.
Gap 2.	Future modeling of disasters and emergent accidents to achieve risk reduction and resilience improvement should be consistent, validated and verifiable to an international standard and code of practice.
Gap 3.	Education, training and documentation related to disasters and accident risk reduction and resilience improvement should be standardised, establishing standard terms / glossary.
Gap 4.	New and improved holistic system modeling techniques for analysing disasters and emergent accidents to achieve risk reduction and resilience improvement should be developed. {For example:- the HIT or Holistic Integrity Test}.
Gap 5.	Holistic system modeling used to analyse disasters and accidents for risk reduction and resilience improvement should integrate both deterministic and probabilistic quantitative techniques.
Gap 6.	Holistic system modeling used to analyse disasters and accidents for risk reduction and resilience improvement should apply quantitative, contiguous and consistent risk / consequence criteria.
Gap 7.	Holistic system modeling used to analyse disasters and accidents for risk reduction and resilience improvement should model the complete cycle – before, during and after; to sustainability.
Gap 8.	The degree of holistic system structural damage that can be caused by extreme hazards and its ultimate effect to inhibit, hamper and degrade coping (strategy, capability and scale).
Gap 9.	The role and importance of network systems in terms of their vulnerability and possible weakness when exposed to hazards, together with the resultant damage caused to the networks for a given set of extreme hazards.
Gap 10.	The role and importance of structural/technical network systems that are the basis of essential services and supplies. {For example:- water, electricity and gas}.

Gaps	Holistic Disaster & Accident Risk Assessment Gap Issues:
Gap 11.	The role and importance of structural/technical network systems that are the basis of normal, emergency, accident and disaster coping strategies. {For example:- monitoring, surveillance, voice and data communications to command and control}.
Gap 12.	The role and importance of the structural and non-structural emergency coping supply chain to provide supplemental essential water, food and medicines.
Gap 13.	Understanding the economic response to severe shocks, how the economic system can react and adapt.
Gap 14.	Understanding the interactions between the economic intrinsic dynamic shock have can arise during financial crises, compared to the normal business cycle.
Gap 15.	Understanding how immediate financial crises due to severe shocks are coped with by the public household, companies, local and wider government.
Gap 16.	The explicit and implicit nature of disaster and accident mitigation coping cycles before, during and after the severe shock event.
Gap 17.	The standard and practical basis for disaster and accident response, recovery, reconstruction, rehabilitation, re-economisation and future long term sustainability.
Gap 18.	Uncertainty and variability of the analysis techniques for disaster risk reduction and resilience improvement in terms of best logic, methodology and process practice.
Gap 19.	The need to minimise data and analysis biases that introduce uncertainty and erroneous modelling results due to (i) hazard bias, (ii) temporal bias, (iii) accounting bias, (iv) criteria bias, (v) geography bias, (vi) systemic bias, (vii) lower threshold bias, (viii) upper artificial frequency / magnitude cut bias and (ix) geographical bias.
Gap 20.	Monitoring and collection of data from hazards, disasters and accidents should be standardised and be based on a generally accepted code of practice.

The past conceptual basis for risk has been and still is:

Probability x Consequence = a form of theoretical *value*

Probability x Consequence = *A Number* ~ 1.23 x 10-6 per annum

or

Vulnerability x Hazard = another form of theoretical *value*

Vulnerability x Hazard = *A Number'ish* ~ *I Think?*

Simple (too simple maybe), Fixed, A Number and Useful…?

WASH-1400 (NUREG-75/014)
Reactor Safety Study;
Norman Rasmussen et al.,
United States Regulatory Commission, October 1975.

1975

Reactor Safety Study

An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants

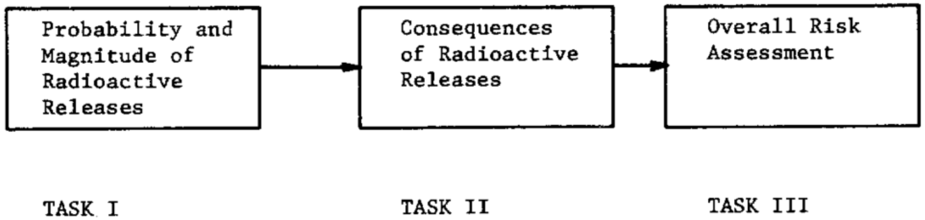


FIGURE 4-1 Major Tasks of Study

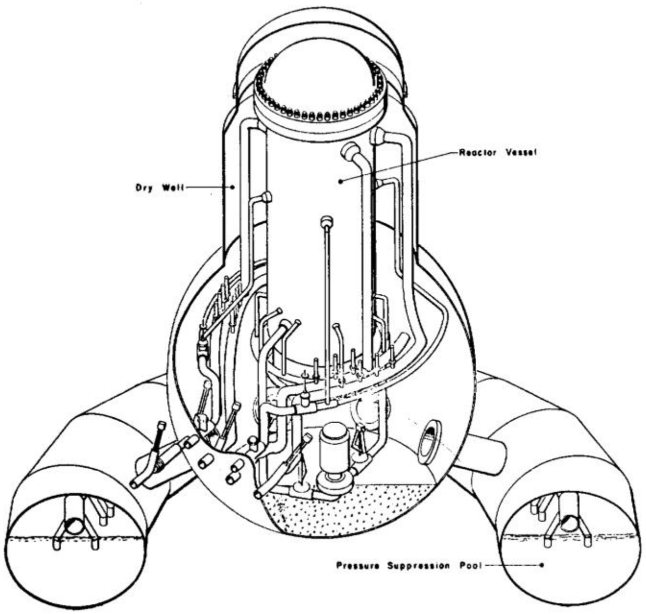


FIGURE 3-5 Schematic of Reactor Coolant System for BWR - Inside of the Primary Containment

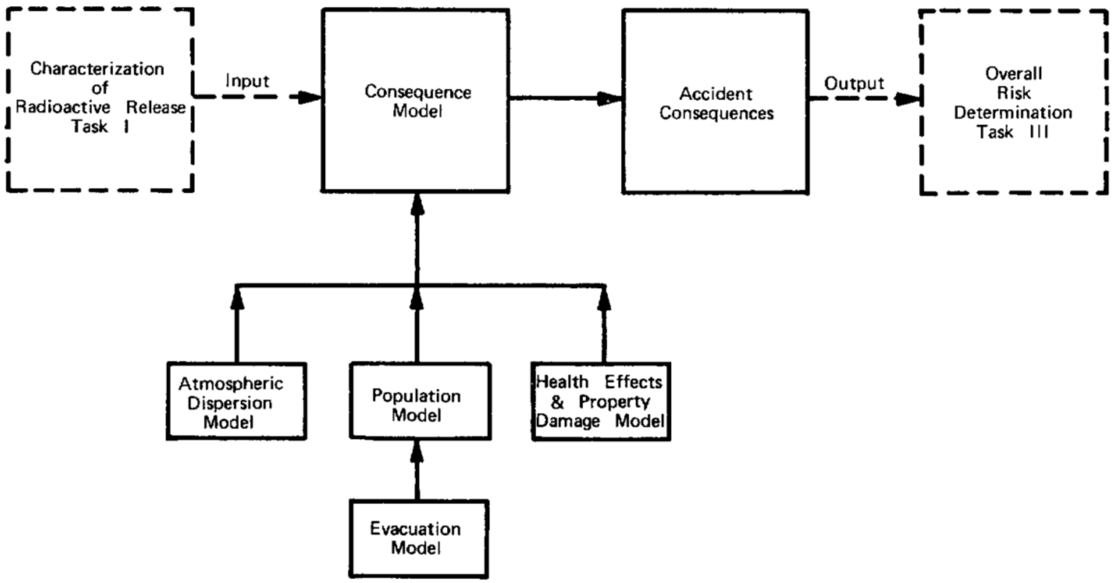


FIGURE 4-6 Subtasks in the Determination of the Consequences of Radioactive Releases Task II (Appendix VI)

WASH-1400 (NUREG-75/014)
Reactor Safety Study;
Norman Rasmussen et al.,
United States Regulatory Commission, October 1975.

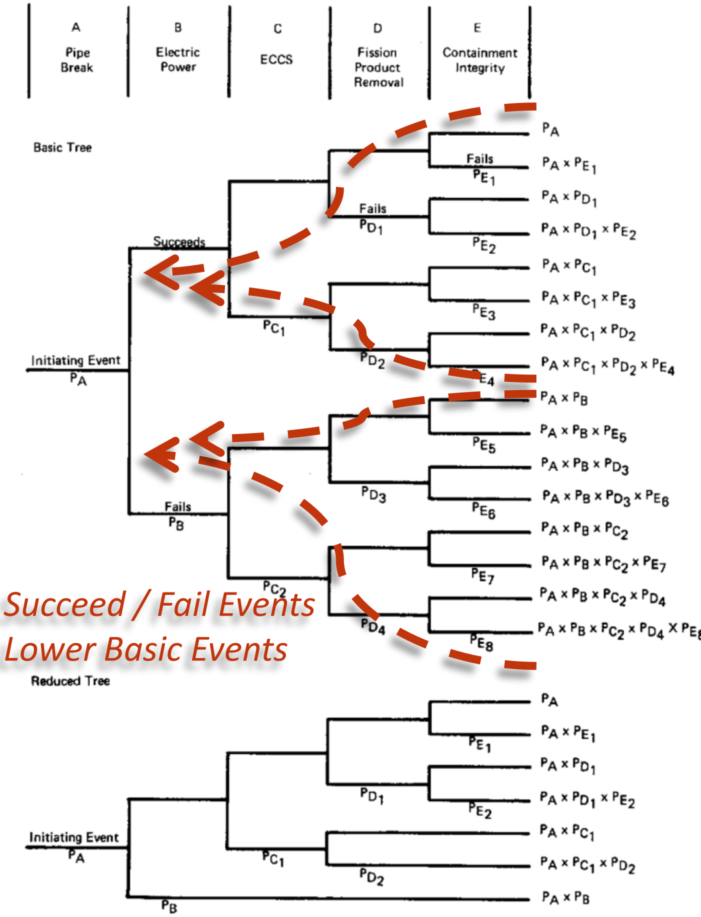
1975

Reactor Safety Study

An Assessment of
Accident Risks in U.S. Commercial
Nuclear Power Plants

Symbolic Event Tree

- Systematic Evaluation
- Inductive Reasoning
- Causal Direction
- Forward Method
- Start at Basic Events
- Hazard and Risk Analysis
- Single Point Failures
- Need System Knowledge
- Need Basic Events
- Need Conditional Data
- Complete Causal Tree



Induce Succeed / Fail Events from Lower Basic Events

Note - Since the probability of failure, P, is generally less than 0.1, the probability of success (1-P) is always close to 1. Thus, the probability associated with the upper (success) branches in the tree is assumed to be 1.

FIGURE 4-4 Simplified Event Trees for a Large LOCA

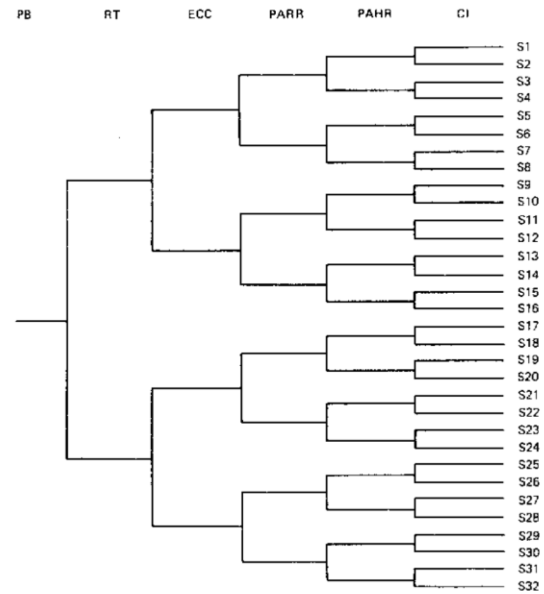


Figure 1 Illustrative Event Tree for LOCA Functions

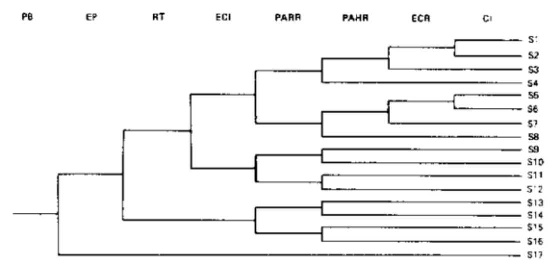


Figure 2 Functional LOCA Event Tree Showing Effects of Inter-relationships

WASH-1400 (NUREG-75/014)
Reactor Safety Study;
Norman Rasmussen et al.,
United States Regulatory Commission, October 197⁻

1975

Reactor Safety Study

An Assessment of
Accident Risks in U.S. Commercial
Nuclear Power Plants

Symbolic Fault Tree

- Partial-Expert Evaluation
- Deductive Reasoning
- Anti-Causal Direction
- Backward Method
- Start at System Failure
- Backwards to Possible Causes
- Consequence Analysis
- Don't Need System Knowledge
- Don't Need Basic Events
- Need Good Sense
- Limit to Anti-Causal Tree

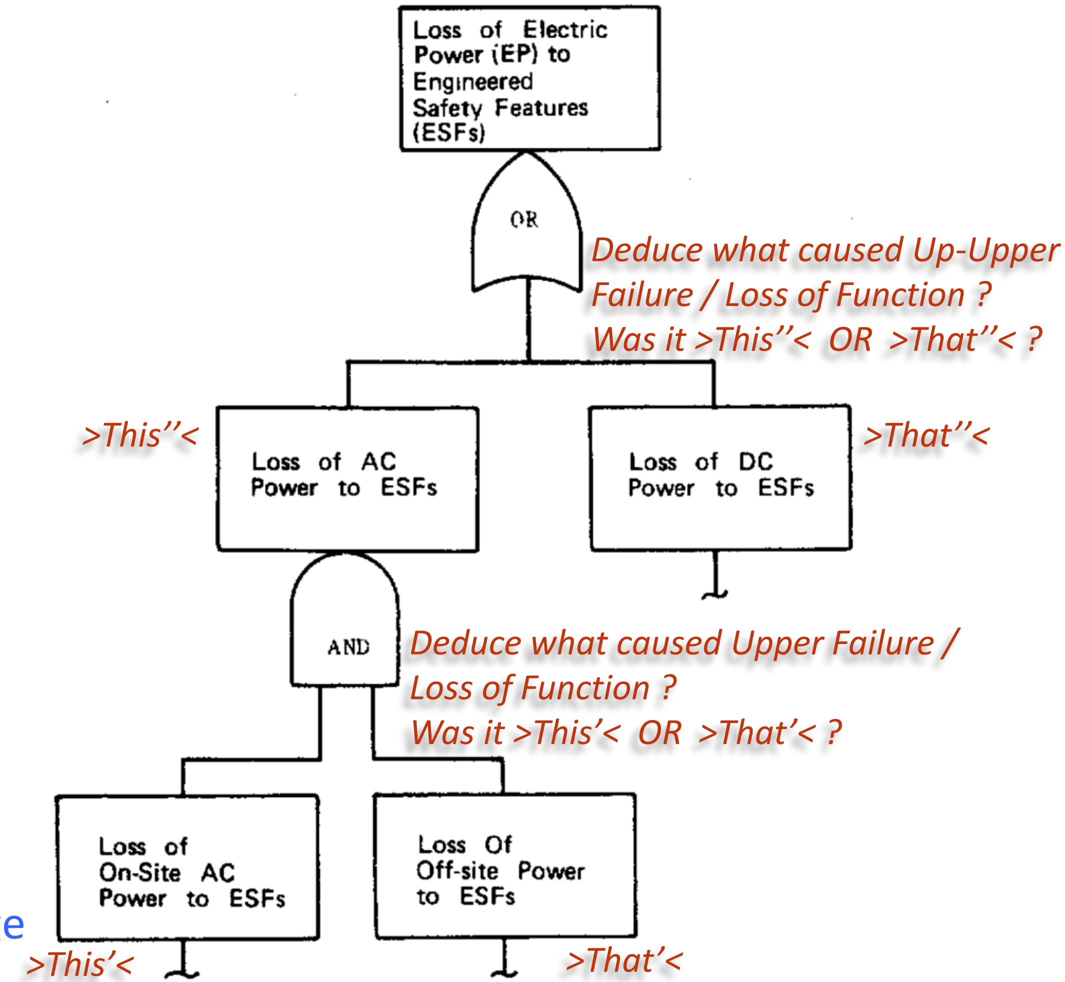
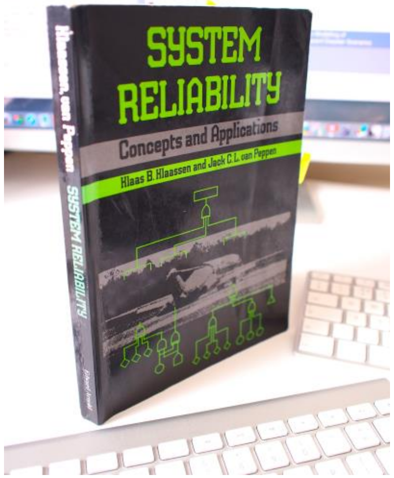
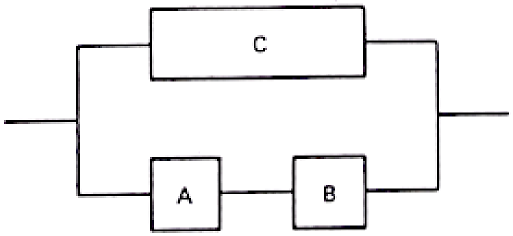


FIGURE 4-5 Illustration of Fault Tree Development

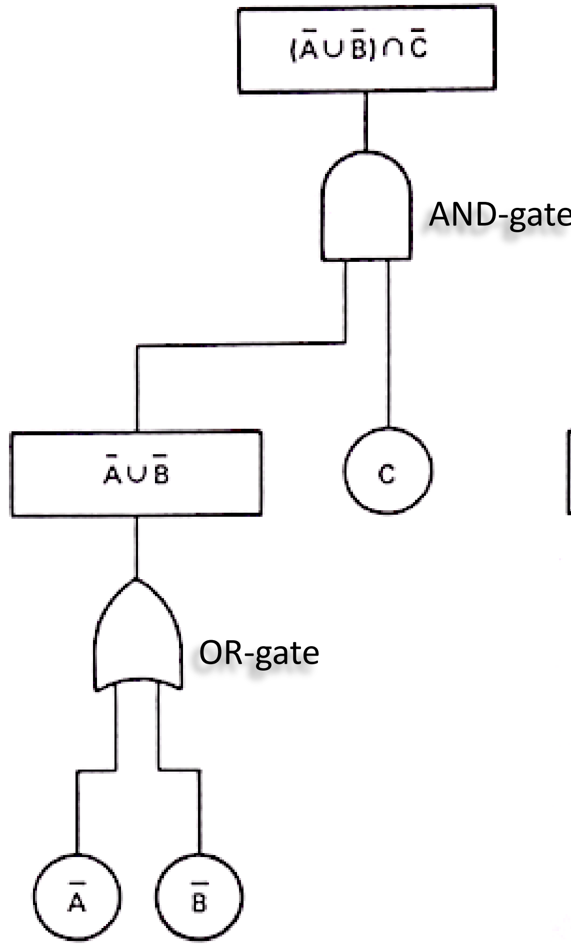
System Reliability – Concepts and Applications;
Klaas B. Klaassen and Jack C.L. van Peppen,
Edward Arnold,1989.

1989

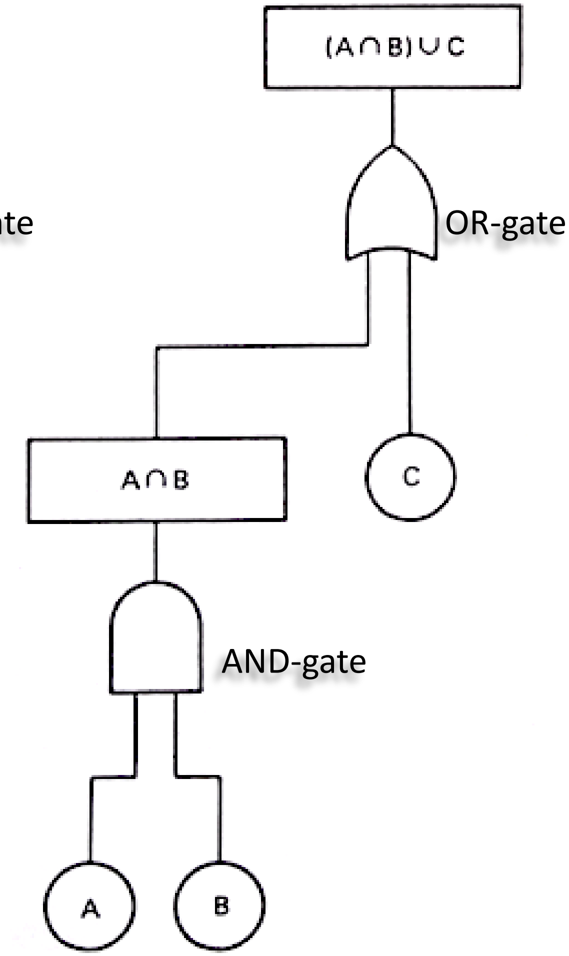




A Functional “System” of
Components A, B and C



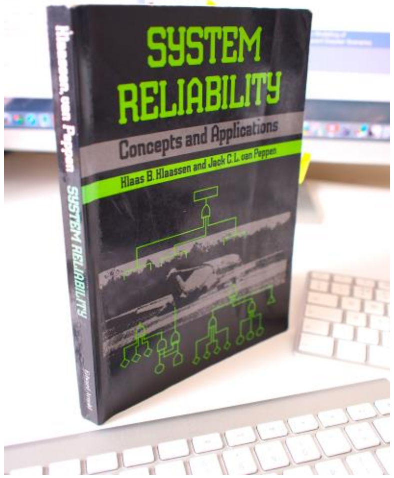
Symbolic Fault Tree of the
“System”
~ Negative Approach ~

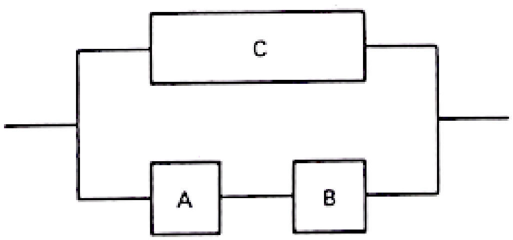


Symbolic Success Tree of
the “System”
~ Positive Approach ~

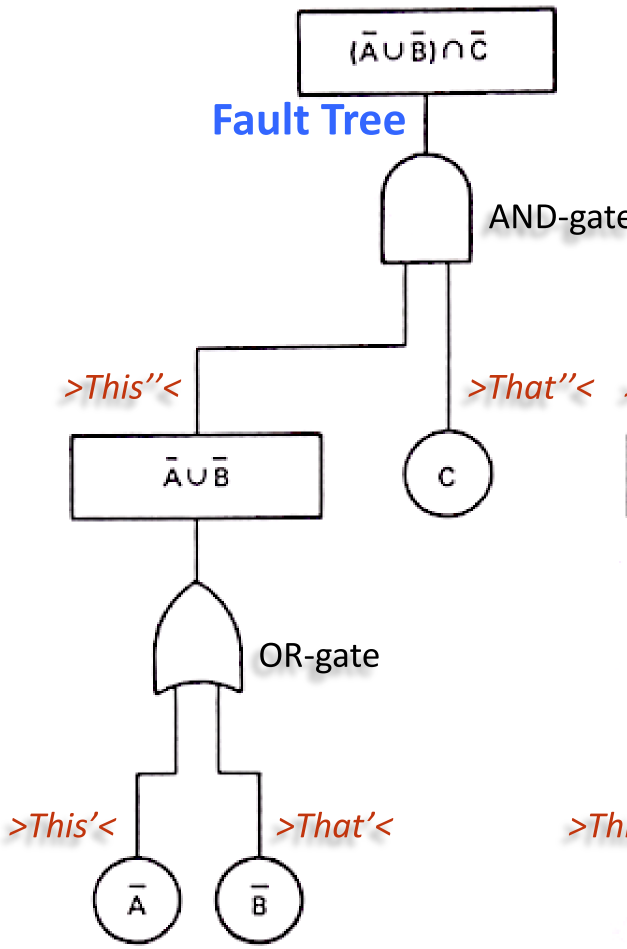
System Reliability – Concepts and Applications;
Klaas B. Klaassen and Jack C.L. van Peppen,
Edward Arnold,1989.

1989

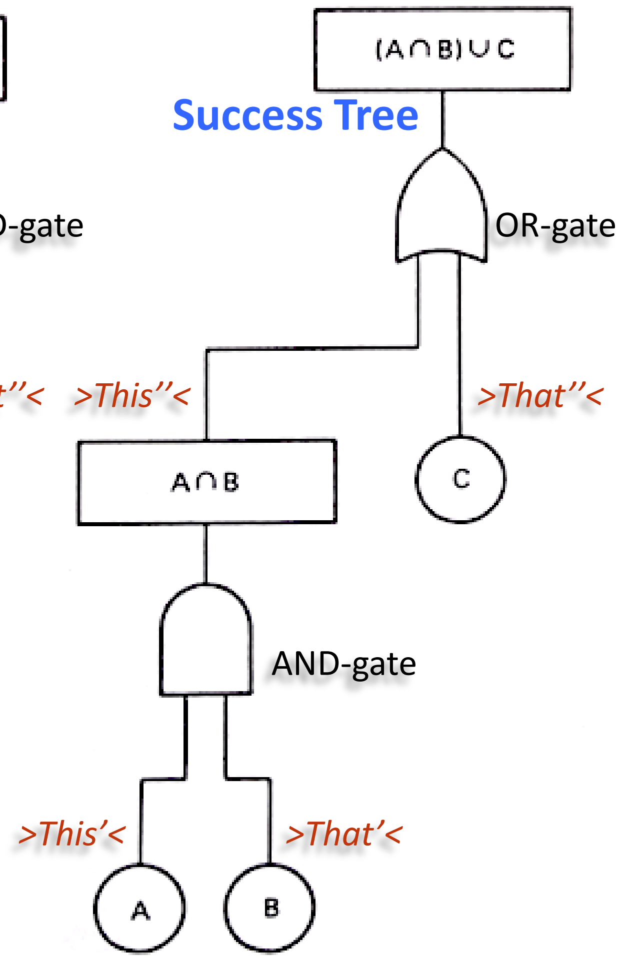




A Functional “System” of Components A, B and C



Symbolic Fault Tree of the “System”
~ Negative Approach ~

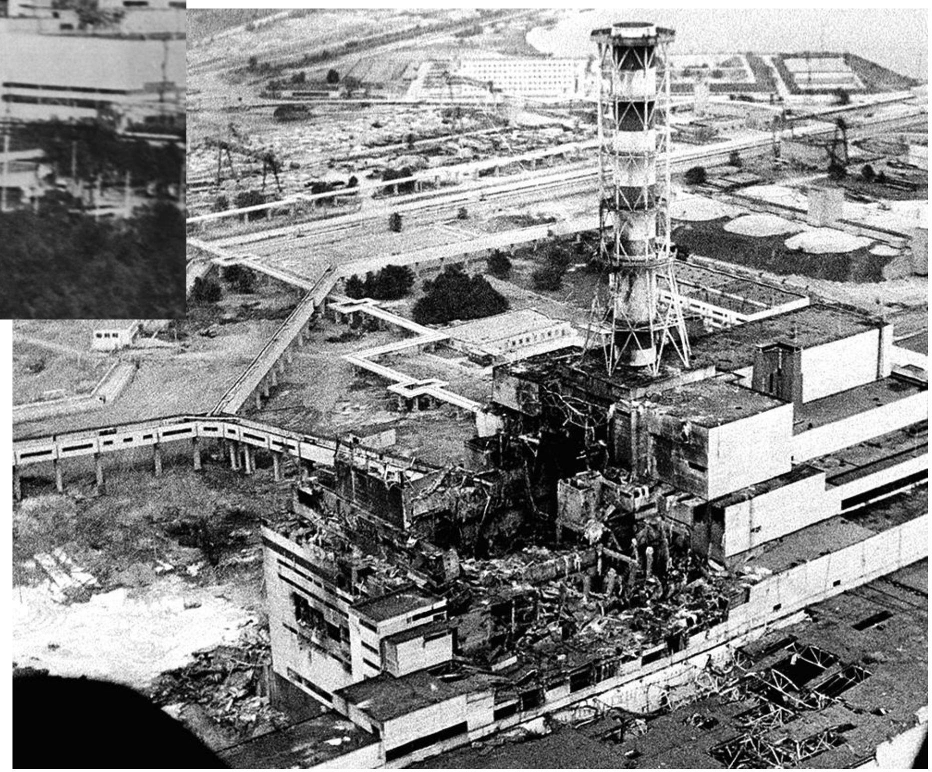


Symbolic Success Tree of the “System”
~ Positive Approach ~

1979

Three Mile Island Nuclear Accident – 28th March 1979

1986



Chernobyl Nuclear Accident – 26th April 1986

2011

Fukushima Daiichi Nuclear Accident – 11th March 2011

This report is meant to reinforce the administrative authority of the legislative body and strengthen oversight activities on issues related to nuclear power. As the first independent commission chartered by the Diet in the history of Japan's constitutional government, we would like to emphasize how important it is that this report be utilized, for the Japanese people and for the people of the world.

THE EARTHQUAKE AND TSUNAMI of March 11, 2011 were natural disasters of a magnitude that shocked the entire world. Although triggered by these cataclysmic events, the subsequent accident at the Fukushima Daiichi Nuclear Power Plant cannot be regarded as a natural disaster. It was a profoundly manmade disaster – that could and should have been foreseen and prevented. And its effects could have been mitigated by a more effective human response.

Our report catalogues a multitude of errors and willful negligence that left the Fukushima plant unprepared for the events of March 11th 2011. For all the extensive detail it provides, what this report cannot fully convey – especially to a global audience – is the mindset that supported the negligence behind this disaster.

CHAIRMAN:

KIYOSHI KUROKAWA

2012

The National Diet of Japan

The official report of
The Fukushima
Nuclear Accident Independent
Investigation Commission

THE NATIONAL DIET OF JAPAN
FUKUSHIMA NUCLEAR ACCIDENT INDEPENDENT INVESTIGATION COMMISSION
(NAIIC)

To:
MR. TAKAHIRO YOKOMICHI, SPEAKER OF THE HOUSE OF REPRESENTATIVES
MR. KENJI HIRATA, PRESIDENT OF THE HOUSE OF COUNCILLORS
THE NATIONAL DIET OF JAPAN

THE UNPRECEDENTED NUCLEAR ACCIDENT that began on March 11, 2011 is the subject of the following report, which we hereby present to the members of the National Diet of Japan for their review. We do this in accordance with the Act Regarding the Fukushima Nuclear Accident Independent Investigation Commission.

Our investigative task is adjourned today, some six months after the appointment of our Chairman and Members in December of 2011.

This report is meant to reinforce the administrative authority of the legislative body and strengthen oversight activities on issues related to nuclear power. As the first independent commission chartered by the Diet in the history of Japan's constitutional government, we would like to emphasize how important it is that this report be utilized, for the Japanese people and for the people of the world.

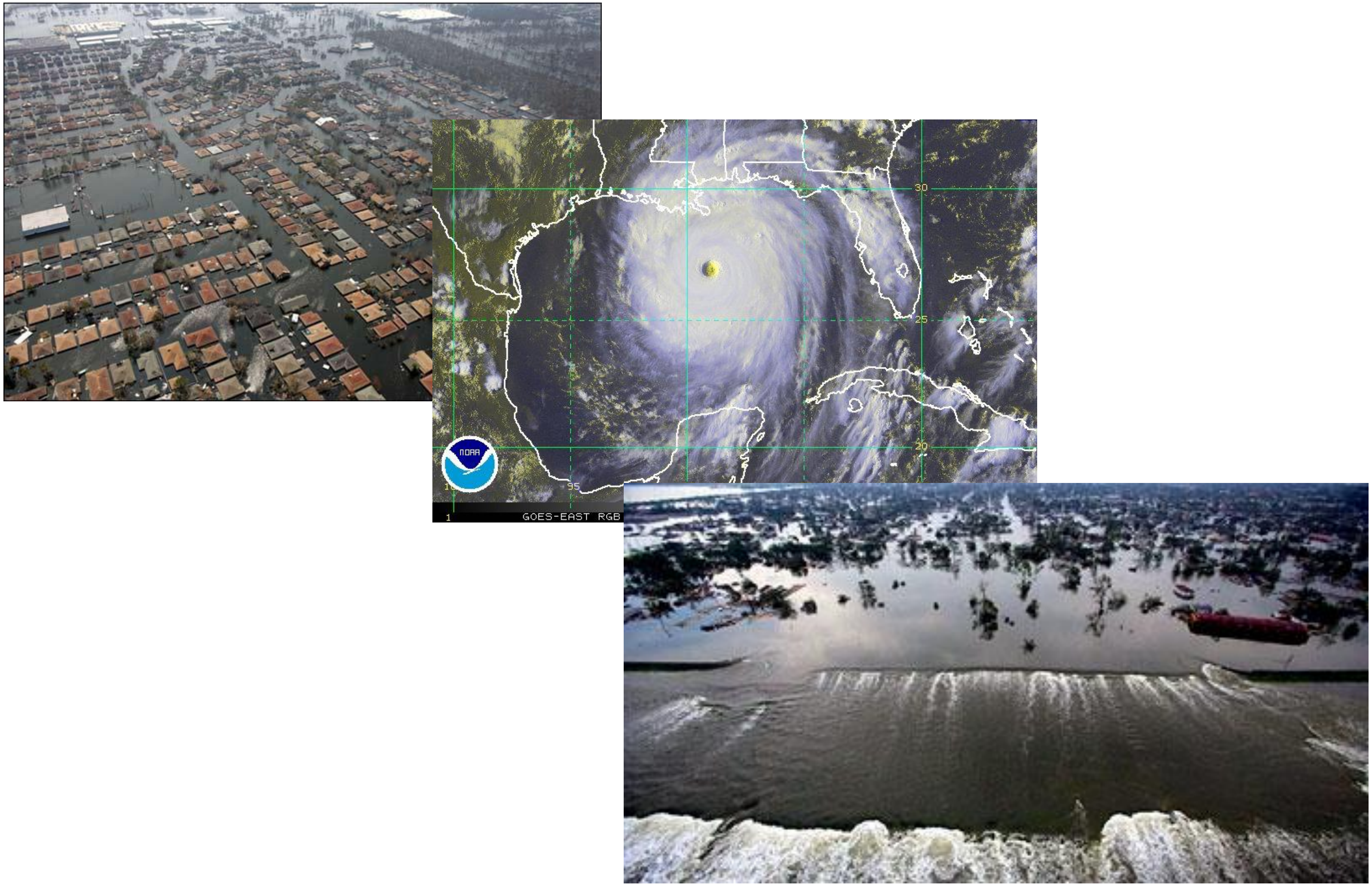
CHAIRMAN:

KIYOSHI KUROKAWA

MEMBERS:

KENZO OSHIMA	HISAKO SAKIYAMA	MASAFUMI SAKURAI
YOSHINORI YOKOYAMA	MITSUHIKO TANAKA	KOICHI TANAKA
KATSUHIKO ISHIBASHI	REIKO HACHISUKA	SHUYA NOMURA

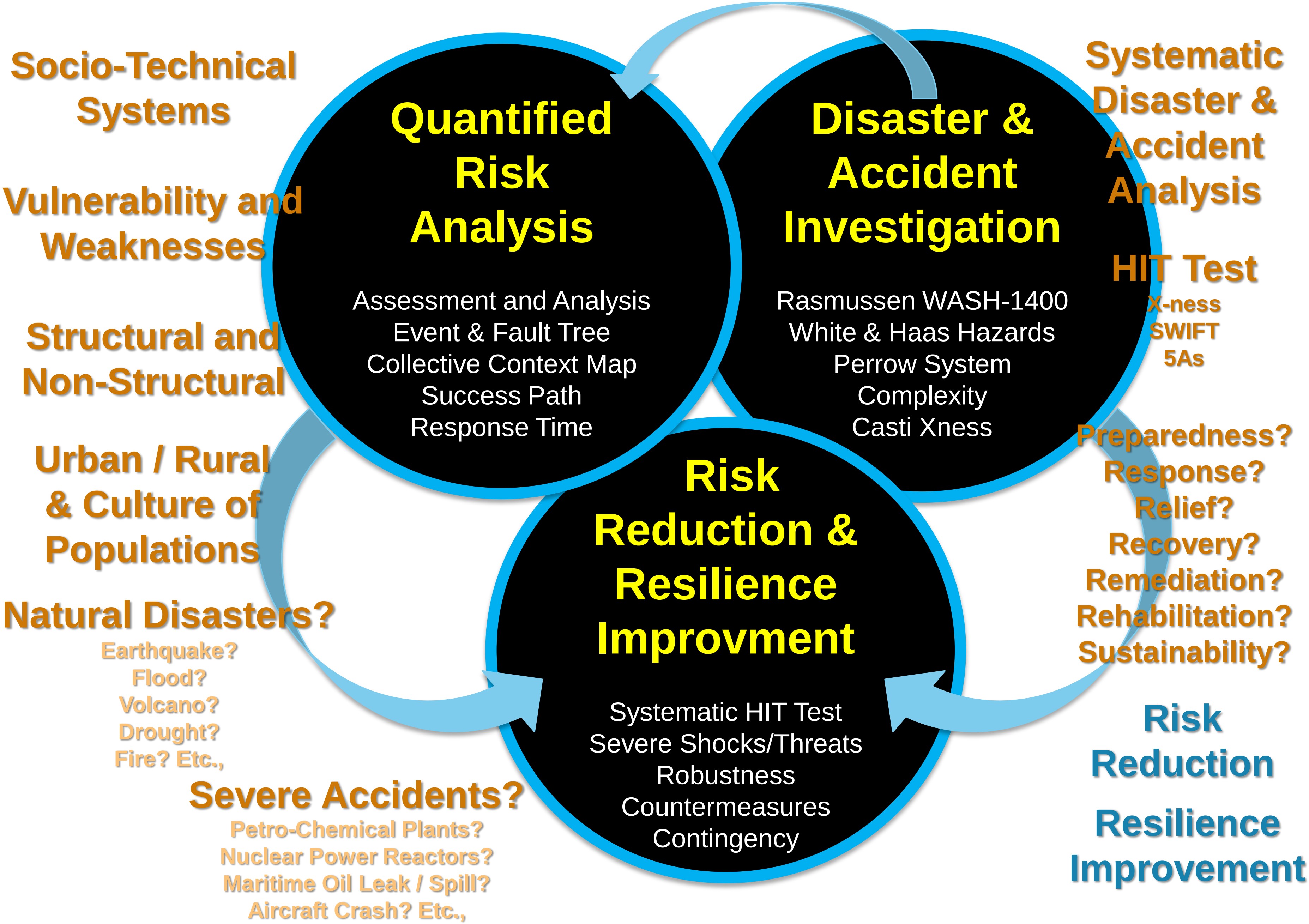
2005



Hurricane Katrina – 23rd to 31st August, 2005

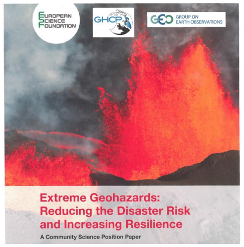
2012

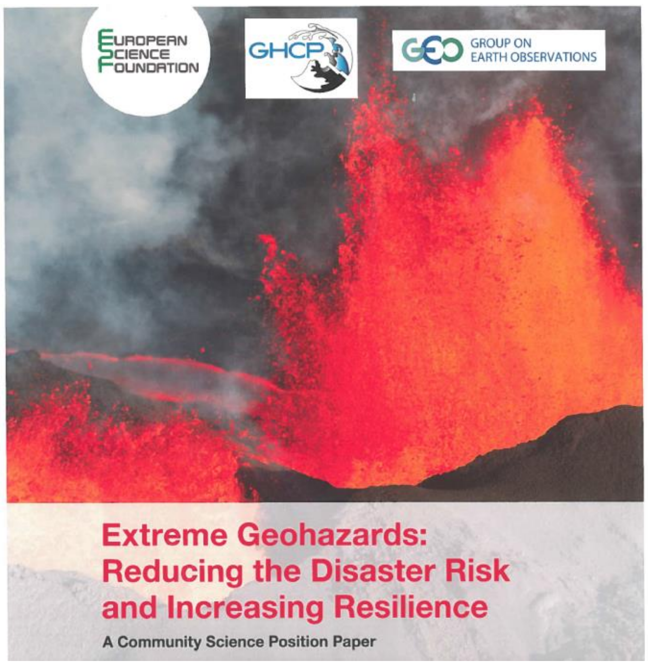
Hurricane Sandy - 22nd to 31st October, 2012


Socio-Technical Systems
Vulnerability and Weaknesses
Structural and Non-Structural
Urban / Rural & Culture of Populations
Natural Disasters?
Earthquake?
Flood?
Volcano?
Drought?
Fire? Etc.,
Severe Accidents?
Petro-Chemical Plants?
Nuclear Power Reactors?
Maritime Oil Leak / Spill?
Aircraft Crash? Etc.,
Quantified Risk Analysis
Assessment and Analysis
Event & Fault Tree
Collective Context Map
Success Path
Response Time
Disaster & Accident Investigation
Rasmussen WASH-1400
White & Haas Hazards
Perrow System
Complexity
Casti Xness
Risk Reduction & Resilience Improvment
Systematic HIT Test
Severe Shocks/Threats
Robustness
Countermeasures
Contingency
Systematic Disaster & Accident Analysis
HIT Test
X-ness
SWIFT
5As
Preparedness?
Response?
Relief?
Recovery?
Remediation?
Rehabilitation?
Sustainability?
Risk Reduction
Resilience Improvement

European Science Foundation (ESF), Group on Earth Observations (GEO), and the Geohazard Community of Practice (GHCP); Extreme Geohazards: Reducing the Disaster Risk and Increasing Resilience.

2015





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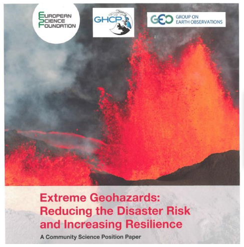
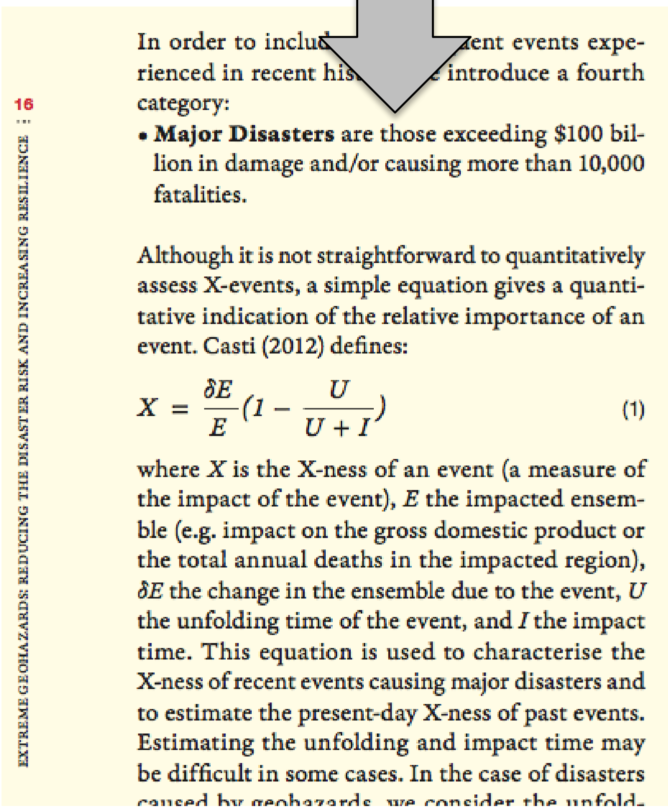
European Science Foundation (ESF), Group on Earth Observations (GEO), and the Geohazard Community of Practice (GHCP); Extreme Geohazards: Reducing the Disaster Risk and Increasing Resilience.

2015





16 EXTREME GEOHAZARDS: REDUCING THE DISASTER RISK AND INCREASING RESILIENCE

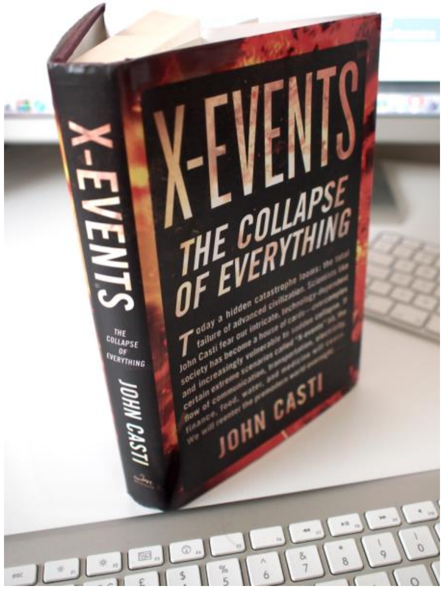
In order to includ[...]ent events experienced in recent his[...]e introduce a fourth category:

- **Major Disasters** are those exceeding $100 billion in damage and/or causing more than 10,000 fatalities.

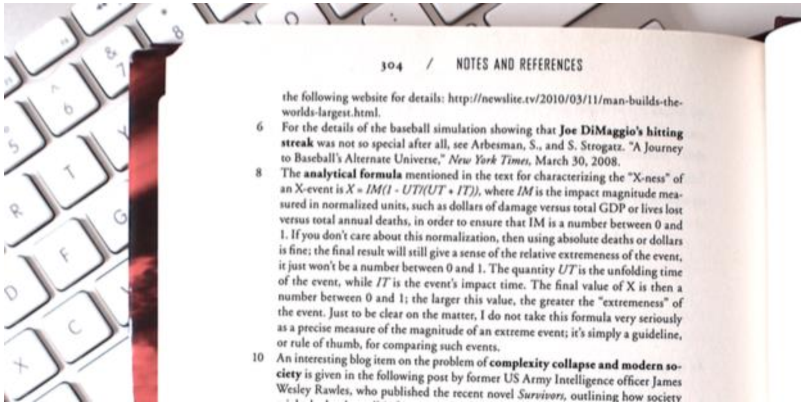
Although it is not straightforward to quantitatively assess X-events, a simple equation gives a quantitative indication of the relative importance of an event. Casti (2012) defines:

$$X = \frac{\delta E}{E}\left(1 - \frac{U}{U + I}\right) \qquad (1)$$

where X is the X-ness of an event (a measure of the impact of the event), E the impacted ensemble (e.g. impact on the gross domestic product or the total annual deaths in the impacted region), δE the change in the ensemble due to the event, U the unfolding time of the event, and I the impact time. This equation is used to characterise the X-ness of recent events causing major disasters and to estimate the present-day X-ness of past events. Estimating the unfolding and impact time may be difficult in some cases. In the case of disasters caused by geohazards, we consider the unfold-



$X_{ness} \sim dE/E\,(1 - (U/[U+I])$ Casti 2012



304 / NOTES AND REFERENCES

the following website for details: http://newslite.tv/2010/03/11/man-builds-the-worlds-largest.html.

6 For the details of the baseball simulation showing that **Joe DiMaggio's hitting streak** was not so special after all, see Arbesman, S., and S. Strogatz. "A Journey to Baseball's Alternate Universe," *New York Times*, March 30, 2008.

8 The **analytical formula** mentioned in the text for characterizing the "X-ness" of an X-event is *X = IM(1 - UT/(UT + IT))*, where *IM* is the impact magnitude measured in normalized units, such as dollars of damage versus total GDP or lives lost versus total annual deaths, in order to ensure that IM is a number between 0 and 1. If you don't care about this normalization, then using absolute deaths or dollars is fine; the final result will still give a sense of the relative extremeness of the event, it just won't be a number between 0 and 1. The quantity *UT* is the unfolding time of the event, while *IT* is the event's impact time. The final value of X is then a number between 0 and 1; the larger this value, the greater the "extremeness" of the event. Just to be clear on the matter, I do not take this formula very seriously as a precise measure of the magnitude of an extreme event; it's simply a guideline, or rule of thumb, for comparing such events.

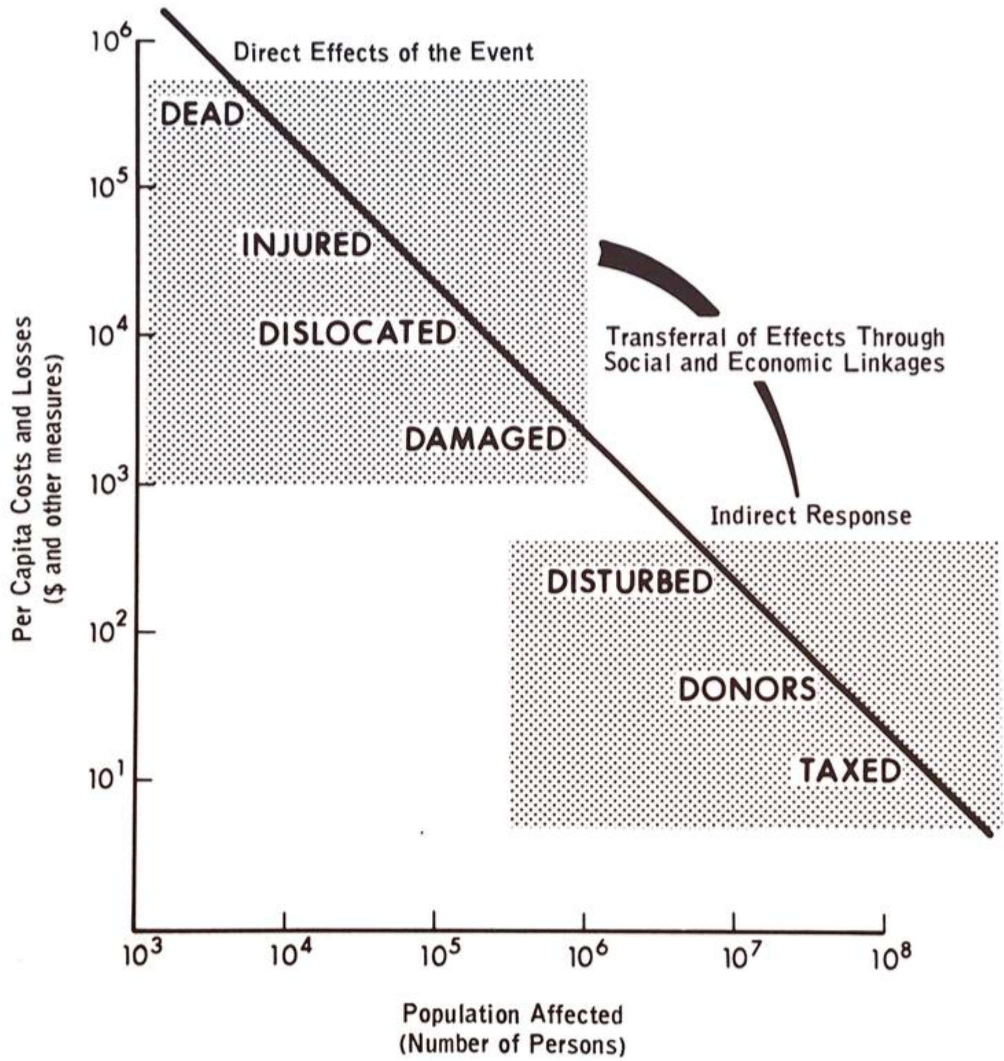
10 An interesting blog item on the problem of **complexity collapse and modern society** is given in the following post by former US Army Intelligence officer James Wesley Rawles, who published the recent novel *Survivors*, outlining how society

Assessment of Research on Natural Hazards; Editors - Gilbert F. White and J. Eugene Haas, MIT Press, 1975.

1975

FIGURE 3–8

IMPACT OF DISASTER: A CONTINUUM OF EFFECTS



(adapted from Bowden and Kates, 1974)

Assessment of Research on Natural Hazards; Editors - Gilbert F. White and J. Eugene Haas, MIT Press, 1975.

1975

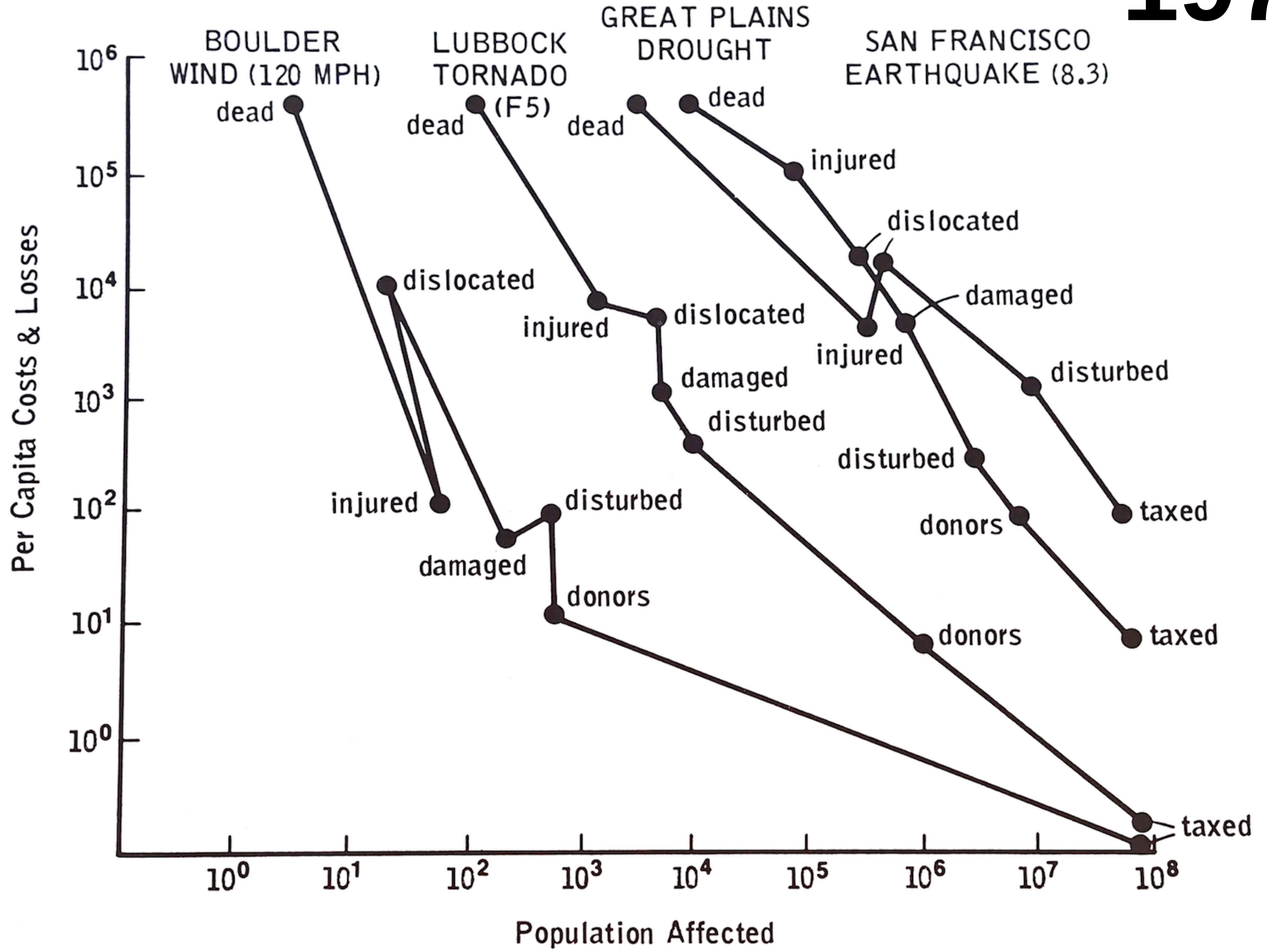


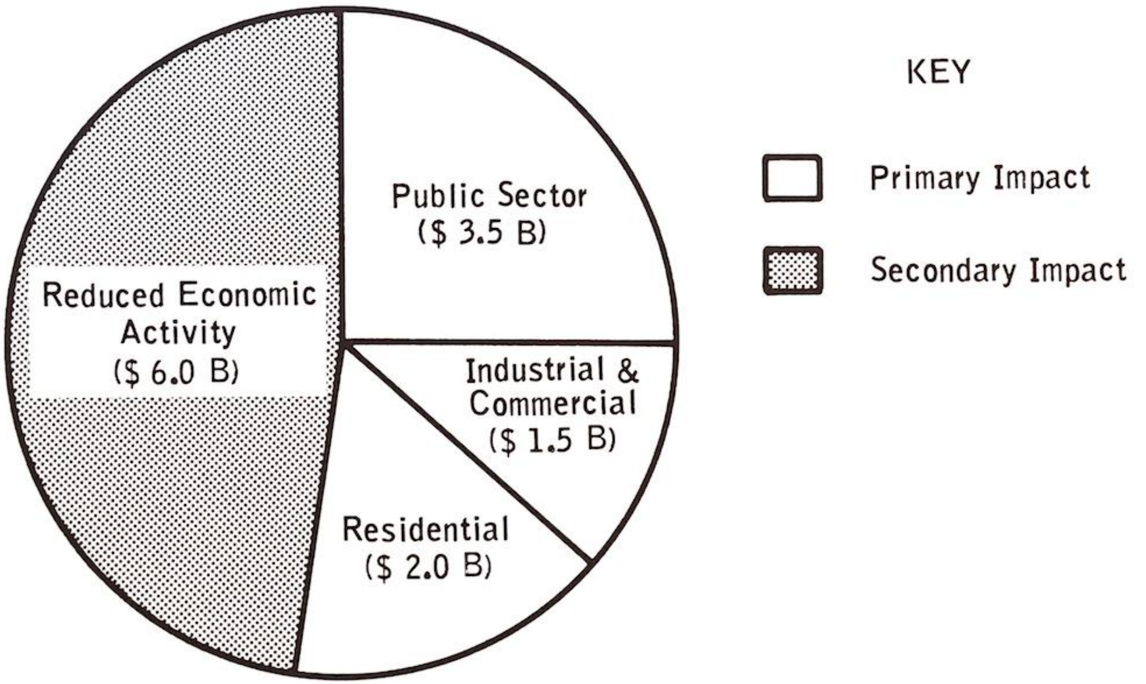
FIGURE 3–9
DISRUPTIVE EFFECTS COMPARED

Assessment of Research on Natural Hazards; Editors - Gilbert F. White and J. Eugene Haas, MIT Press, 1975.

1975

FIGURE 3–10

BREAKDOWN OF LOSSES FROM A REPETITION OF AN EARTHQUAKE IN SAN FRANCISCO OF THE SAME MAGNITUDE OF THAT IN 1906

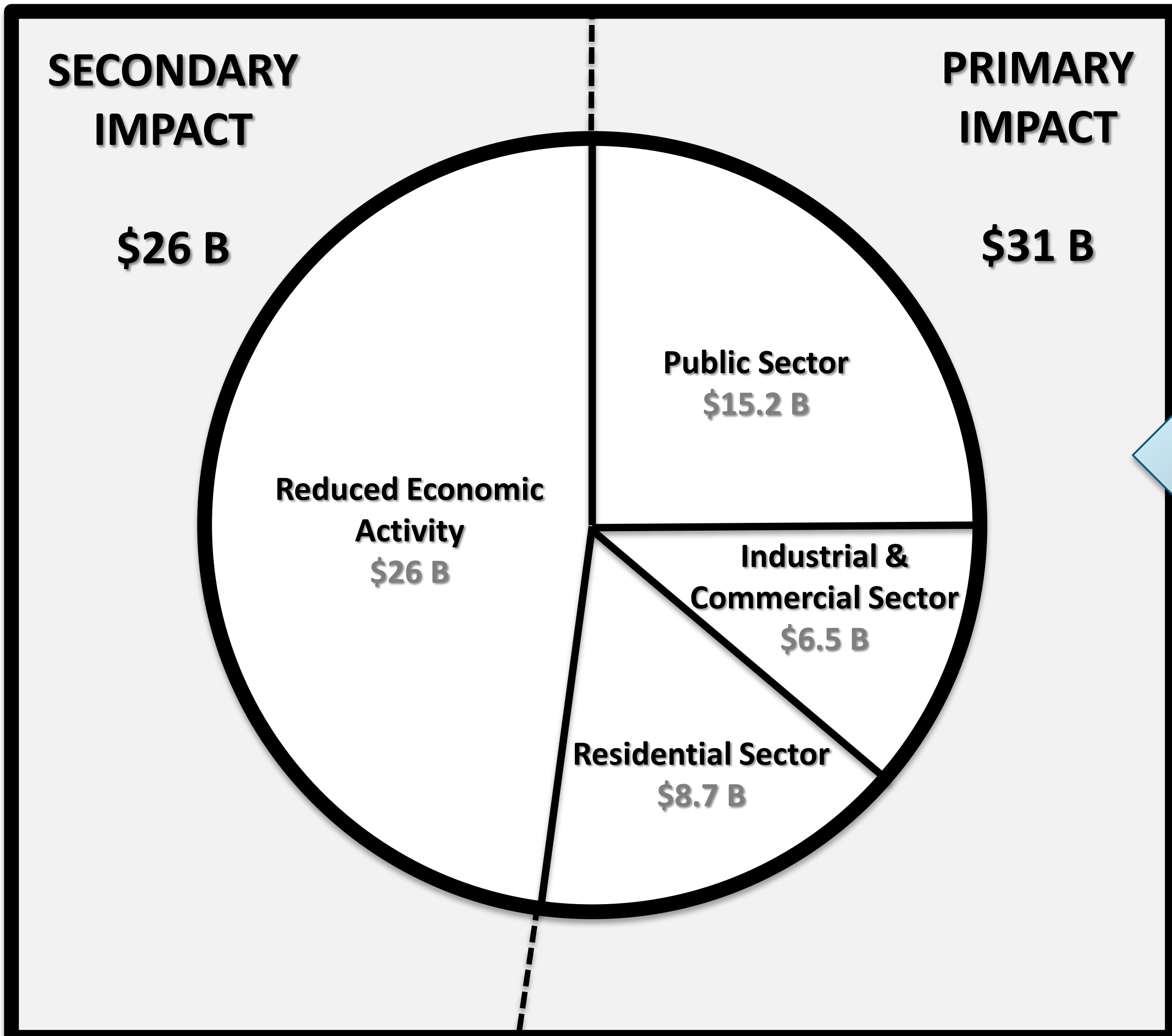


TOTAL COST
$ 13.0 Billion

(Cochrane, 1974)

PRIMARY + SECONDARY IMPACT = $57 B

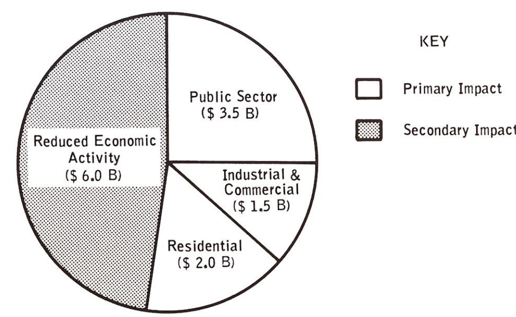
2014



Breakdown of Primary and Secondary Economic Losses for an imagined repeat of the 1906 San Francisco Earthquake, based on 2014 cost projection from 1975; using Cochrane, White & Haas natural hazard analyses.

FIGURE 3–10

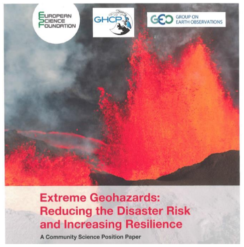
BREAKDOWN OF LOSSES FROM A REPETITION OF AN EARTHQUAKE IN SAN FRANCISCO OF THE SAME MAGNITUDE OF THAT IN 1906

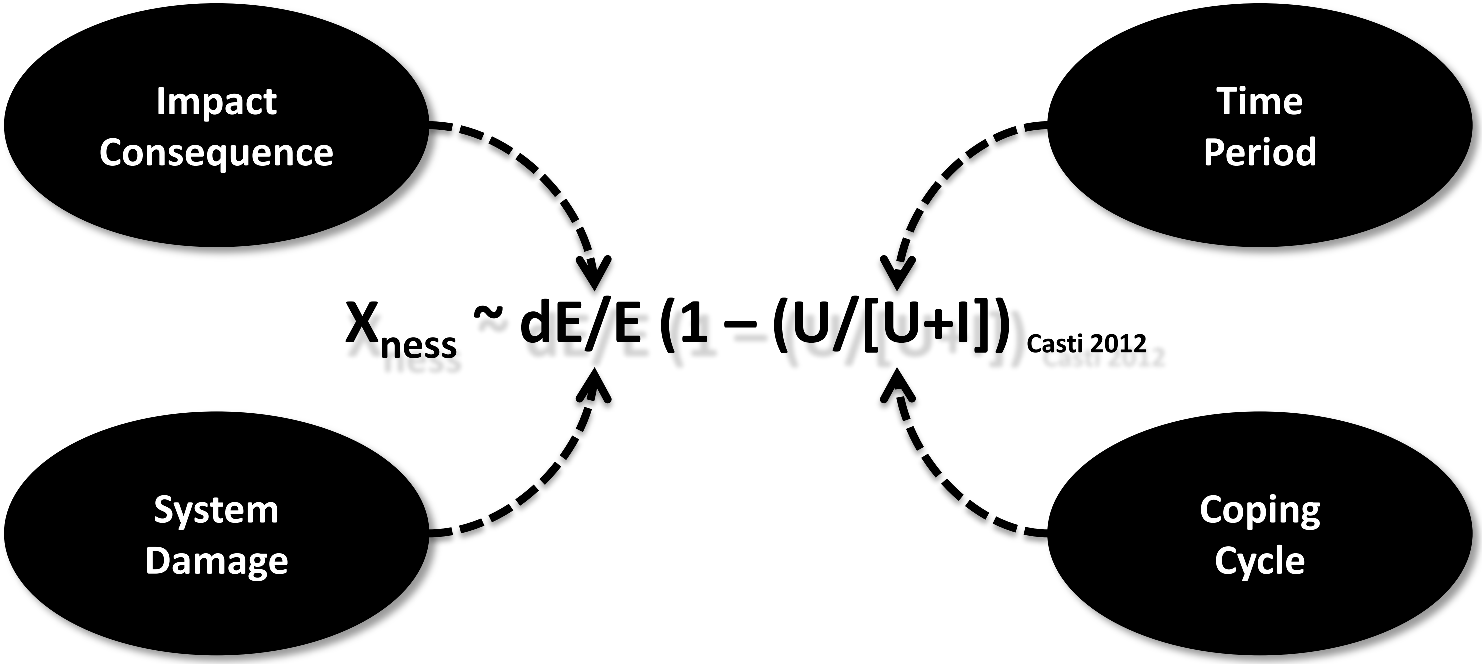


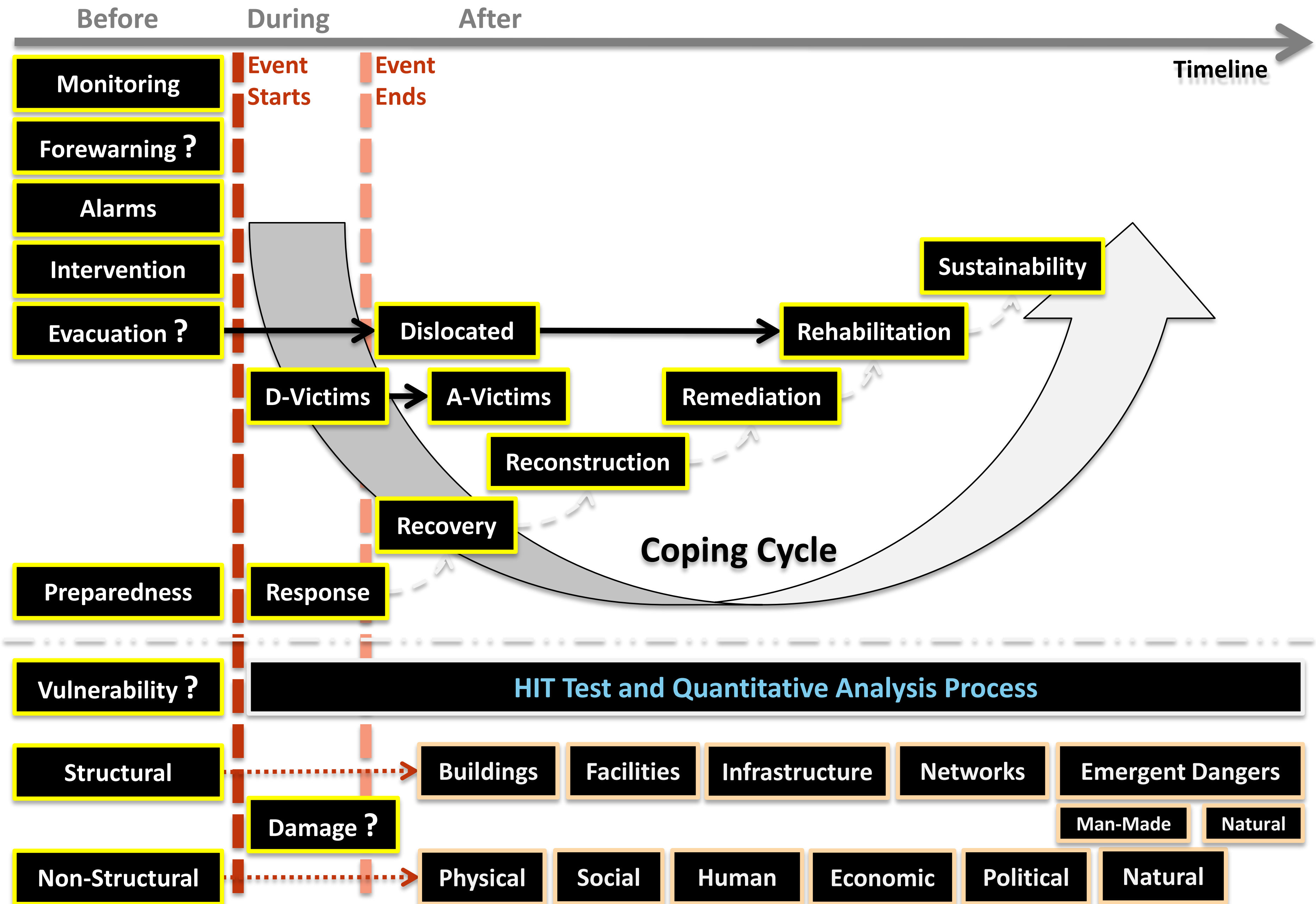
TOTAL COST
$ 13.0 Billion

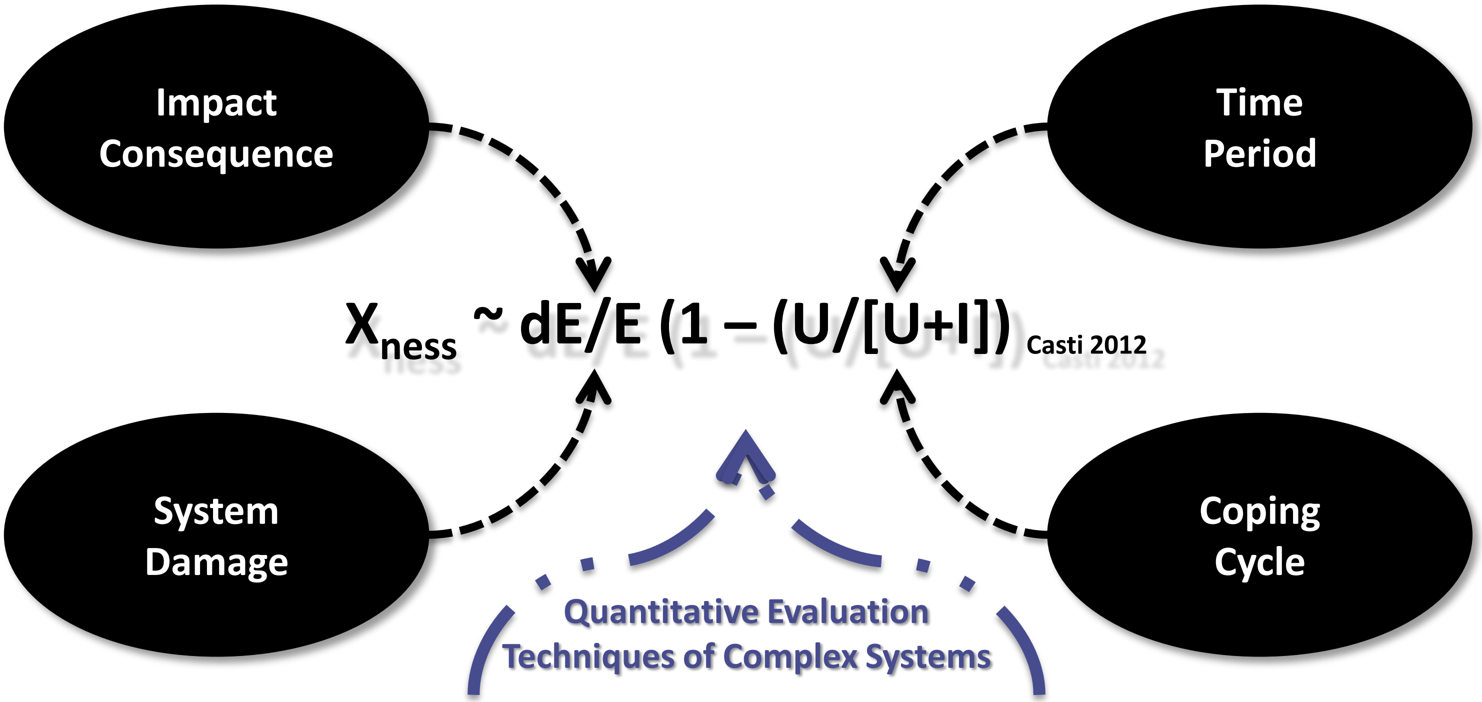
(Cochrane, 1974)

European Science Foundation (ESF), Group on Earth Observations (GEO), and the Geohazard Community of Practice (GHCP); Extreme Geohazards: Reducing the Disaster Risk and Increasing Resilience.






Before
During
After
Timeline
Event Starts
Event Ends
Monitoring
Forewarning ?
Alarms
Intervention
Evacuation ?
Dislocated
Rehabilitation
Sustainability
D-Victims
A-Victims
Remediation
Reconstruction
Recovery
Coping Cycle
Preparedness
Response
Vulnerability ?
HIT Test and Quantitative Analysis Process
Structural
Buildings
Facilities
Infrastructure
Networks
Emergent Dangers
Man-Made
Natural
Damage ?
Non-Structural
Physical
Social
Human
Economic
Political
Natural



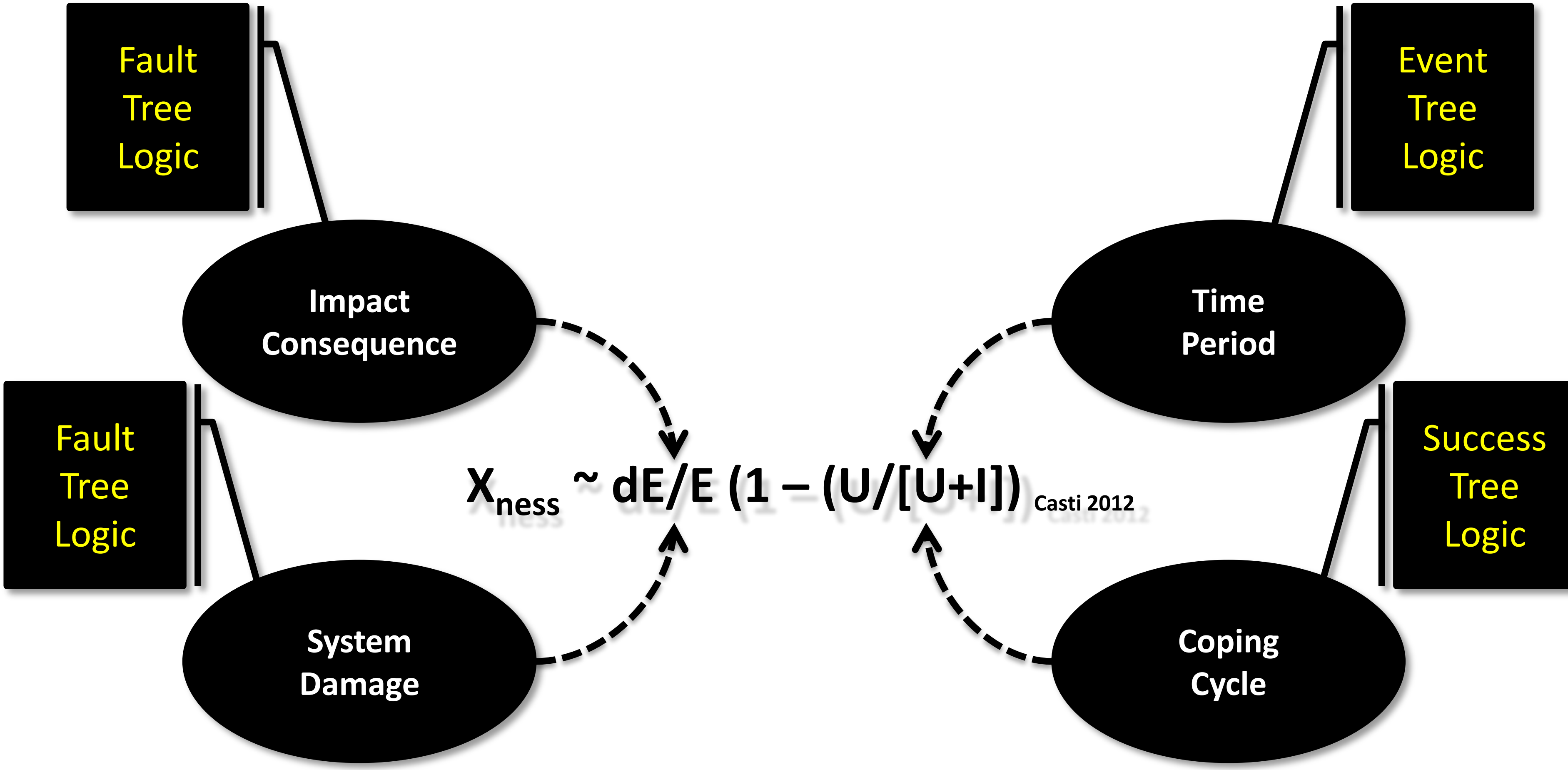
$X_{ness} \sim dE/E\,(1 - (U/[U+I])$ Casti 2012

Symbolic Event Tree

- Systematic Evaluation
- Inductive Reasoning
- Causal Direction
- Forward Method
- Start at Basic Events
- Hazard and Risk Analysis
- Single Point Failures
- Need System Knowledge
- Need Basic Events
- Need Conditional Data
- Complete Causal Tree

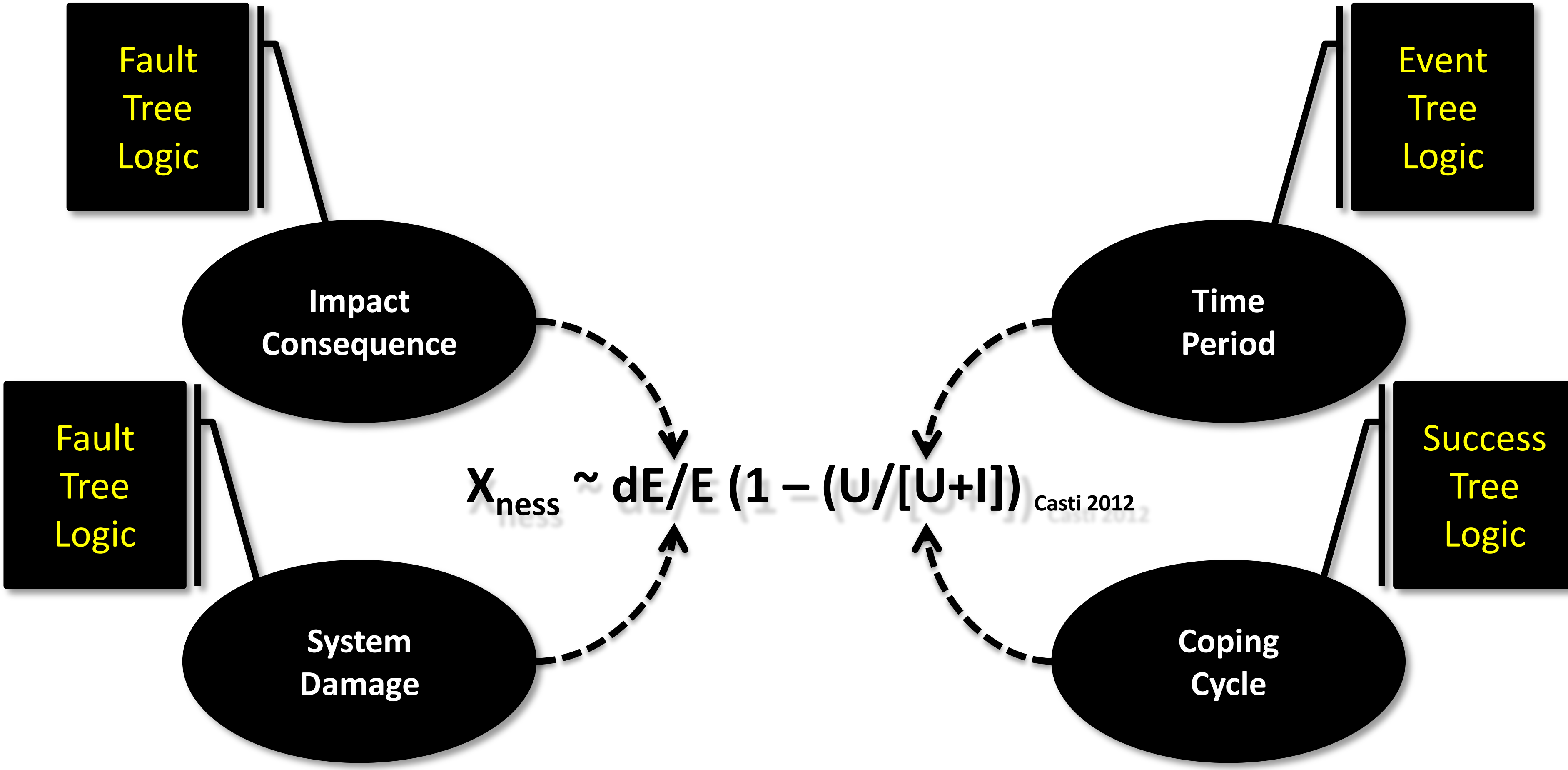
Symbolic Fault Tree

- Partial-Expert Evaluation
- Deductive Reasoning
- Anti-Causal Direction
- Backward Method
- Start at System Failure
- Backwards to Possible Causes
- Consequence Analysis
- Don't Need System Knowledge
- Don't Need Basic Events
- Need Good Sense
- Limit to Anti-Causal Tree

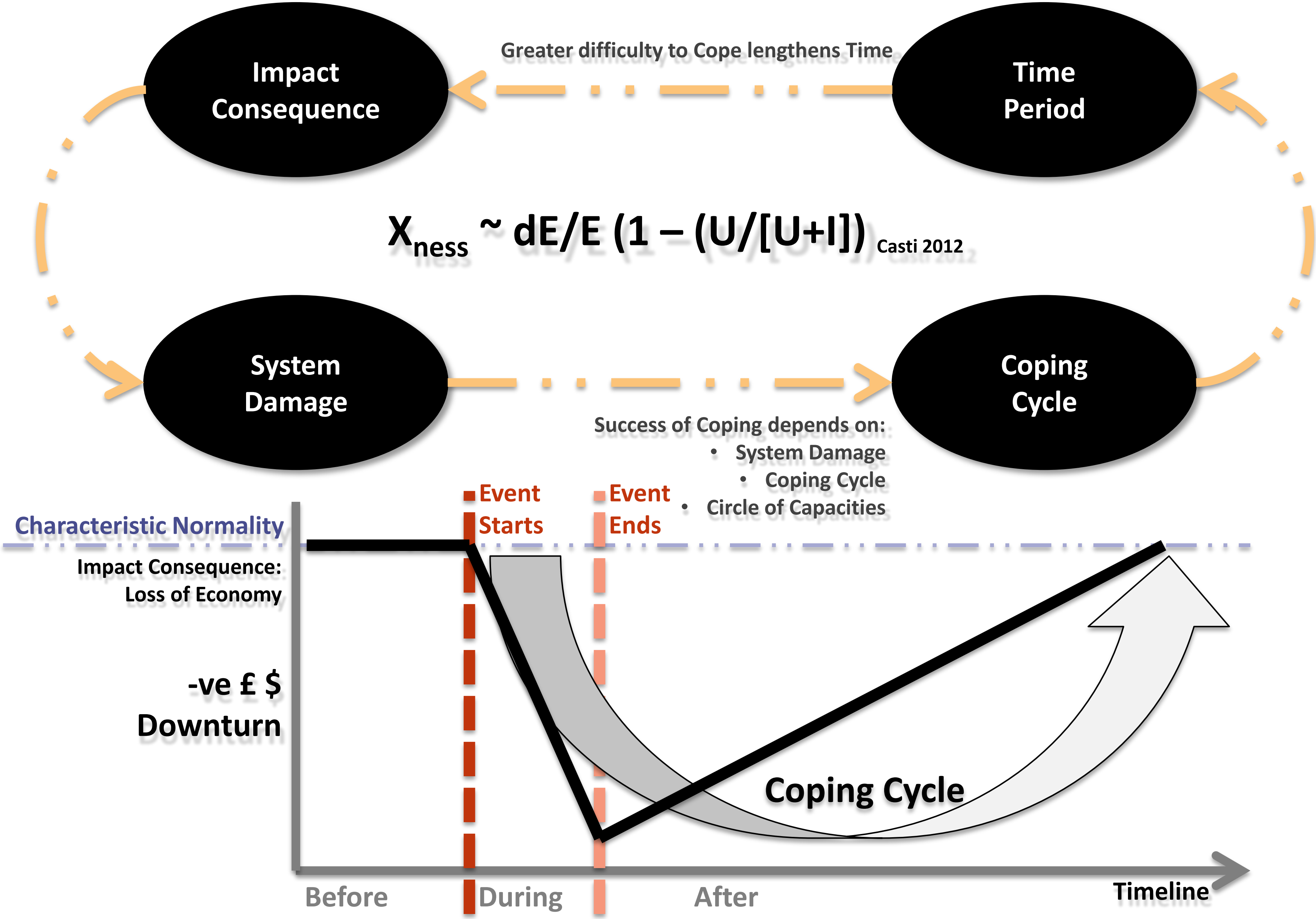


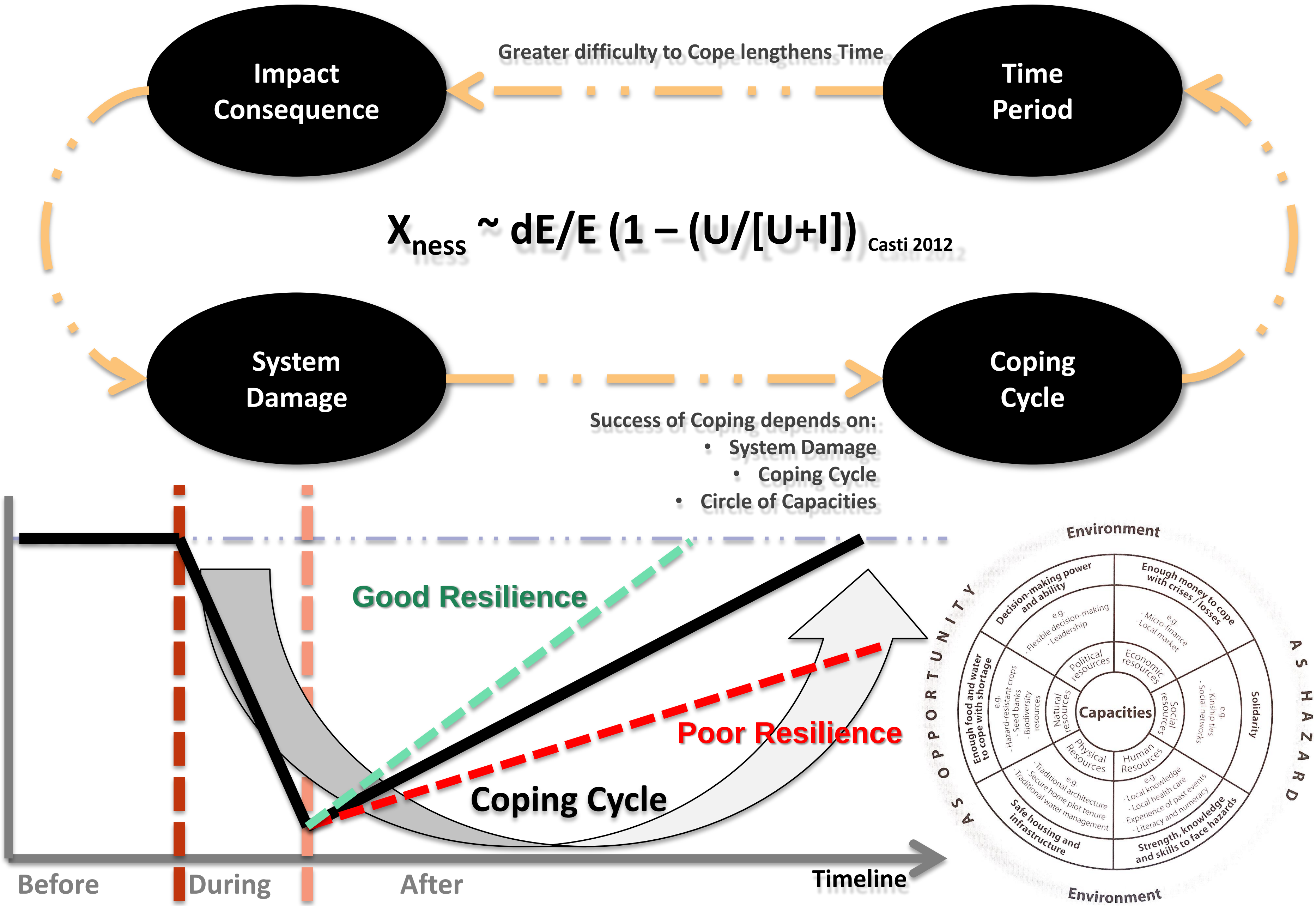
Key Criteria breakout of the extremeness of accidents and disaster for particular hazards:

- **Impact Consequence:** **| Victims | Injured | Dislocated | Economic-loss |**
- **System Damage:** **| Buildings | Facilities | Infrastructure | Networks |**
- **Time Period:** **| Event | -Ve Risk | Lowest | +Ve Resilience | Normal|**
- **Coping Cycle:** **| Response | Recovery | Reconstruct | Remediate |**

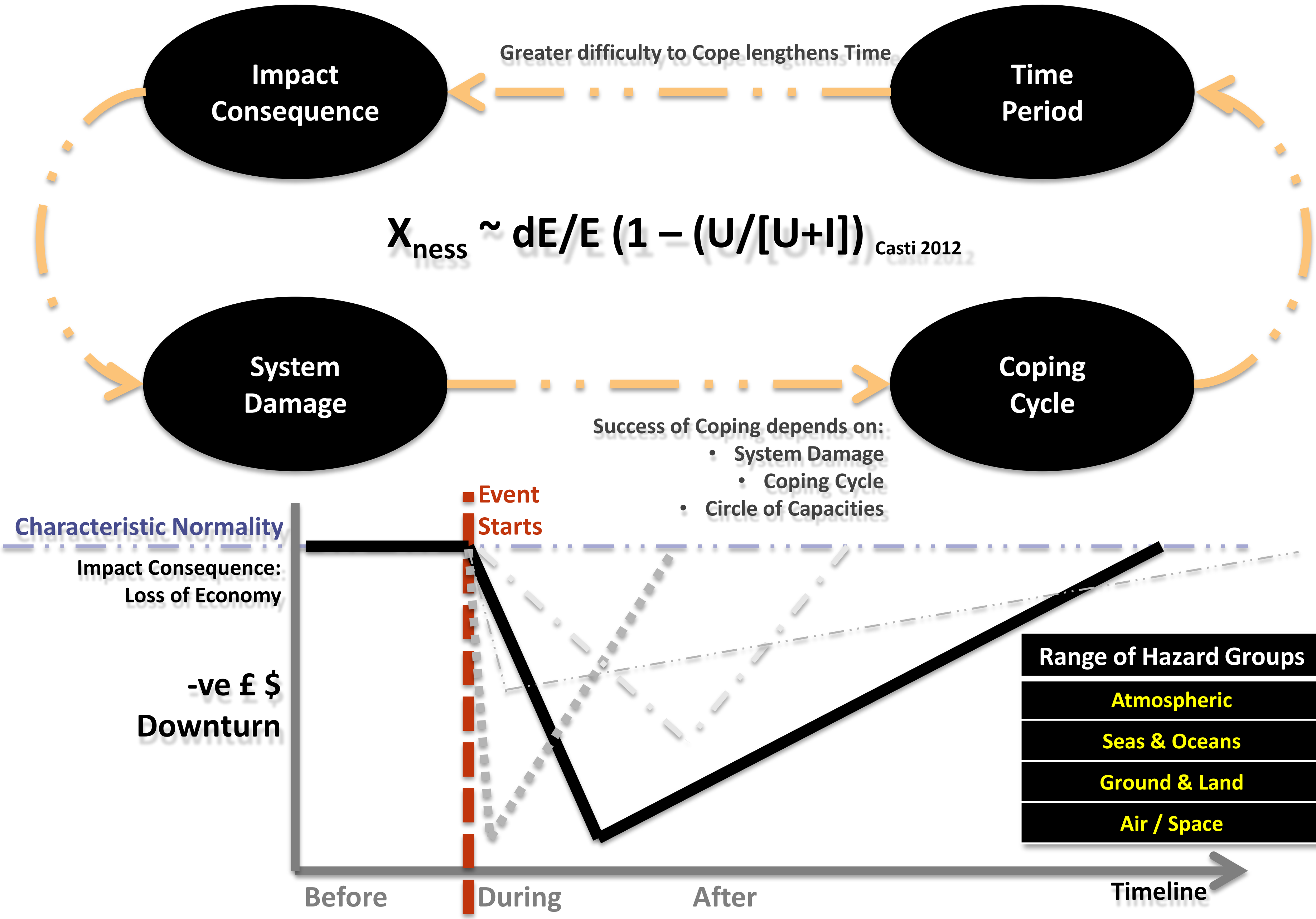


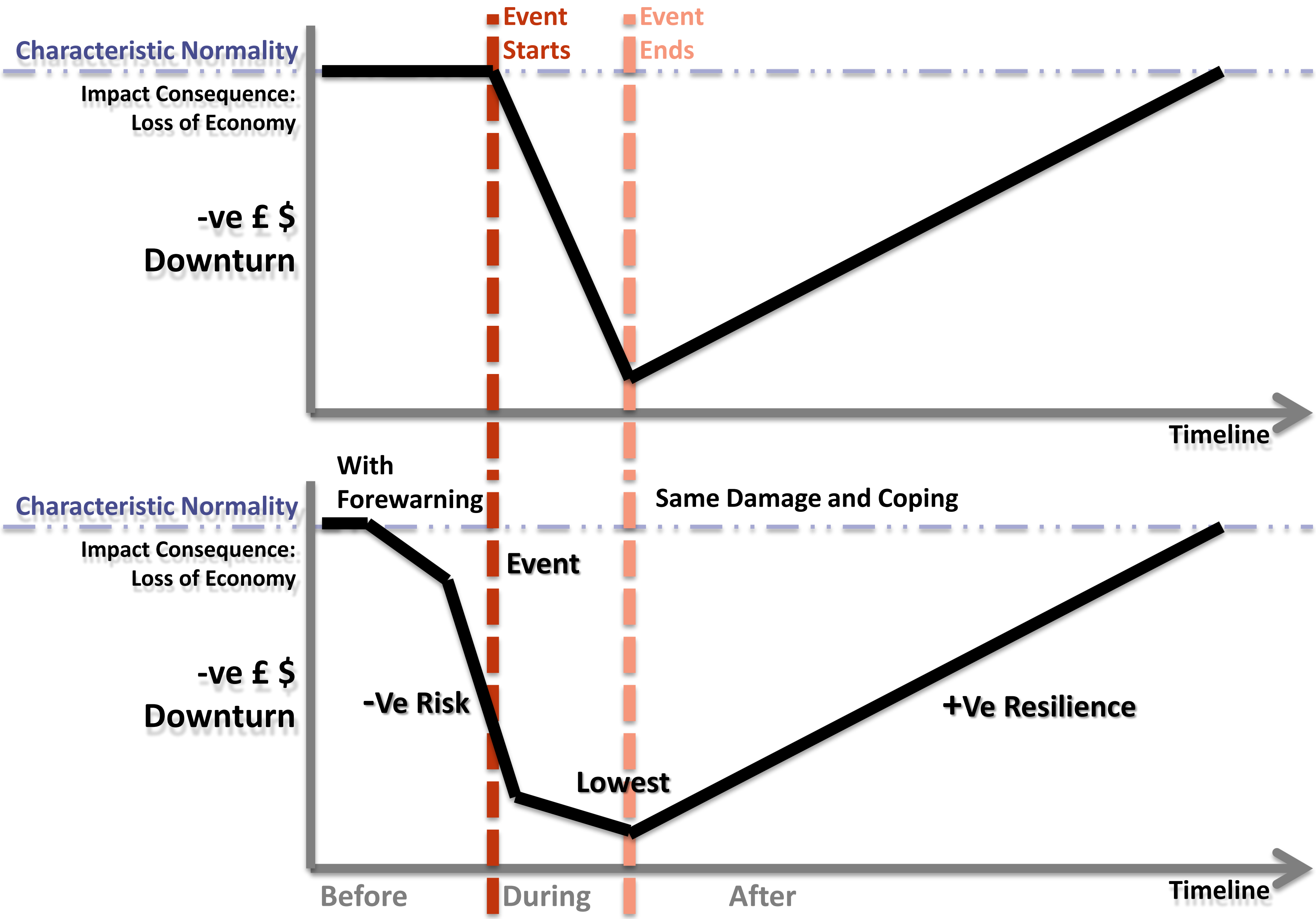
Groups of Criteria (initial appraisal – to be developed)	Range of Hazard Groups (for example)
Impact Consequence: | Victims | Injured | Dislocated | Economic-loss |	**Atmospheric:** | Wind | Hurricane | Tornado | Rain |
System Damage: | Buildings | Facilities | Infrastructure | Networks |	**Seas & Oceans:** | Storm Surge | Tsunami | LSL |
Time Period: | Event | -Ve Risk | Lowest | +Ve Resilience | Normal |	**Ground & Land:** | Earthquake | Landslide | Land Rise |
Coping Cycle: | Response | Recovery | Reconstruct | Remediate |	**Air / Space:** | Aircraft Crash |Bolide | Space Debris |

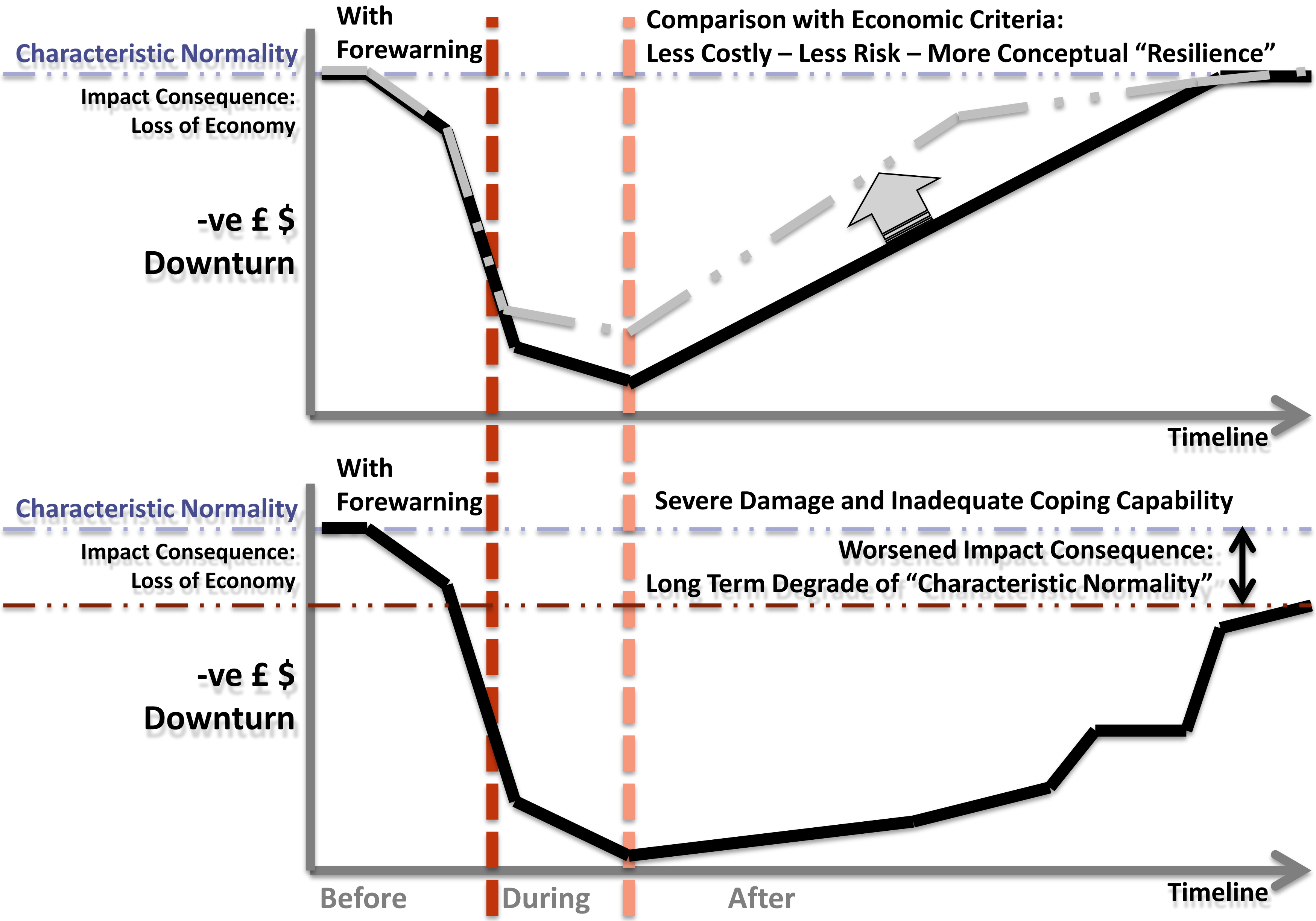

Impact Consequence
Greater difficulty to Cope lengthens Time
Time Period
Xness ~ dE/E (1 – (U/[U+I]) Casti 2012
System Damage
Coping Cycle
Success of Coping depends on:
• System Damage
• Coping Cycle
• Circle of Capacities
Event Starts
Event Ends
Characteristic Normality
Impact Consequence:
Loss of Economy
-ve £ $
Downturn
Coping Cycle
Before
During
After
Timeline



$$X_{ness} \sim dE/E\,(1 - (U/[U+I]))_{\text{Casti 2012}}$$


Impact Consequence
Greater difficulty to Cope lengthens Time
Time Period
$X_{ness} \sim dE/E\,(1 - (U/[U+I]))$ Casti 2012
System Damage
Coping Cycle
Success of Coping depends on:
• System Damage
• Coping Cycle
• Circle of Capacities
Event Starts
Characteristic Normality
Impact Consequence:
Loss of Economy
-ve £ $
Downturn
Range of Hazard Groups
Atmospheric
Seas & Oceans
Ground & Land
Air / Space
Before
During
After
Timeline


Event
Starts
Event
Ends
Characteristic Normality
Impact Consequence:
Loss of Economy
-ve £ $
Downturn
Timeline
With
Forewarning
Same Damage and Coping
Characteristic Normality
Impact Consequence:
Loss of Economy
Event
-ve £ $
Downturn
-Ve Risk
+Ve Resilience
Lowest
Before
During
After
Timeline


With Forewarning
Comparison with Economic Criteria:
Less Costly – Less Risk – More Conceptual "Resilience"
Characteristic Normality
Impact Consequence:
Loss of Economy
-ve £ $
Downturn
Timeline
With Forewarning
Severe Damage and Inadequate Coping Capability
Characteristic Normality
Worsened Impact Consequence:
Long Term Degrade of "Characteristic Normality"
Impact Consequence:
Loss of Economy
-ve £ $
Downturn
Before
During
After
Timeline

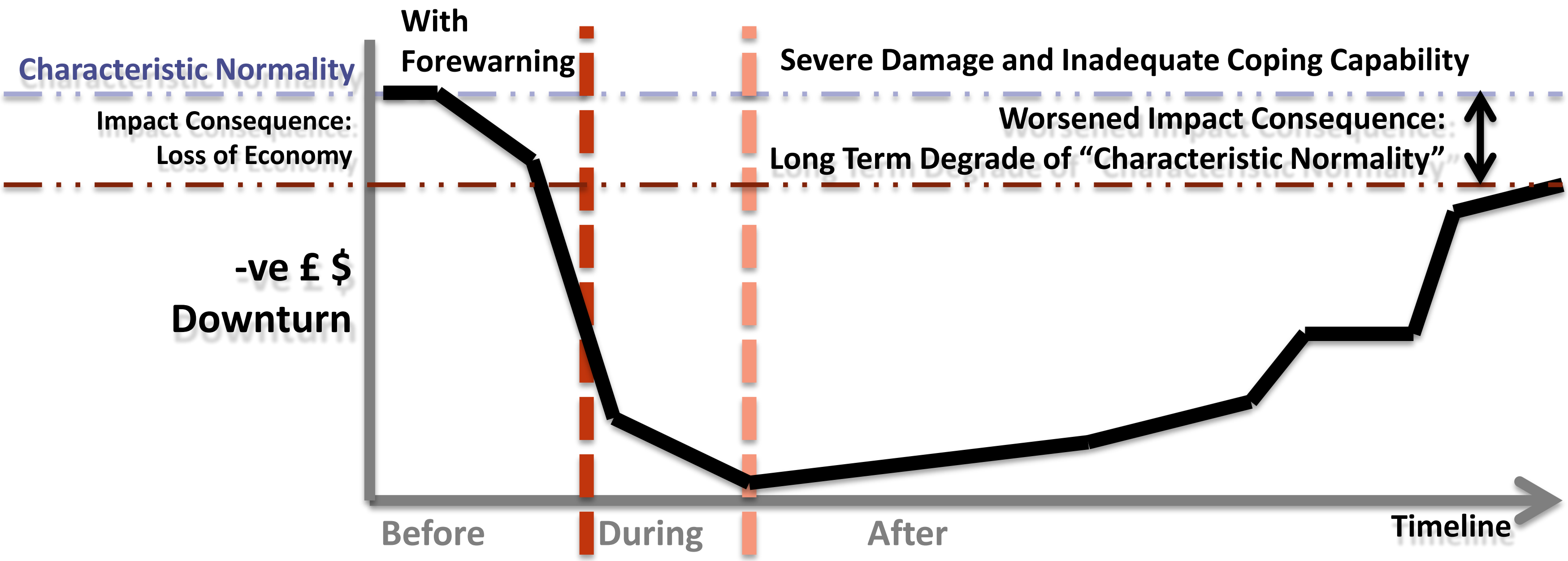
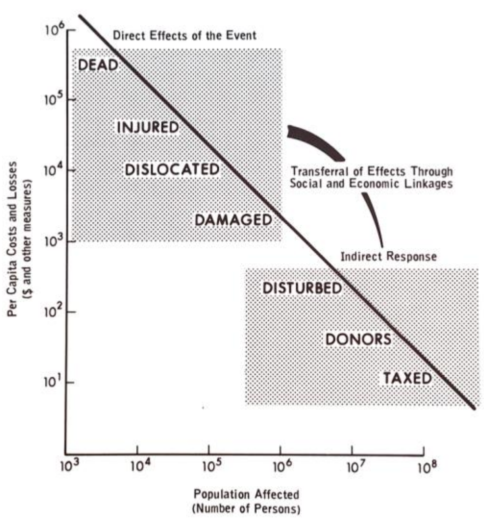


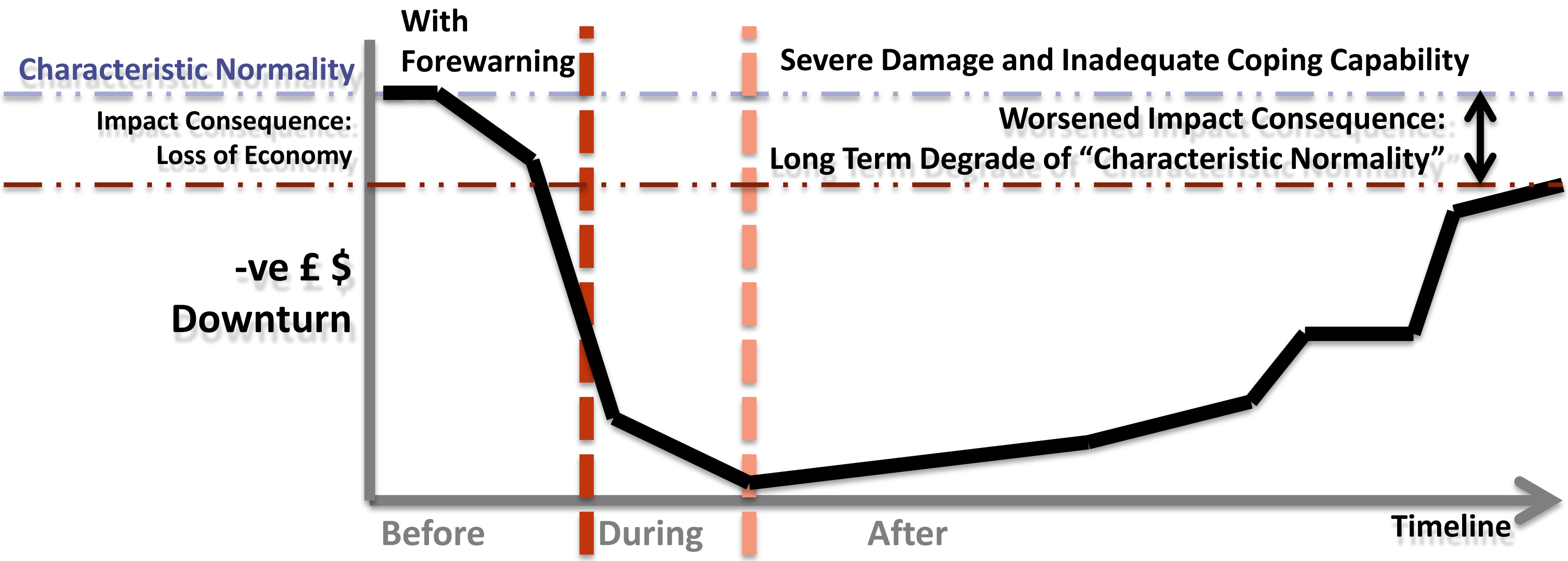
FIGURE 3–8

IMPACT OF DISASTER: A CONTINUUM OF EFFECTS



(adapted from Bowden and Kates, 1974)

Groups of Criteria (initial appraisal – to be developed)	
Impact Consequence:	| Victims | Injured | Dislocated | Economic-loss |
System Damage:	| Buildings | Facilities | Infrastructure | Networks |
Time Period:	| Event | -Ve Risk | Lowest | +Ve Resilience | Normal |
Coping Cycle:	| Response | Recovery | Reconstruct | Remediate |



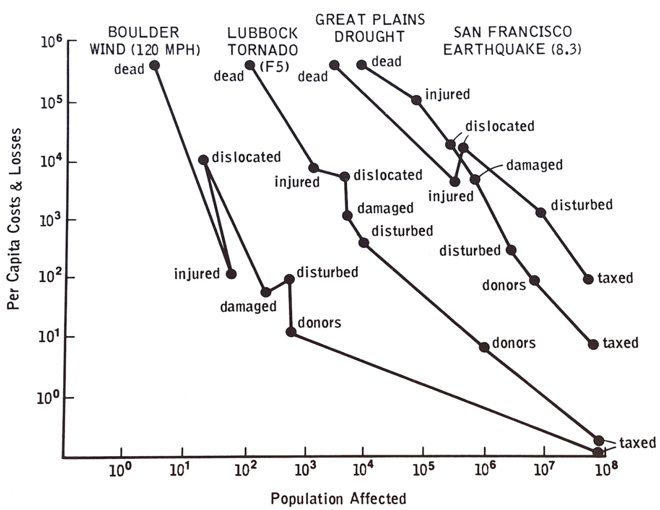
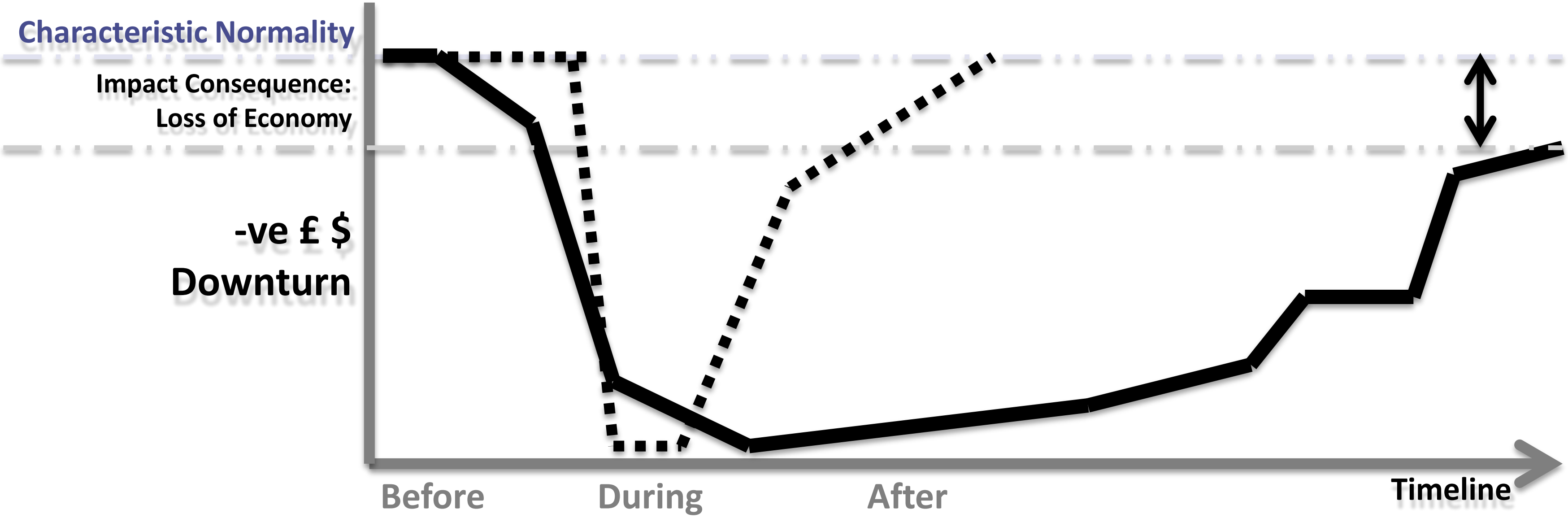


FIGURE 3–9
DISRUPTIVE EFFECTS COMPARED

Range of Hazard Groups (for example)
Atmospheric: | Wind | Hurricane | Tornado | Rain |
Seas & Oceans: | Storm Surge | Tsunami | LSL |
Ground & Land: | Earthquake | Landslide | Land Rise |
Air / Space: | Aircraft Crash |Bolide | Space Debris |
Combined: *| Hurricane + Precipitation + Storm Surge |*



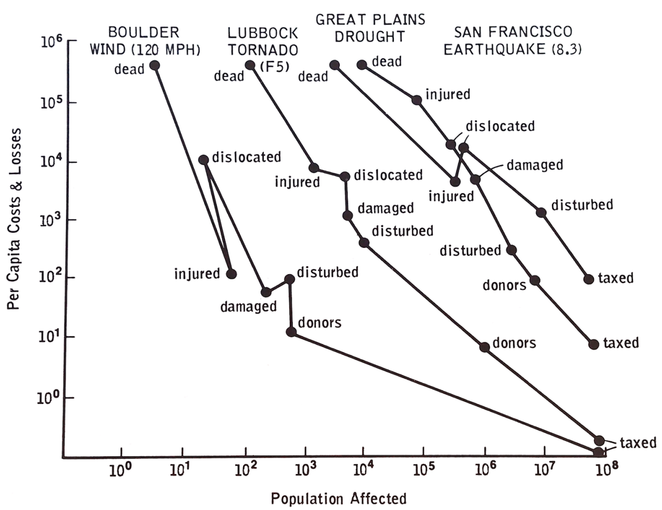


FIGURE 3–9
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Atmospheric: | Wind | Hurricane | Tornado | Rain |
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Air / Space: | Aircraft Crash |Bolide | Space Debris |
Combined: *| Hurricane + Precipitation + Storm Surge |*

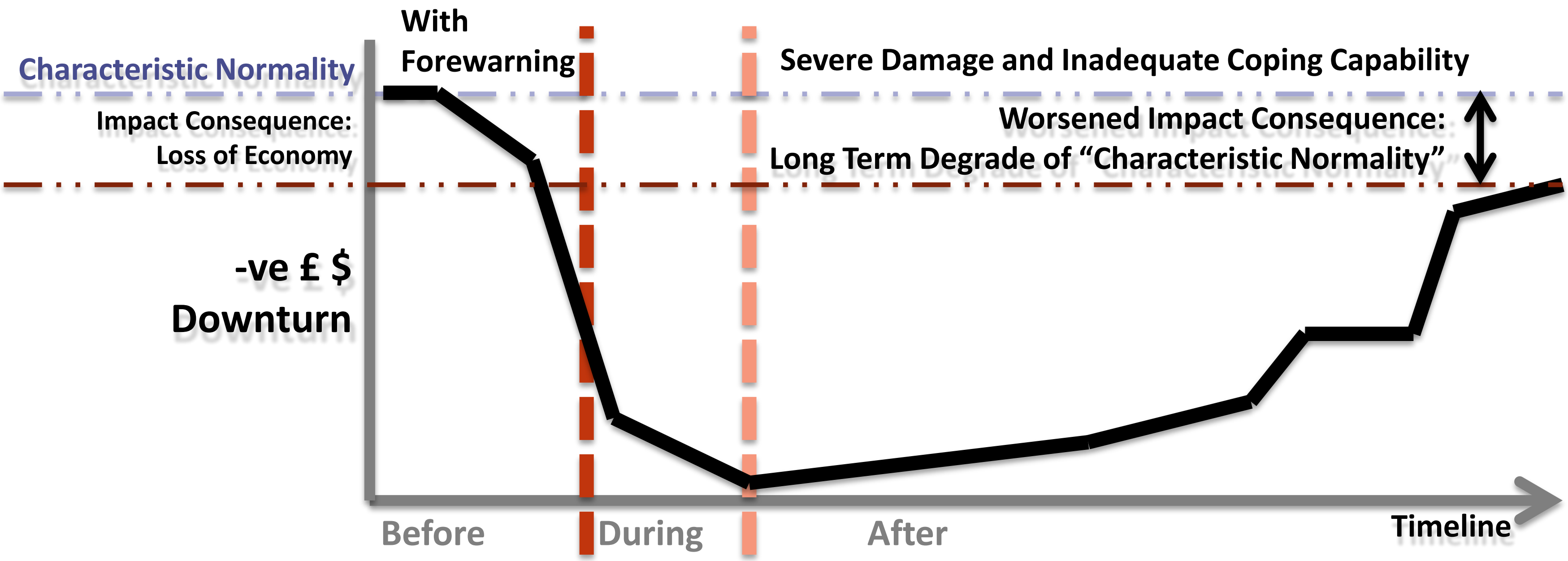
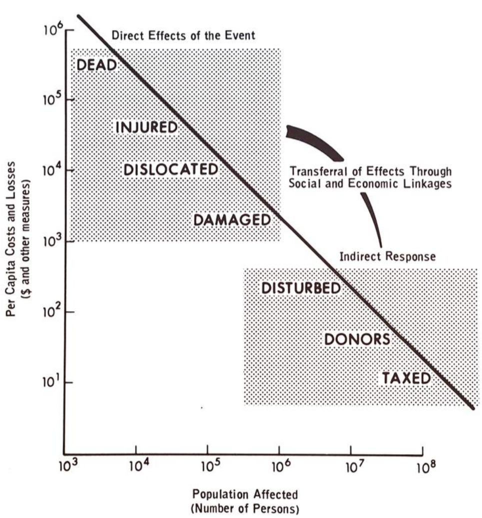


FIGURE 3–8

IMPACT OF DISASTER: A CONTINUUM OF EFFECTS



(adapted from Bowden and Kates, 1974)

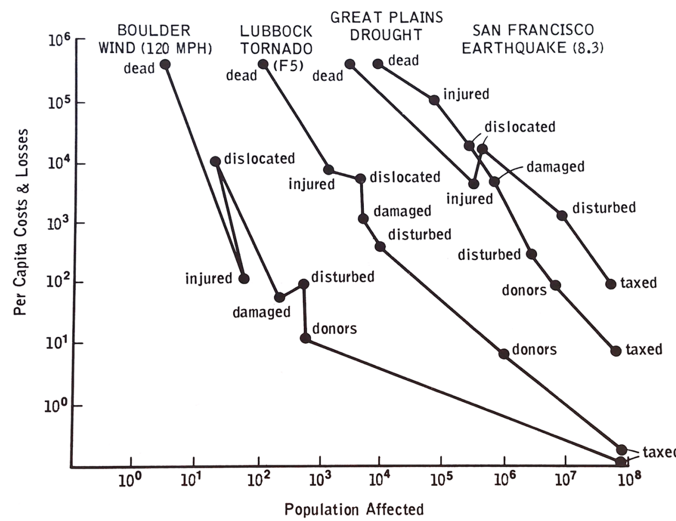
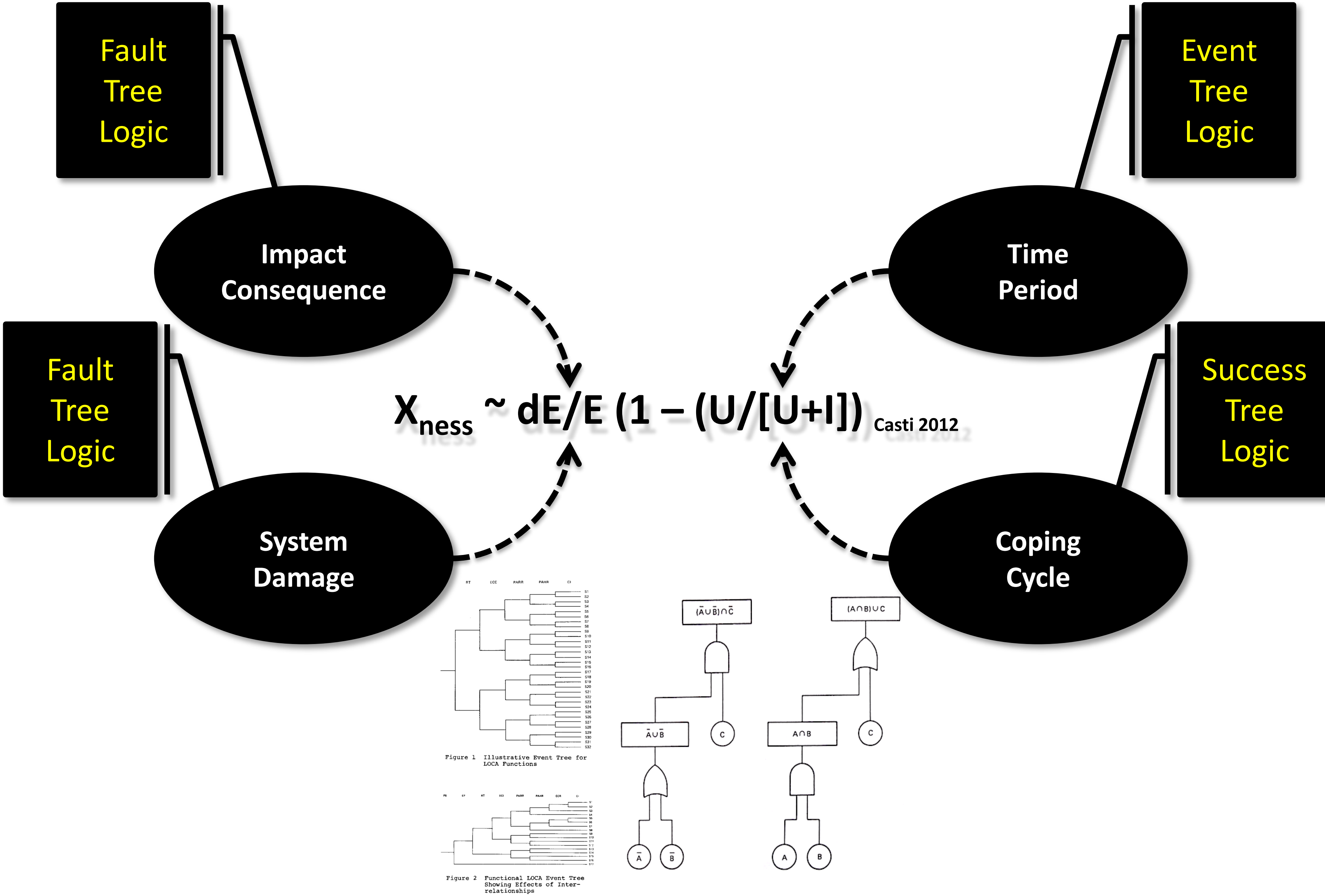
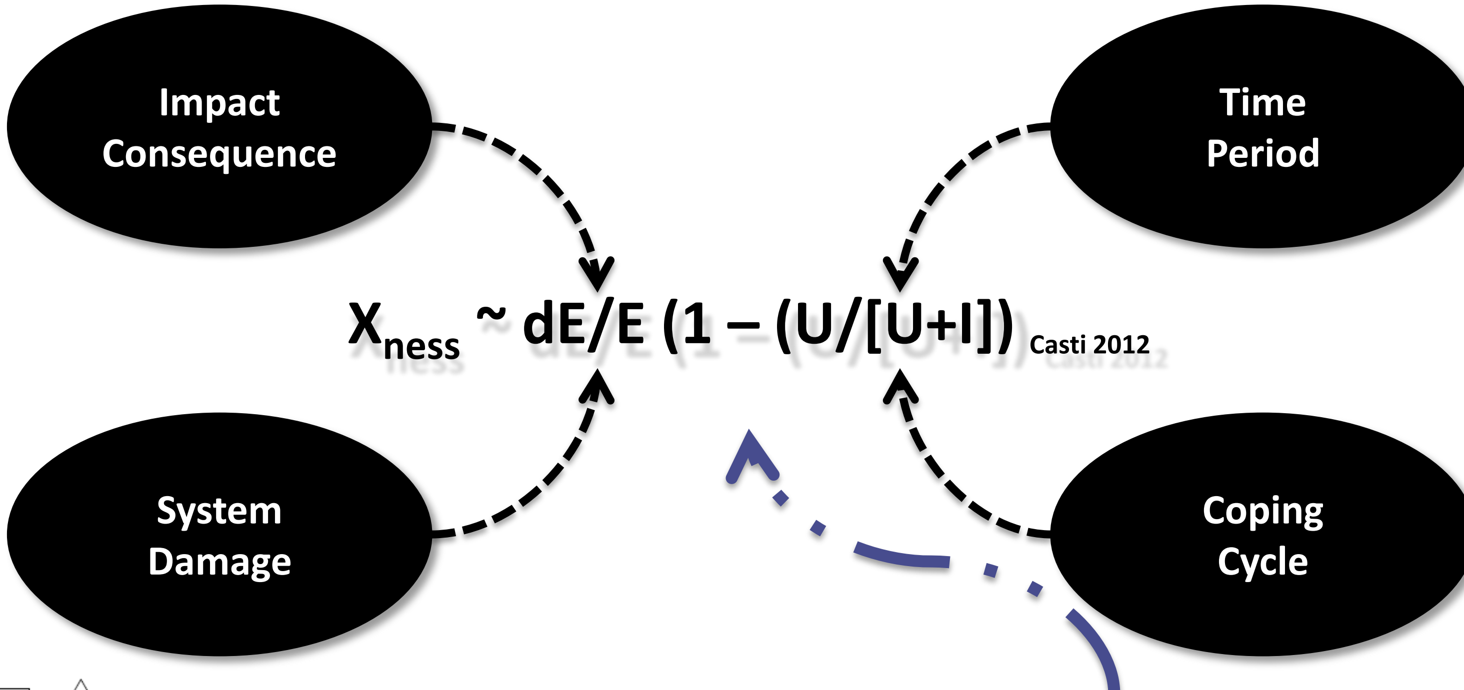
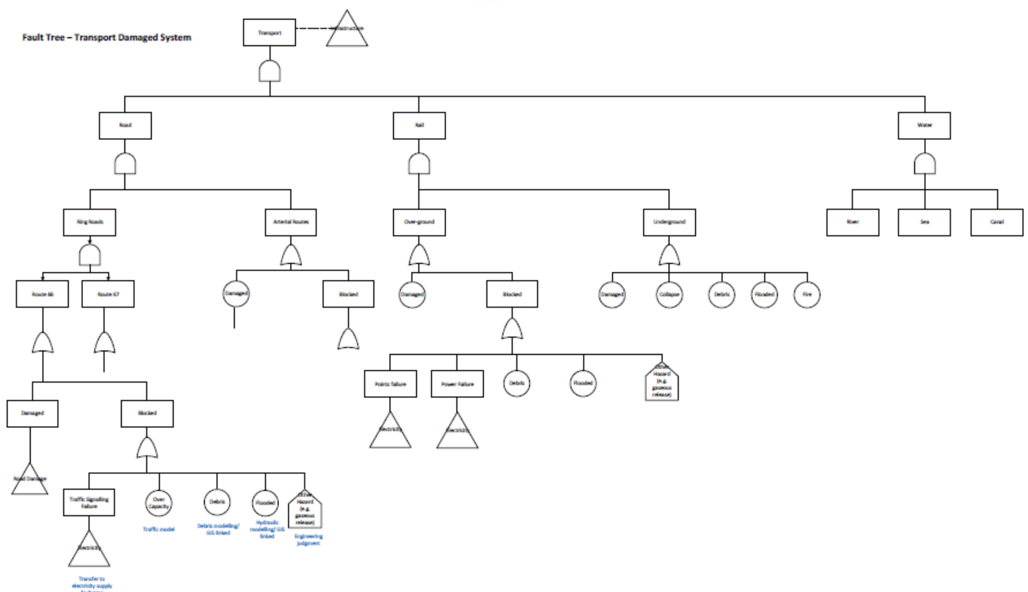


FIGURE 3–9

DISRUPTIVE EFFECTS COMPARED

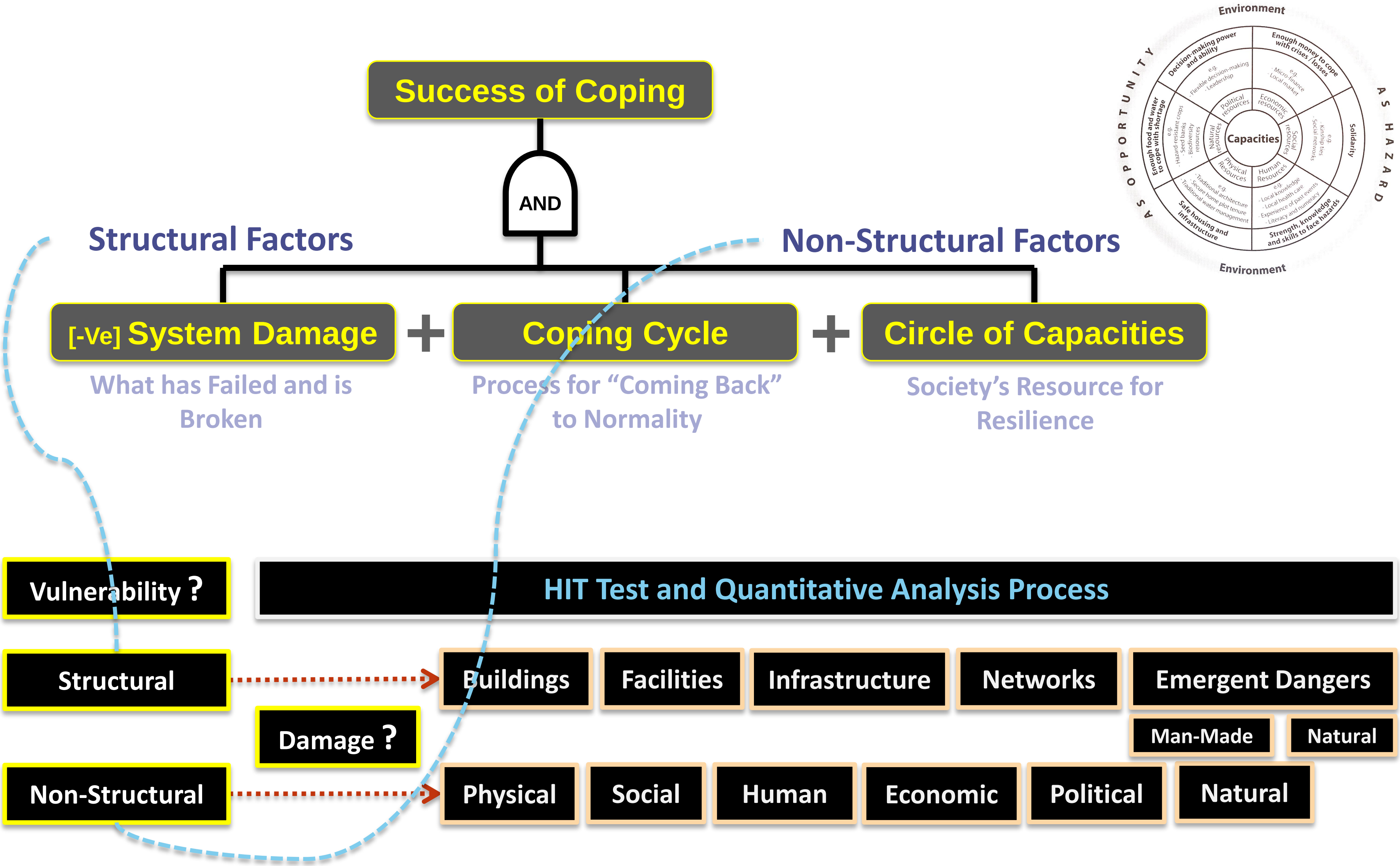

Fault Tree Logic
Impact Consequence
Fault Tree Logic
System Damage
Event Tree Logic
Time Period
Success Tree Logic
Coping Cycle
X_ness ~ dE/E (1 – (U/[U+I])) Casti 2012
Figure 1 Illustrative Event Tree for LOCA Functions
Figure 2 Functional LOCA Event Tree Showing Effects of Inter-relationships
(Ā∪B̄)∩C̄
Ā∪B̄
C
Ā
B̄
(A∩B)∪C
A∩B
C
A
B

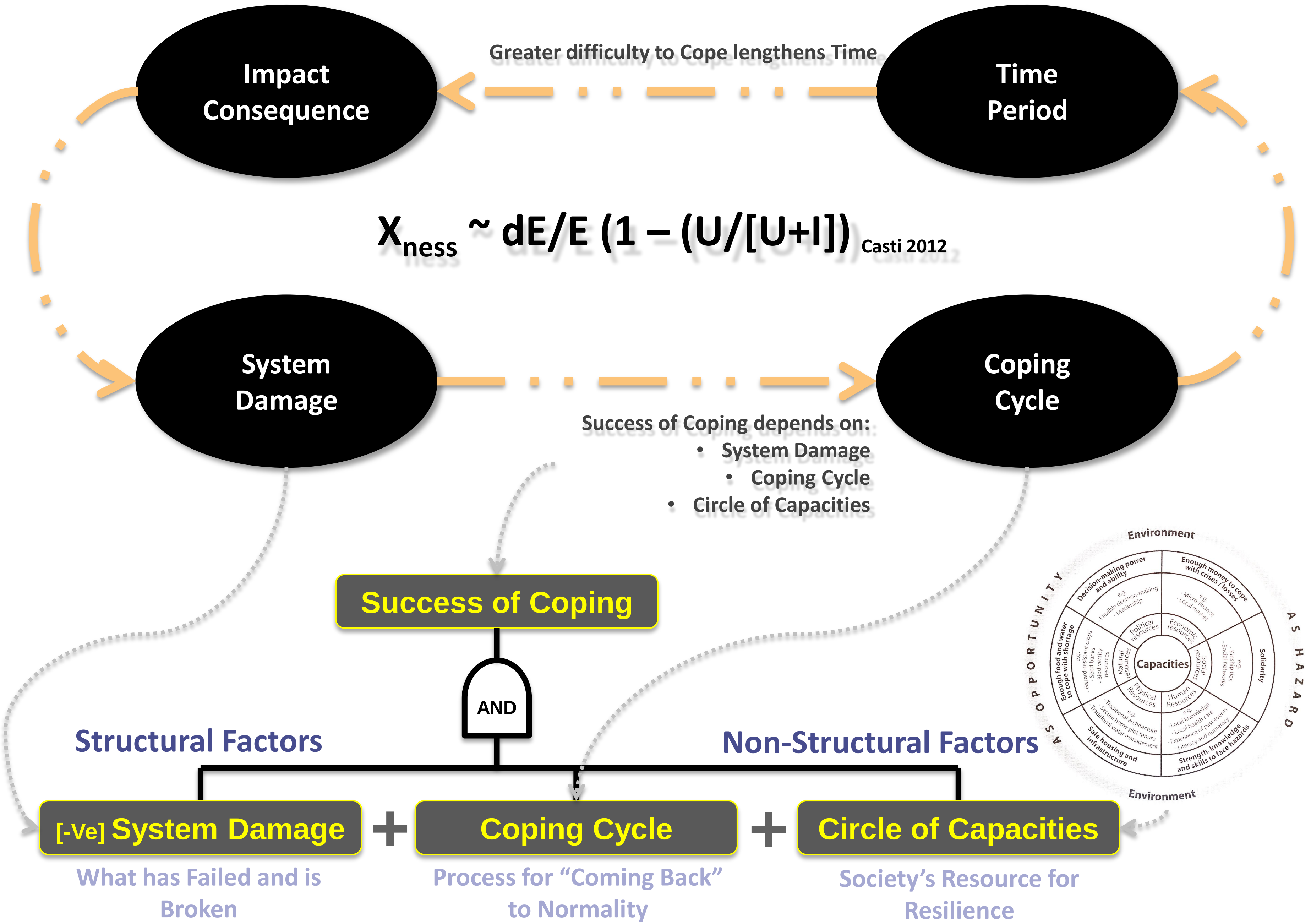




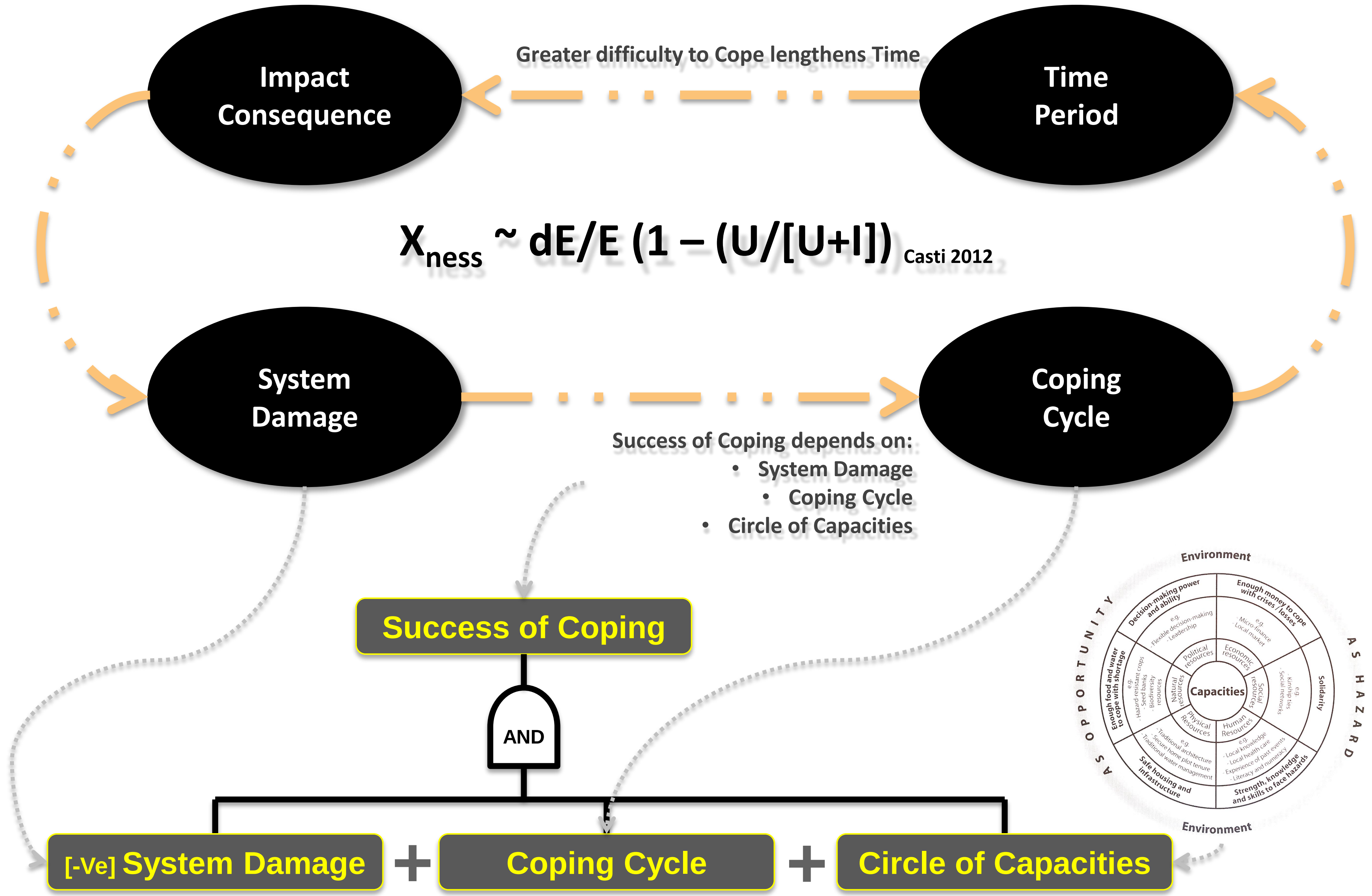
Symbolic Fault Tree

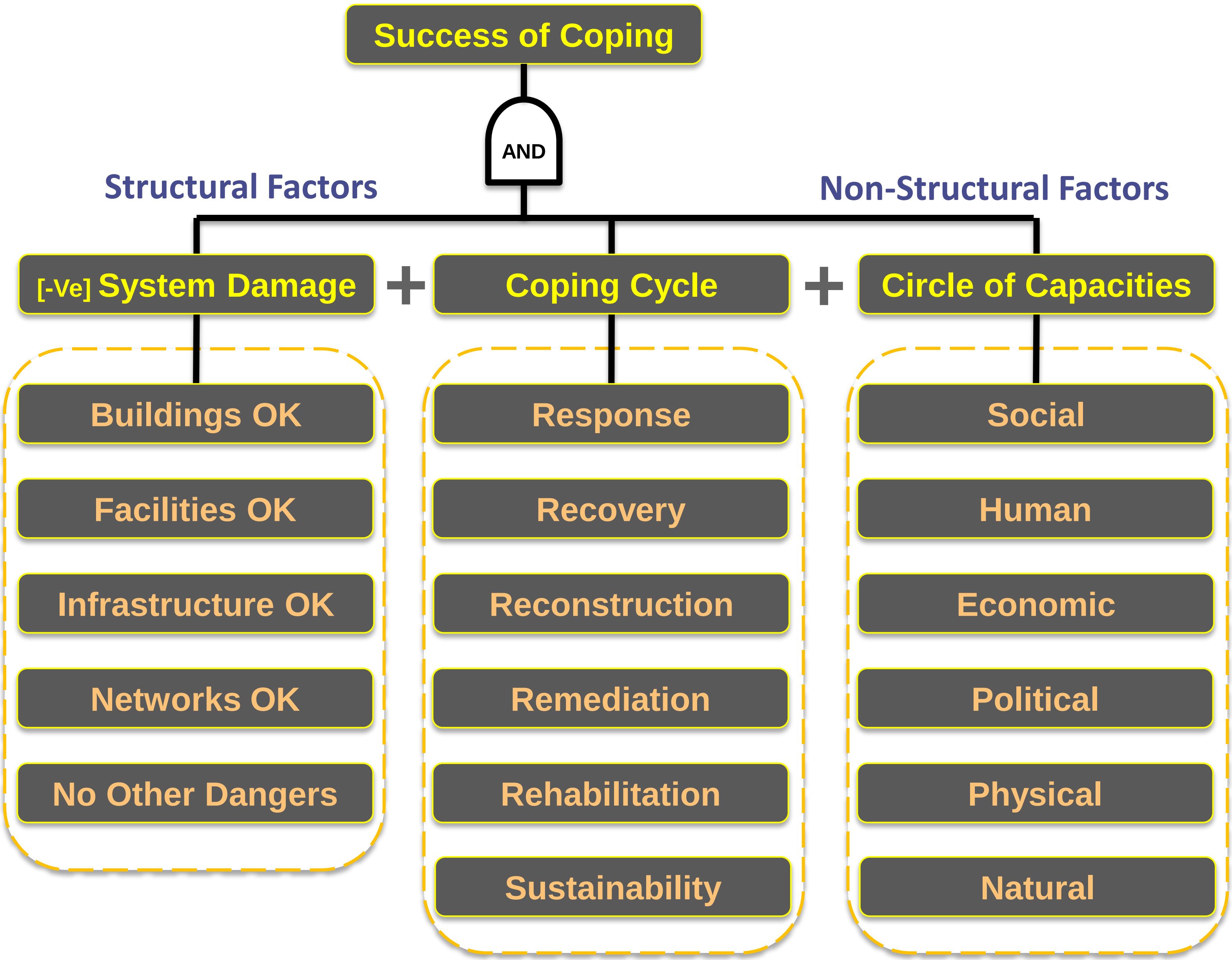
- Partial-Expert Evaluation
- Deductive Reasoning
- Anti-Causal Direction
- Backward Method
- Start at System Failure
- Backwards to Possible Causes
- Consequence Analysis
- Don't Need System Knowledge
- Don't Need Basic Events
- Need Good Sense
- Limit to Anti-Causal Tree

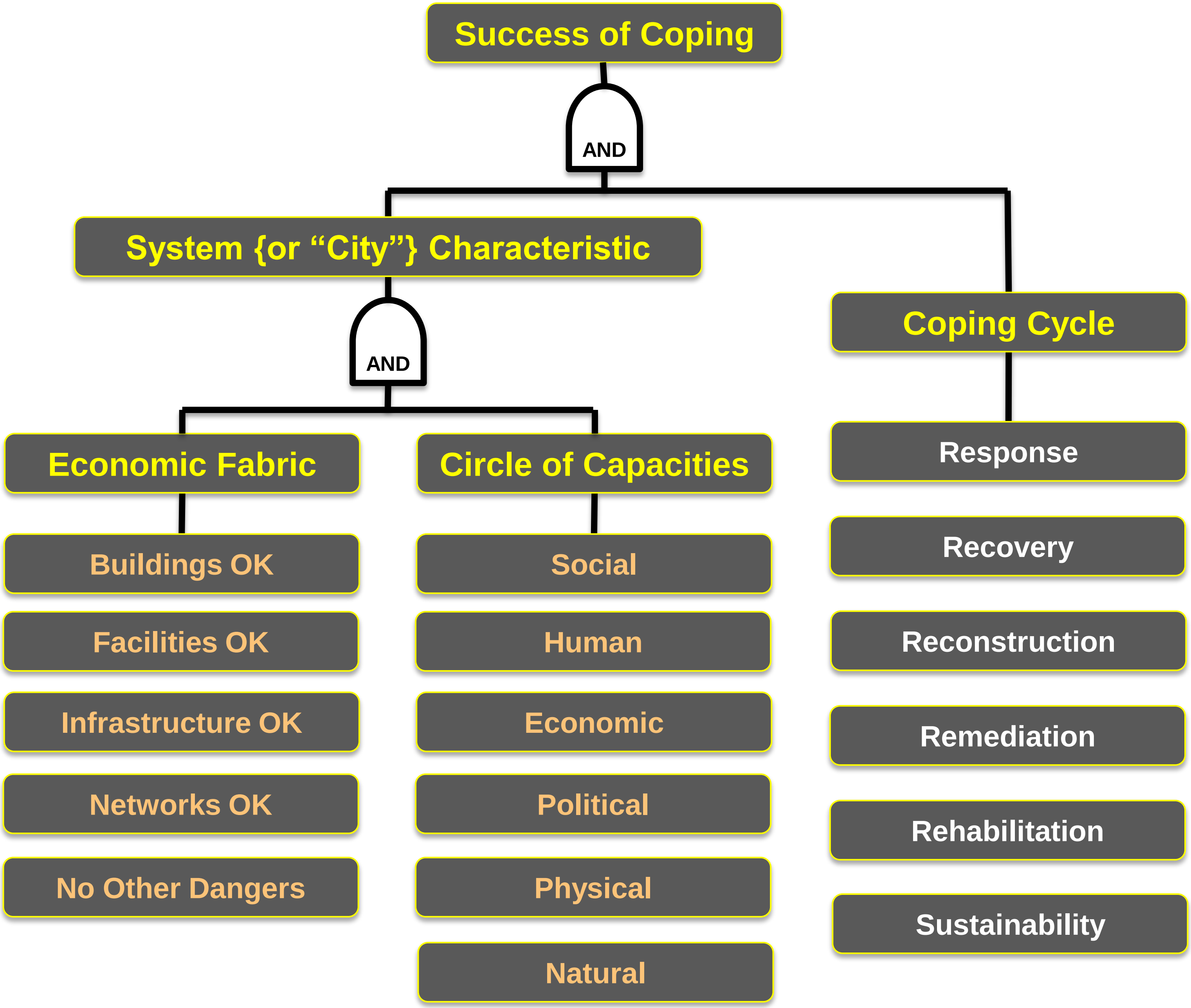

Success of Coping
AND
Structural Factors
Non-Structural Factors
[-Ve] System Damage
+
Coping Cycle
+
Circle of Capacities
What has Failed and is Broken
Process for “Coming Back” to Normality
Society’s Resource for Resilience
Environment
AS OPPORTUNITY
AS HAZARD
Decision-making power and ability
e.g. - Flexible decision-making - Leadership
Enough money to cope with crises / losses
e.g. - Micro-finance - Local market
Political resources
Economic resources
Enough food and water to cope with shortage
e.g. - Hazard-resistant crops - Seed banks - Biodiversity resources
Natural resources
Capacities
Social resources
e.g. - Kinship ties - Social networks
Solidarity
Physical Resources
Human Resources
e.g. - Traditional architecture - Secure home plot tenure - Traditional water management
e.g. - Local knowledge - Local health care - Experience of past events - Literacy and numeracy
Safe housing and infrastructure
Strength, knowledge and skills to face hazards
Environment
Vulnerability ?
HIT Test and Quantitative Analysis Process
Structural
Buildings
Facilities
Infrastructure
Networks
Emergent Dangers
Man-Made
Natural
Damage ?
Non-Structural
Physical
Social
Human
Economic
Political
Natural


Greater difficulty to Cope lengthens Time
Impact Consequence
Time Period
$X_{ness} \sim dE/E\,(1 - (U/[U+I]))$ Casti 2012
System Damage
Coping Cycle
Success of Coping depends on:
• System Damage
• Coping Cycle
• Circle of Capacities
Success of Coping
AND
Structural Factors
Non-Structural Factors
[-Ve] System Damage
+
Coping Cycle
+
Circle of Capacities
What has Failed and is Broken
Process for "Coming Back" to Normality
Society's Resource for Resilience
Environment
AS OPPORTUNITY
AS HAZARD
Capacities
Political resources
Economic resources
Social resources
Human Resources
Physical Resources
Natural resources
Decision-making power and ability
e.g. - Flexible decision-making - Leadership
Enough money to cope with crises / losses
e.g. - Micro-finance - Local market
Solidarity
e.g. - Kinship ties - Social networks
Strength, knowledge and skills to face hazards
e.g. - Local knowledge - Local health care - Experience of past events - Literacy and numeracy
Safe housing and infrastructure
e.g. - Traditional architecture - Secure home plot tenure - Traditional water management
Enough food and water to cope with shortage
e.g. - Hazard-resistant crops - Seed banks - Biodiversity resources
Environment

ARUP


Impact Consequence
Greater difficulty to Cope lengthens Time
Time Period
X_{ness} ~ dE/E (1 – (U/[U+I]) Casti 2012
System Damage
Coping Cycle
Success of Coping depends on:
• System Damage
• Coping Cycle
• Circle of Capacities
Success of Coping
AND
[-Ve] System Damage
+
Coping Cycle
+
Circle of Capacities
Environment
Capacities
Solidarity
AS OPPORTUNITY
AS HAZARD
Environment

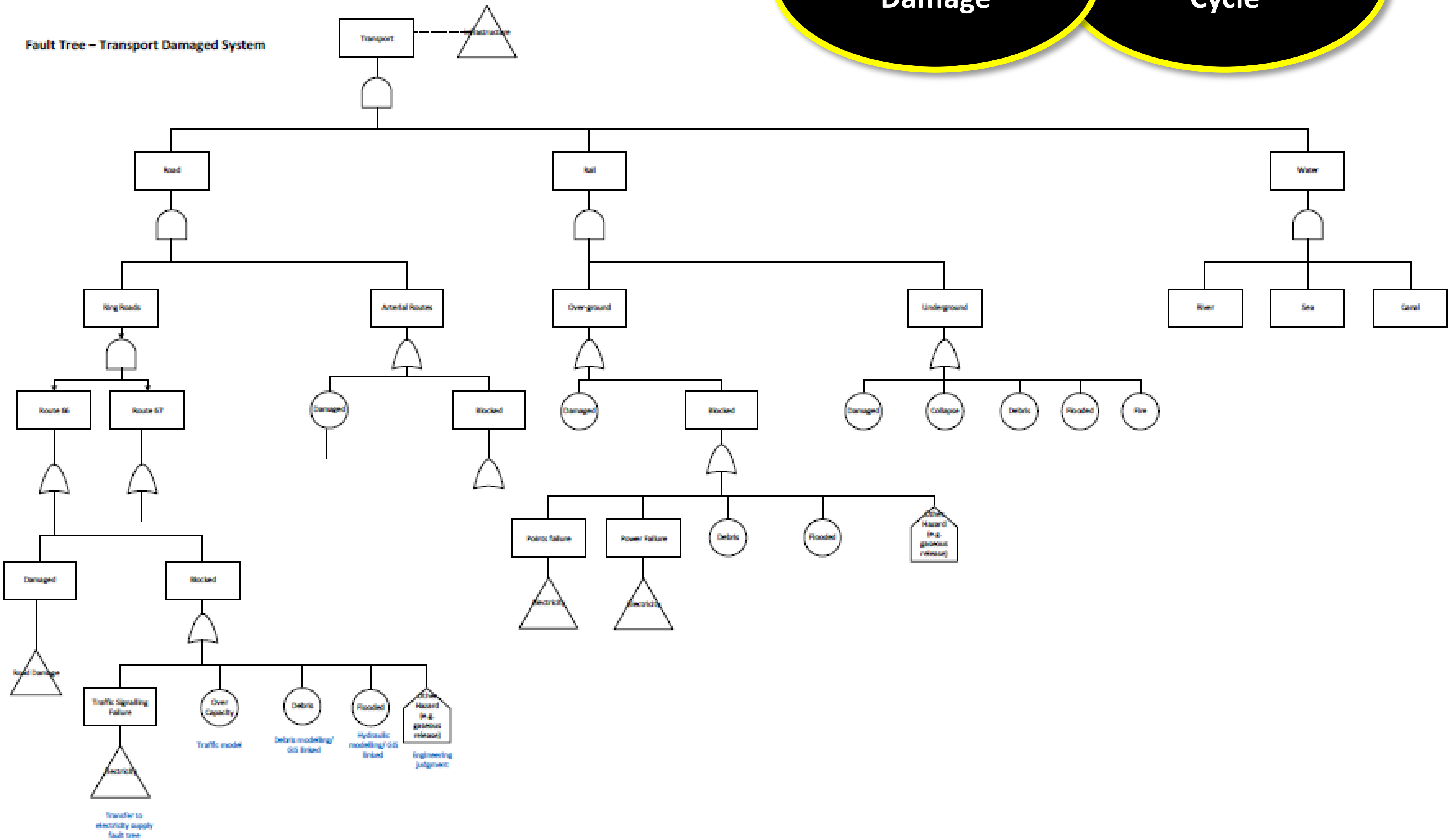

Success of Coping
AND
Structural Factors
Non-Structural Factors
[-Ve] System Damage
+
Coping Cycle
+
Circle of Capacities
Buildings OK
Facilities OK
Infrastructure OK
Networks OK
No Other Dangers
Response
Recovery
Reconstruction
Remediation
Rehabilitation
Sustainability
Social
Human
Economic
Political
Physical
Natural

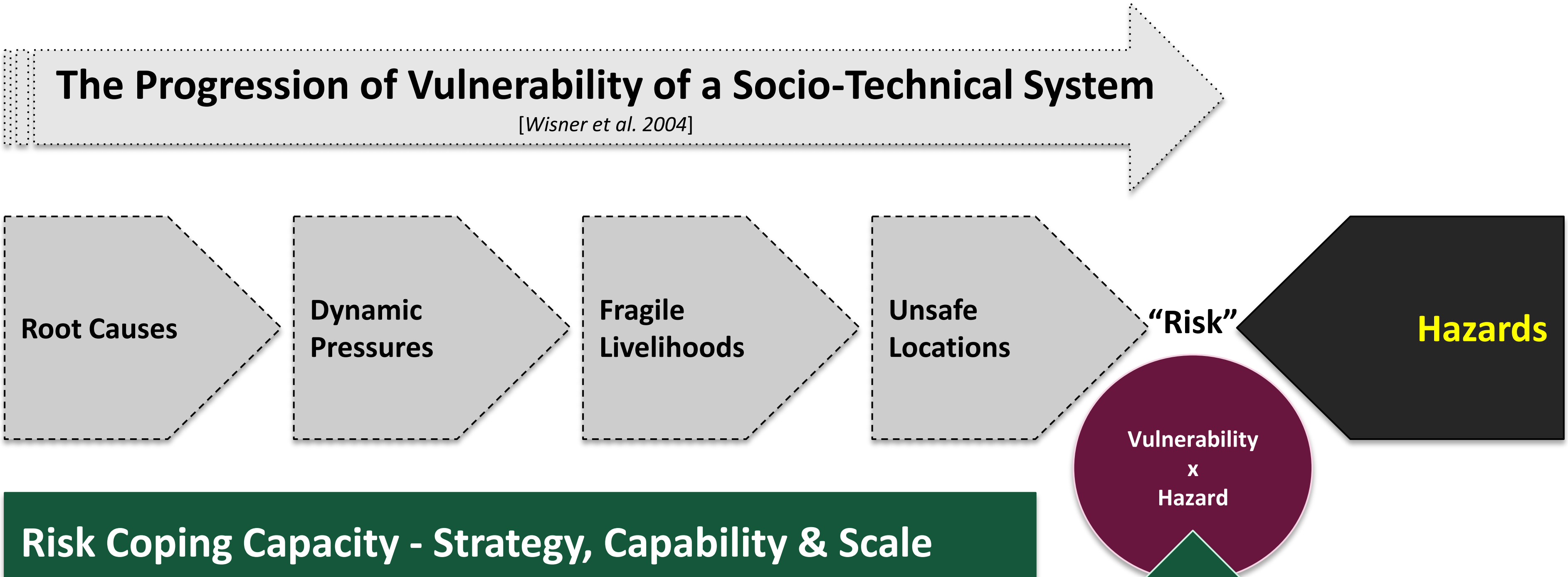

Success of Coping
AND
System {or "City"} Characteristic
AND
Coping Cycle
Economic Fabric
Circle of Capacities
Response
Buildings OK
Facilities OK
Infrastructure OK
Networks OK
No Other Dangers
Social
Human
Economic
Political
Physical
Natural
Recovery
Reconstruction
Remediation
Rehabilitation
Sustainability

System Damage

Coping Cycle

Fault Tree – Transport Damaged System





Risk Coping Capacity - Strategy, Capability & Scale

Physical Fabric:

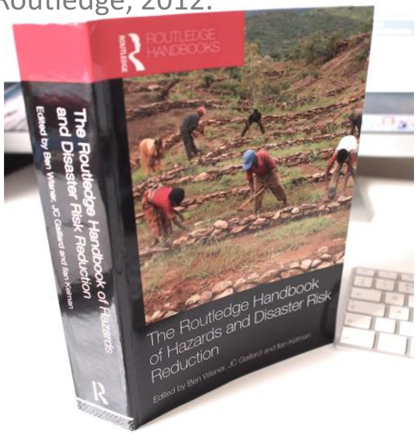
- Robustness of infrastructure, facilities, safe housing and shelter
- Emergency services and countermeasures
- Availability of essential services and supplies network
- Availability of communications and monitoring equipment
- Availability of adequacy of potable water and food to cope

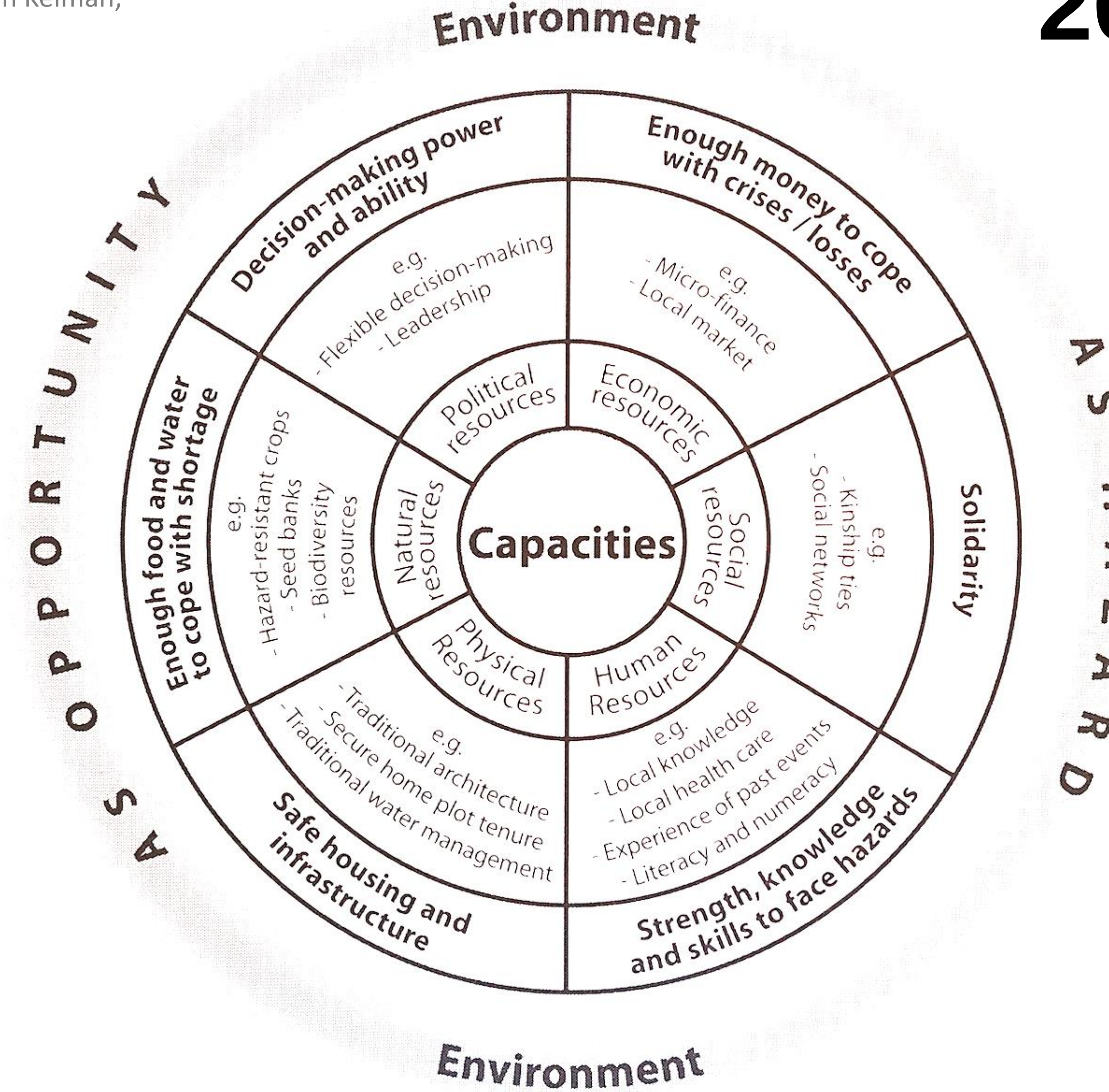
Societal-People Tapestry:

- Decision-making power, agreements and overall wisdom
- Strength, knowledge and skills to face hazards
- Solidarity, cohesiveness and shear gumption
- Adequate finances to cope with crises and losses

The Routledge Handbook of Hazards and Disaster Risk Reduction;
Editors – Ben Wiser, J.C. Gaillard and Ilan Kelman,
Routledge, 2012.

2012





Basis of a System	Characteristics
Normal Accident Theory (NAT) *	(chart and table below)

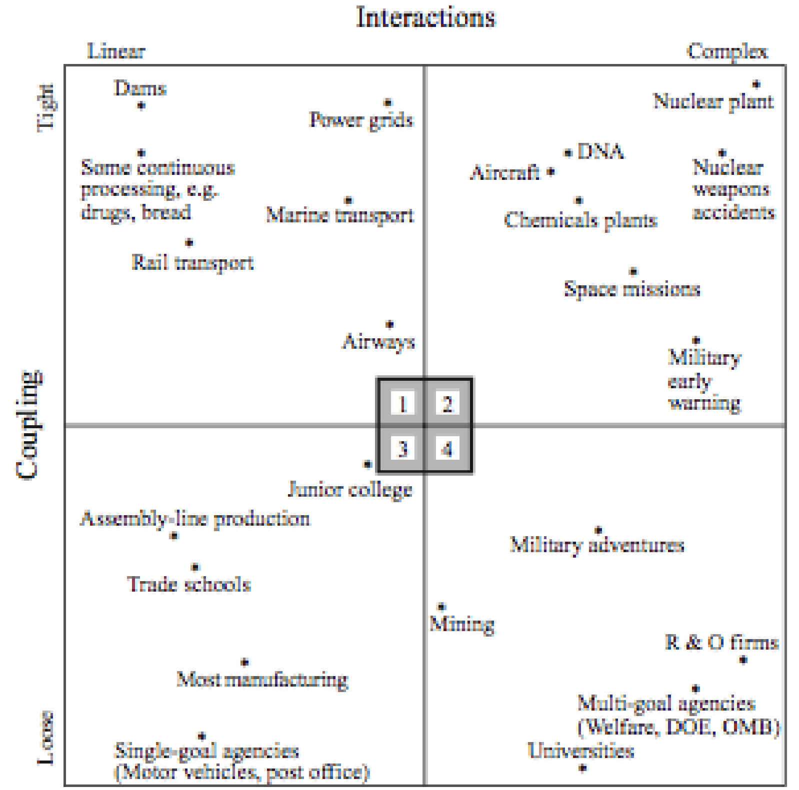
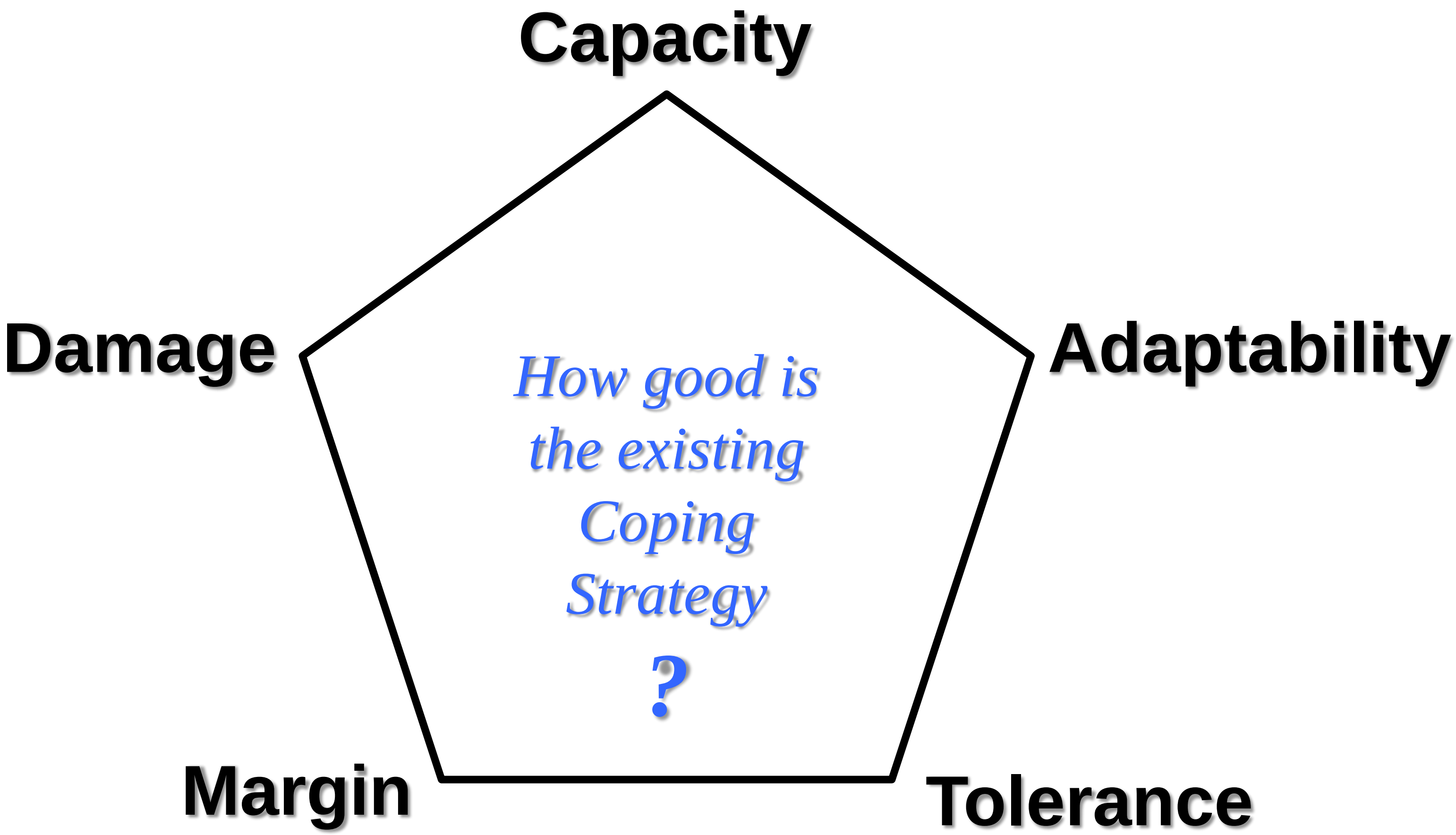


Figure 2
Interaction/coupling chart showing which systems are most vulnerable to system accidents

Complex systems	*Linear systems*
Proximity	Spatial segregation
Common-mode connections	Dedicated connections
Interconnected subsystems	Segregated subsystems
Limited substitutions	Easy substitutions
Feedback loops	Few feedback loops
Multiple and interacting controls	Single purpose, segregated controls
Indirect information	Direct information
Limited understanding	Extensive understanding
Tight coupling	*Loose coupling*
Delays in processing not possible	Processing delays possible
Invariant sequences	Order of sequences can be changed
Only one method to achieve goal	Alternative methods available
Little slack possible in supplies, equipment, personnel	Slack in resources possible
Buffers and redundancies are designed-in, deliberate	Buffers and redundancies fortuitously available
Substitutions of supplies, equipment, personnel limited and designed-in	Substitutions fortuitously available

* Perrow, C; 1984 Normal Accidents, Basic Books, New York.


Capacity
Damage
Adaptability
How good is the existing Coping Strategy ?
Margin
Tolerance

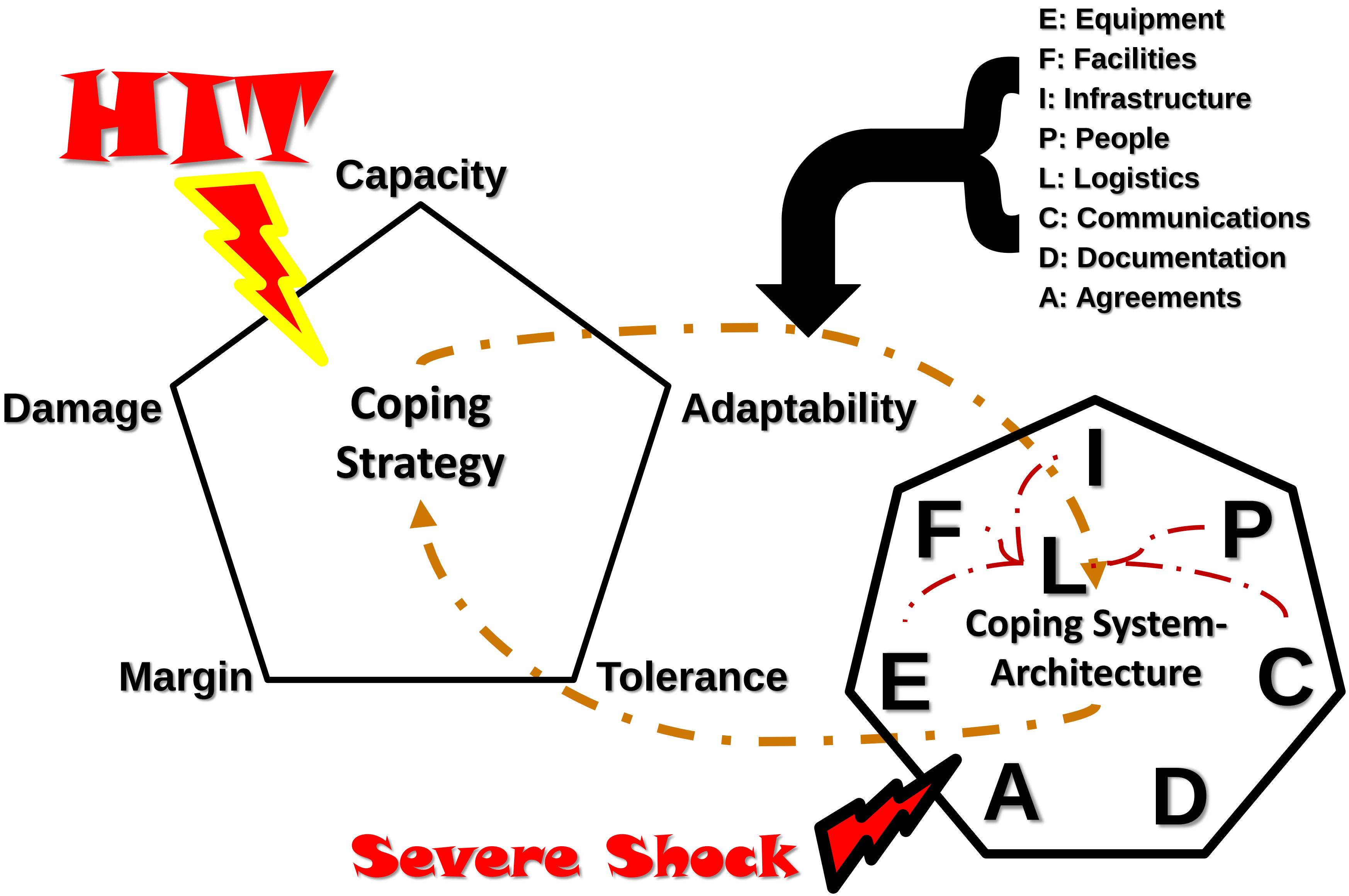
Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

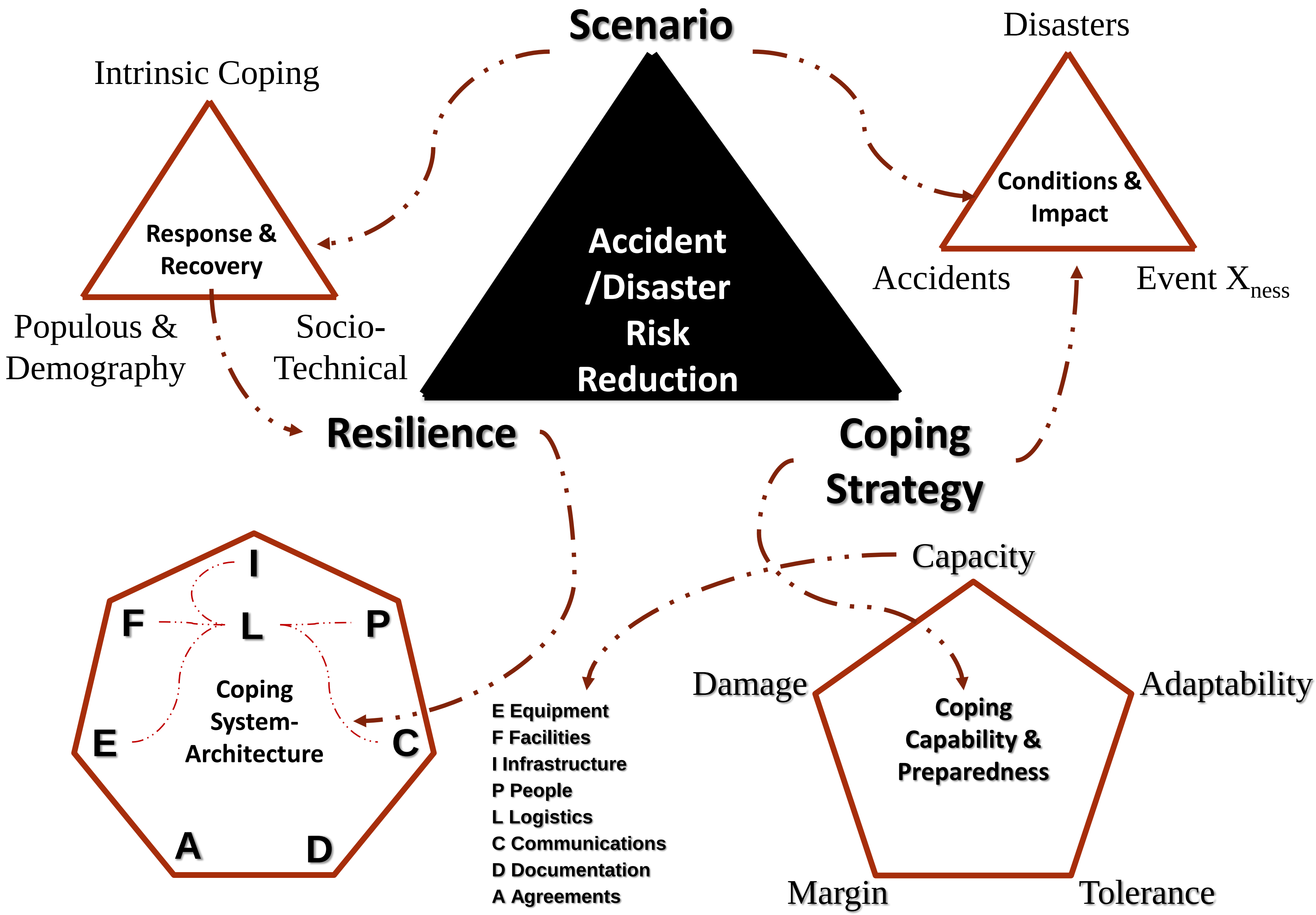
2014

Technical Innovation in Nuclear Civil Engineering – TINCE 2014
Paris (*France*), September 1st – 4th, 2014

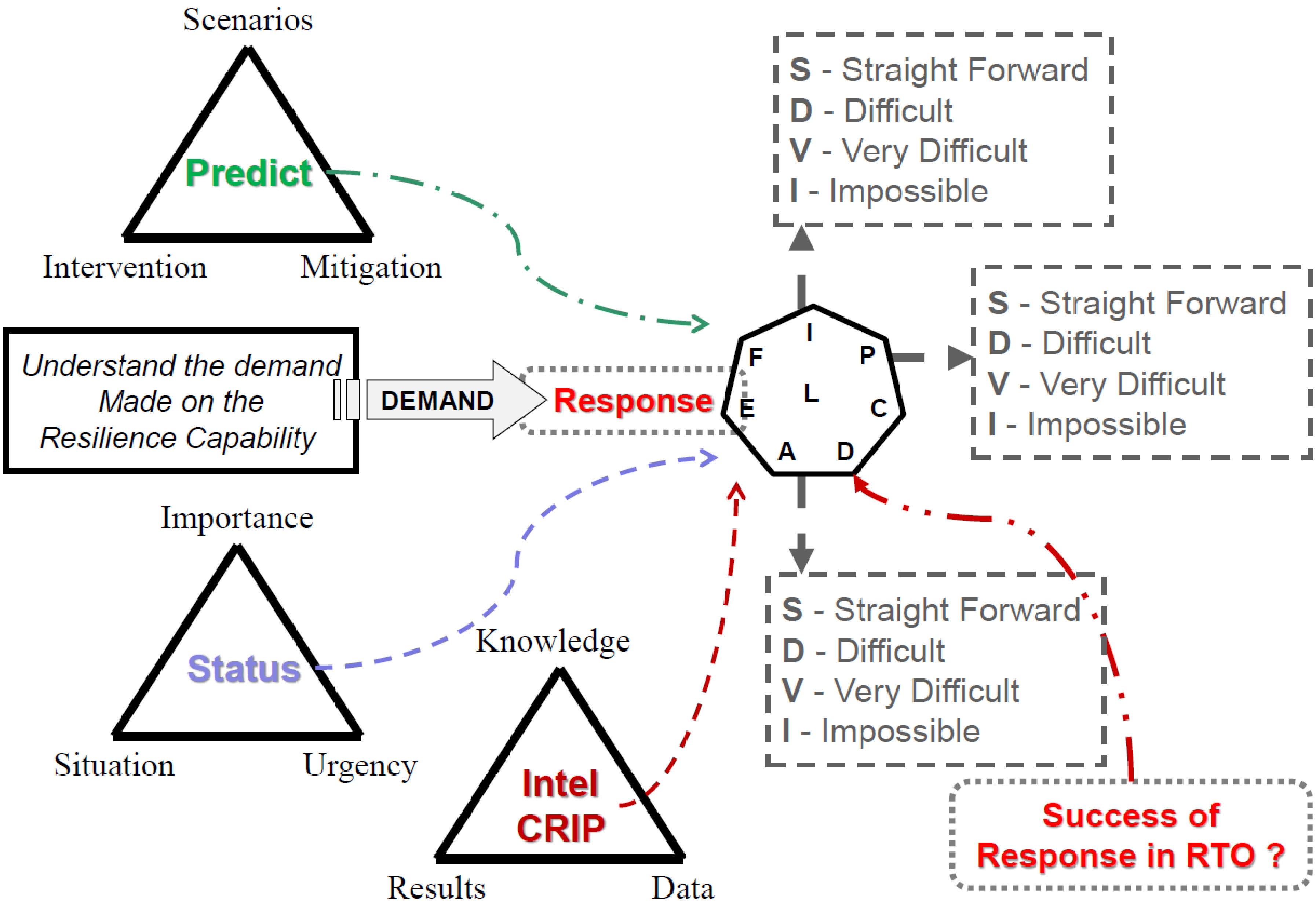
The Holistic Integrity Test (HIT[1]) for Designers.

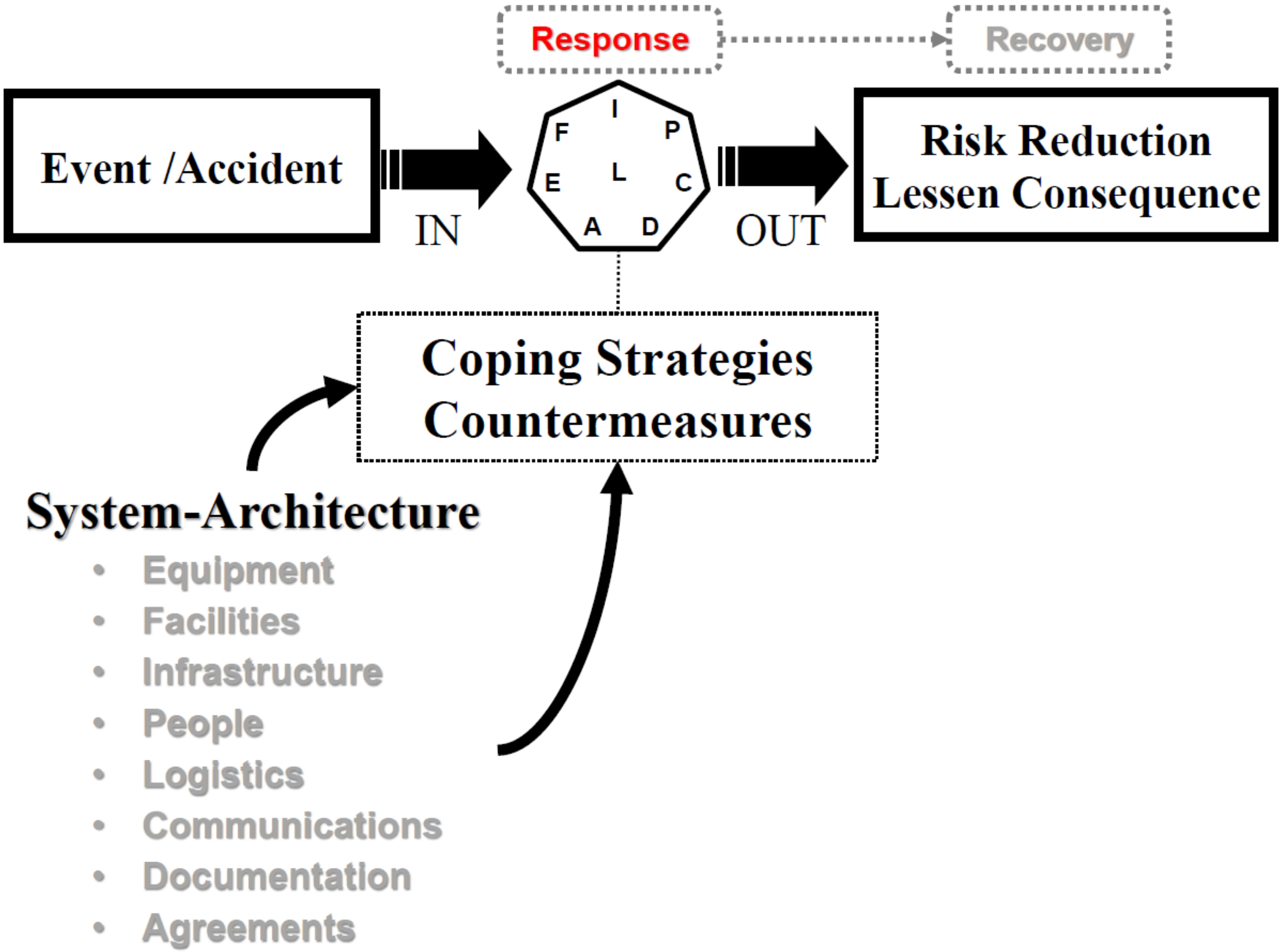
Knowledge →	Deterministic +	Probabilistic +	Uncertainty
Holistic →	Shock / Threat +	Effect +	Integrity
Systemic →	Type(s) +	Bounds +	Interfaces
Socio-Technical System →	Human +	Machine +	Demand
Importance →	Function +	Control +	Capability
What-If - Events →	Natural +	Man-Made +	Chance?
Scenarios →	Damage +	Failure +	Losses
Behaviour →	Causal +	Acausal +	Time-history
Measures →	Abnormal +	Emergency +	Preparedness
Mitigation →	Minimise +	Inhibit +	Stabilise
Intervention →	On-Site +	Off-Site +	Logistics


HIT
Capacity
Damage
Coping Strategy
Adaptability
Margin
Tolerance
E: Equipment
F: Facilities
I: Infrastructure
P: People
L: Logistics
C: Communications
D: Documentation
A: Agreements
I
F
P
L
Coping System-Architecture
E
C
A
D
Severe Shock


Scenario
Disasters
Intrinsic Coping
Conditions &
Impact
Response &
Recovery
Accident
/Disaster
Risk
Reduction
Accidents
Event X_{ness}
Populous &
Demography
Socio-
Technical
Resilience
Coping
Strategy
Capacity
I
F
L
P
Coping
System-
Architecture
E
C
A
D
E Equipment
F Facilities
I Infrastructure
P People
L Logistics
C Communications
D Documentation
A Agreements
Damage
Adaptability
Coping
Capability &
Preparedness
Margin
Tolerance

Arup IRSA, Paul C. Smith.



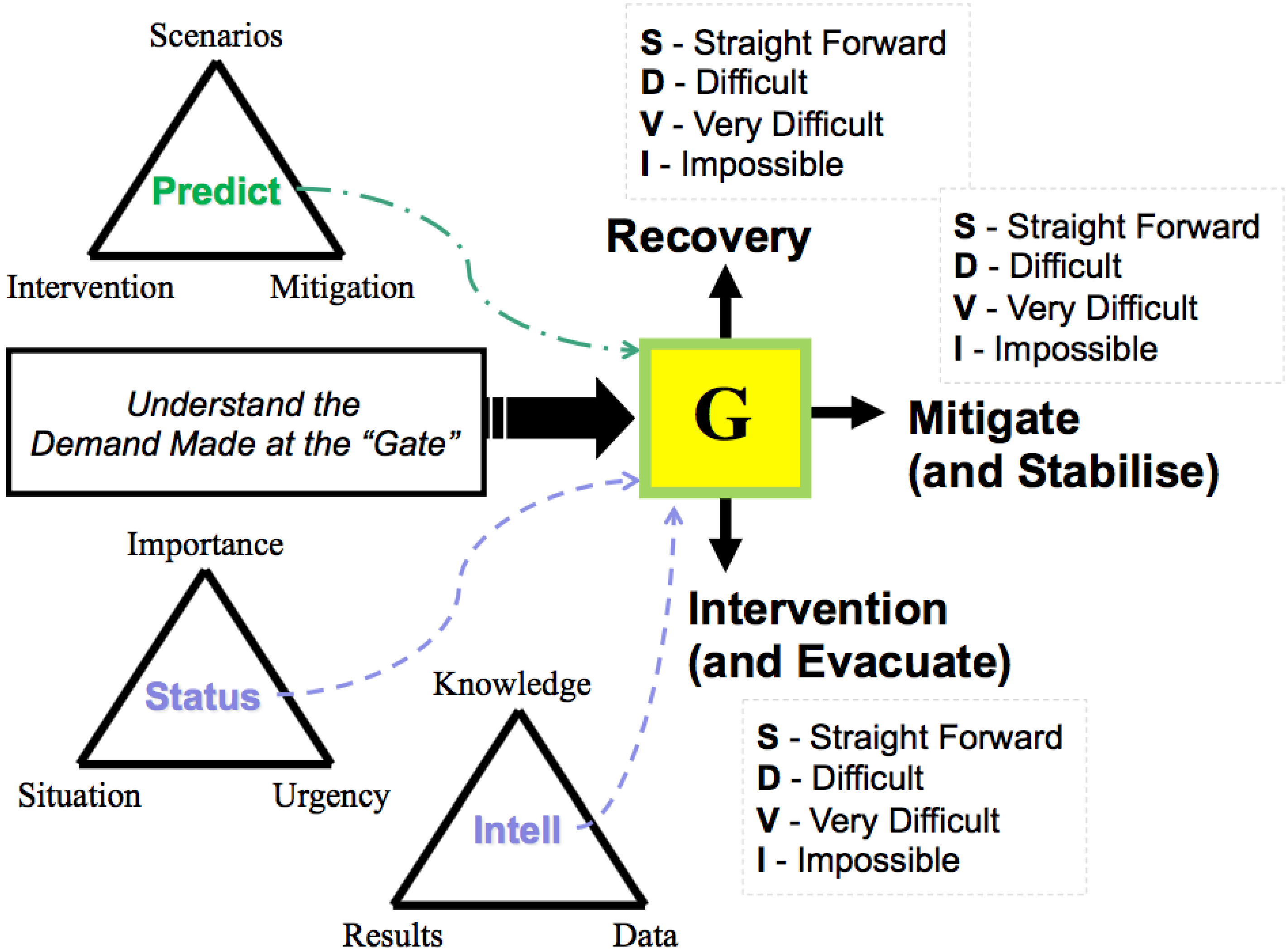

Response
Recovery
Event /Accident
IN
I
F
P
E
L
C
A
D
OUT
Risk Reduction
Lessen Consequence
Coping Strategies
Countermeasures
System-Architecture
• Equipment
• Facilities
• Infrastructure
• People
• Logistics
• Communications
• Documentation
• Agreements

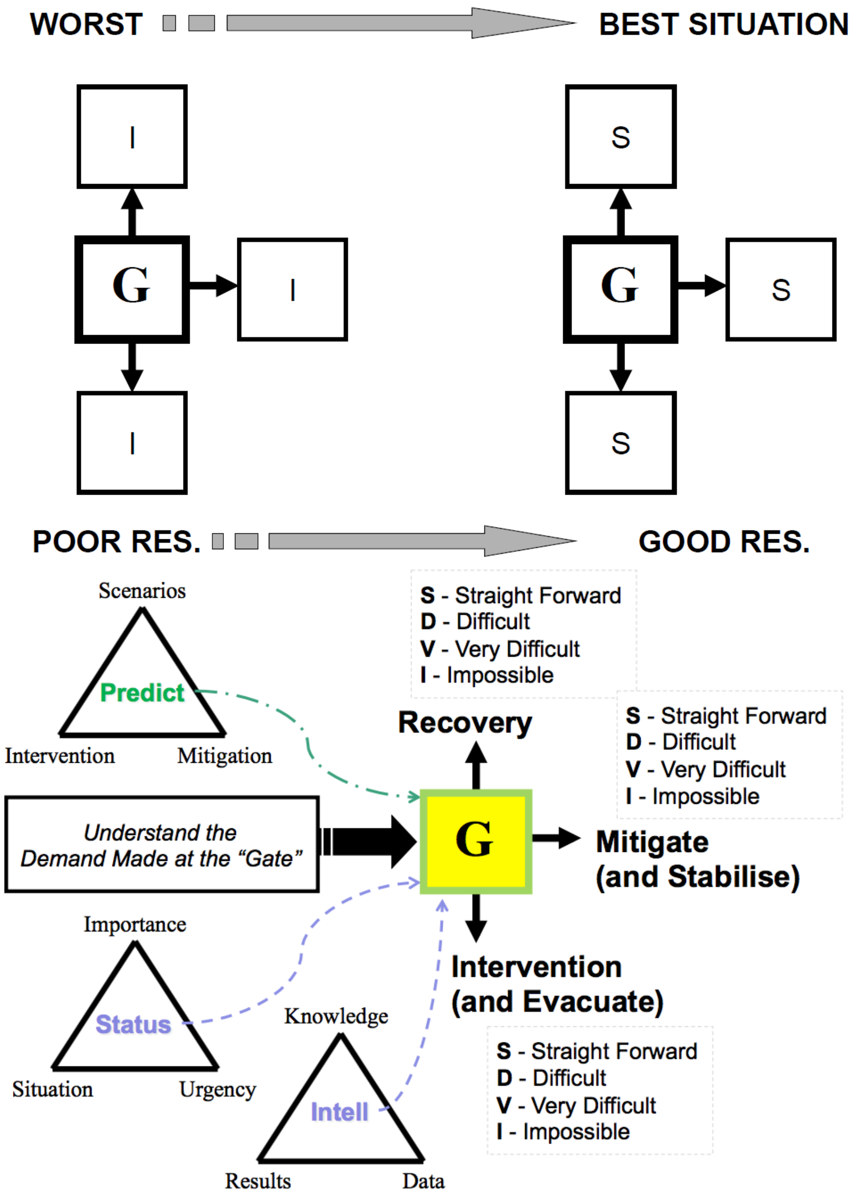
Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

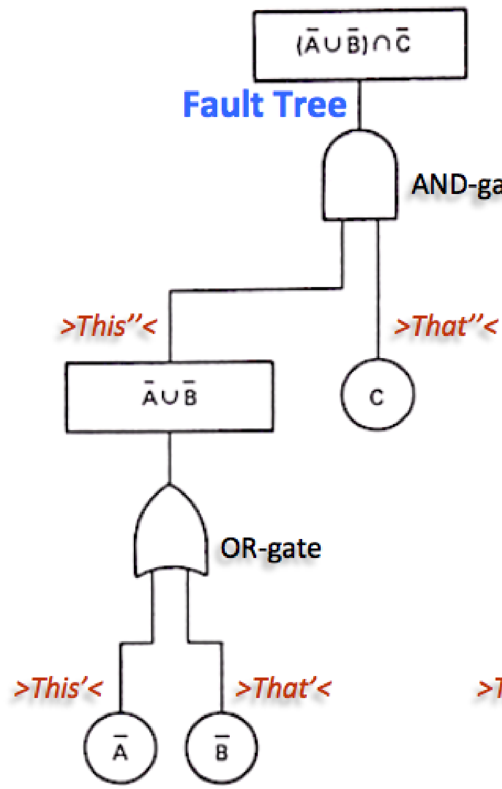
2014

Technical Innovation in Nuclear Civil Engineering – TINCE 2014
Paris (*France*), September 1st – 4th, 2014

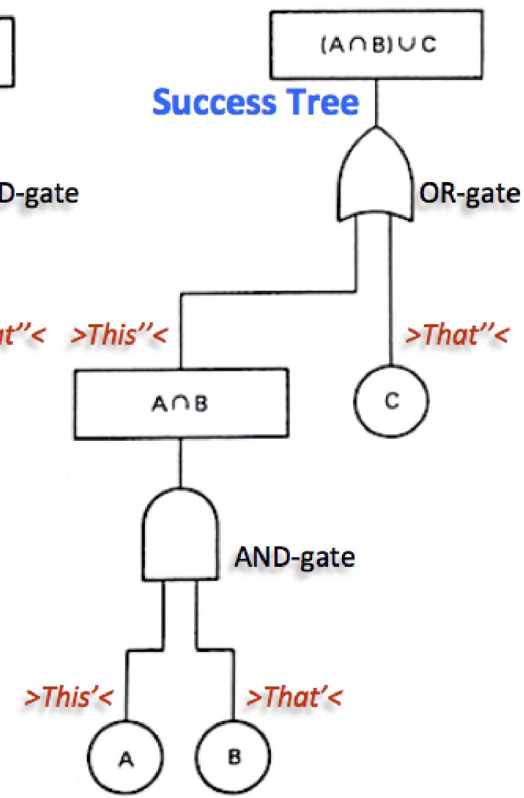
The Holistic Integrity Test (HIT[1]) for Designers.



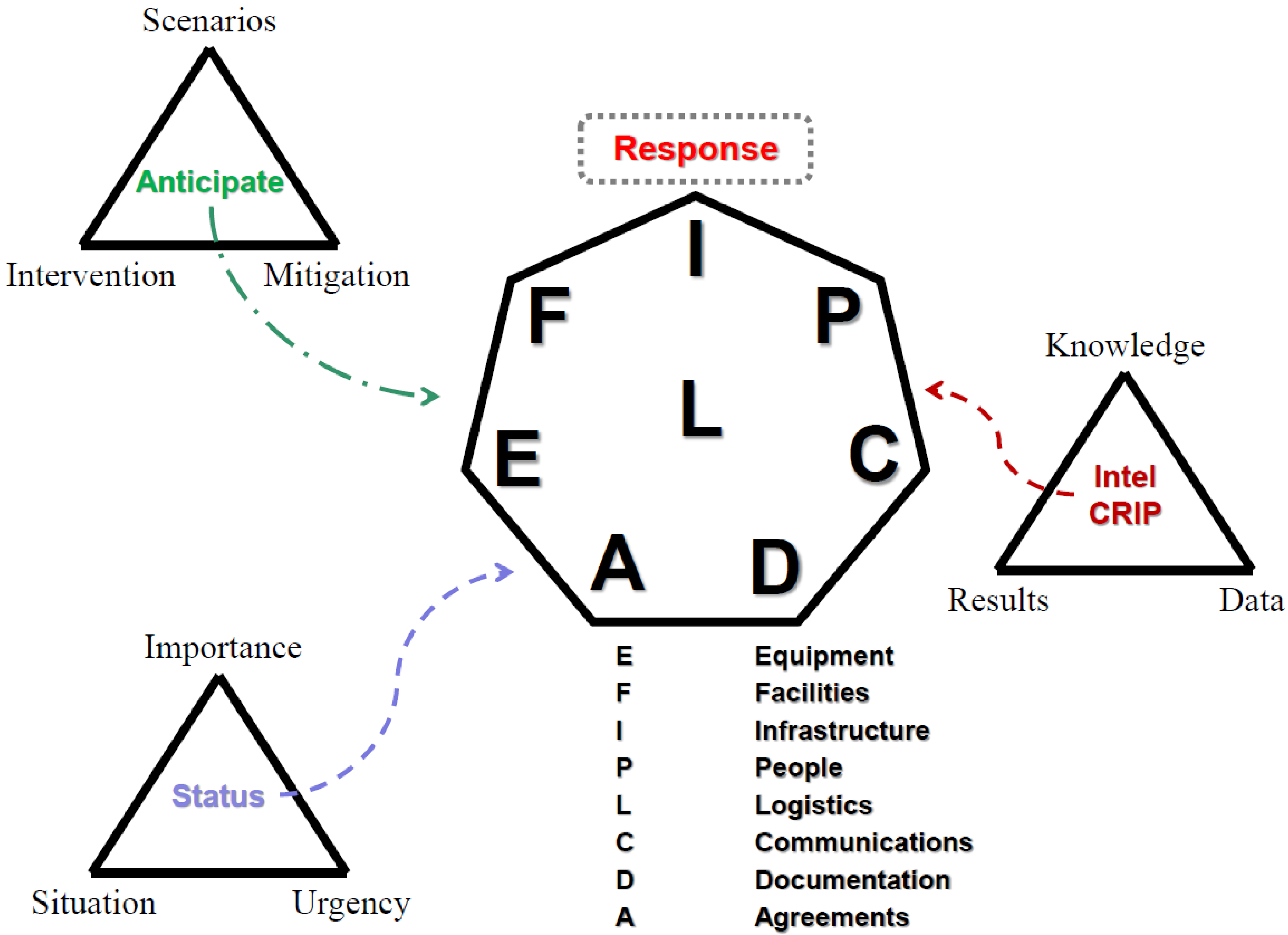




Symbolic Fault Tree of the "System"
~ Negative Approach ~



Symbolic Success Tree of the "System"
~ Positive Approach ~


Scenarios
Anticipate
Intervention
Mitigation
Response
I
F
P
L
E
C
A
D
Knowledge
Intel
CRIP
Results
Data
Importance
Status
Situation
Urgency
E Equipment
F Facilities
I Infrastructure
P People
L Logistics
C Communications
D Documentation
A Agreements

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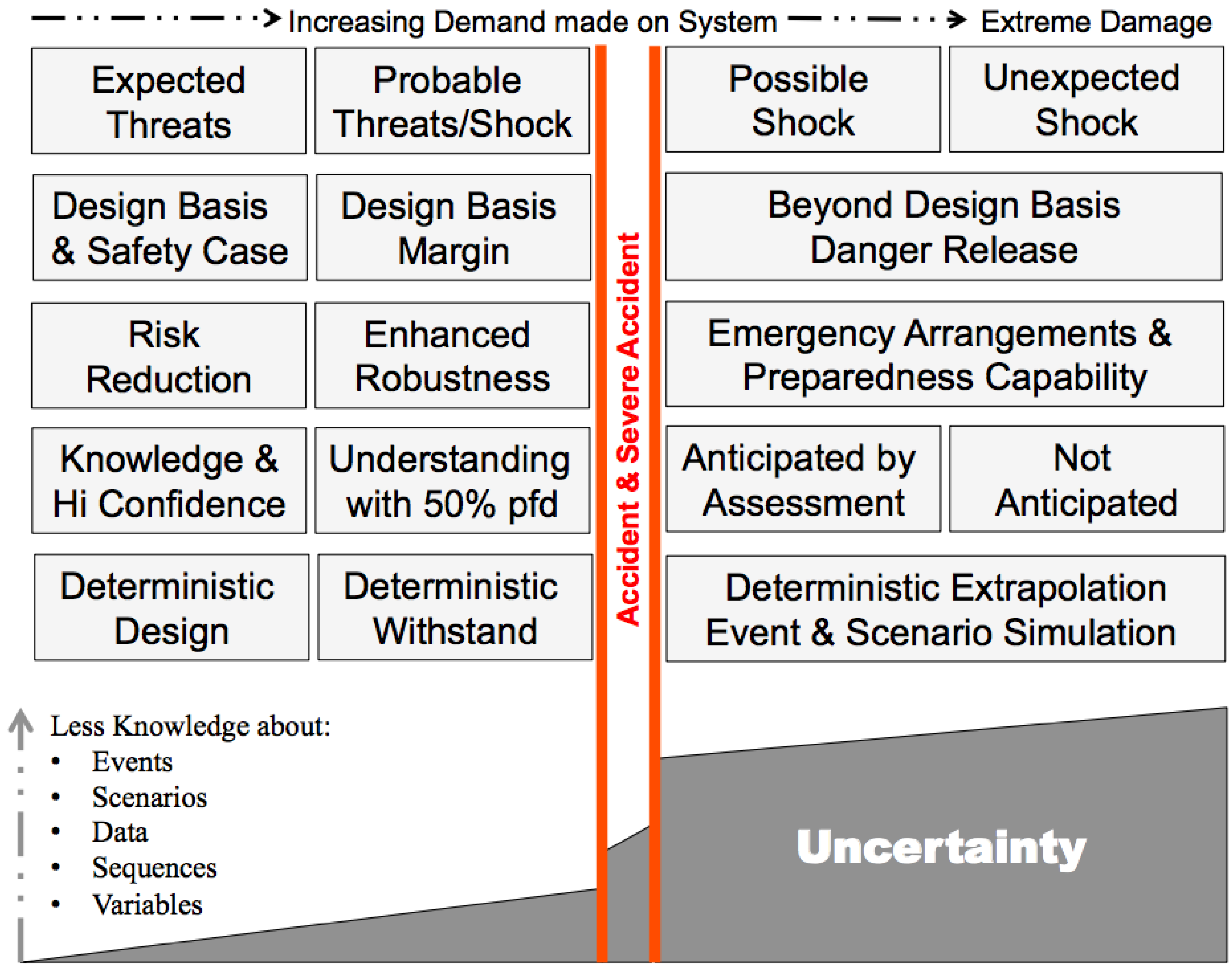

Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

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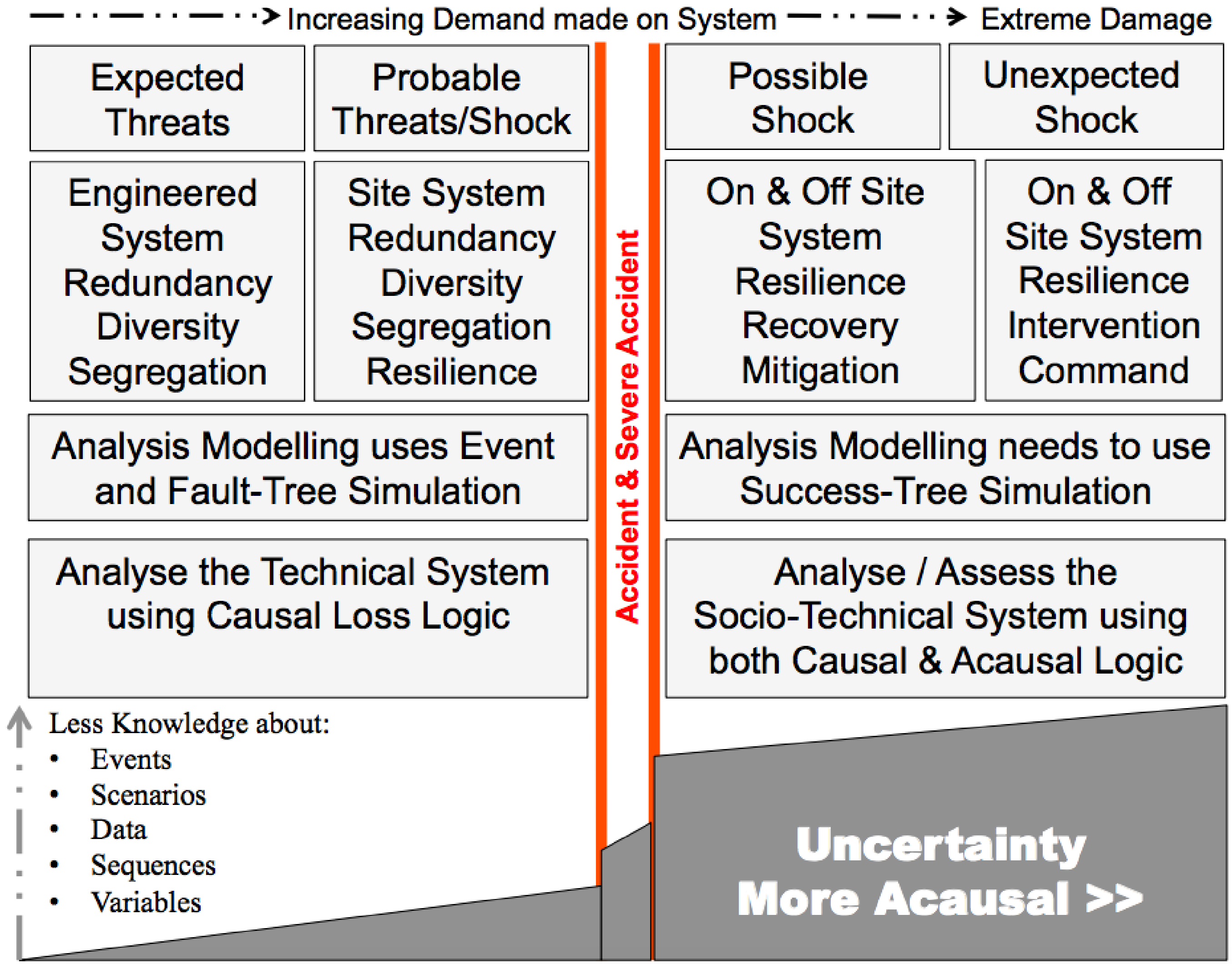
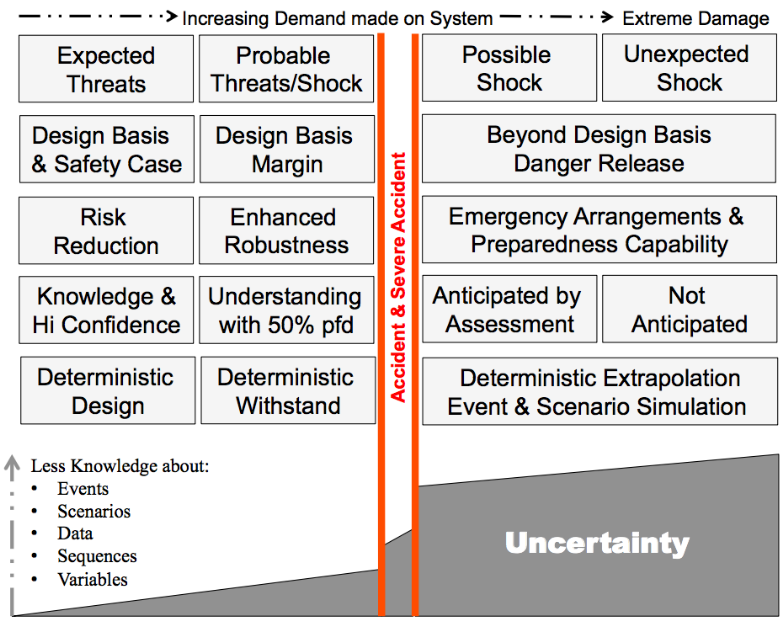




More Extreme the Hazardous Event

Extreme'ness, or X_{ness}

Advocated by Casti 2012

$X_{ness} \sim dE/E\,(1 - (U/[U+I]))$ Casti 2012

dE

Extreme Event Impact Loss.
Impact loss consequences caused by the extreme event.

E

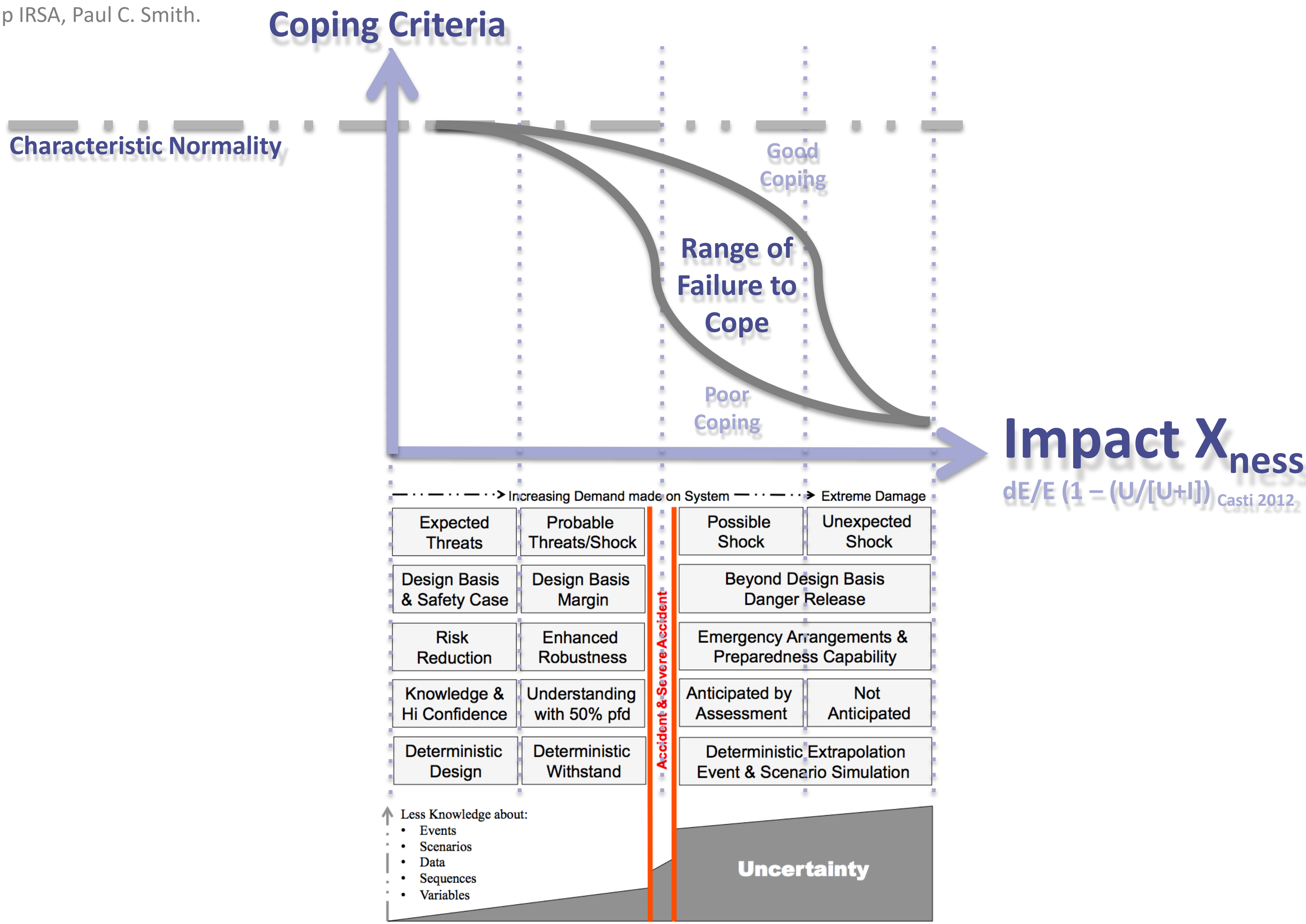
Normal Characteristic Loss.
Regular normality of losses characteristic for the region's particular demography and societal conditions.

U

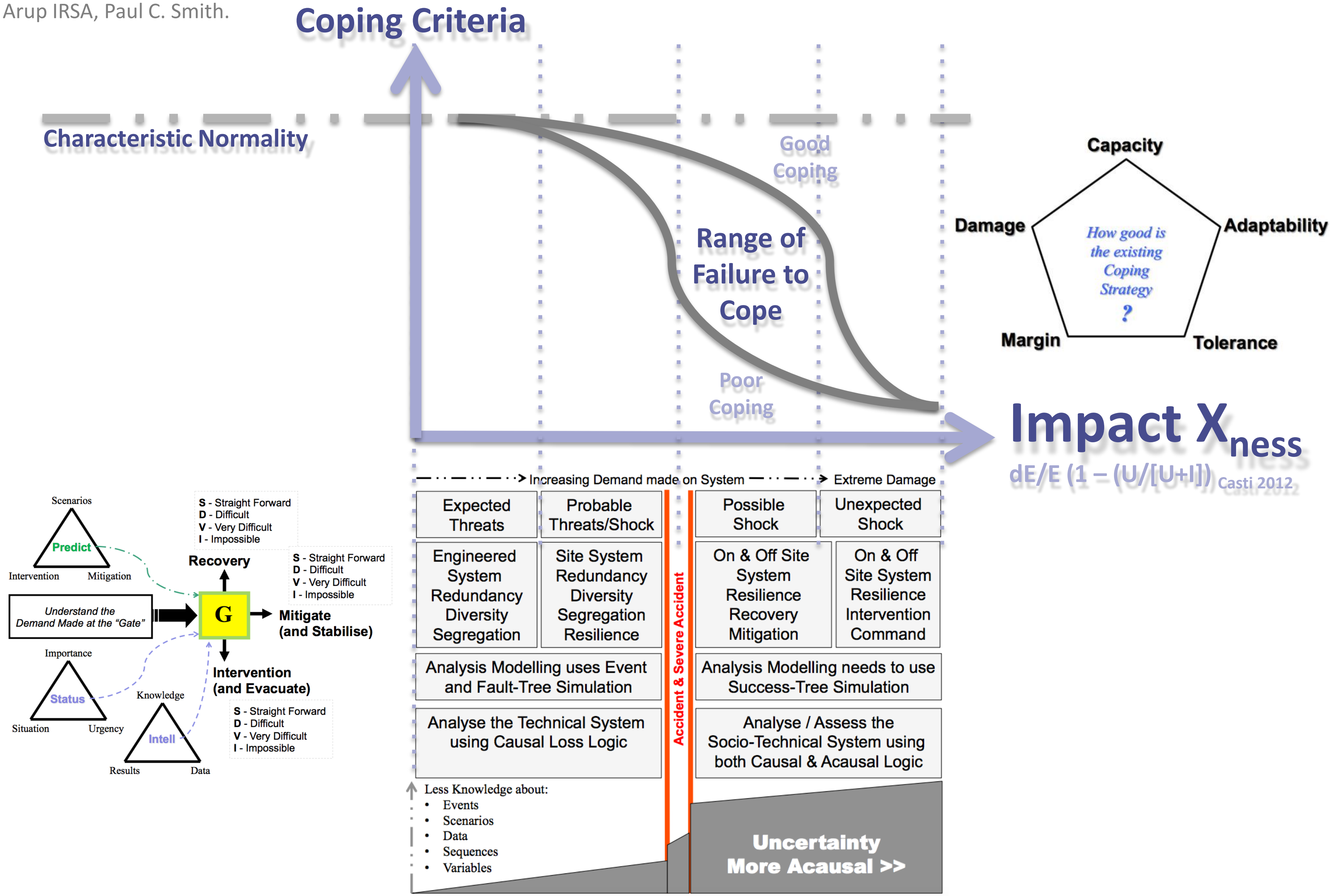
Extreme Event Period.
Period of the extreme event whether Hurricane, Tornado, Earthquake, Drought etc.,

I

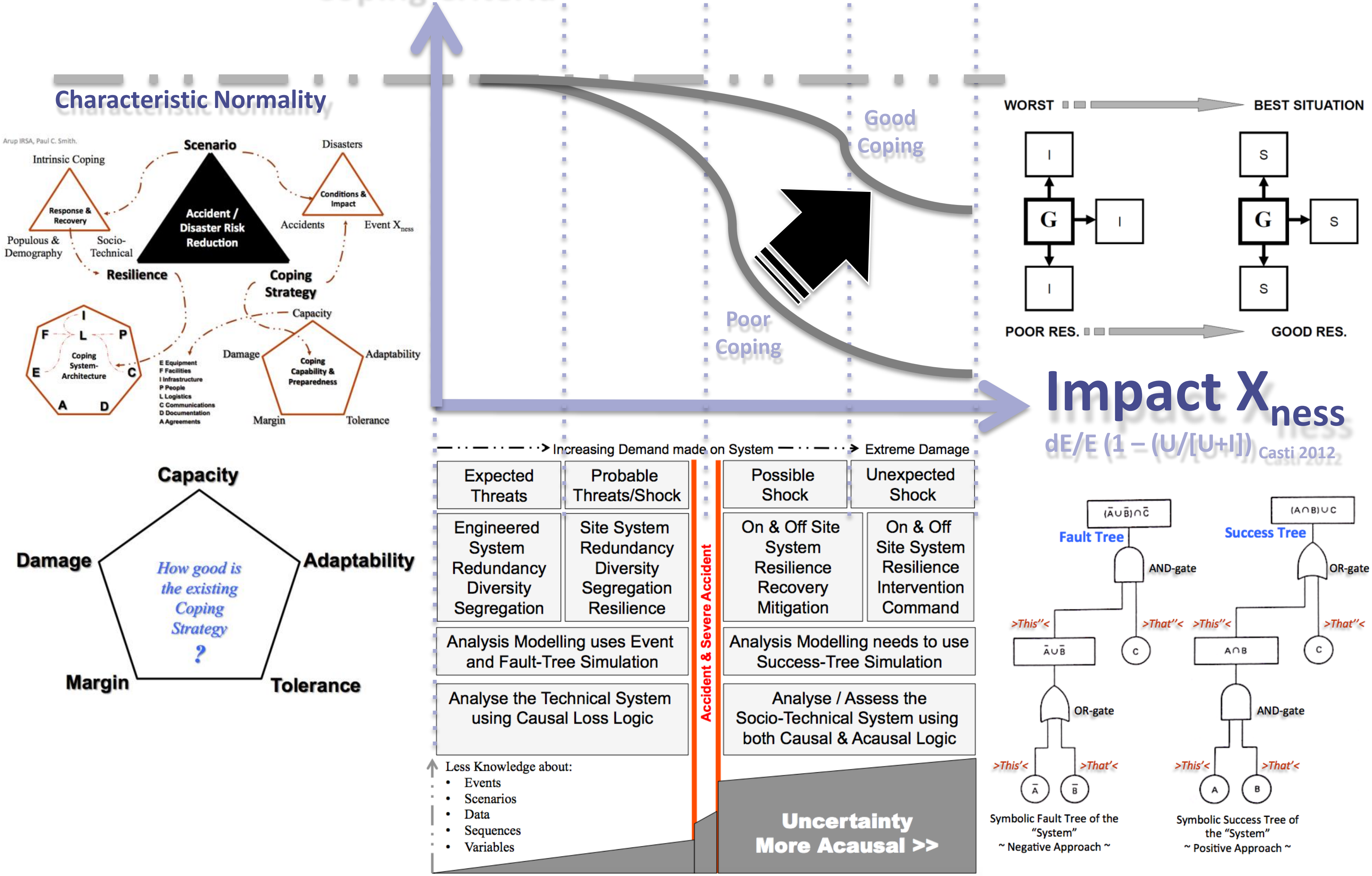
Resulting Impact Period.
Impact period resulting from the extreme event extending in time until a new sustained normality can be achieved.


Coping Criteria
Characteristic Normality
Good Coping
Range of Failure to Cope
Poor Coping
Impact Xness
dE/E (1 – (U/[U+I]) Casti 2012
Increasing Demand made on System
Extreme Damage
Expected Threats
Probable Threats/Shock
Possible Shock
Unexpected Shock
Design Basis & Safety Case
Design Basis Margin
Beyond Design Basis Danger Release
Risk Reduction
Enhanced Robustness
Emergency Arrangements & Preparedness Capability
Knowledge & Hi Confidence
Understanding with 50% pfd
Anticipated by Assessment
Not Anticipated
Deterministic Design
Deterministic Withstand
Deterministic Extrapolation Event & Scenario Simulation
Accident & Severe Accident
Less Knowledge about:
Events
Scenarios
Data
Sequences
Variables
Uncertainty

Arup IRSA, Paul C. Smith.



Coping Criteria



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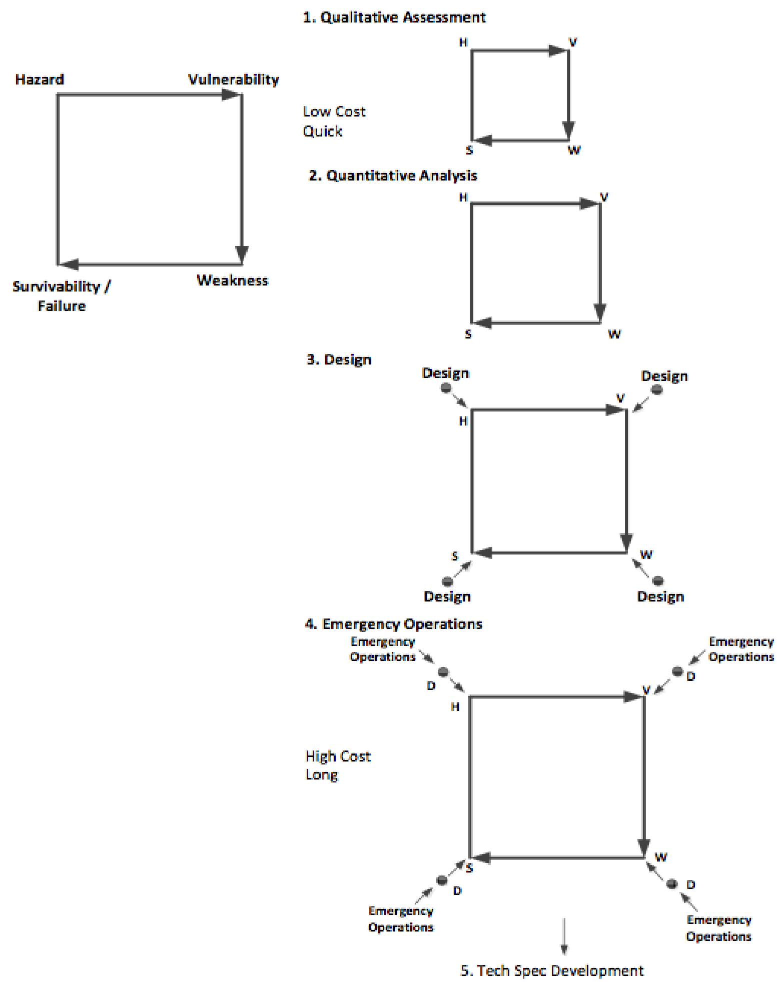
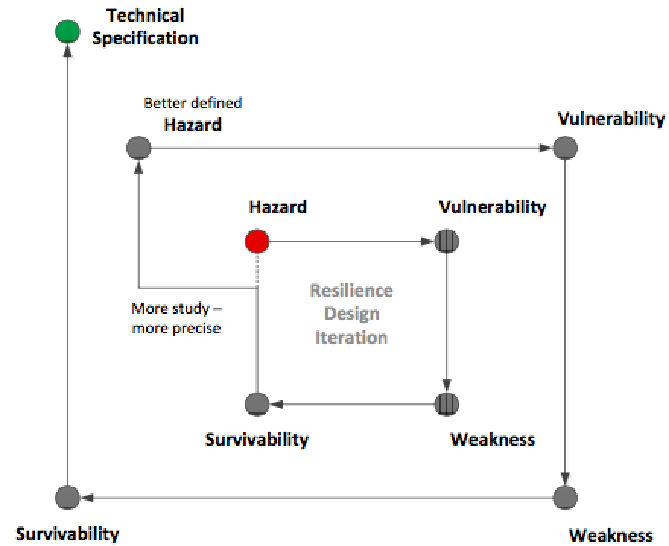
Paris (*France*), September 1st – 4th, 2014

The Holistic Integrity Test (HIT[1]) for Designers.

HVWS Assessment- Analysis Model





ODU 2015: Resilient Region Reality Check: Rising Above the Waters

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Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

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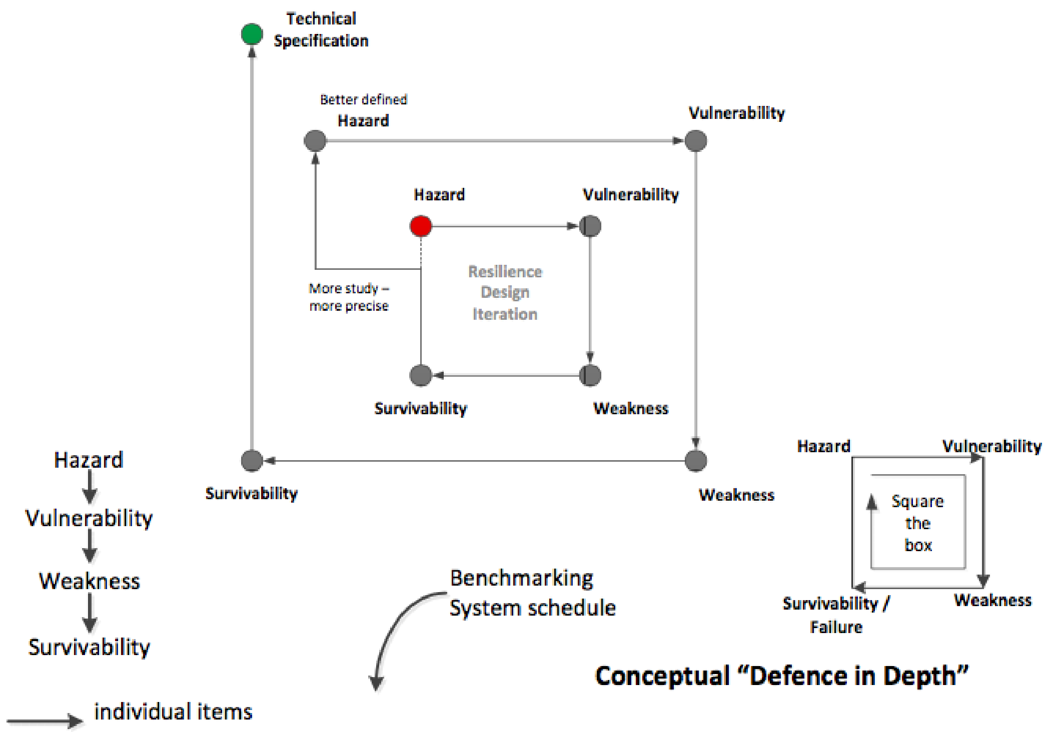


HAZARD	VULNERABILITY	WEAKNESS	SURVIVABILITY
• Forewarn • Off-site barriers • Temporary Restrictions • Seismic Triggers	• Avoidance • Barrier • Re-position • Safer mode	• Insufficient strength • Obsolescence • Badly designed • Better design • Better engineering • Withstand • Tolerance • Active / Passive	• Damaged but useable • No functional loss • What has failed? • What has survived?

Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

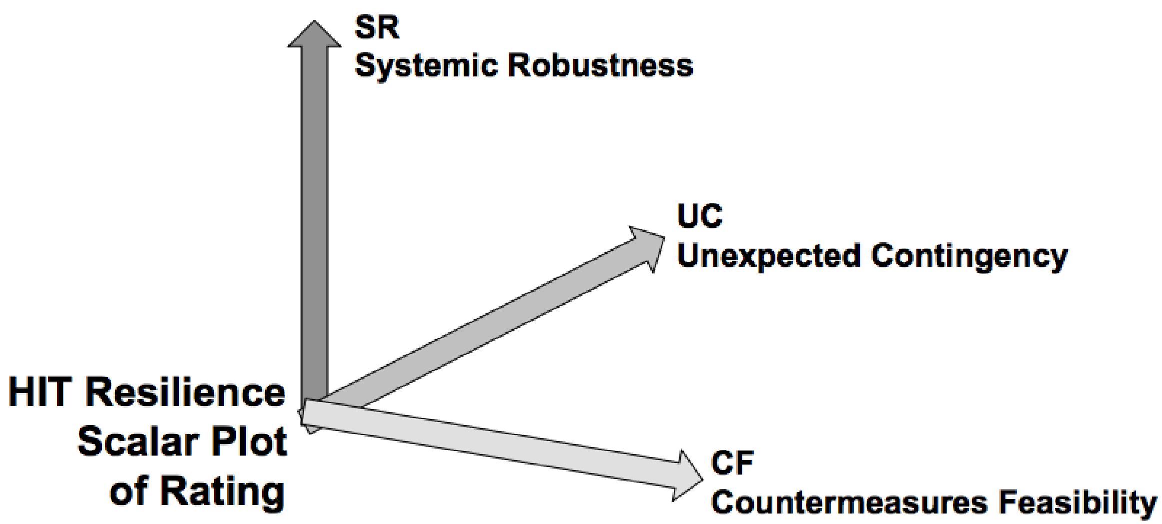
Technical Innovation in Nuclear Civil Engineering – TINCE 2014
Paris (*France*), September 1st – 4th, 2014

The Holistic Integrity Test (HIT[1]) for Designers.

2014

The Arup Holistic Integrity Test (HIT) process:

Phase I	**SYSTEMIC analysis.**
Phase II	**HAZARD scenarios.**
Phase III	**BEHAVIOUR knowledge.**
Phase IV	**COUNTERMEASURES feasibility.**
Phase V	**UNCERTAINTY determination.**
Phase VI	**HIT rating {for Resilience}.**



Technical Innovation in Nuclear Civil Engineering (TINCE);
Paul C. Smith, Paris, 2014.

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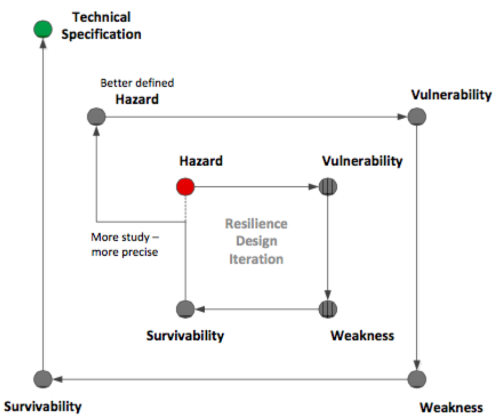

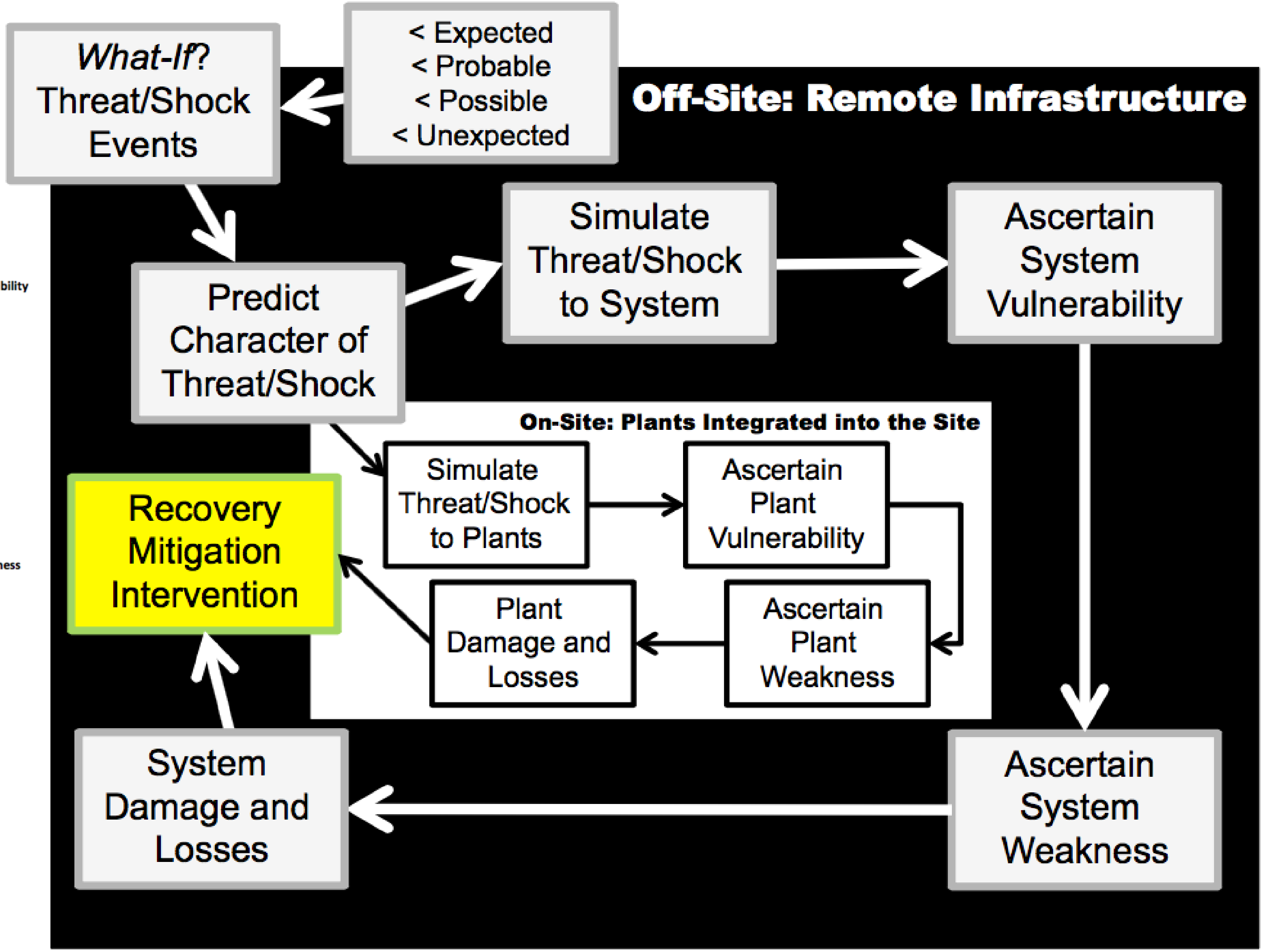

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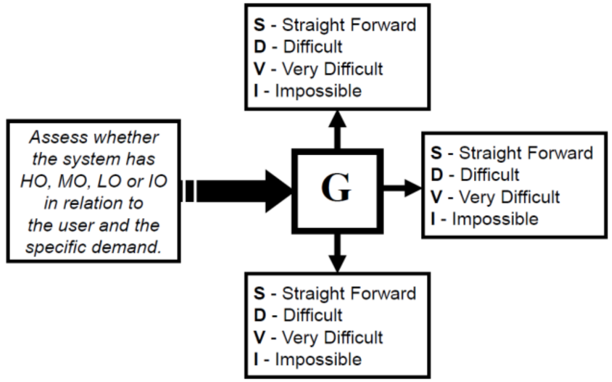
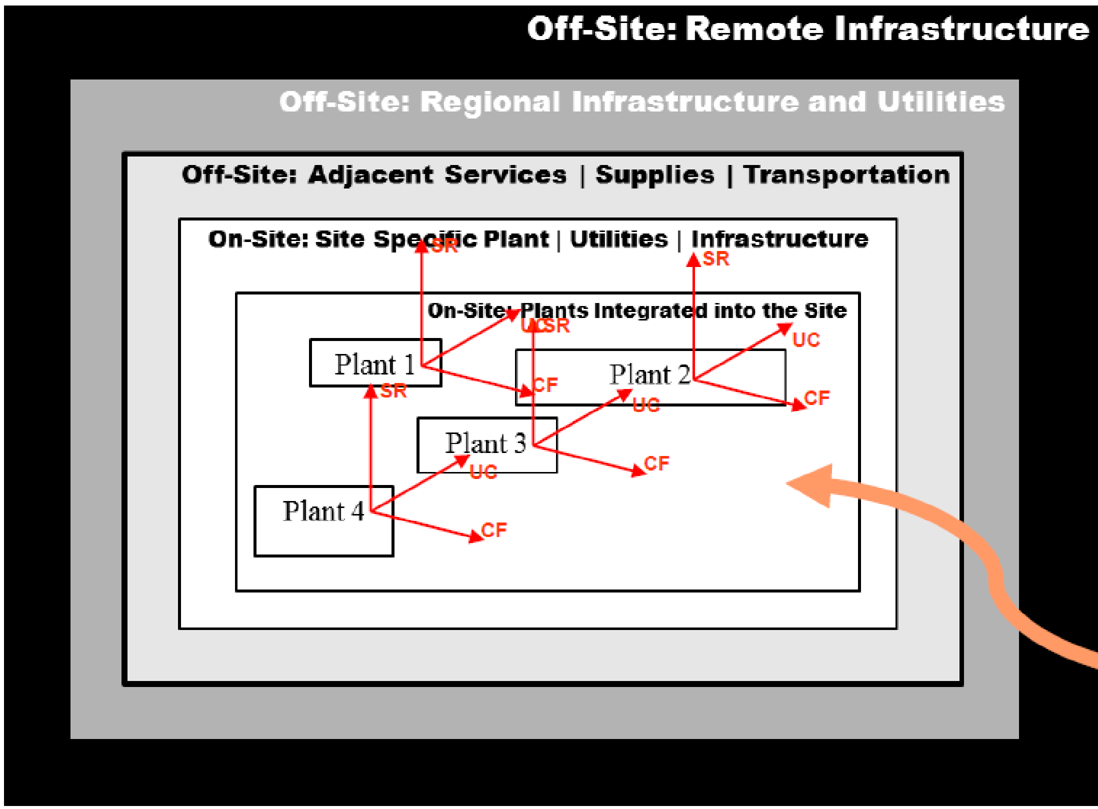
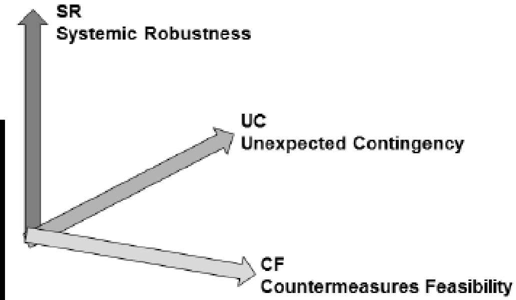


The Arup Holistic Integrity Test (HIT) process:

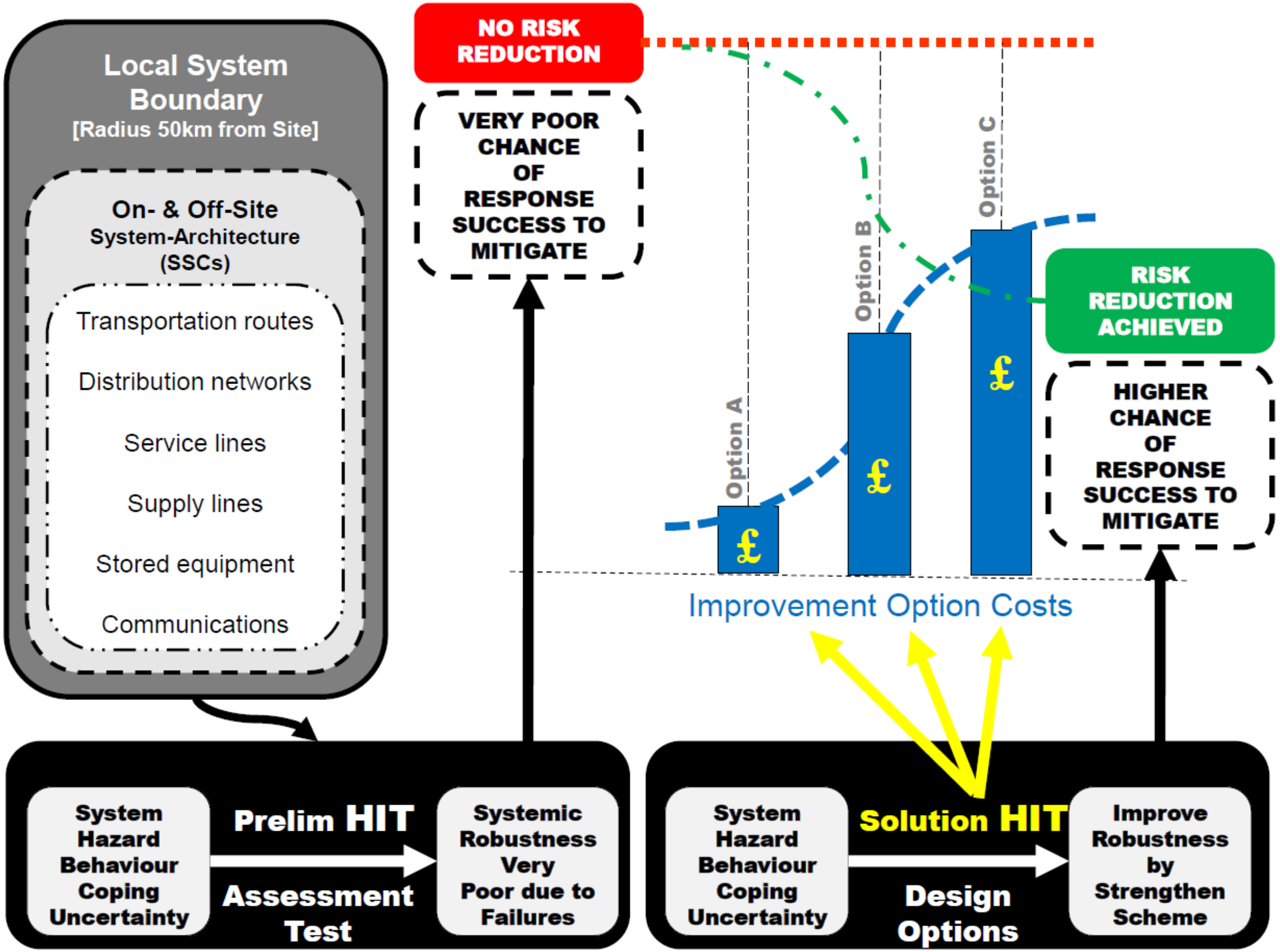
Phase I	SYSTEMIC analysis.
Phase II	HAZARD scenarios.
Phase III	BEHAVIOUR knowledge.
Phase IV	COUNTERMEASURES feasibility.
Phase V	UNCERTAINTY determination.
Phase VI	HIT rating {for Resilience}.

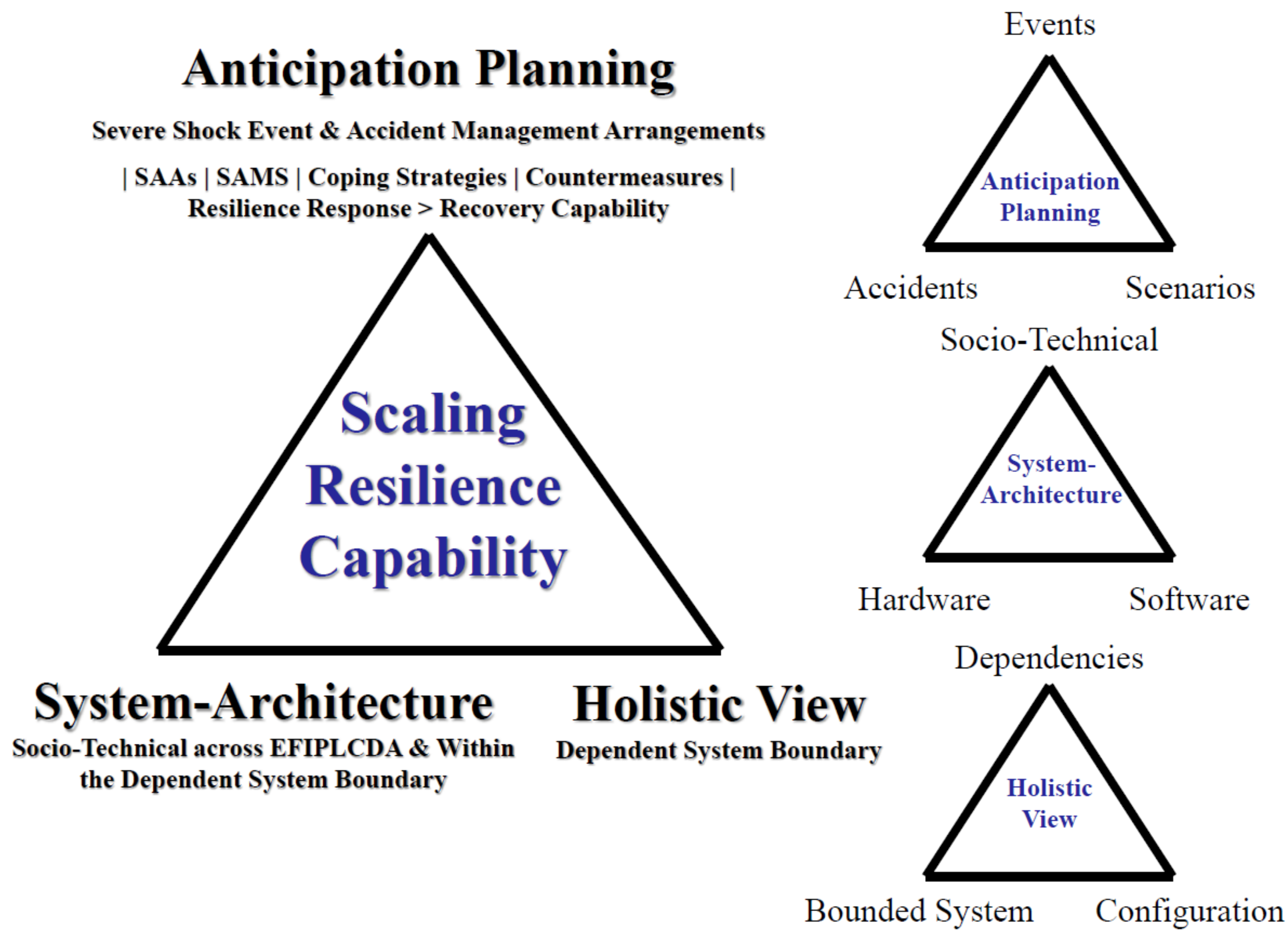
Holistic Perspective of the Socio-Technical System

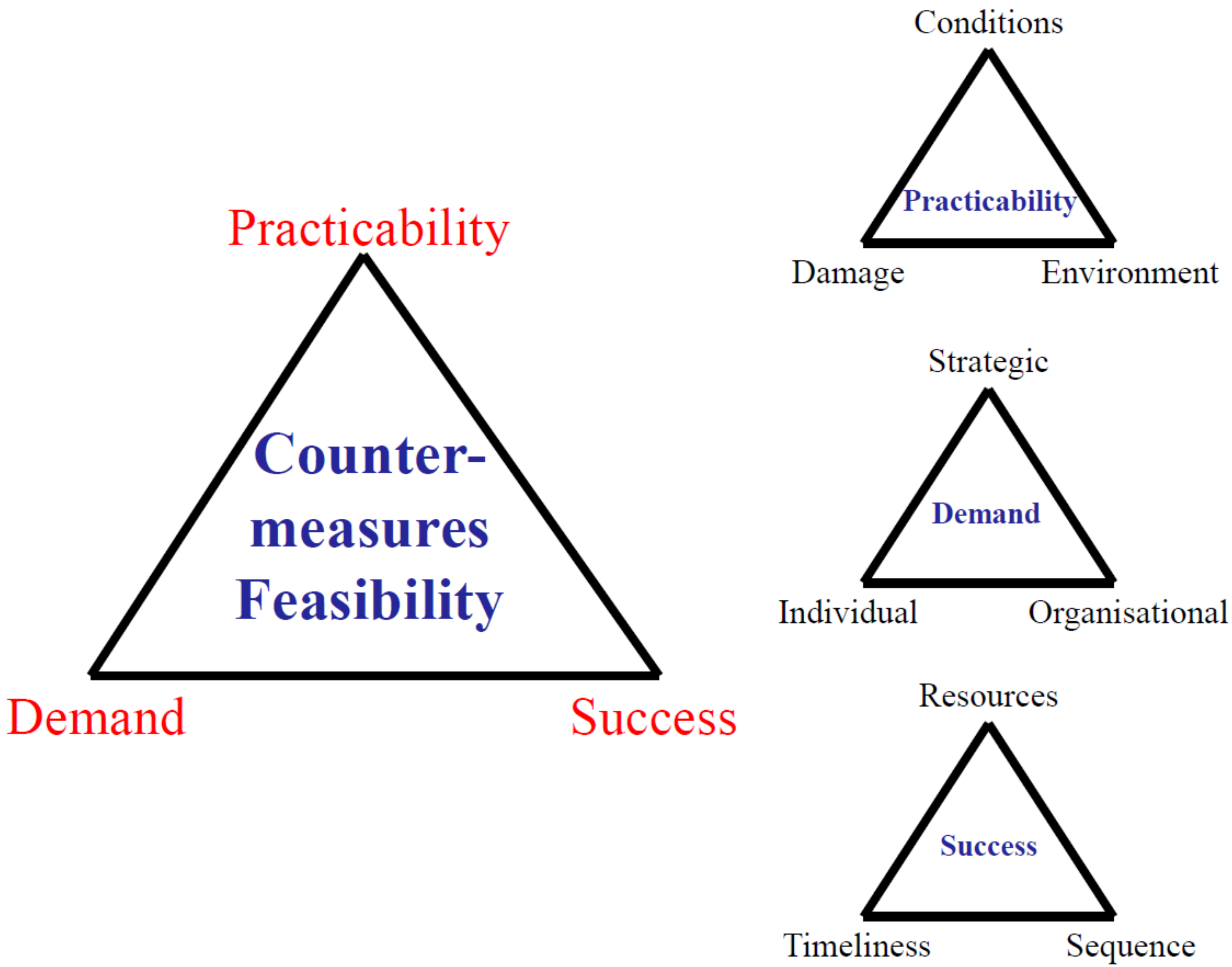


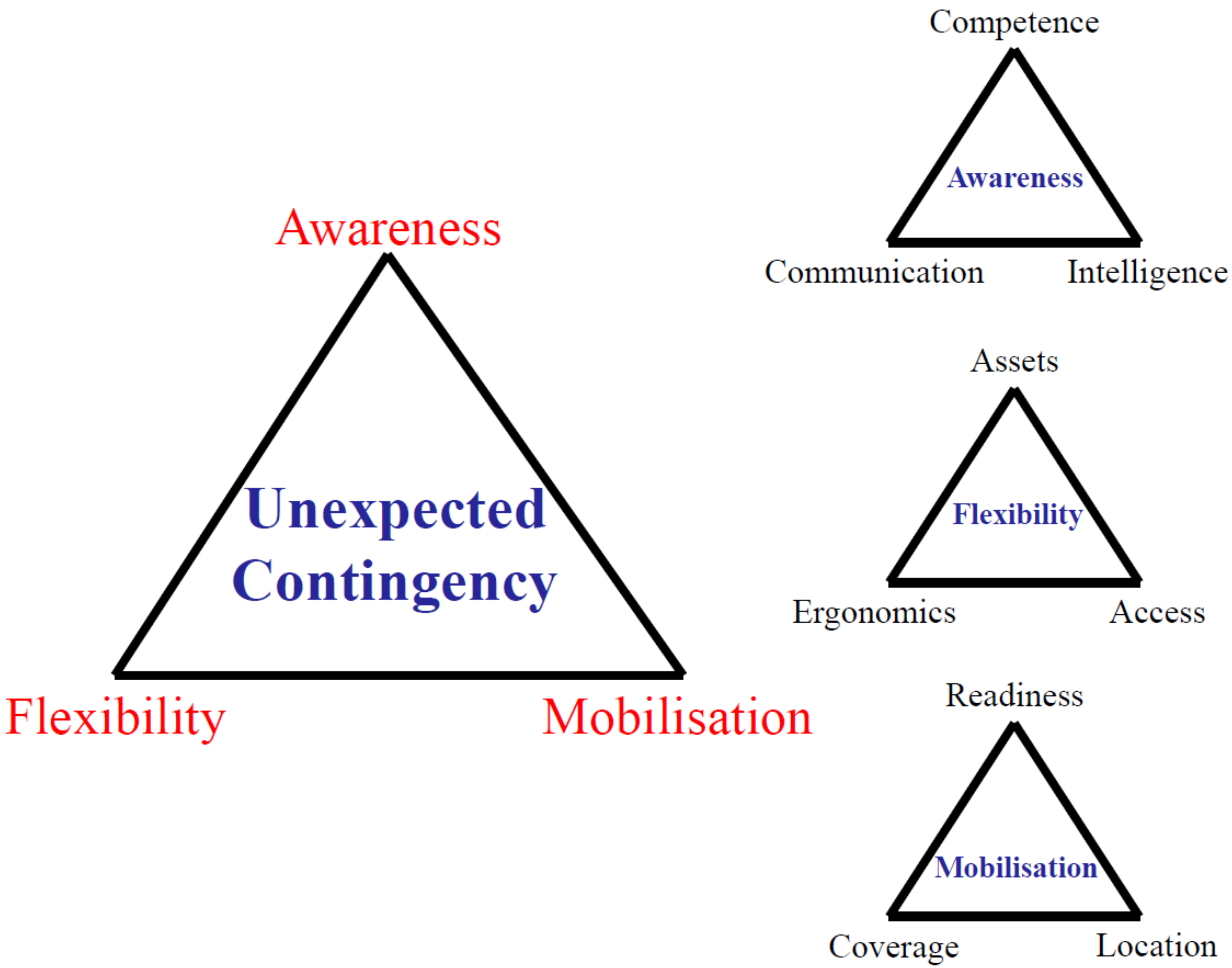


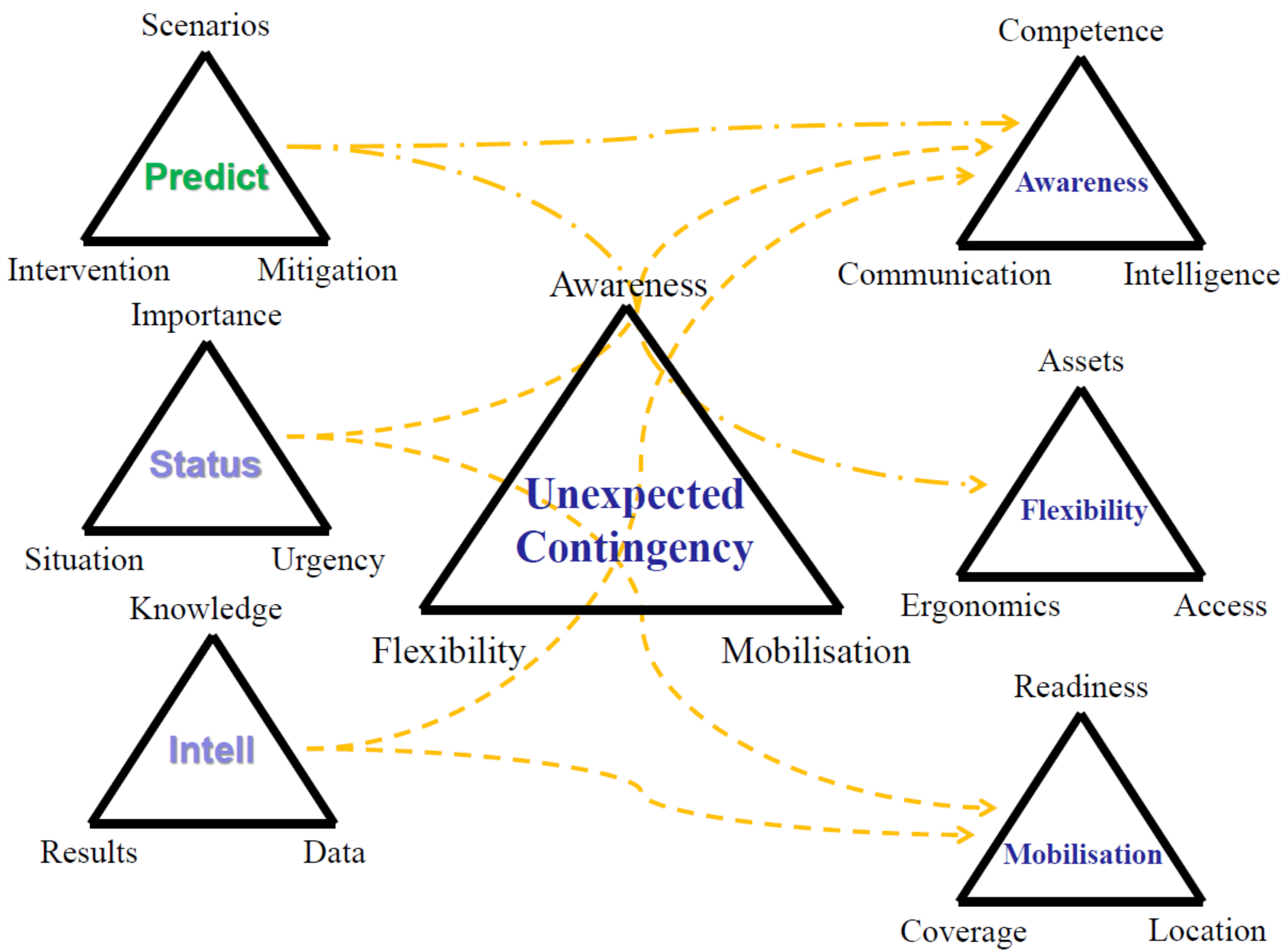
- Facilities
- Infrastructure
- People
- Logistics
- Communications
- Documentation
- Agreements

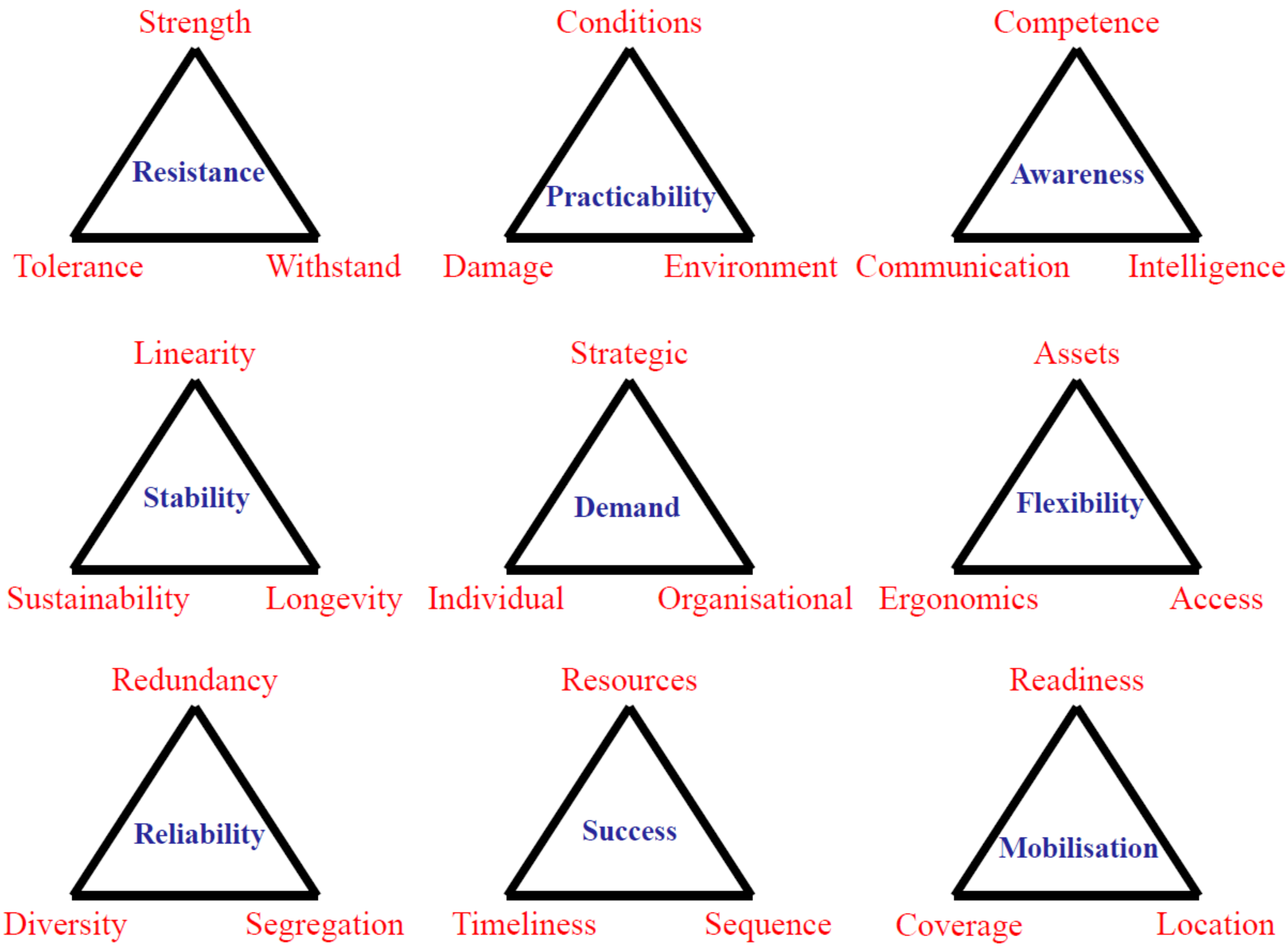

Local System Boundary
[Radius 50km from Site]
On- & Off-Site
System-Architecture
(SSCs)
Transportation routes
Distribution networks
Service lines
Supply lines
Stored equipment
Communications
NO RISK REDUCTION
VERY POOR CHANCE OF RESPONSE SUCCESS TO MITIGATE
Option A
Option B
Option C
£
£
£
RISK REDUCTION ACHIEVED
HIGHER CHANCE OF RESPONSE SUCCESS TO MITIGATE
Improvement Option Costs
System Hazard Behaviour Coping Uncertainty
Prelim HIT
Assessment Test
Systemic Robustness Very Poor due to Failures
System Hazard Behaviour Coping Uncertainty
Solution HIT
Design Options
Improve Robustness by Strengthen Scheme

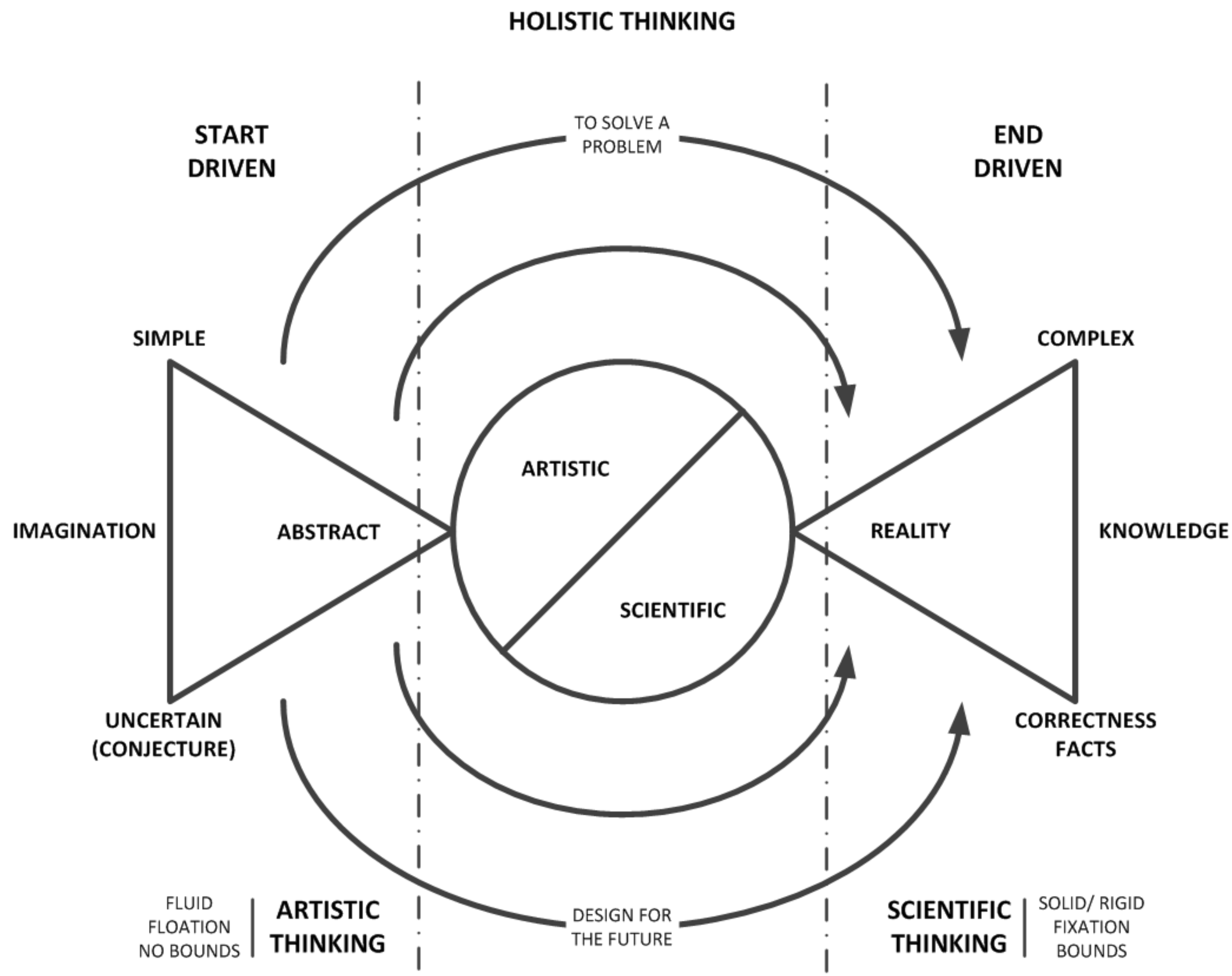

Anticipation Planning
Severe Shock Event & Accident Management Arrangements
| SAAs | SAMS | Coping Strategies | Countermeasures |
Resilience Response > Recovery Capability
Scaling Resilience Capability
System-Architecture
Socio-Technical across EFIPLCDA & Within the Dependent System Boundary
Holistic View
Dependent System Boundary
Events
Anticipation Planning
Accidents
Scenarios
Socio-Technical
System-Architecture
Hardware
Software
Dependencies
Holistic View
Bounded System
Configuration


Practicability
Counter-
measures
Feasibility
Demand
Success
Conditions
Practicability
Damage
Environment
Strategic
Demand
Individual
Organisational
Resources
Success
Timeliness
Sequence


Awareness
Unexpected Contingency
Flexibility
Mobilisation
Competence
Awareness
Communication
Intelligence
Assets
Flexibility
Ergonomics
Access
Readiness
Mobilisation
Coverage
Location


Scenarios
Predict
Intervention
Mitigation
Importance
Status
Situation
Urgency
Knowledge
Intell
Results
Data
Awareness
Unexpected Contingency
Flexibility
Mobilisation
Competence
Awareness
Communication
Intelligence
Assets
Flexibility
Ergonomics
Access
Readiness
Mobilisation
Coverage
Location


Strength
Resistance
Tolerance
Withstand
Conditions
Practicability
Damage
Environment
Competence
Awareness
Communication
Intelligence
Linearity
Stability
Sustainability
Longevity
Strategic
Demand
Individual
Organisational
Assets
Flexibility
Ergonomics
Access
Redundancy
Reliability
Diversity
Segregation
Resources
Success
Timeliness
Sequence
Readiness
Mobilisation
Coverage
Location


HOLISTIC THINKING
START DRIVEN
TO SOLVE A PROBLEM
END DRIVEN
SIMPLE
COMPLEX
ARTISTIC
IMAGINATION
ABSTRACT
REALITY
KNOWLEDGE
SCIENTIFIC
UNCERTAIN (CONJECTURE)
CORRECTNESS FACTS
FLUID
FLOATION
NO BOUNDS
ARTISTIC THINKING
DESIGN FOR THE FUTURE
SCIENTIFIC THINKING
SOLID/ RIGID
FIXATION
BOUNDS

End

ARUP

Thank You

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