Decision Support for Flexible Design of Urban Water Distribution Systems

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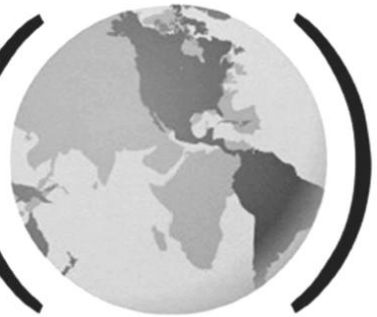
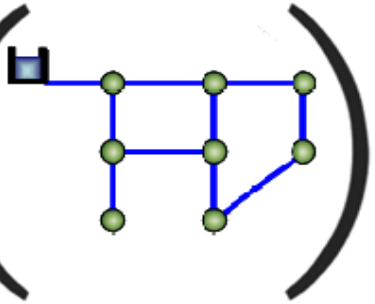
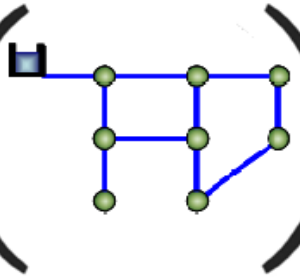
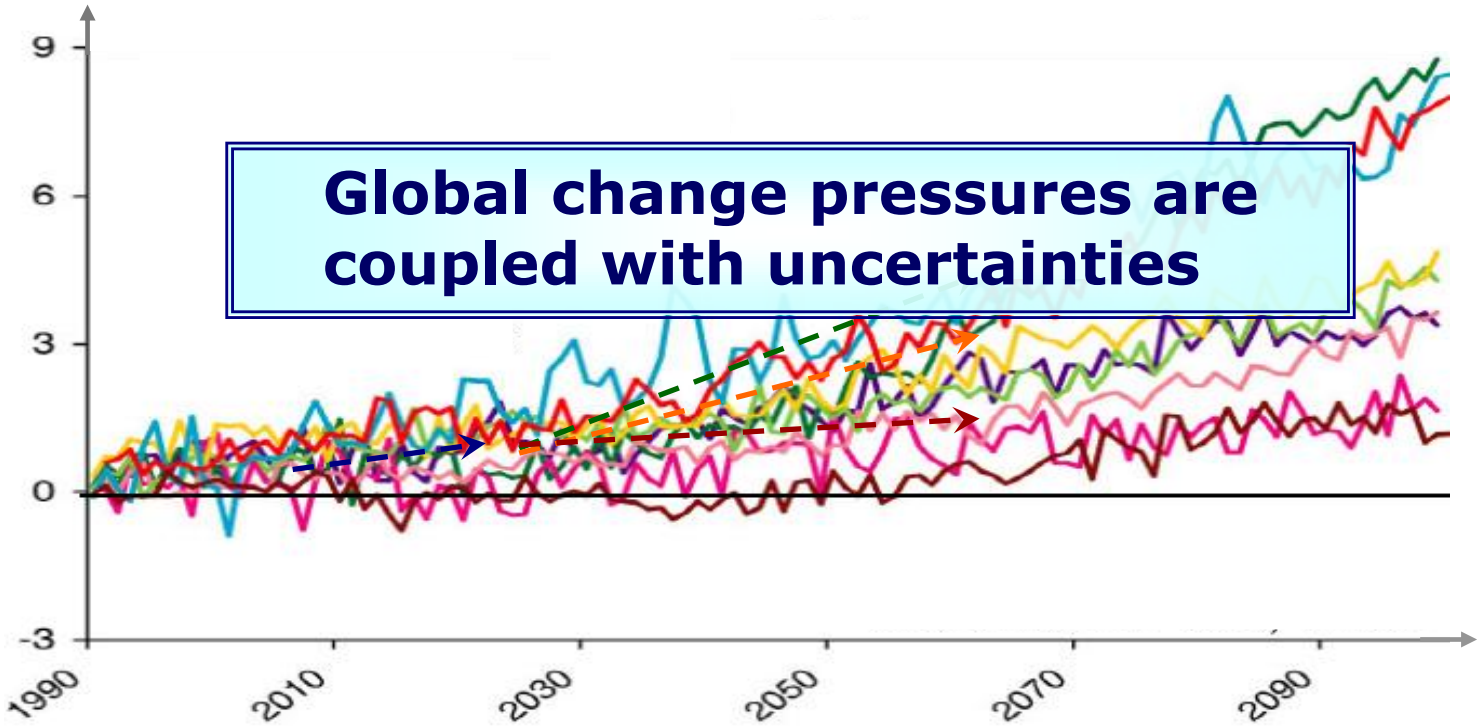
Introduction

Our glob is changing rapidly

$$\frac{d}{dt}\left(\text{  }\right) \Rightarrow \frac{d}{d\,\text{  }}\left(\text{  }\right) \Rightarrow$$

$$\frac{d}{dt}\left(\text{  }\right) \; ?$$

Introduction



Source: Hadley Centre (2003)

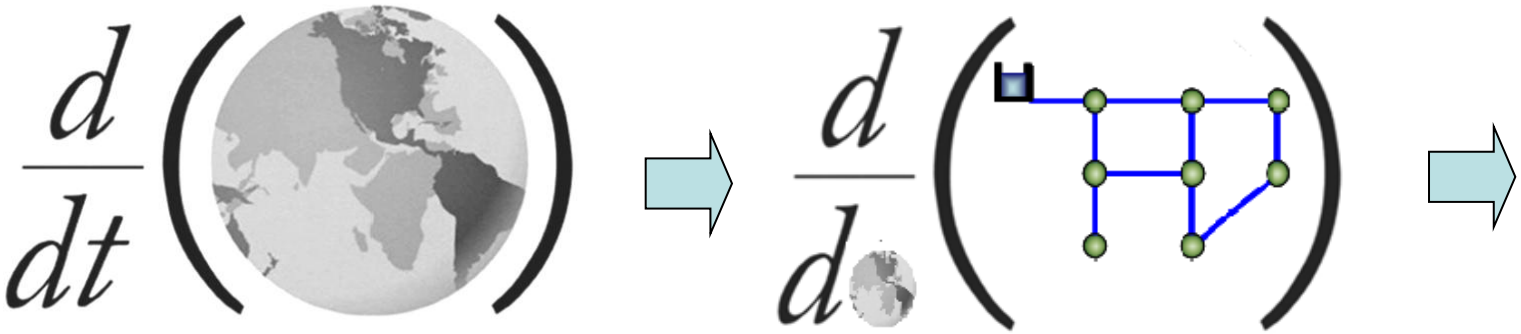
Why Flexibility

UWDS have been designed to satisfies a fixed set of requirements. These systems

- **Don't give the opportunity to use the positive side of uncertainties**
- **Don't encourage changeability**
- **Don't offer ability to change in cost effective and timely manner**

Need: System which allows a number of decision choices for a variety of different future alterations

Why Flexibility



Flexibility has been proposed as a key decision criteria

Why Flexibility

The ability of a system to use their active capacity to act or respond to future alterations in a timely, performance efficient and cost effective manner (Eckart et al., 2010).

It is recognized as a way to deal with future alteration.

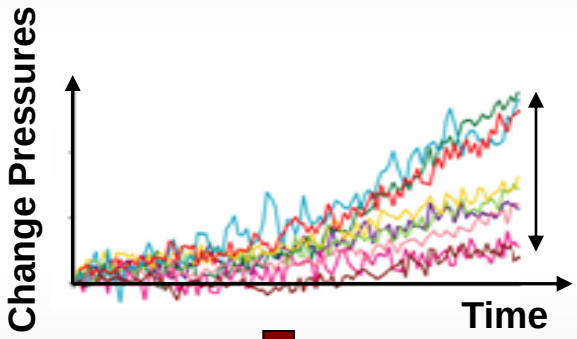
Turning Uncertainty into Opportunity!

Decision Support in Design for Flexibility

The three major issues for decision support in designing of flexible UWDS are:

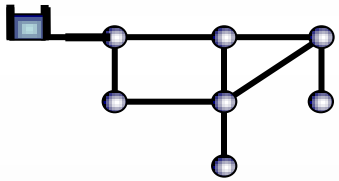
1. Drivers/uncertainty **2. Options** **3.Level**

For Which & When is flexibility required?



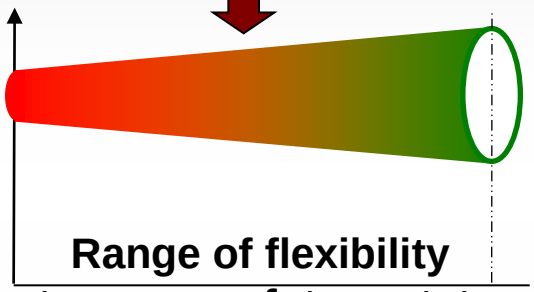
• Model uncertainty

What flexibility& Where to embed?



• Identify option

How much flexibility?



• Embed flexibility
• Evaluate

Uncertainties

Scenario tree Method

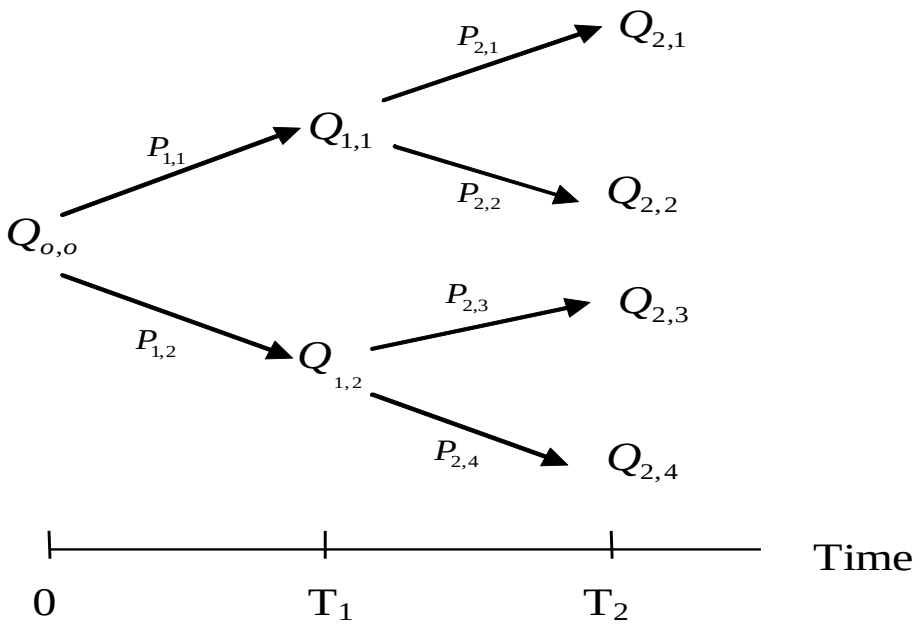


Fig: Scenario tree with two forecast periods to express the future states

Flexible Option Identification

In designing for flexibility, Suits of options in WDS that most likely offer better life time flexibility in the uncertain environment are crucial.

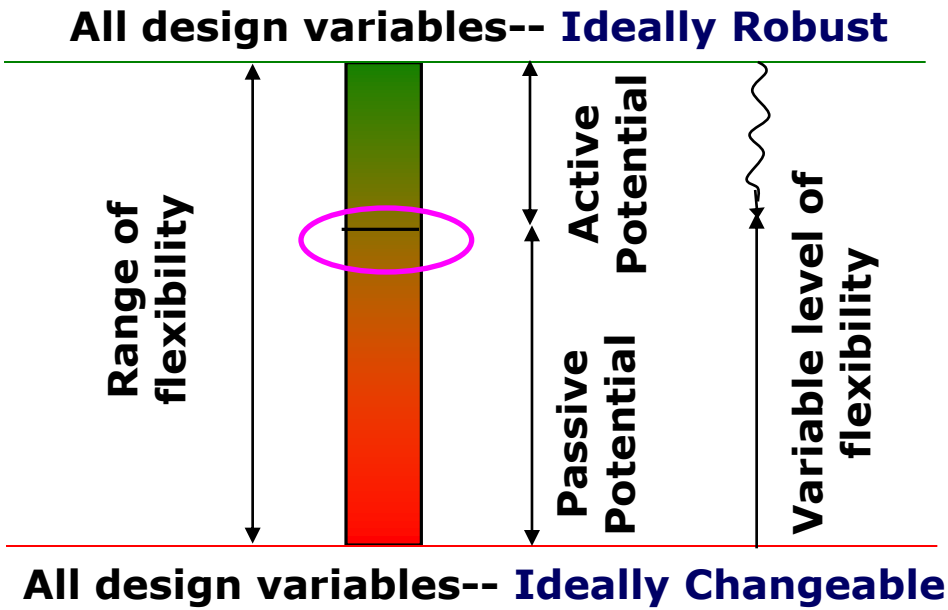
According to (de Neufville, 2002) options in engineering systems are identified as flexibility "on" and "in" a system.

Flexibility "on" a system- Relates to management decision

Flexibility "in" a system- Relates to the technical aspect of the design

How much flexibility?

A systematic approach for the level of flexibility



Optimal level of flexibility?

The trade-off between the cost of capturing the options and the expected benefit that may arise from future uncertainties.

How much flexibility?

Trade-off between cost of embedding system ability to overcome alterations and cost needed to change the system.

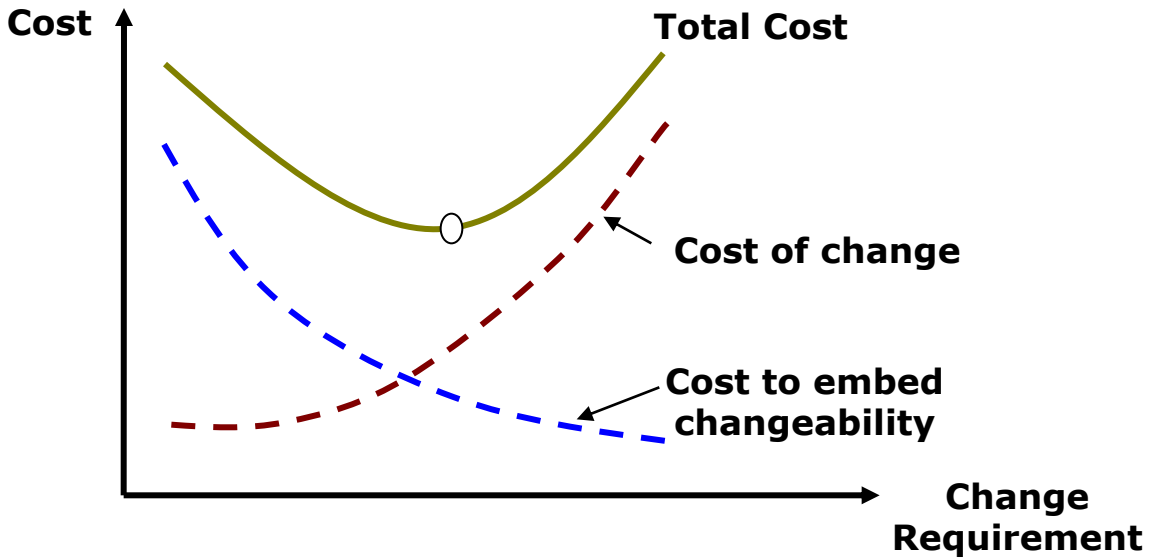


Fig: Degree of change Vs Cost (adapted from Schulz *et al.*, 2000)

Flexibility based decisions making

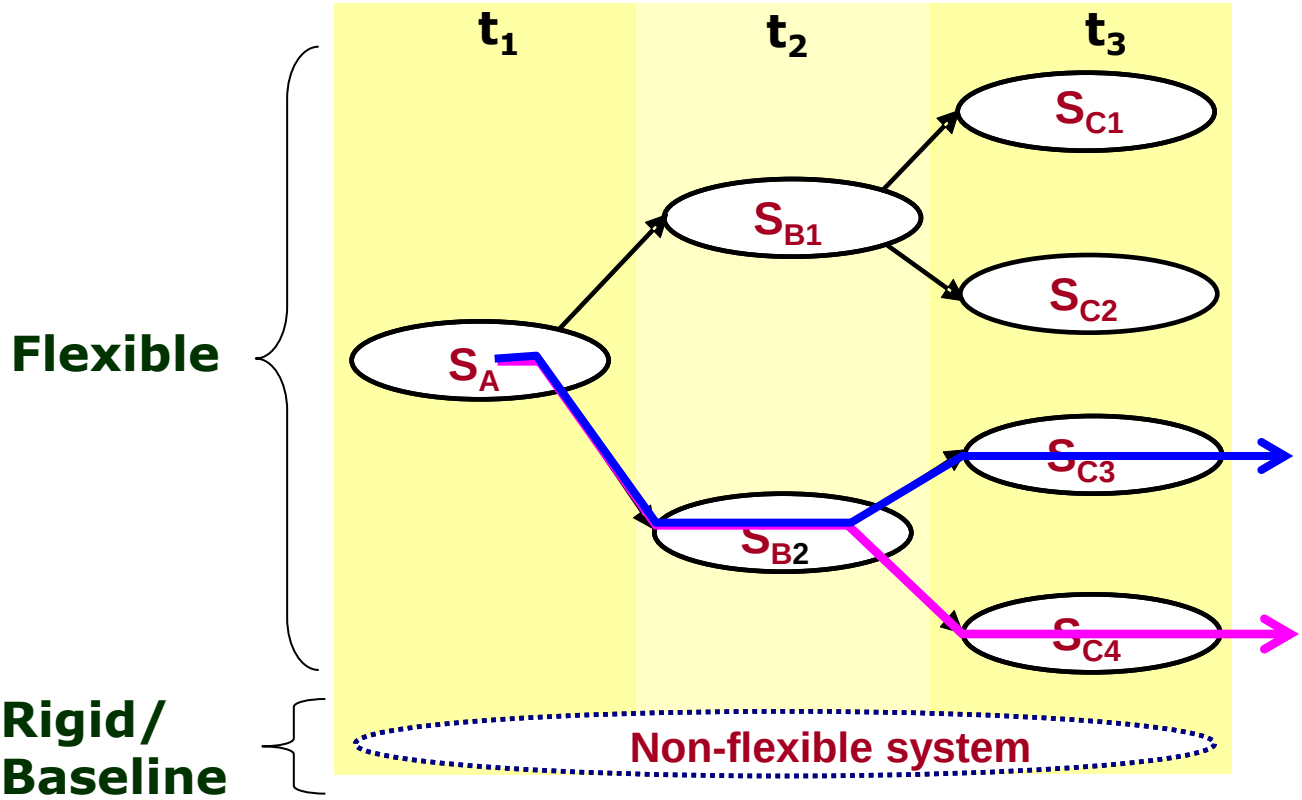


Fig: Decision tree with a range of system alternatives.

The decision on the choice of the set of alternatives (systems) is be based on the decision criteria's.

Flexibility based decisions making

Decisions criteria under uncertainty

Maximin: "best worst" payoff establishes the minimum outcome.

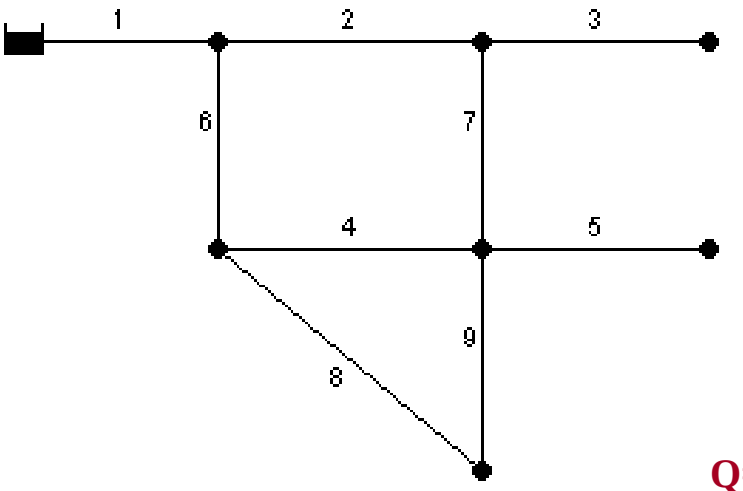
Maximax: "best best" payoff establishes the best possible outcome

Laplace: "best average" payoff establishes the average payoff

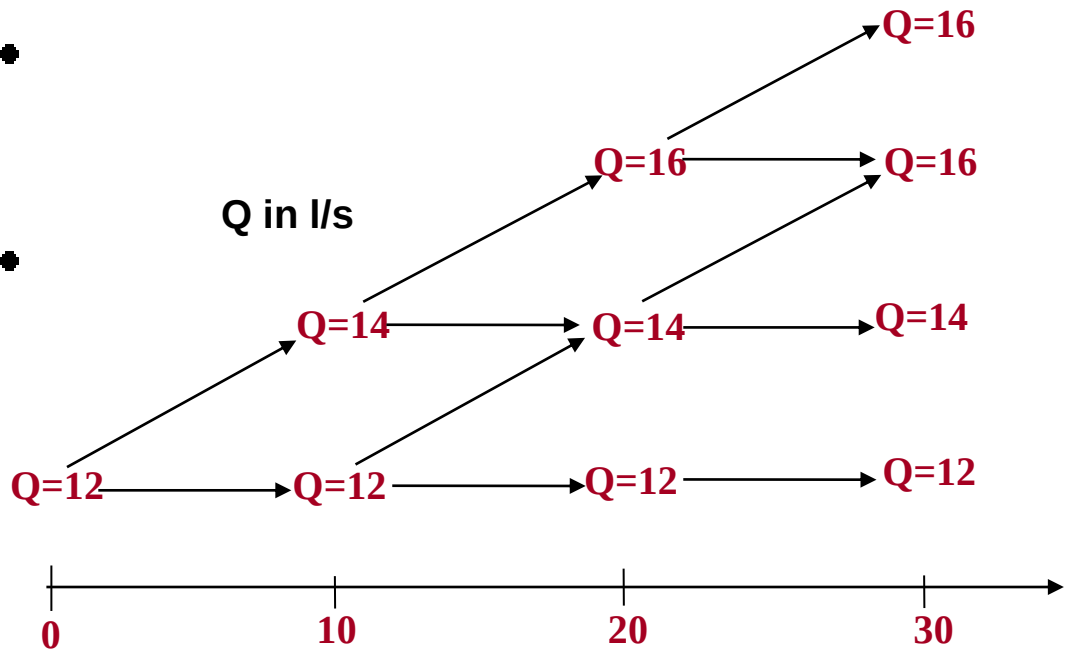
Minimax regret: "best worst" regret minimizes the difference between the realized payoff and the best payoff for each future condition

Design for flexibility

Hypothetical WDN



Range of possible future states



Design for flexibility

Robust design

Pipe	Pipe dia. (mm)	Cost ($)
1	355.6	60,000
2	254	32,000
3	152.4	16,000
4	50.8	5,000
5	203.2	23,000
6	203.2	23,000
7	203.2	23,000
8	152.4	16,000
9	25.4	2,000
Total Cost		**200,000**

Design for flexibility

Design without flex. element

Pipe	Pipe diameter in mm			
	Q=12	Q=14	Q=16	Q=18
1	254	304.8	304.8	355.6
2	254	254	254	254
3	152.4	152.4	152.4	152.4
4	76.2	76.2	76.2	76.2
5	152.4	152.4	203.2	203.2
6	203.2	203.2	203.2	203.2
7	203.2	203.2	203.2	203.2
8	152.4	152.4	152.4	152.4
9	25.4	25.4	25.4	25.4

Pipe	Pipe cost			
	1	2	3	4
1	32,000	18,000	0	10,000
2	32,000	0	0	0
3	16,000	0	0	0
4	8,000	0	0	0
5	16,000	0	7,000	0
6	23,000	0	0	0
7	23,000	0	0	0
8	16,000	0	0	0
9	2,000	0	0	0
Cost	**168,000**	**18,000**	**7,000**	**10,000**

Design for flexibility

Design with flexible option

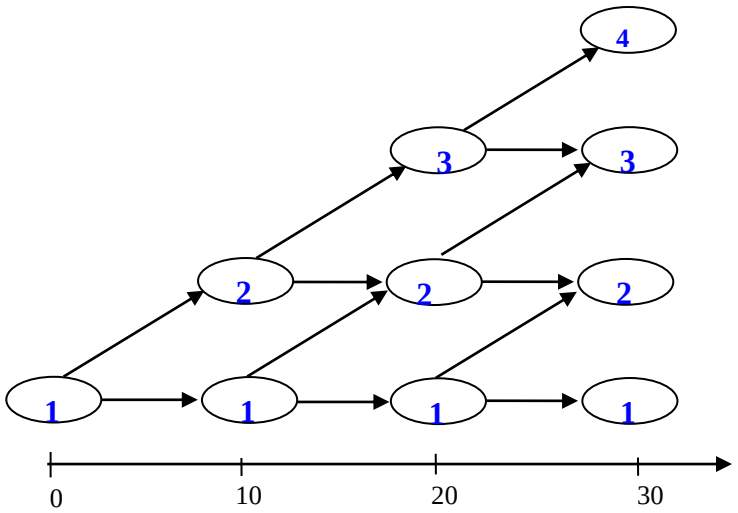
Pipe	Pipe diameter in mm			
	1	2	3	4
1	254	304.8	304.8	355.6
2	254	254	254	254
3	152.4	152.4	152.4	152.4
4	25.4	25.4	50.8	50.8
5	203.2	203.2	203.2	203.2
6	203.2	203.2	203.2	203.2
7	203.2	203.2	203.2	203.2
8	152.4	152.4	152.4	152.4
9	25.4	25.4	25.4	25.4

Pipe	Pipe Cost			
	S1	S2	S3	S4
1	32,000	18,000	0	10,000
2	32,000	0	0	0
3	16,000	0	0	0
4	2,000	0	3,000	0
5	23,000	0	0	0
6	23,000	0	0	0
7	23,000	0	0	0
8	16,000	0	0	0
9	2,000	0	0	0
Cost	**169,000**	**18,000**	**3,000**	**10,000**

Decisions making

Decisions criteria under uncertainty

- **Maximax**
- **Laplace**
- **Minimax regret**



Cost Comparison

No	Deci. Paths	Alternatives		
		Robust	Without flex. ele	With flex.ele.
1	1-1-1-1		168000	169000
2	1-1-1-2		175415.8	176415.8
3	1-1-2-2		177966.2	178966.2
4	1-1-2-3		180850.1	180202.1
5	1-2-2-2		181393.7	182393.7
6	1-2-2-3		184277.6	183629.7
7	1-2-3-3		185269.4	184054.7
8	1-2-3-4	200,000	189389.3	187749.5

Flexibility based decisions making

Decision based on Minmax regret decision criteria

No	Decision Paths	Alternatives		
		Robust	Without flex. Elet	With flex.element
1	1-1-1-1	32,000	0	1,000
2	1-1-1-2	24,584	0	1,000
3	1-1-2-2	22,034	0	1,000
4	1-1-2-3	19,798	648	0
5	1-2-2-2	18,606	0	1,000
6	1-2-2-3	16,370	648	0
7	1-2-3-3	15,945	1,215	0
8	1-2-3-4	12,250	1,640	0
Max regret		**32,000**	**1,640**	**1,000**
Minmax regret		**3**	**2**	**1**

Better Solution

The max.regret for the second alternative is 64% higher than the third alternative

Flexibility based decisions making

This Decision support system for designing flexible UWDS

- **Create system ability to adjust with future change requirements**
- **Offer the option to explore the positive side of uncertainties (add value out of future alterations)**
- **Used to explore a range of alternatives that consider the future uncertain environment**

Flexibility based decisions making

Uncertainty is not always a negative to be mitigated,

but can also be a positive to be exploited