

# Introduction to the Theory of Constraints



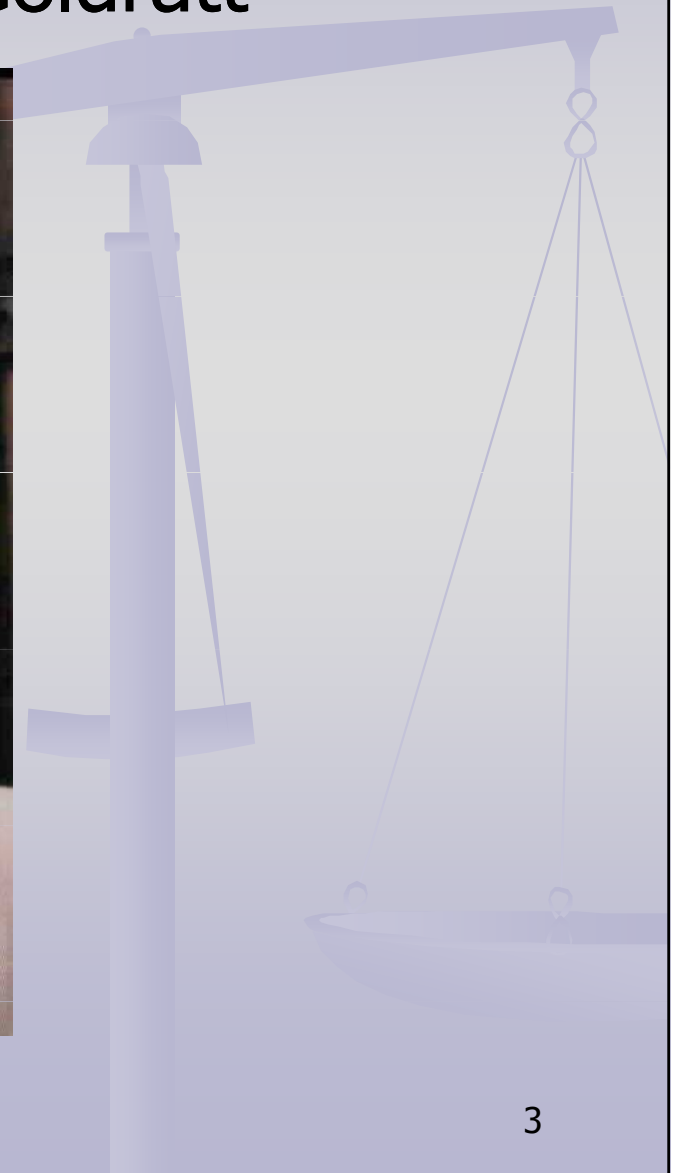
J.Skorkovský, PhD.; KPH ESF MU

# Introduction

- Theory of Constraints - TOC) was formulated approximately in 1980 in the USA. Some important roots of this theory were connected to the ideas incorporated in programs for planning and production control (Optimized Production Technology)

# Introduction

- Author: Eliyahu Moshe Goldratt



# The Goal by Eliyahu Goldratt

- The goal of a manufacturing company?

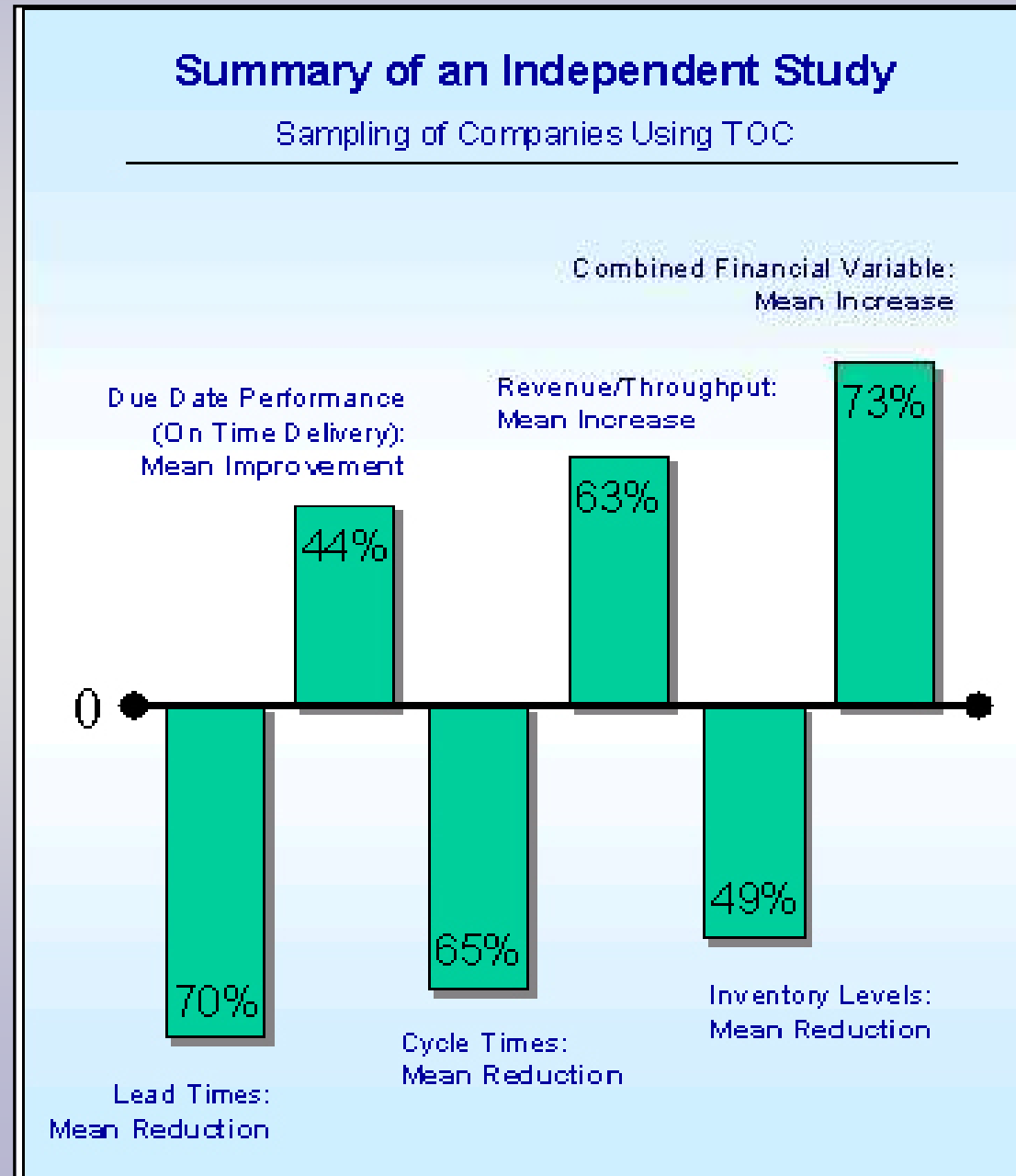
**Make money !!!**

# Introduction -novels

**TOC has become popular particularly thanks to the novels :**

- The Goal - A Process of Ongoing Improvement
- It's Not Luck
- The Race
- The Critical Chain
- The Haystack Syndrome
- Necessary But Not Sufficient
- Late night discussion
- TOC was together with TQM (Total Quality Management ) and JIT (Just-In-Time) TOC classified as one of the most important managerial methods of the last two decades of the twentieth century .

# Some impacts of TOC implementation



# Some impacts of TOC implementation

## Ford Motor – Electronics Div.

**Revenue: \$3,000,000,000**

**Number of employees: 15,000**

**Implementation Date: 1991**

**TOC Applications: DBR**

**Comment: Drum-Buffer-Rope** : will be presented later in  
this course)

# Some impacts of **TOC** implementation

## **IMPLEMENTATION RESULTS**

**Inventory Decrease:** Reduced 100 million dollars (50%)

**On-time performance:** From 89% - to 98%

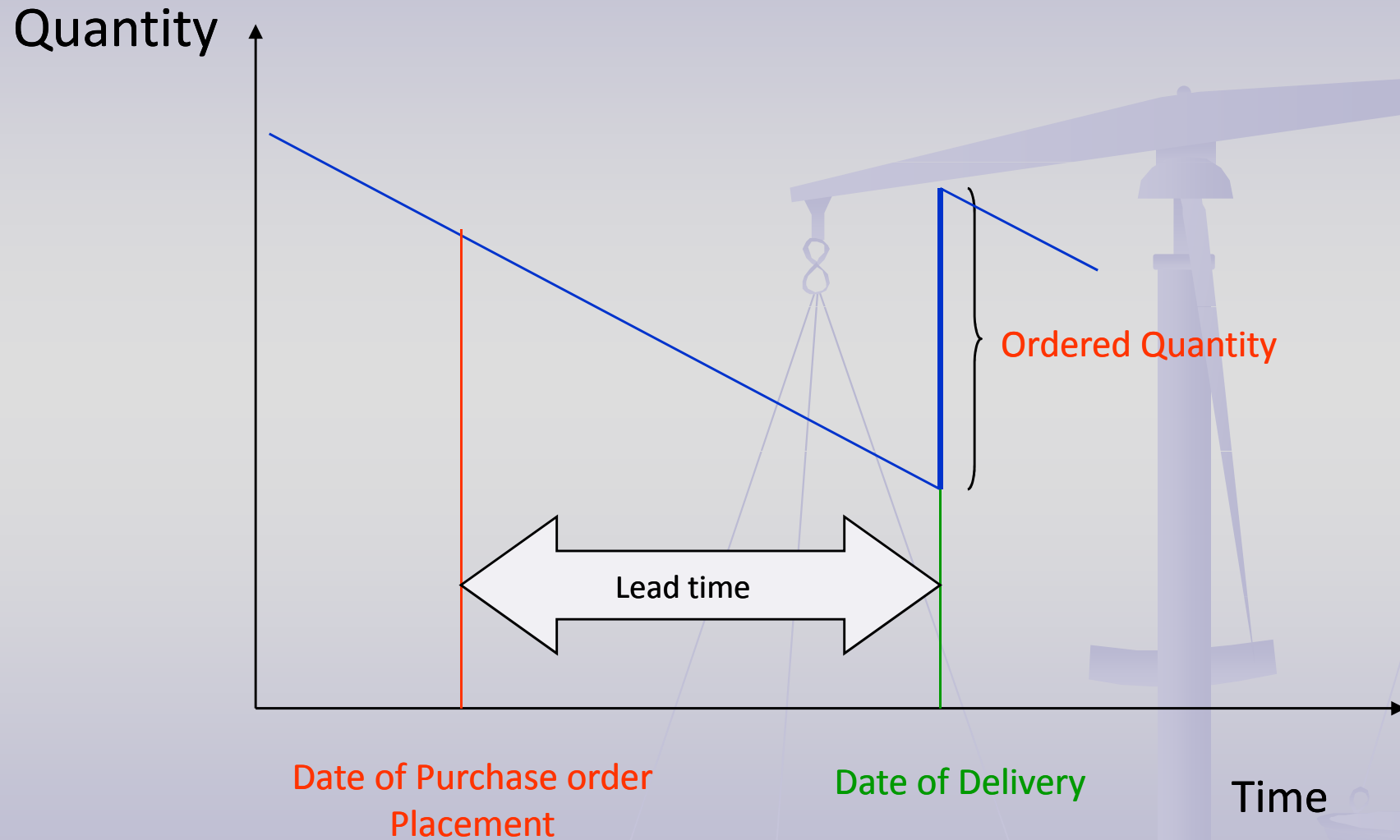
**Lead times:** From 6.4 days with JIT to 2.6 days

**Cost efficiency:** Reduced floor space by 57%

**Quality:** Reduced quality defects by 50%



# LEAD Time explanation-purchase



# LEAD Time explanation-purchase

1027 The Device Shop - Sales Order

General Invoicing Shipping Foreign Trade E - Commerce Prepayment

No. . . . . 1027 Posting Date . . . . . 15.12.08

Sell-to Customer No. . . . . 62000 Order Date . . . . . 15.12.08

Sell-to Contact No. . . . . CT000138 Document Date . . . . . 15.12.08

Sell-to Customer Name . . The Device Shop Requested Delivery Date 12.01.09

Sell-to Address . . . . . 273 Basin Street Promised Delivery Date . . . . .

Sell-to Address 2 . . . . . Quote No. . . . .

Sell-to Post Code/City . . N16 34Z London External Document No. . . . .

Sell-to Contact . . . . . Salesperson Code . . . . . PS

No. of Archived Versions. . . . . 0 Campaign No. . . . .

Responsibility Center . . . LONDON

Status . . . . . Open

Type	No.	Description	Quantity	Location Code	Unit of Measure Code	Qty. to Ship	Reserved Quantity	Qty. to Invoice
Item	1906-5	ATHENS Mobile Ped	4	BLUE	PCS			

Customer Information

- Sell-to Customer
- Ship-to Addresses (0)
- Contacts (1)
- Sales History
- Bill-to Customer
- Avail. Credit 0

Item Information

- Item Card
- Availability (39)
- Substitutions (0)
- Sales Prices (0)
- Sales Line Di... (0)

Order Line Functions Posting Print Help

# LEAD Time explanation-production

101004 Bicycle - Released Production Order

General Schedule Posting

No. . . . . 101004 Search Description . . . BICYCLE

Description . . . . . Bicycle Quantity . . . . . 16

Description 2 . . . . . Due Date . . . . . 31.01.08

Source Type . . . . . Item Assigned User ID . . . . .

Source No. . . . . 1000 Blocked . . . . .

Last Date Modified . . . . .

Item No.	Due Date	Description	Starting Date-Time	Ending Date-Time	Quantity	Unit of M...
▶ 1000	31.01.08	Bicycle	25.01.08 10:04	30.01.08 16:00	16	PCS

Order Line Functions Print Help

# Some impacts of **TOC** implementation

## McDonagh Furniture Ltd

**Revenue:** \$8,000,000

**Number of employees:** 100

**Implementation Date:** 2000

**TOC Applications:** DBR



# Some impacts of **TOC** implementation

## **IMPLEMENTATION RESULTS**

**Revenue Increase:** 28% Yr 1; 17% Yr 2

**On-time performance:** From 70% - To 98%

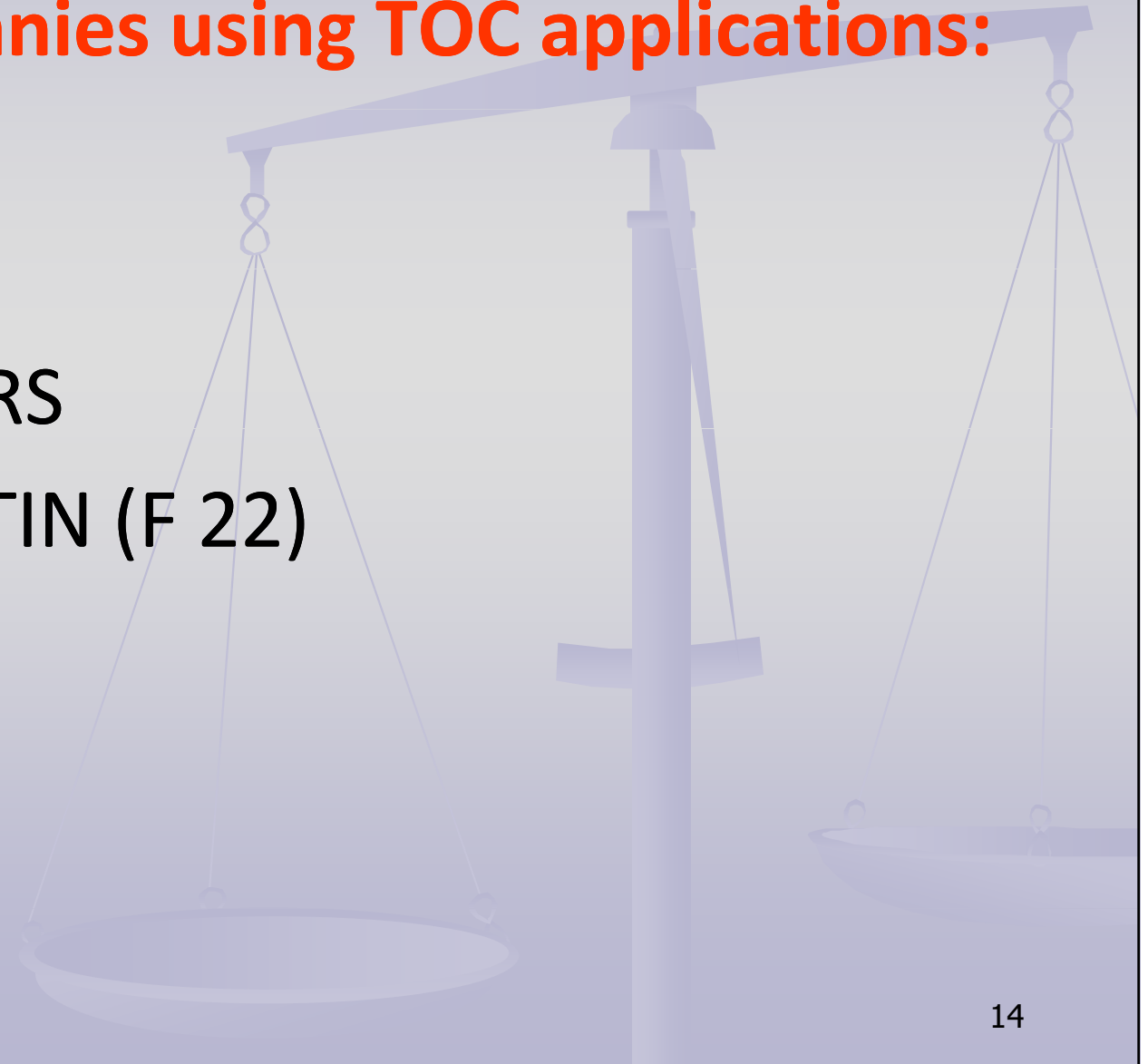
**Lead times decrease:** 20 %

**Net profit increase:** over 300%

# Some impacts of **TOC** implementation

## Some other companies using TOC applications:

- BOEING
- MOTOROLA
- GENERAL MOTORS
- LOCKHEAD MARTIN (F 22)
- BAE SYSTEMS
- .....



# Measuring the goal (TOC metric)

- Net profit ( $NP=T-OE$ ) : ( T, I and OE will be explained later in this course)
- Cash
- Return on Investment ( $ROI=NP/I$ )

**For a manufacturing enterprise, the goal can also be measured by:**

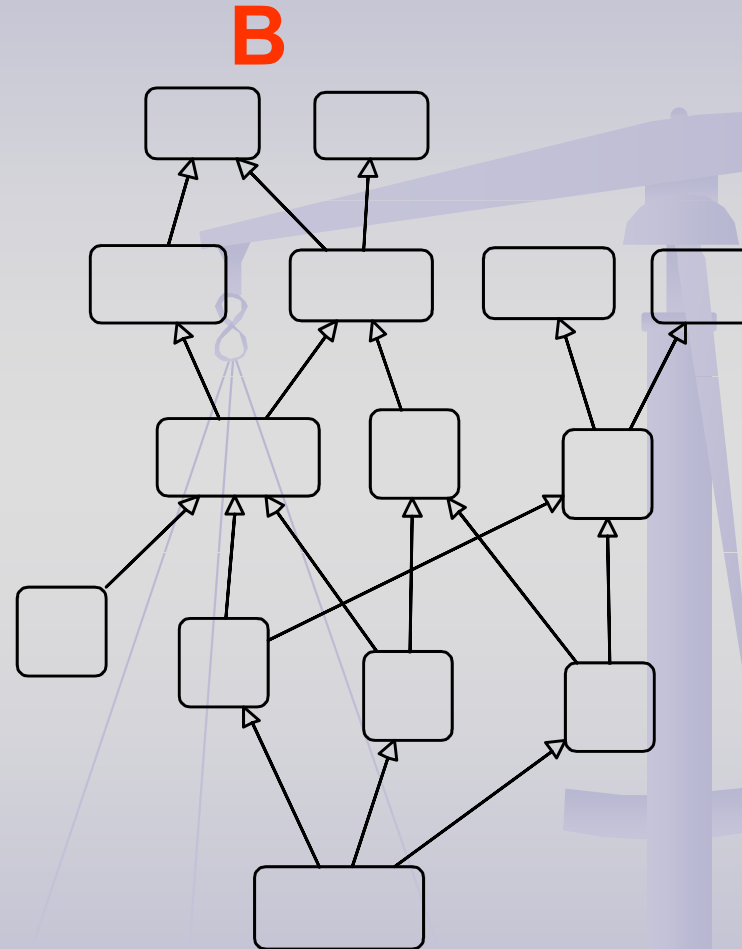
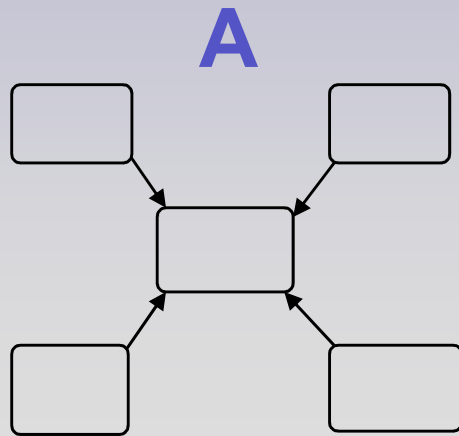
- Throughput
- Inventory
- Operating Expenses

# Definition (TOC metric)

- **Throughput:** The rate at which the system generates **money** through sales.
  - Note that the money is generated through sales and not production because if you produce something and don't sell it, you have not really had throughput. (You've just put it into inventory).
- **Inventory:** All the **money** that the system has invested in purchasing things which it intends to sell.
- **Operational Expense:** All the **money** the system spends in order to turn inventory into throughput.



# TOC

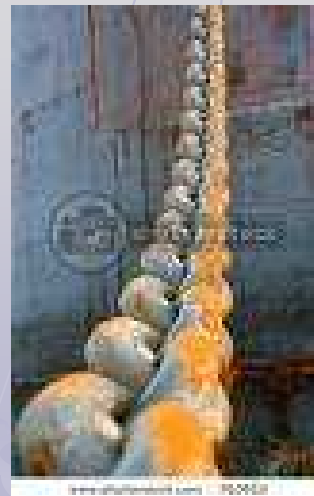


Which is harder to manage? **Left** or **Right**?

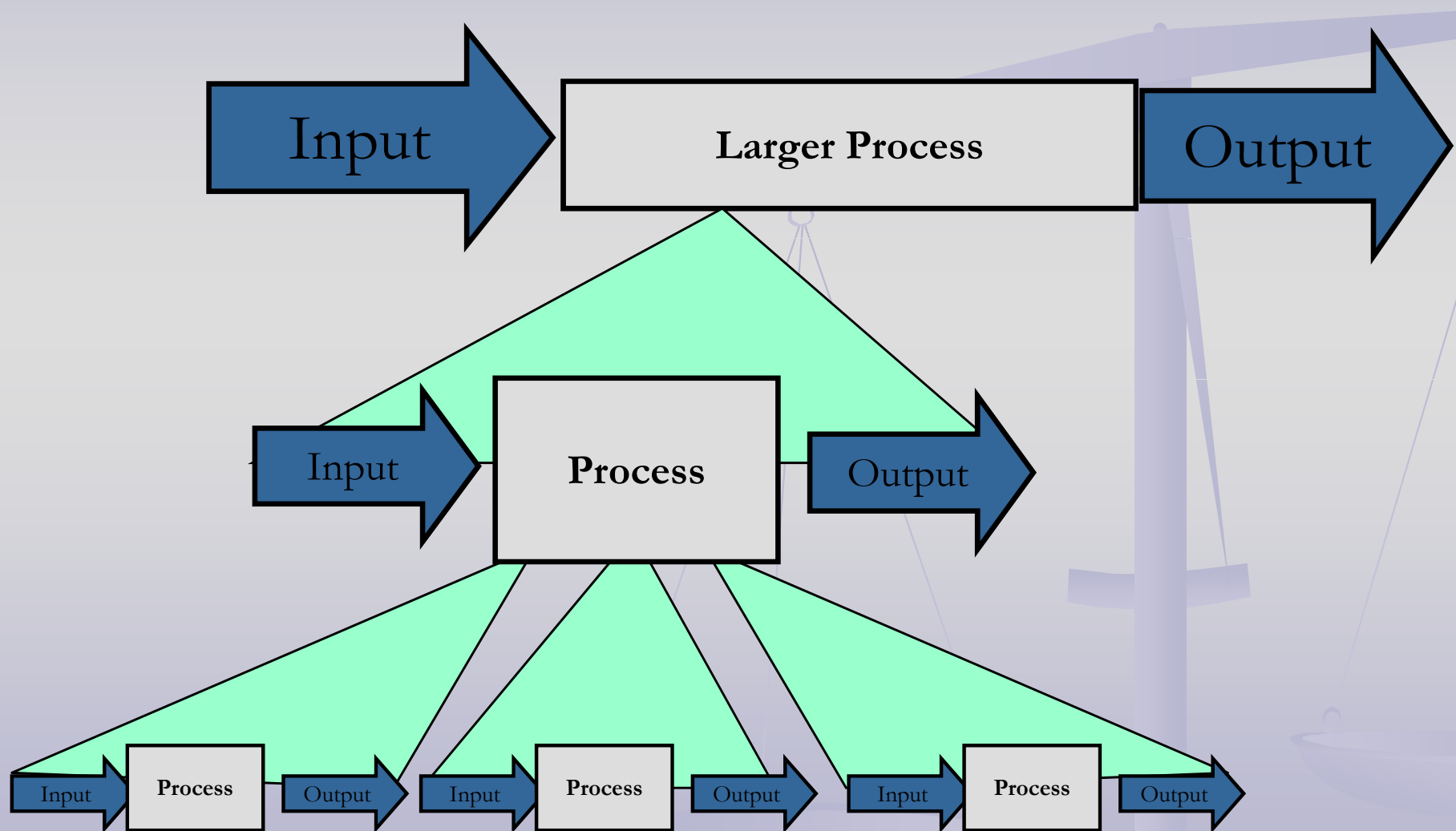
# TOC

- It is based on **system approach**
- A company (enterprise) is to be understood as a chain of dependent processes – **this picture below is very simplified**

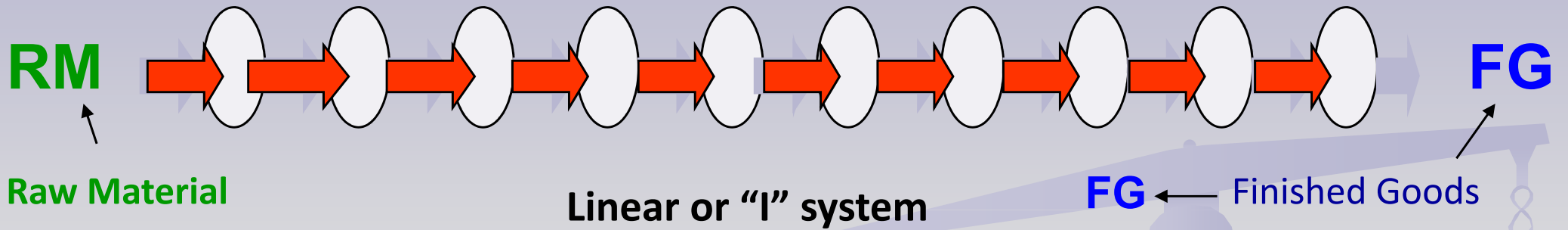
See next slide



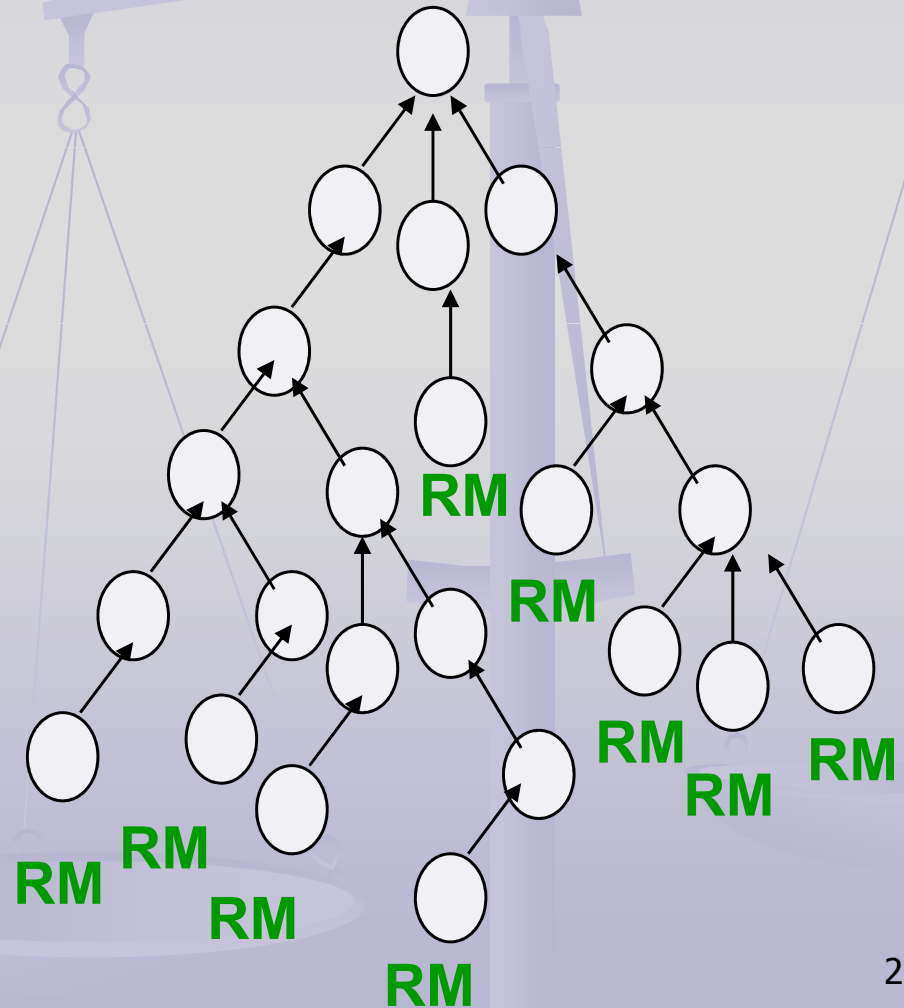
# Process Theory – more complex than one way chain



# Process Theory – more complex than one way chain



Aircraft assembly is more of an "A" Plant



# TOC – system approach

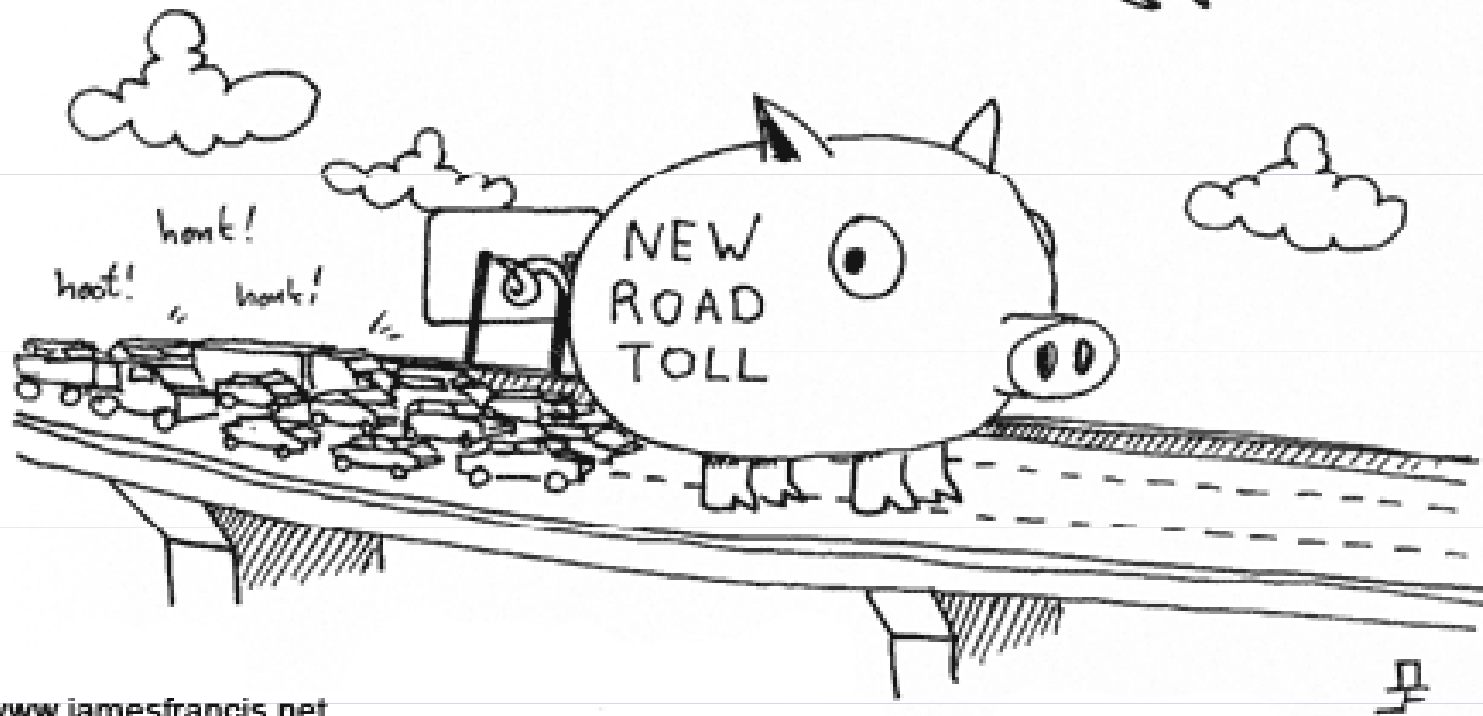
- Organizations / Systems exist for a **purpose**
- That **purpose** is better achieved by cooperation of multiple, independent elements linked together
- Each Inter-linked event depends in some detail upon the other links.
- The system owner determines purpose

# TOC

- Most real systems could be seen in such a way, that there are only a few or better only one element (factor), which is the key point, where and only there all possible managerial methods have to be focused in order to control whole system
- „Every system is based on inherent simplicity”.
- This element in TOC is called **Constraint of the system = bottleneck**
- **Bottleneck:** Any resource whose capacity is equal to or **less than** the demand placed upon it.

Inherent : základní, podstatná. neodmyslitelná....

THERE SEEMS TO BE A NEW BOTTLENECK ON THE HIGHWAY!



# TOC- bottleneck I

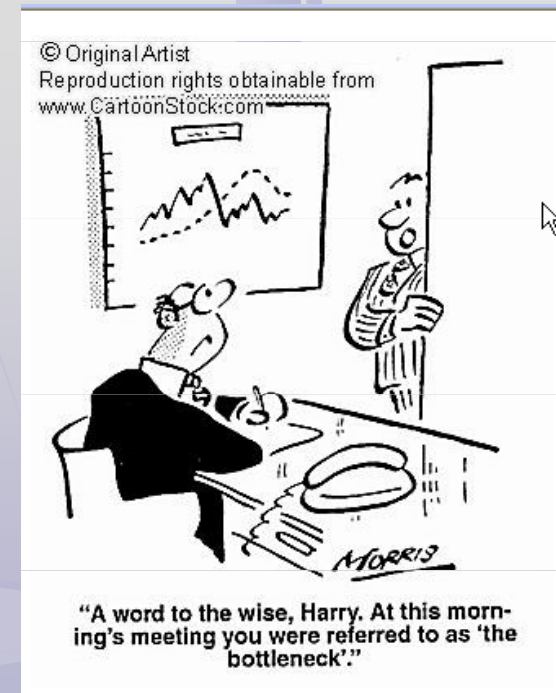
- Different link capabilities, normal variation and changing workload make it impossible to balance everything.
- One element of the system is more limited than another.





# TOC- bottleneck II

- When the whole system is dependent upon the cooperation of all elements, the weakest link determines the strength of the chain.
- An exactly balanced chain (system) is stronger than a non-homogeneous chain, but when close to the breaking point, all links must be managed



# TOC

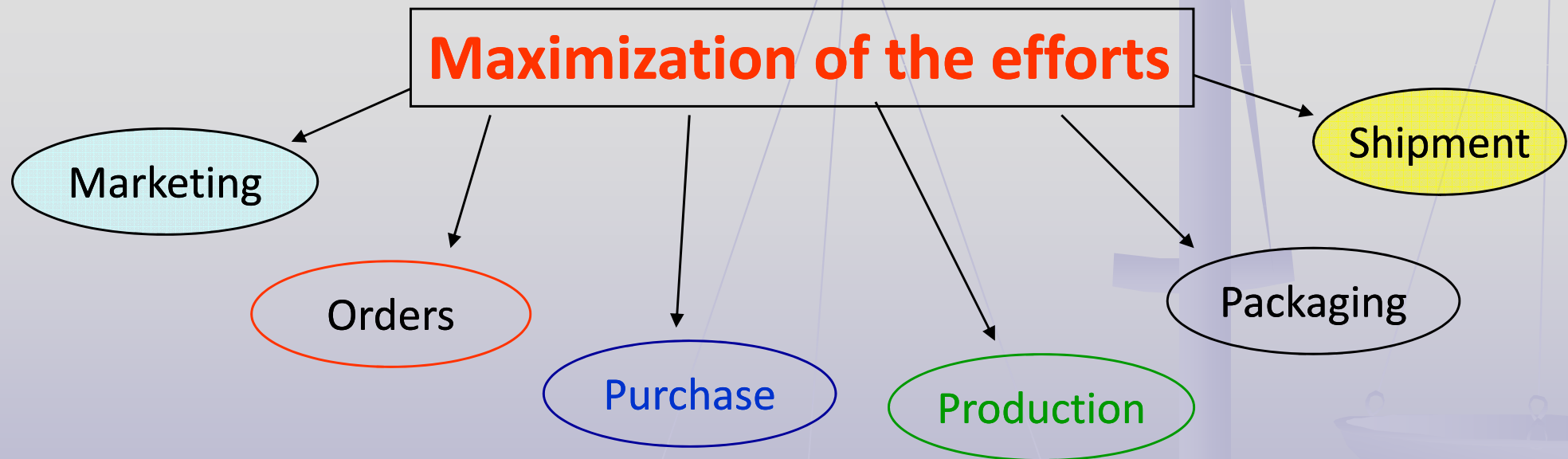
- Why constraint ?
- Constraint prevents to reach the goal (make money now and in the future)
- **The TOC goal : „Make money now and in the future“**
- Every system has at least one such a constraint.  
The system without such a bottlenecks would reach the predefined business plans in infinite volumes.

TOC :



of the costs

- **Traditional approach** – world of where the aim of any endeavour is to optimize locally every segment of the chain, meaning balancing **the capacity** of every element and **not the flow** through the chain



TOC :



of the throughput

- Use of : „common sense“
- The consistent focus of the bottleneck-  
– global optimization

**Maximization of the efforts**



# TOC



# TOC

## World of costs:

- **main metric** – the weight of the chain (every decrease of the weight of any components will result in better efficiency (performance))
- **Total improvement** = sum of local improvements

## World of throughput:

- **main metric** – the compactness of the chain
- Only improvement of bottleneck will improve performance of the whole chain
- **Total improvement** = improvement of the bottleneck

# Life show

- <http://www.tocca.com.au/>



# TOC

## Five steps process:

**Step 0. Identify the Goal of the System/Organization**

**Step 0.5 Establish a way to measure progress to Goal**

- **Step 1. *Identify*** the system's constraint.
- **Step 2. *Exploit*** the system's constraint.
- **Step 3. *Subordinate*** everything else to the above decision.
- **Step 4. *Elevate*** the system's constraint.
- **Step 5.** If a constraint is broken (that is, relieved or improved), go back to Step 1. But don't allow *inertia* to become a constraint.

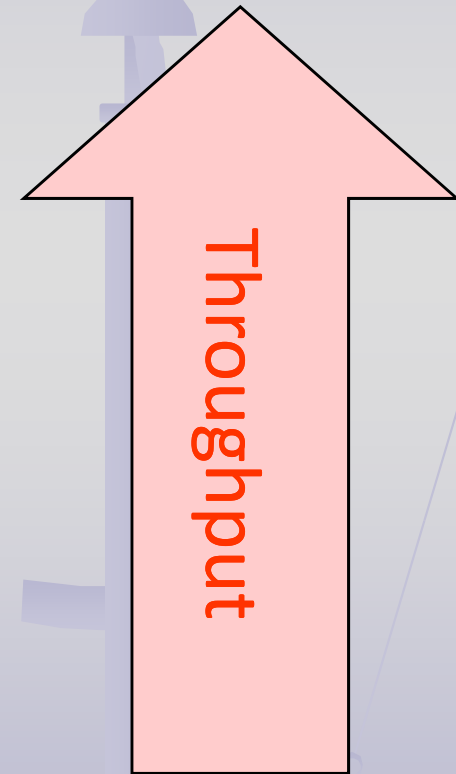
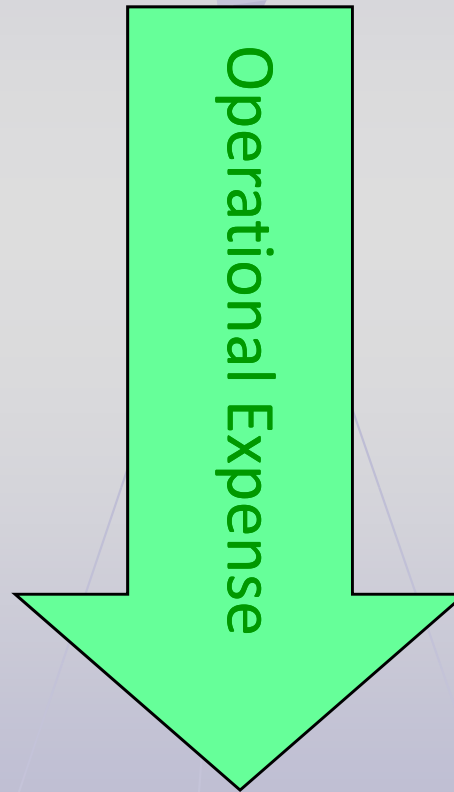
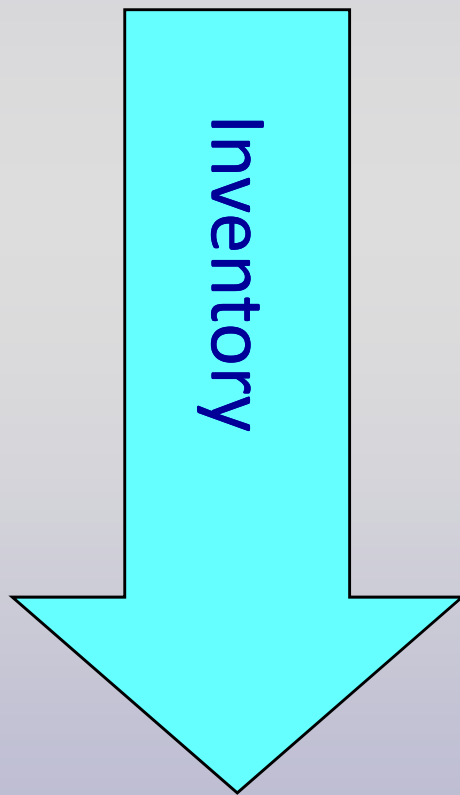


# TOC

- „Cost Accounting is enemy number one of productivity“. \*
- Impact on the behaviour of the people and they habits of finding and improvements of local elements having reason in optimising of these particles.
- New metrics were introduced – already presented

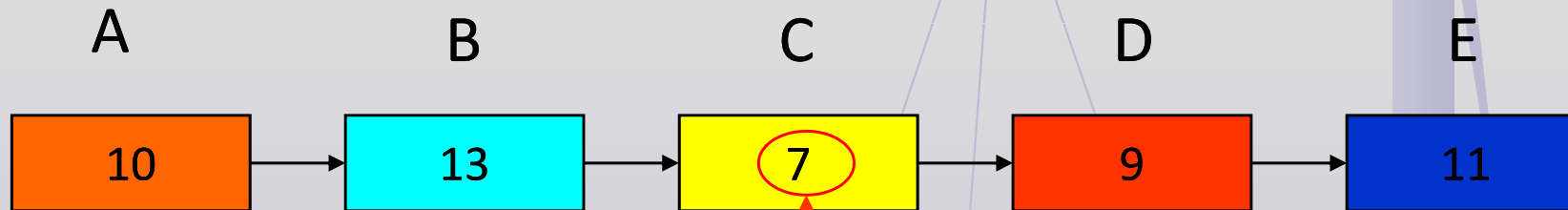
\* Eric Noreen, Debra Smith and James t. Mackey

# TOC –required trends



# T,I,OE,NP and ROI example

- $NP = T - OE$
- $ROI = (T - OE) / I = NP / I$
- where  $T = \text{total throughput}$

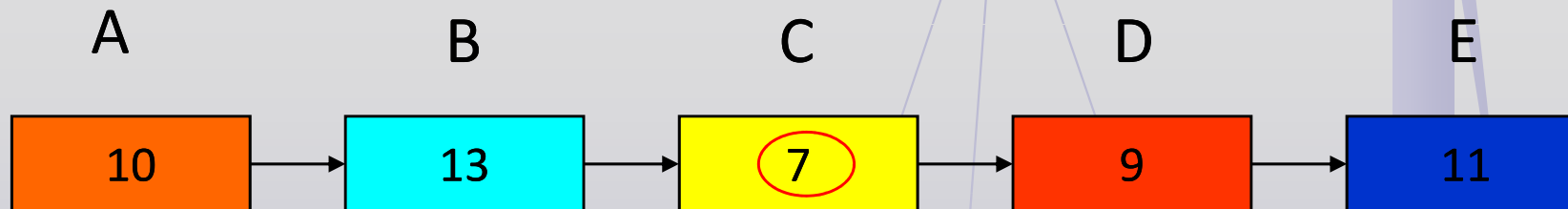


1. Only one product
2. Unit Price (selling price) = 100 USD
3. Raw material /one product = 35 USD
4.  $T/\text{product} = 100 - 35 = 65$
5. 176 hours/month
6.  $T = 176 * 7 = 1232$  parts/month
7. Monthly  $T = 1232 * 65 \text{ USD} = 8\,080 \text{ USD}$

**CCR**=Capacity  
Constraint Resource=  
=weakest link

# T,I,OE,NP and ROI example

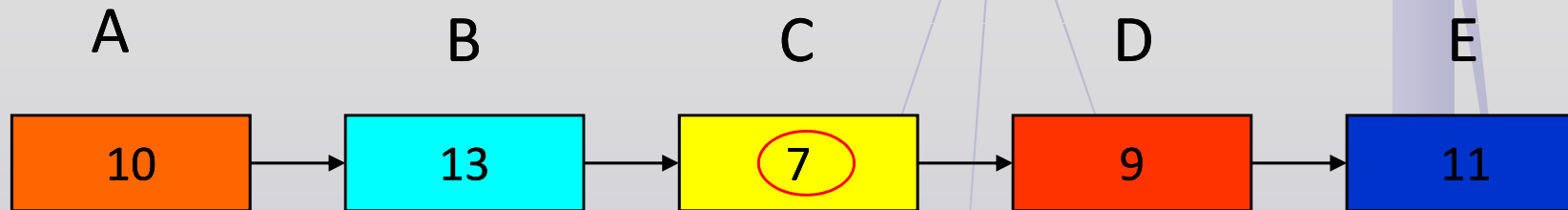
- 1st suggestion is to optimize B from 13->14 parts per hour
- T will not increase ->You cannot produce more than 7
- Investment to optimize B=5000 USD with depreciation 10 %
- $OE/month = (5000 \text{ USD} * 0,1)/12 = 41,67 \rightarrow 42 \text{ USD}$



**CCR**=Capacity  
Constraint Resource=  
=weakest link

# T,I,OE,NP and ROI example

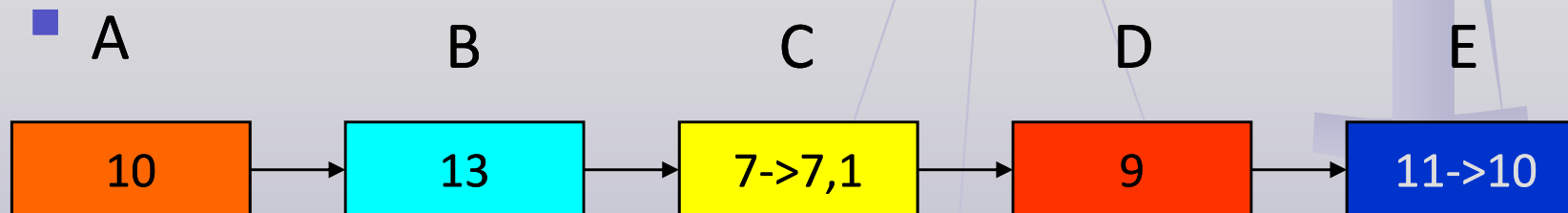
- T will not increase
- NP (net profit) will decrease based on increased OE (41,67 USD /month)
- Based on NP decrease ROI is negative
- **Bad suggestion !!!!!**



**CCR**=Capacity  
Constraint Resource=  
=weakest link

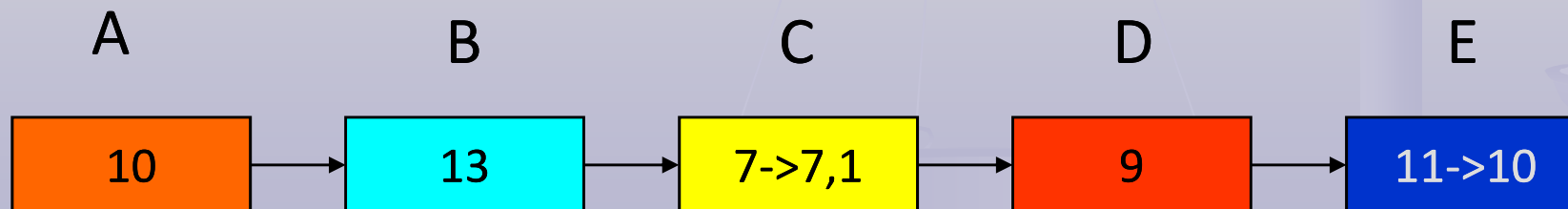
# T,I,OE,NP and ROI example

- 2nd suggestion is to optimize C from 7->7,1 parts/hour
- part of the 2nd suggestion is an extra load of E so it goes from 11->10
- Necessary investment is 5000 USD
- Increase of the production/month =  $0,1 * 176 = 17,6$  parts
- Increase of the company T =  $17,6 * 65 \text{ USD} = 1\,144 \text{ USD}$



# T,I,OE,NP and ROI example

- Necessary investment is **5000** USD = I
- Increase of the production/month =  $0,1 * 176 = 17,6$  parts
- Increase of the company T =  $17,6 * 65$  USD = **1 144** USD
- OE/month =  $(5000 * 0,1) / 12 = 41,67 \rightarrow$  **42** USD
- OE will be increased by 41,67 USD/month
- Annual increase of the NP =  $(T - OE) * 12 = (1144 - 42) * 12 = 13 244$  USD
- $ROI = NP / I = 13 244 / 5000 = 265\% !!!$
- **T** does not measure local efficiencies, except at the constraint



## Implementation of TOC is complicated switchover process

- it represents challenging adventure, where the invested efforts are often not predictable
- it requires cooperation, coordination and use of well informed and trained teams on both sides.
- you will certainly overcome natural resistance against changes and persuade distressed and indolent people
- no one is willing to change anything



# Implementation of TOC is complicated switchover process

- try to find somebody who could accept changes
- you must persuade these guys, that the suggesting changes are in fact their idea and without their creativity TOC would be only toothless beast.
- but how to achieve it ??



# Implementation of TOC is complicated switchover process

- **Socratic teaching** – proving the logic by use of dialog
- **Buy-in approach** – initiator of the changes must have interpersonal and communication talents in order to persuade the targets and squeeze from the people their best ideas.

# Socratic teaching



# Implementation of TOC is complicated switchover process

We have to find out the answers to these questions:

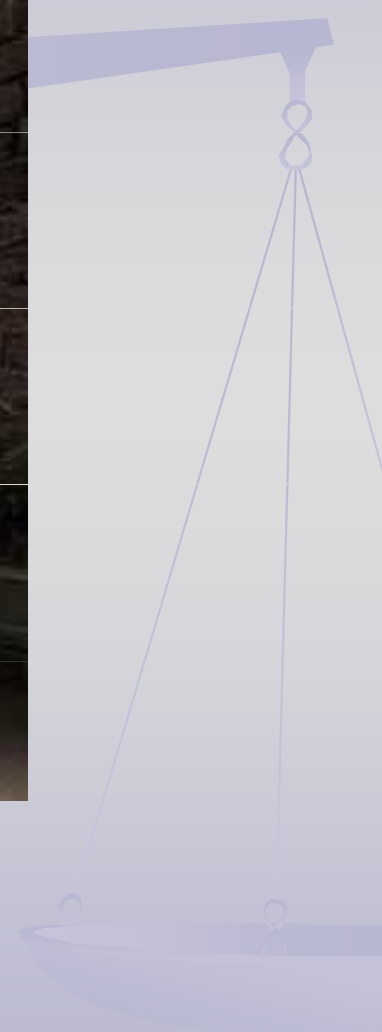
1. What to change?
2. To what to change to ?
3. How to make the change happen?

# Implementation of TOC is complicated switchover process

## What to change?

- **Objectives :** Situation assessment, description of “current reality,” and identification of the core problem or conflict and assumptions that sustain it. **Diagnosis, systemic root cause analysis.**
- **Layers of resistance:** Lack of agreement on the problem

# RESISTANCE



# Implementation of TOC is complicated switchover process

## To what to change?

- **Objectives** : Verbalization of vision/solution, description of strategy to attain the desired state, and avoidance of undesirable side effects. Prescription, decision-making, and solution development.
- **Layers of resistance:**
  - Lack of agreement on a possible direction for a solution
  - Lack of agreement that the solution will truly address the problem
  - Concern that the solution will lead to new undesirable side effects (“Yes, but...”)



# Thinking Process Tools

- offer the answers to three TOC questions about changes
- help to clear away every layers of resistance
- visualisation of the thinking process
- verbalization of the thinking process
- use of **casual logic** (cause ->effect)
- use of **sufficiency logic** - „IF - AND - THEN“
- use of **necessity logic** - „IN ORDER TO - THEN - BECAUSE“



# Thinking Process Tools

## Necessity logic

IN ORDER TO - THEN - BECAUSE



I will survive

in order to survive i must  
eat truffles

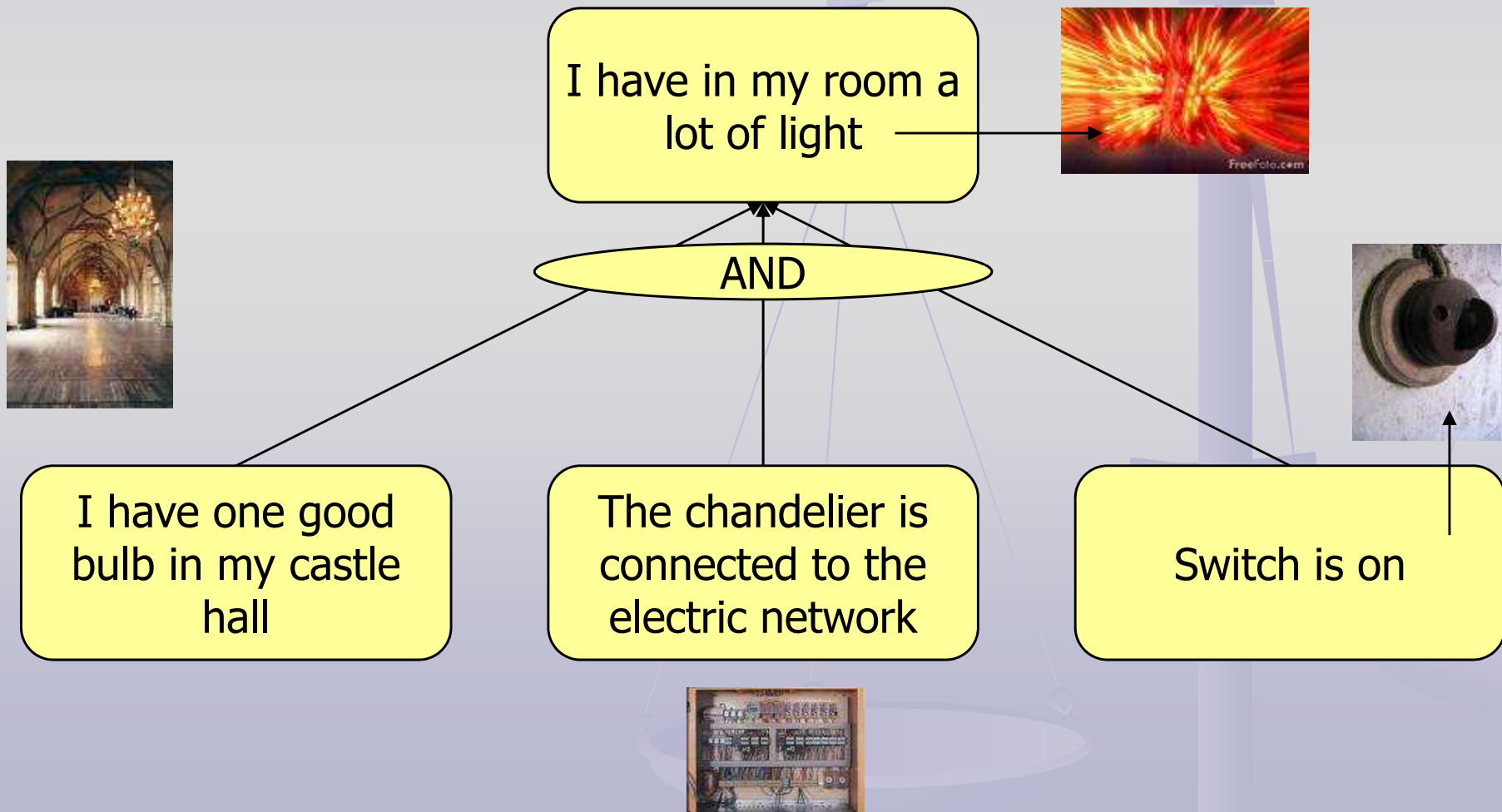
I am eating truffles  
every day



# Thinking Process Tools

## Sufficiency logic

IF - AND - THEN

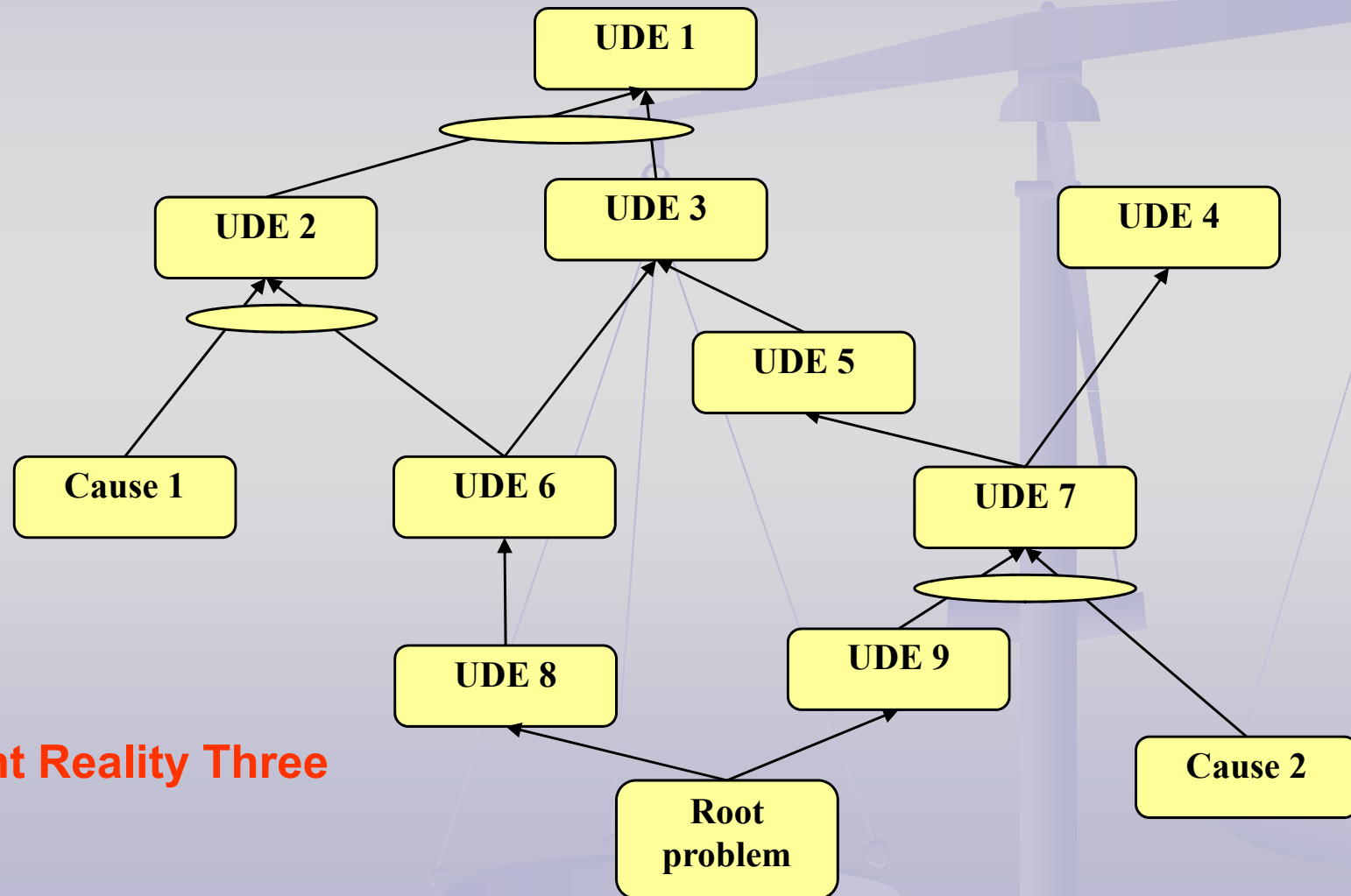


# We have to solve the crucial question: **what is a core problem** (what should be changed)

A tool for solving such a task : **Current Reality Tree**

- Why to change something and what is something (core problem=constraint, bottleneck)
- Summary of all undesirable effects (UDE) and their layout based on **casual logic - sufficiency logic**
- **Core Problem** – common cause of all UDE

We have to solve the crucial question: **what is a core problem** (what should be changed)

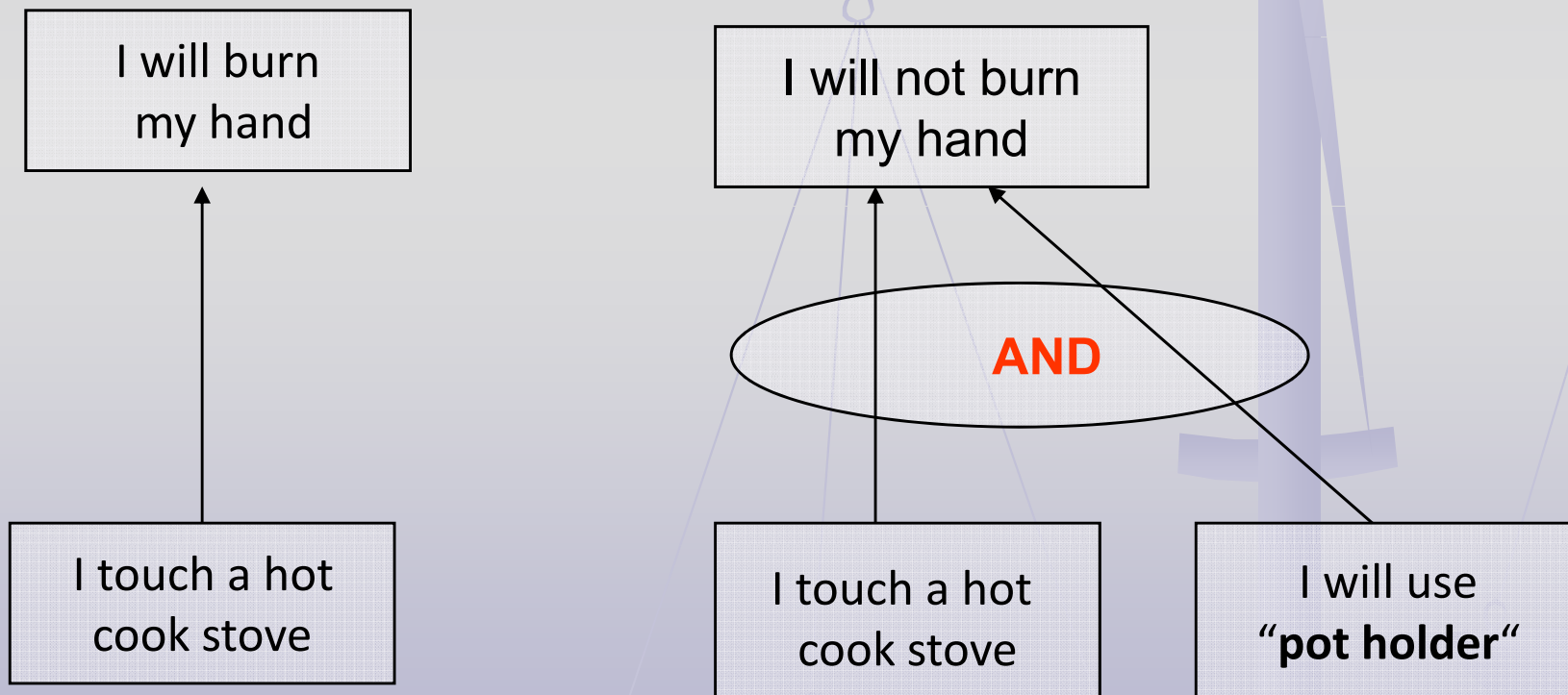


**Current Reality Three**

We have to solve the crucial question: **what is a core problem** (what should be changed)

### Causality:

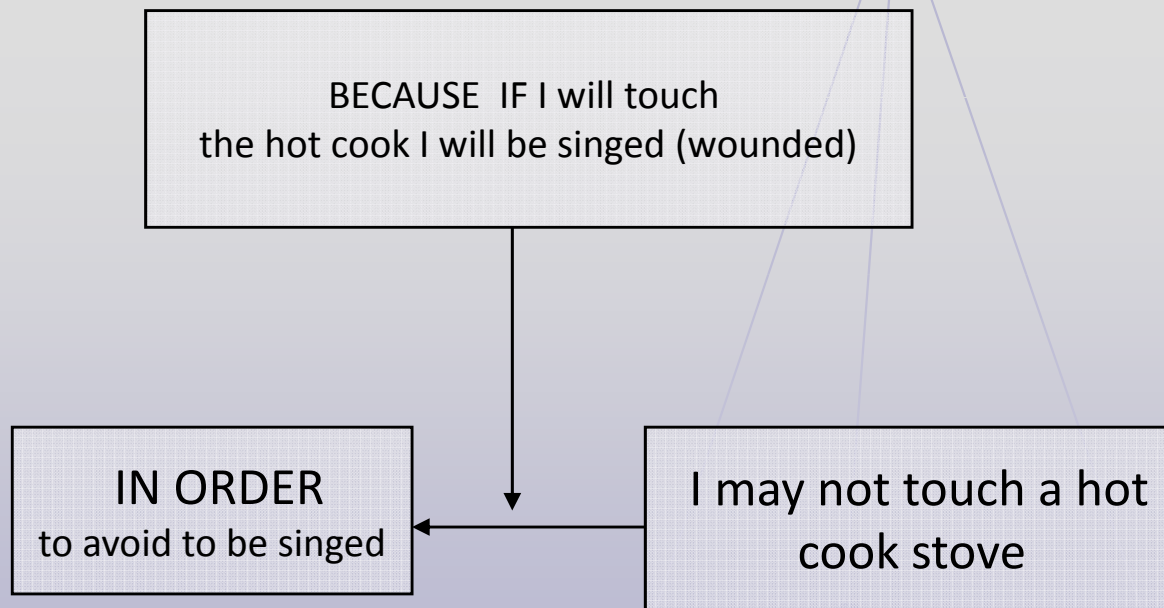
**IF** a lot of snow **AND** snowboarding in restricted area **THEN** avalanche



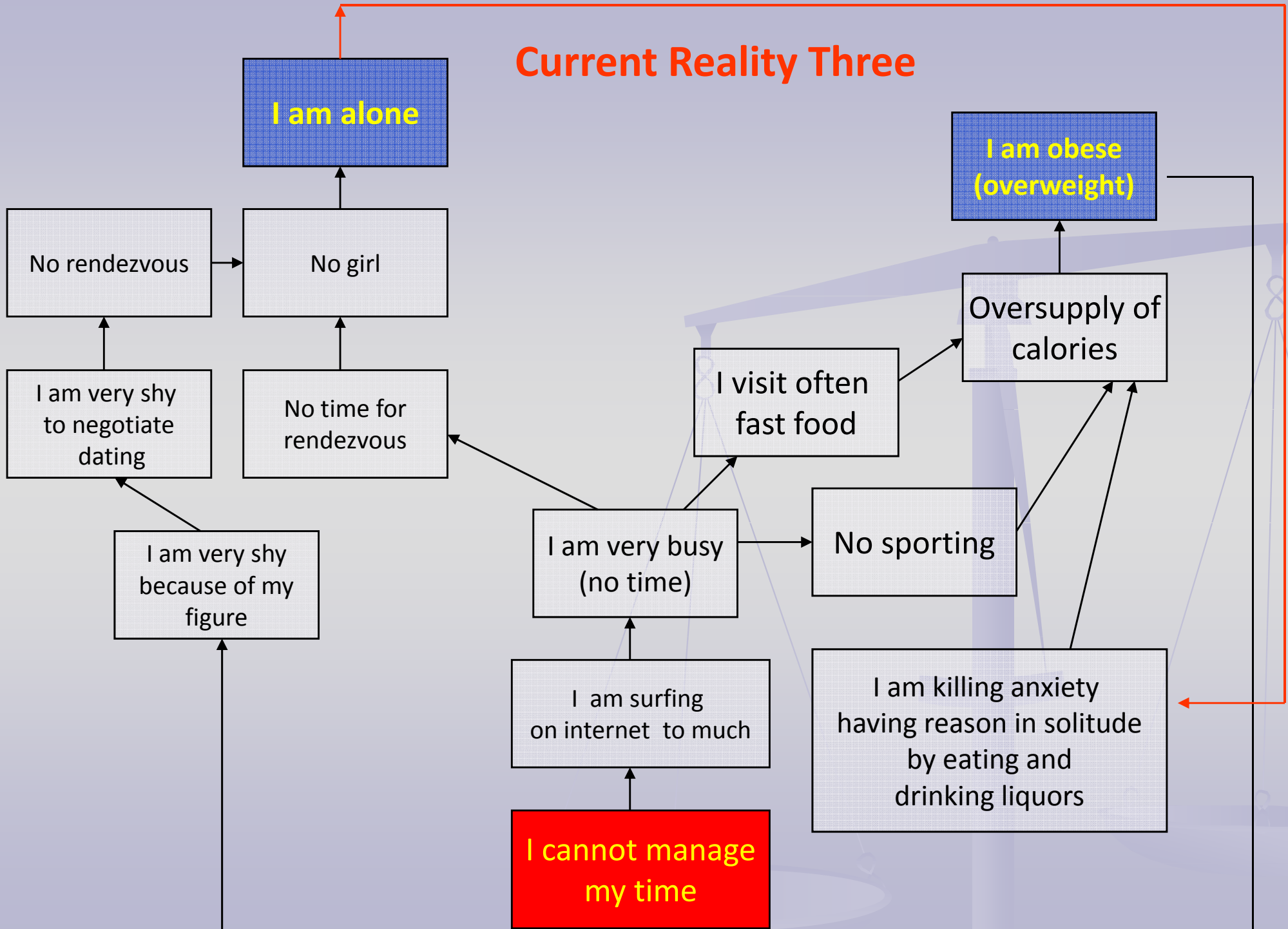
We have to solve the crucial question: **what is a core problem** (what should be changed)

### Necessity logic:

**IN ORDER** to avoid something **I HAVE TO** do this



# Current Reality Three



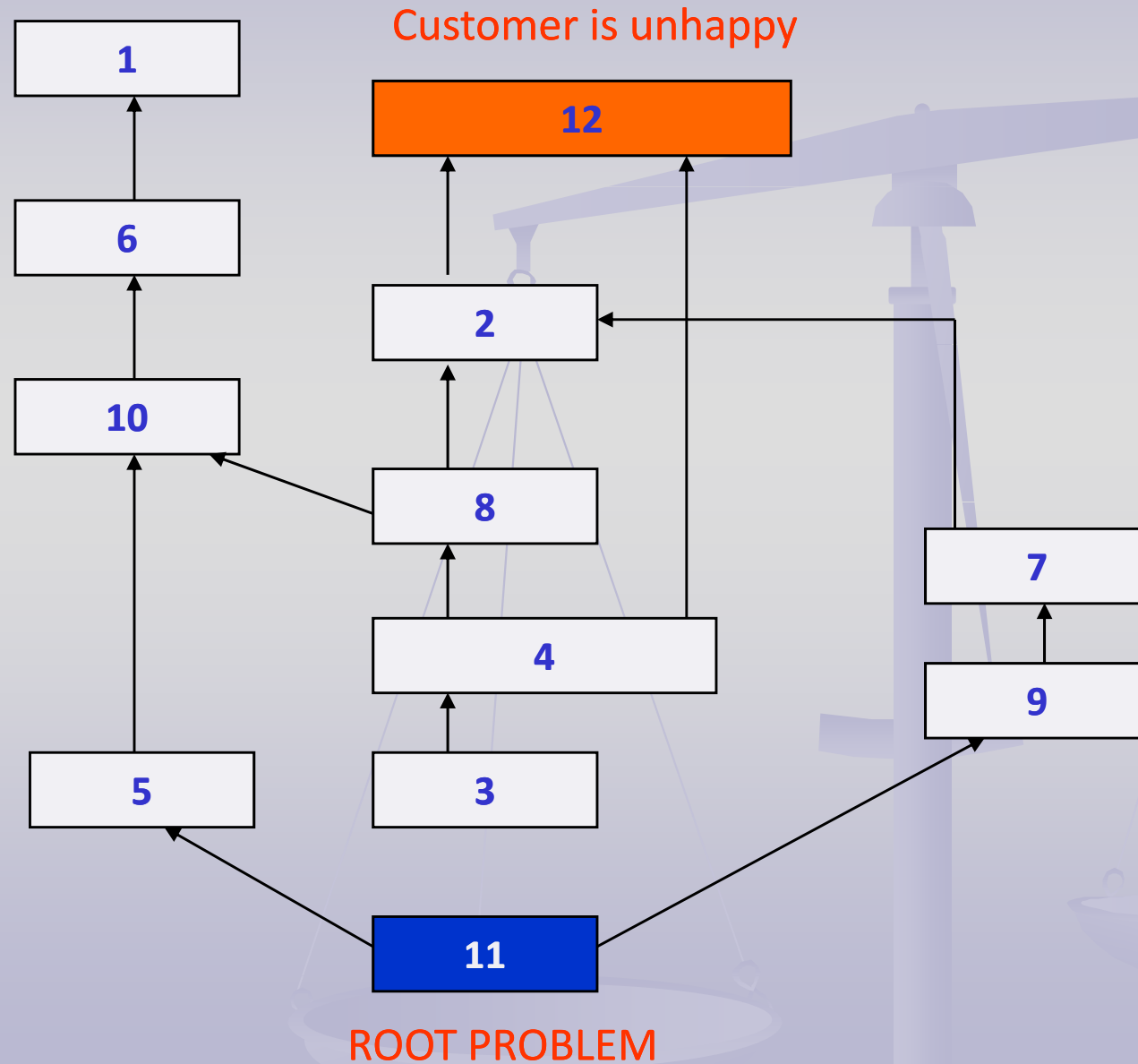
# Current reality three

## List of UDE's :

- **UDE1** : lack of financial consultants (FC)
- **UDE2** : late hand-over of required services during implementation and support
- **UDE3** : a modern design of ERP is not easily understood by rigid customer's accountants
- **UDE4** : the customer's accountants tend to use old fashioned methods and processes which are difficult to manage by using a modern ERP
- **UDE5** : rigid remuneration does not allow to pay more FC than the others
- **UDE6** : high level of fluctuation and job-hopping
- **UDE7** : overburdened FC as a consequence of bad multitasking (will be explained later in Critical Chain PWP)
- **UDE8** : FC are fed up by permanent repetitive explanation to the customer's accountants who do not want to understand
- **UDE9** : bad multitasking
- **UDE10** : FC are unhappy because of a salary, which is much more lower than their expectations
- **UDE11** : The management sticks to Cost world and tend to decrease costs by minimising payroll and having all resources as a CCR (Critical Constraint Resources)
- **UDE12** : Customer is unhappy



# Current reality three



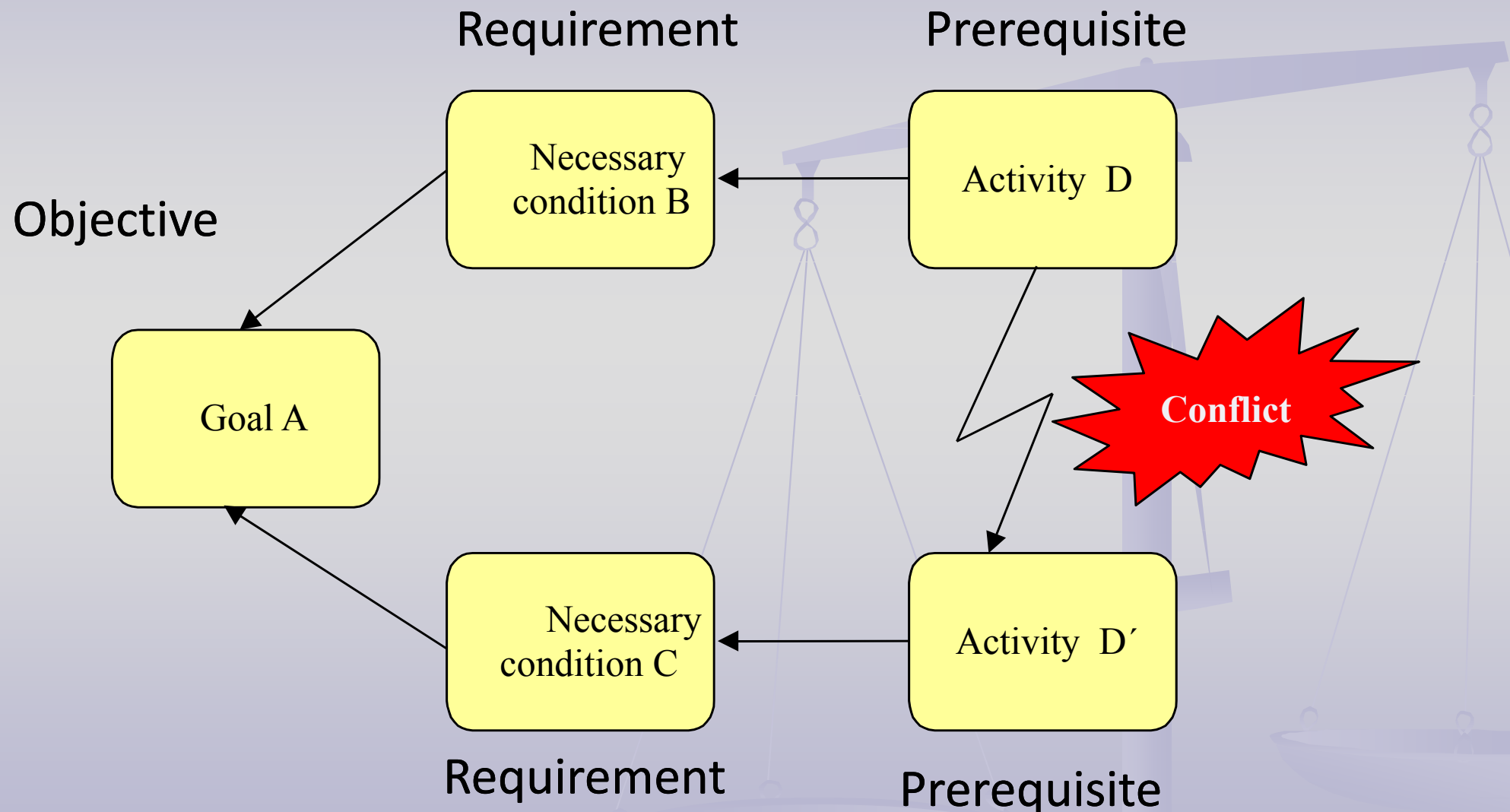
# We have to solve another crucial question: the direction of solving **a core problem**

(what is the main reason (injection) supporting the change)

## Evaporating Cloud Tree

- the change without any compromise - basic and starting impulse for the change
- use of „**necessity logic**“ – common goal, necessary condition to reach this goals, what have to be done and where is a conflict
- „**well thought out from the scratch**“ of the problem, disclosure and verbal definition of hidden assumptions
- Win-win solution of the whole conflict = **injection**

# We have to solve another crucial question: the direction of solving a core problem



Evaporating Cloud tree ( a conflict tree, a conflict resolution diagram)

# How to read this Evaporation tree

In order to have objective A, we must have requirement B..

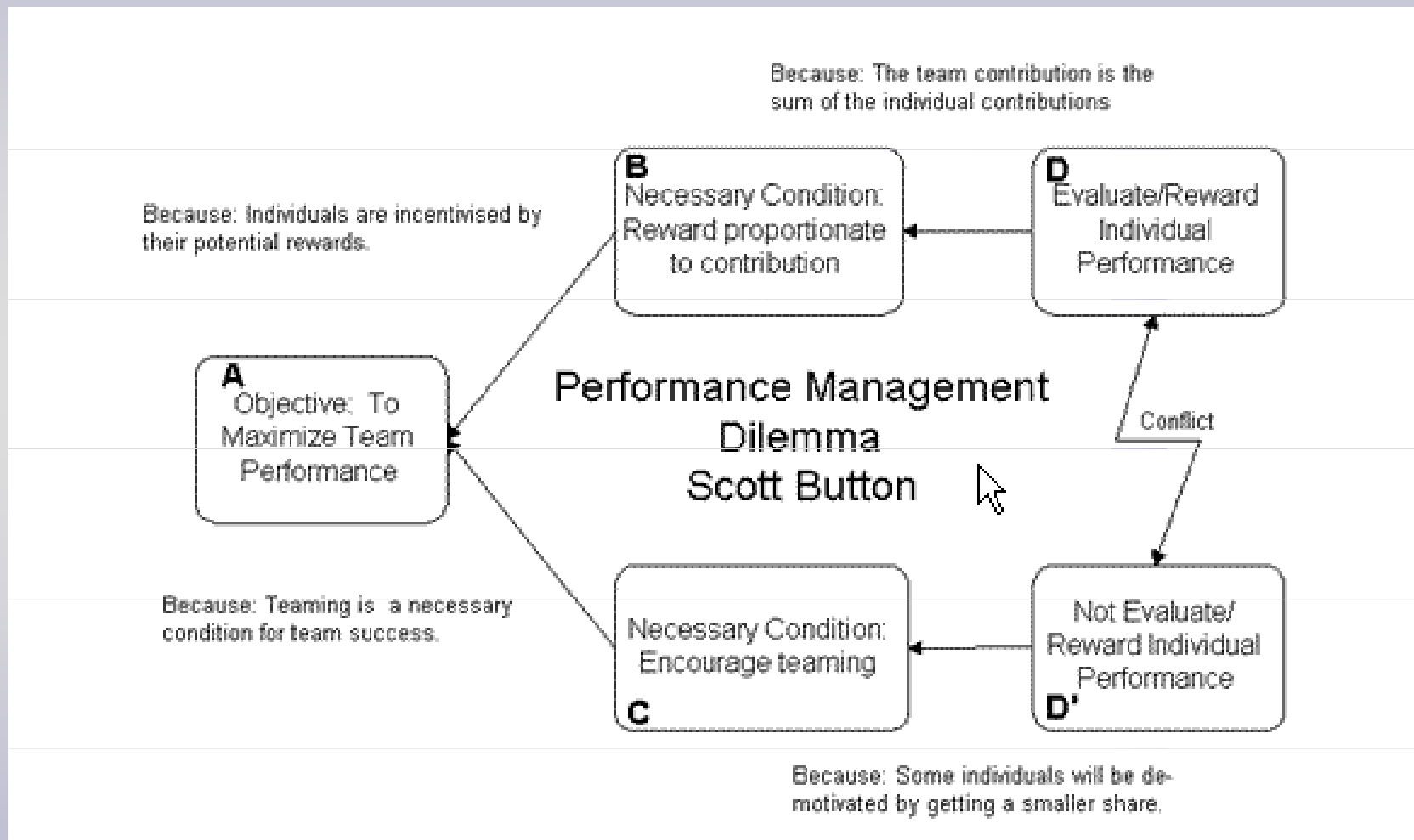
In order to have requirement B, we must have prerequisite D...

In order to have objective A, we must have requirement C...

In order to have requirement C, we must have prerequisite D'...

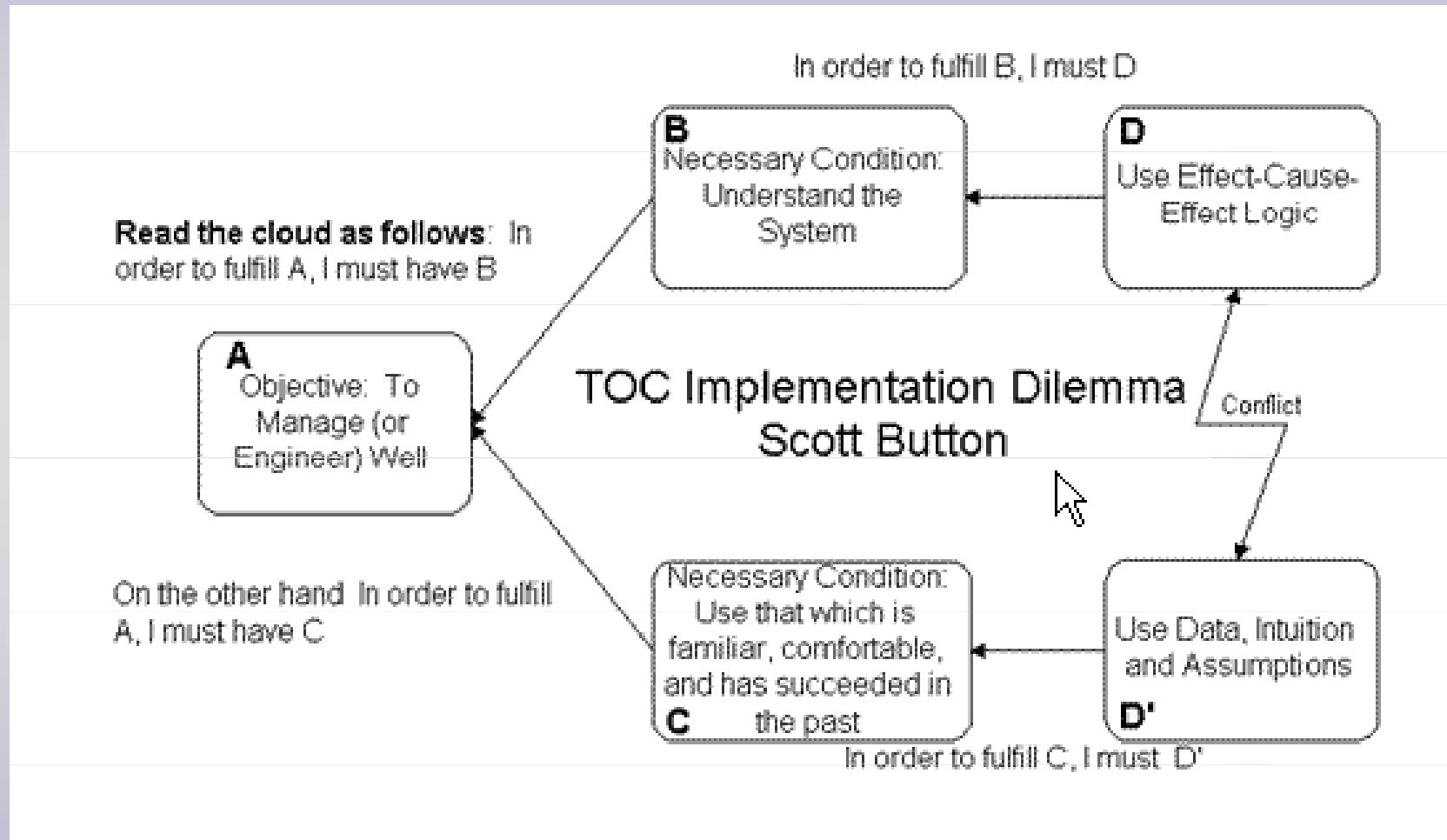
**But prerequisites D and D' are in conflict...**

# Evaporation cloud tree- example 1



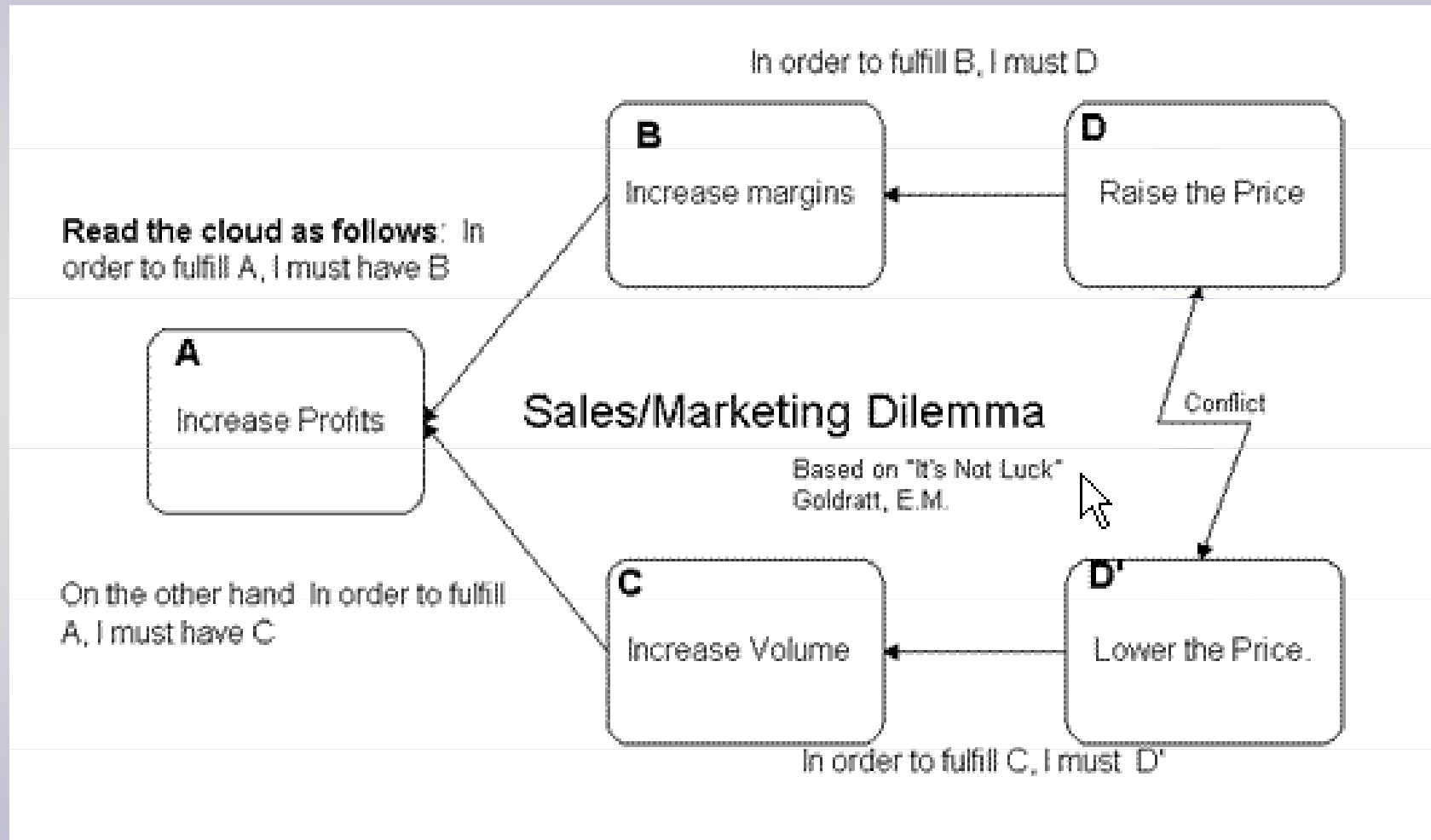
Performance Management

# Evaporation cloud tree- example 2



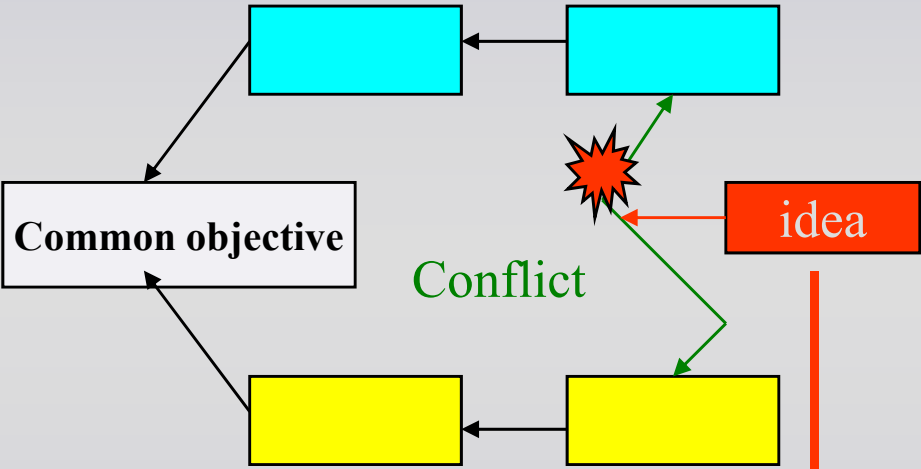
## Implementation of TOC

# Evaporation cloud tree- example 3

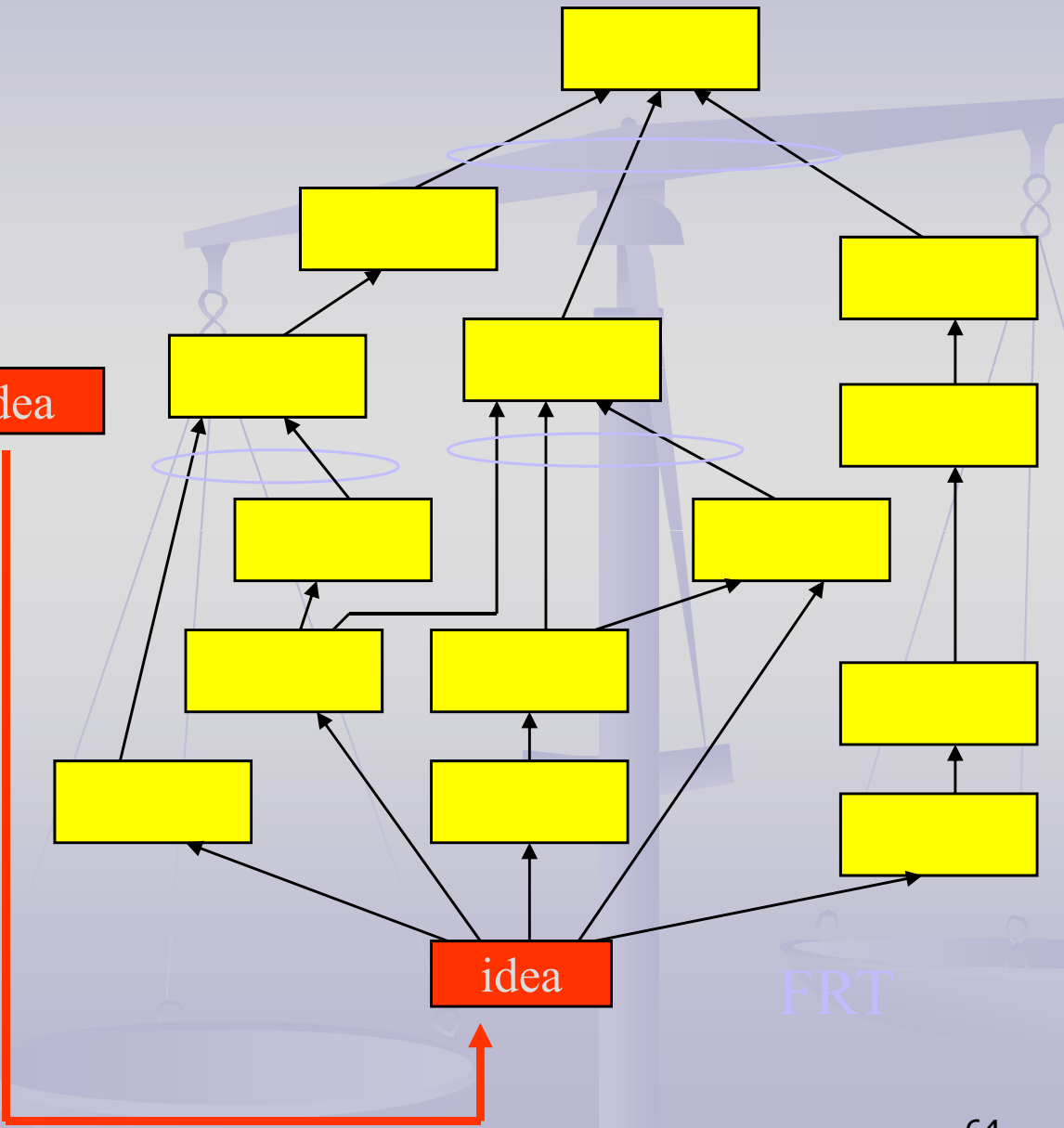


Sales and prices

# Transition Evaporation Cloud Tree Future Reality Tree (FRT)



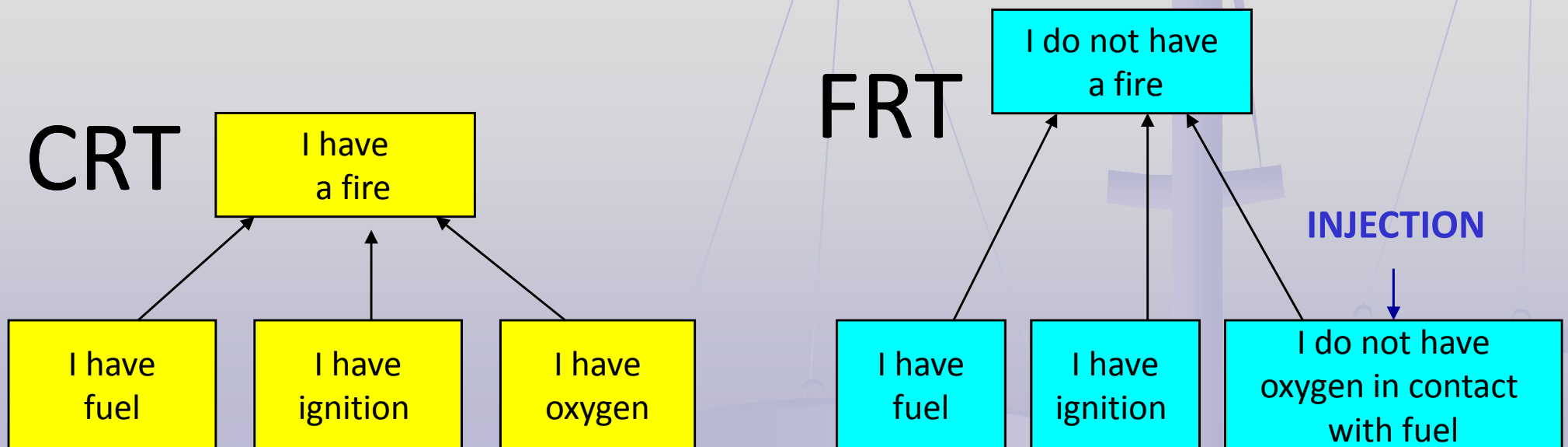
Evaporation Cloud Tree





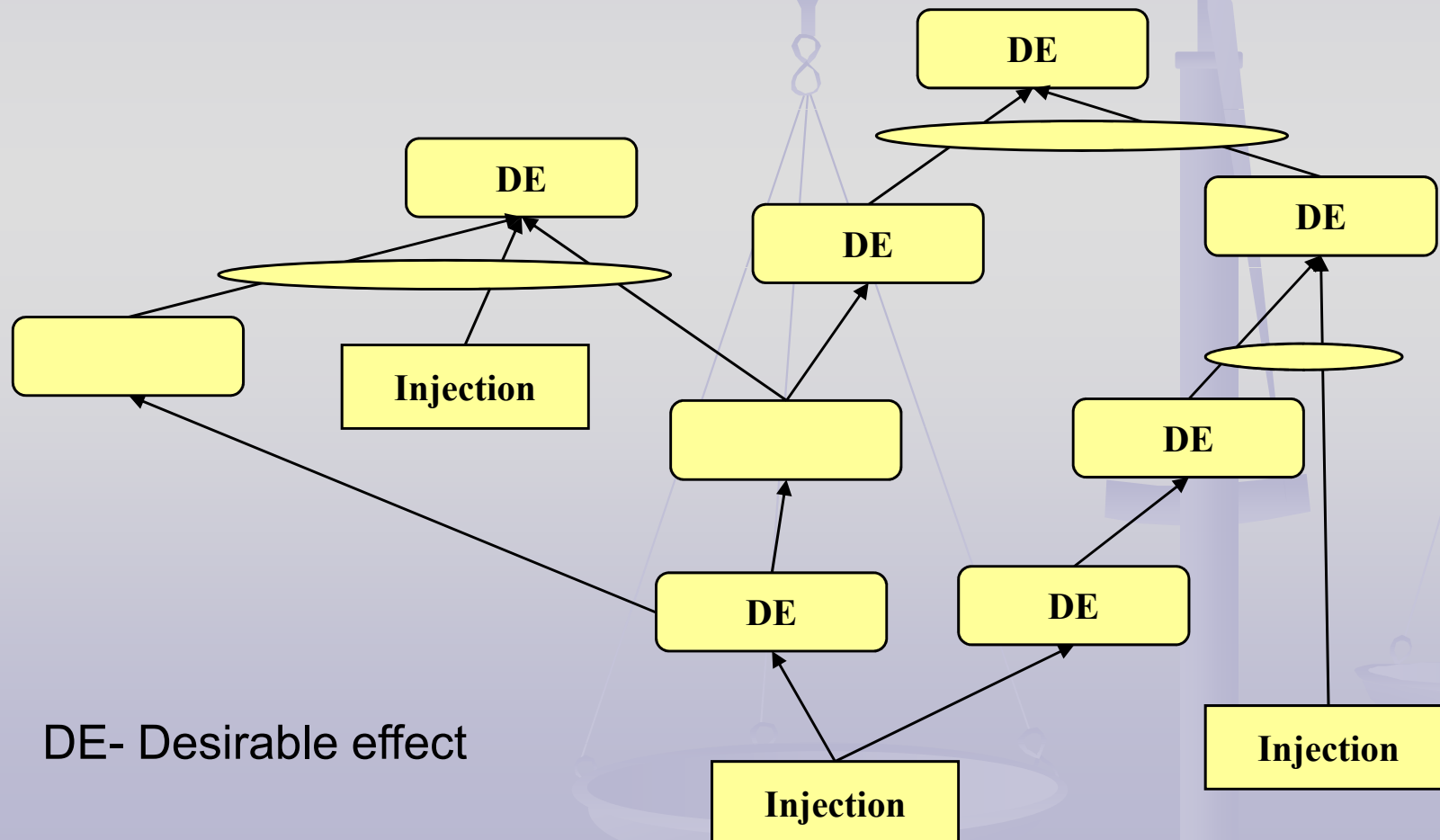
# Future Reality Tree (FRT)

- The FRT **is similar** to the CRT in structure, but with new proposed actions, policies, and behaviour injected into it in order to create a new vision of the future reality of the system.
- The power of the logical **"if-then"** construction is that if any one of the lower-level causes are removed or mitigated, everything that is above it is subject to change.
- If any one of the three „IFs“ are removed or modified, the „THEN“ may be removed from consideration as a problem

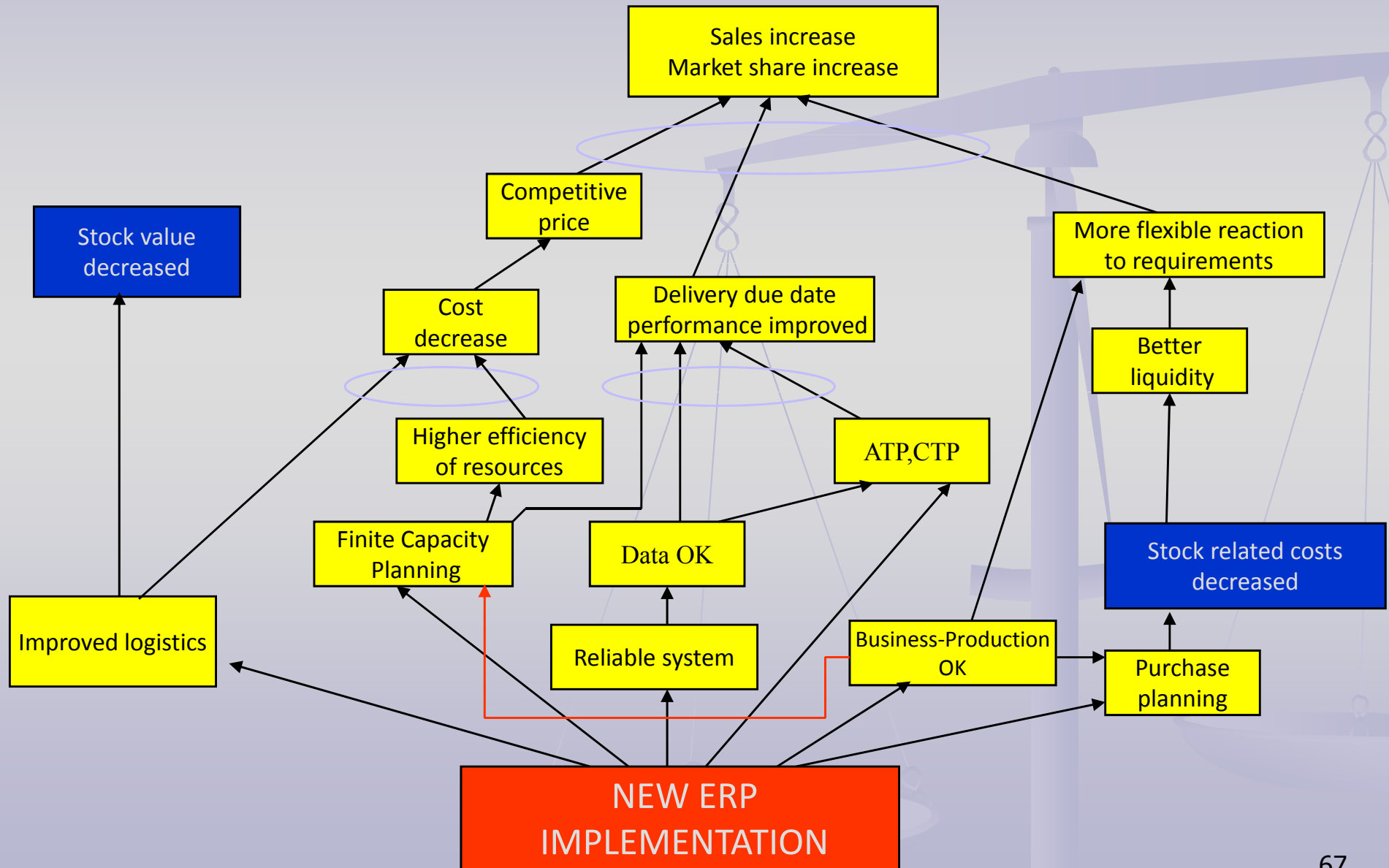


# Future Reality Tree (FRT)

- The objective of the FRT is to communicate a vision of how to change the undesirable effects found in the CRT to desirable effects.



# Future Reality Tree (FRT)

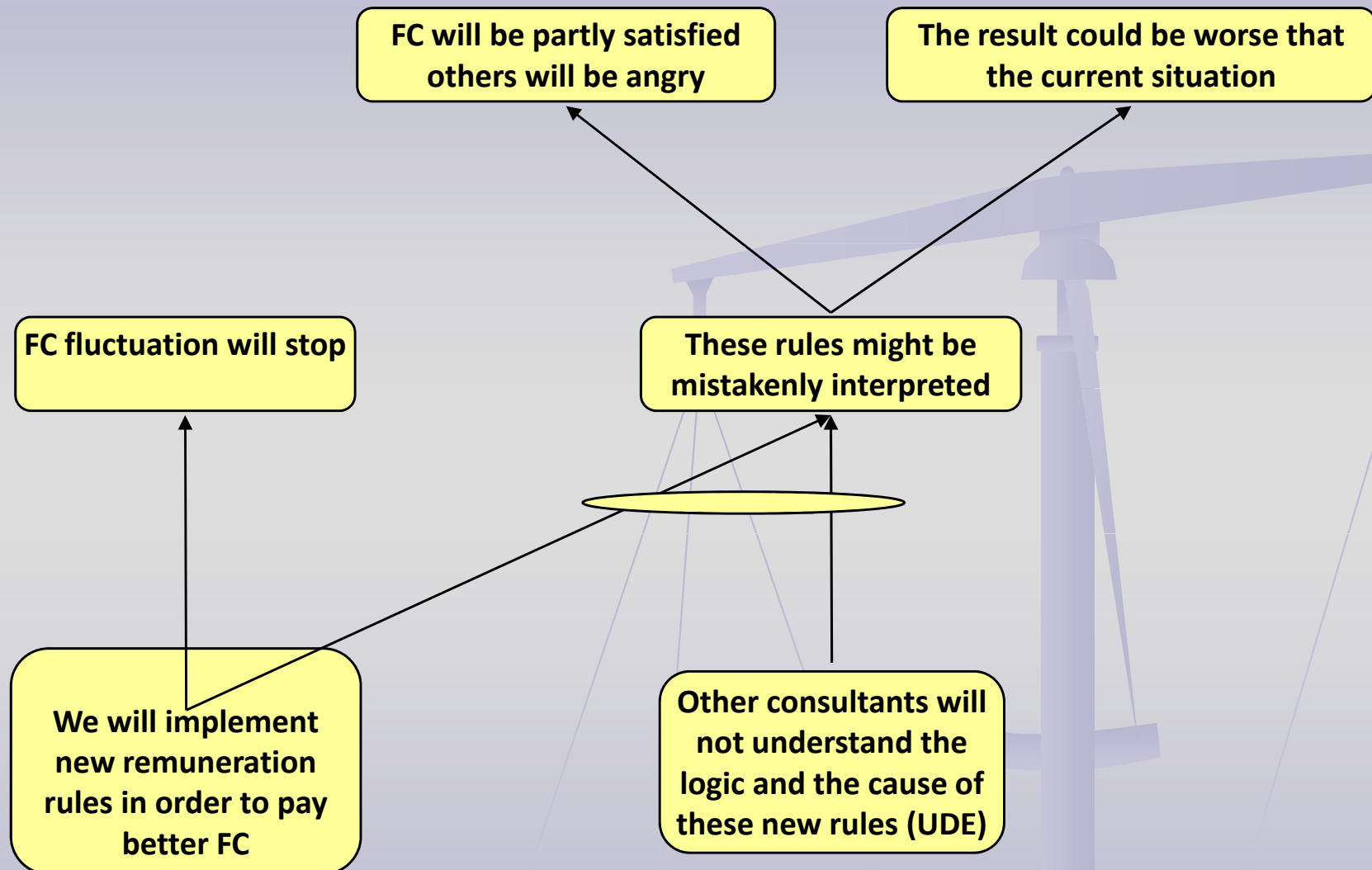


**YES, this could be managed BUT.....**

## Negative Branch Reservations (NBR):

- use of **sufficiency logic** – by taking into consideration objections of other involved persons
- these objections were related to possible undesirable impacts of the injection implementation
- **NBR** is often a part of **FRT**
- Evaporation Cloud Tree, FRT and NBR enable to answer the second question : **To What To change ?**

# YES, this could be managed **BUT**.....



**Negative Branch Reservations**

**We cannot implement it, because . . . .**

(Prerequisite Tree):

- use of necessity logic – identification of obstacles
- use of the human ability to invent any reason

**WHY IT IS NOT FEASIBLE**

- setup of the necessary intermediate objectives
- setup of the schedule for change process

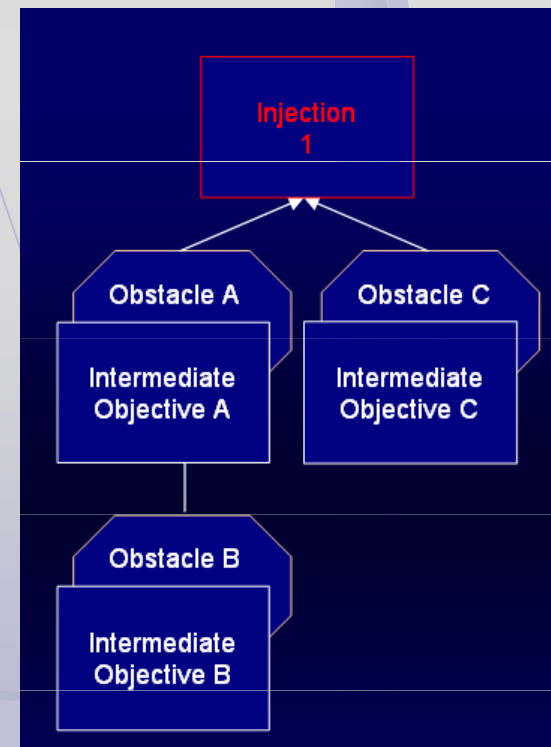
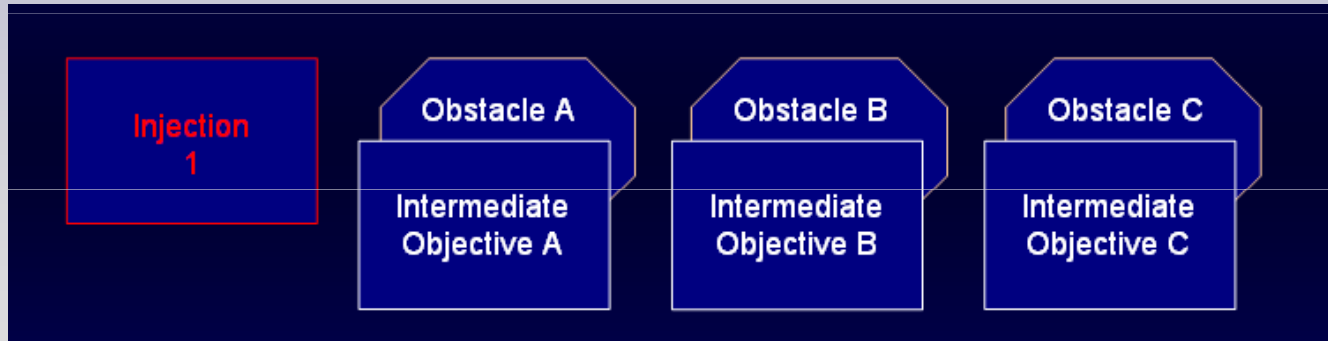
# We cannot implement it, because . . . .

## (Prerequisite Tree):

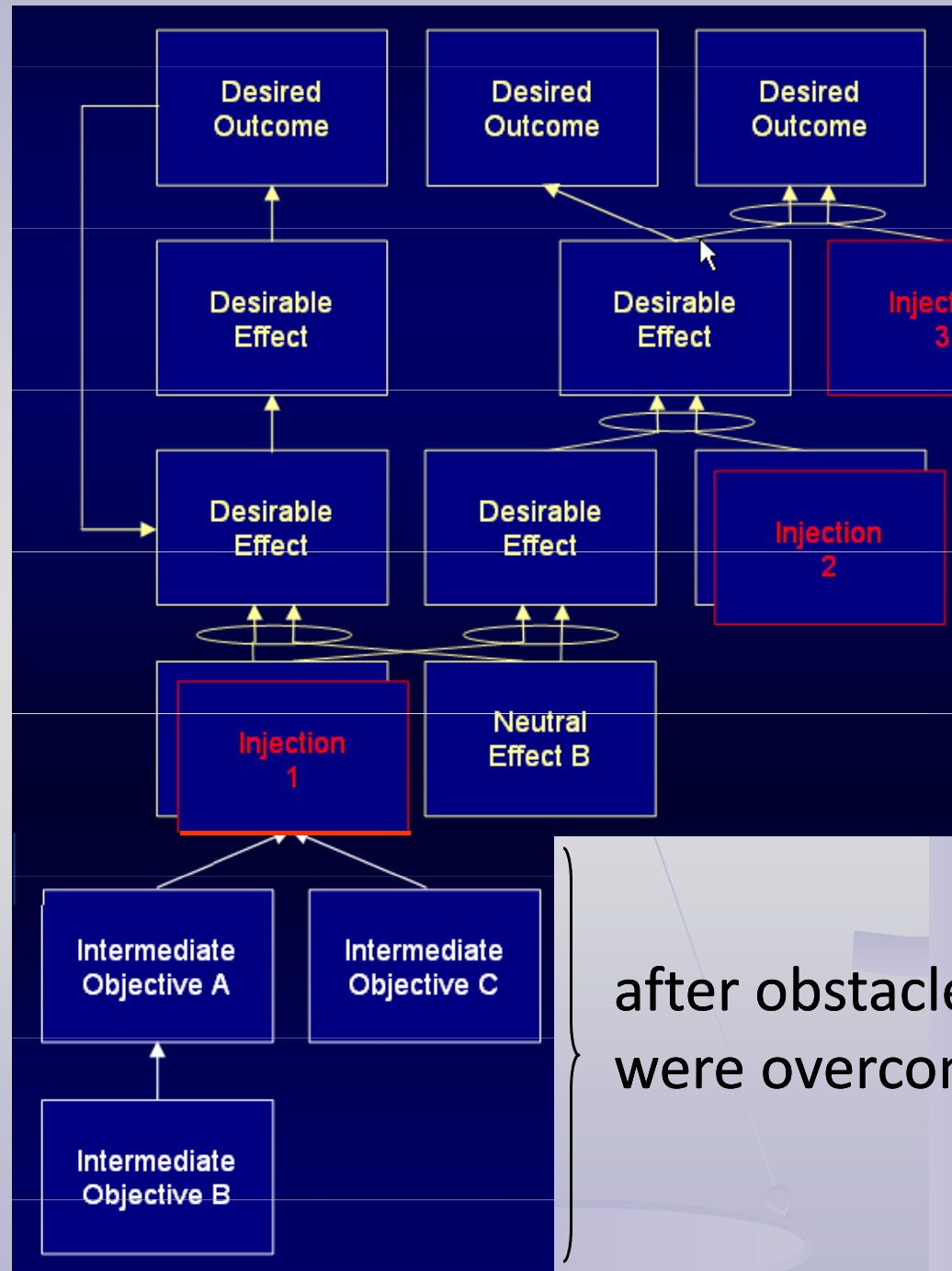
- The pre-requisite tree ought to be considered the most important tree in the **Thinking Process** suite.
- It is the tree that allows us to overcome the obstacles that stop us from implementing our plan.
- It is also the tree that in fact becomes the implementation plan. And it is the tree to which timelines, responsibilities, and accountabilities can be assigned to. It is also the tree that I have most often seen skimmed over.
- There is an English saying that you can plan to fail, or you can fail to plan. The pre-requisite tree occupies the position of “plan” amongst the Thinking Process tools.

# Prerequisite tree - construction

So our first step will look like this



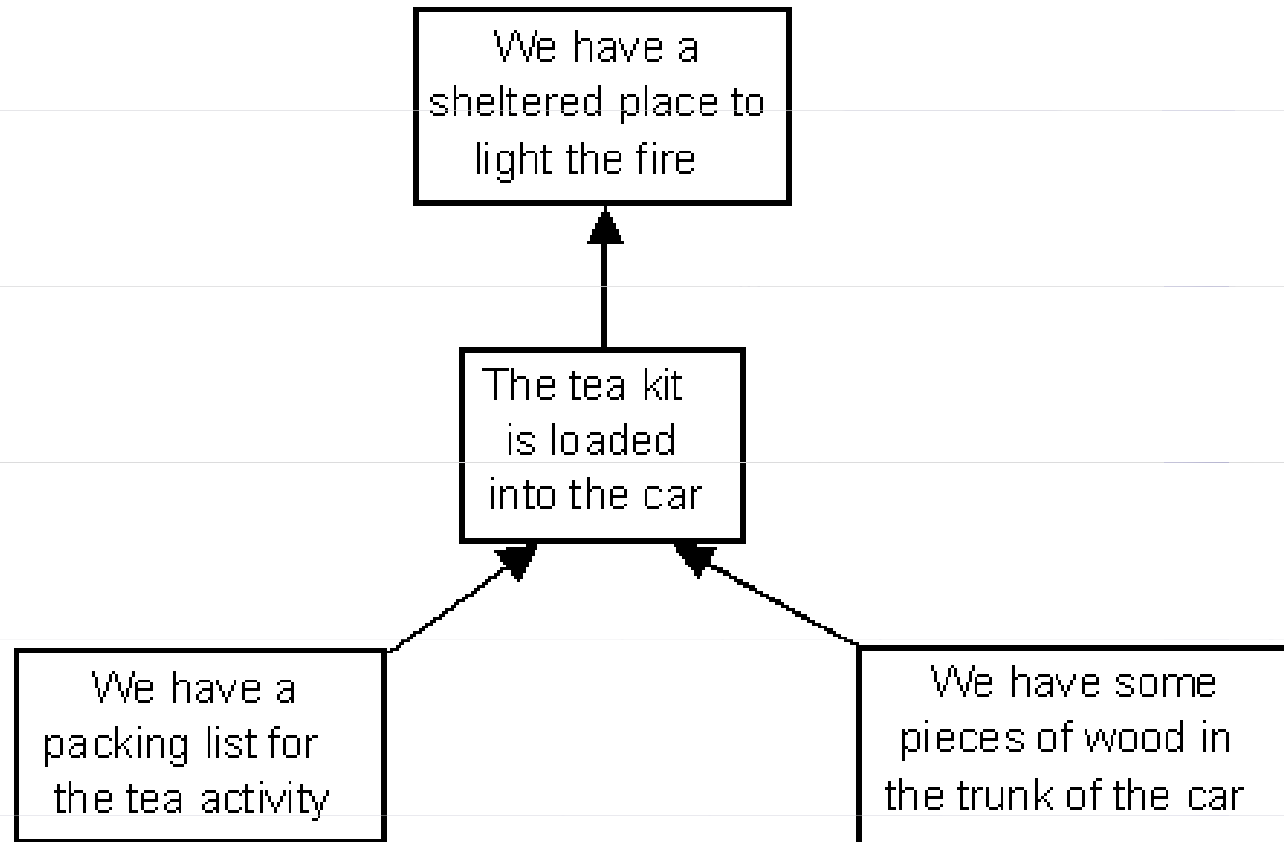




# Prerequisite tree - example

- **Tea Mission** (we want to have a nice cup of tea in the wilderness)
- **Obs-1** : We do not have material to burn
- **Obs-2** : Collection of such material is not allowed in the wilderness.
- **Obs-3** : There could be a strong wind
- **Obs-4** : We do not have matches
- **Obs-5** : We do not have cups
- **Obs-6** : We don't have a container to boil the water
- **IO-1** : We have some pieces of wood in the trunk of the car.
- **IO-3** : We have a sheltered place to light the fire
- **IO-4.1** : We have a packing list for the tea activity
- **IO-4.2** : The tea kit is loaded into the car

# Prerequisite tree - example



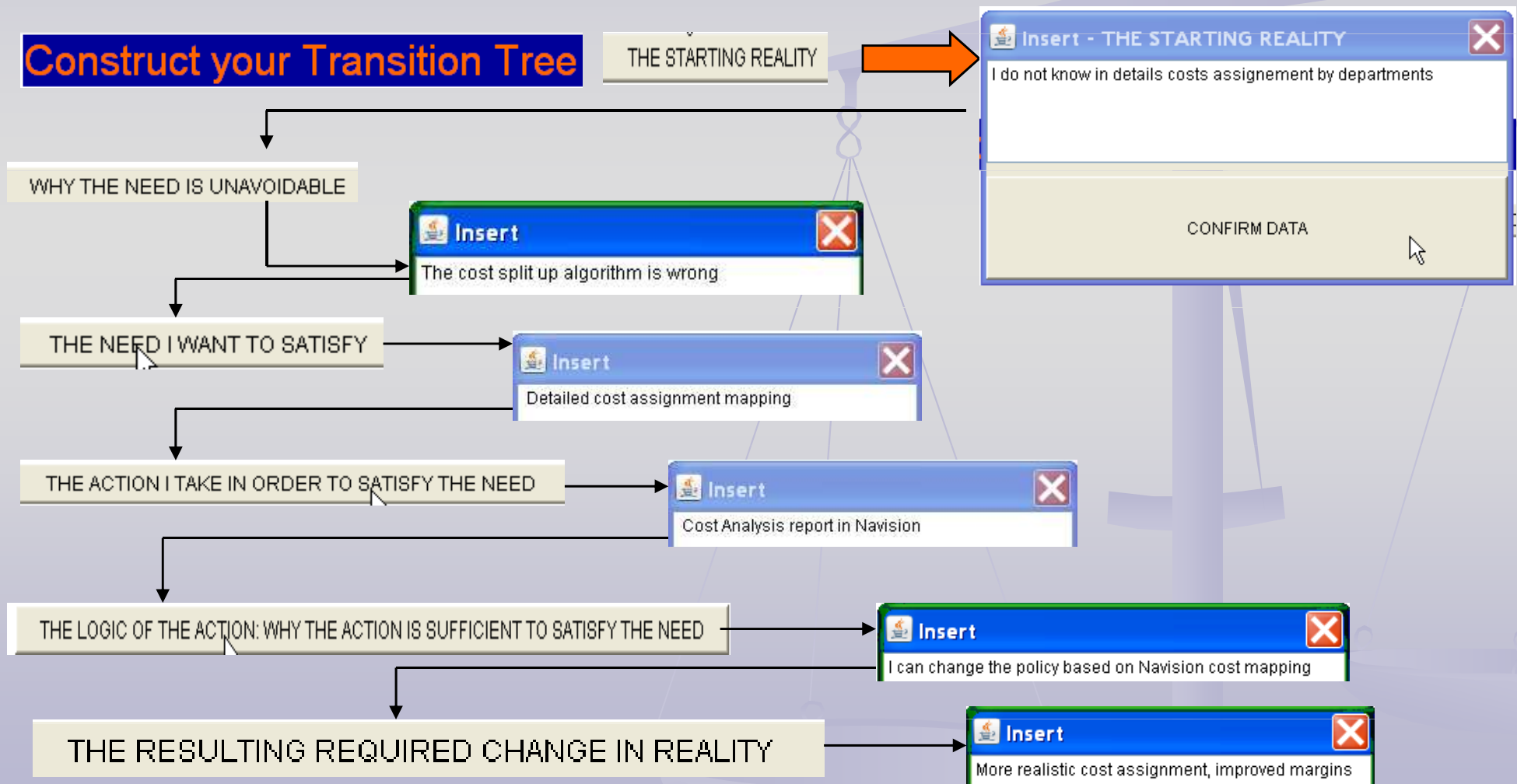
**We cannot implement it, because . . . .**

(Transition Tree):

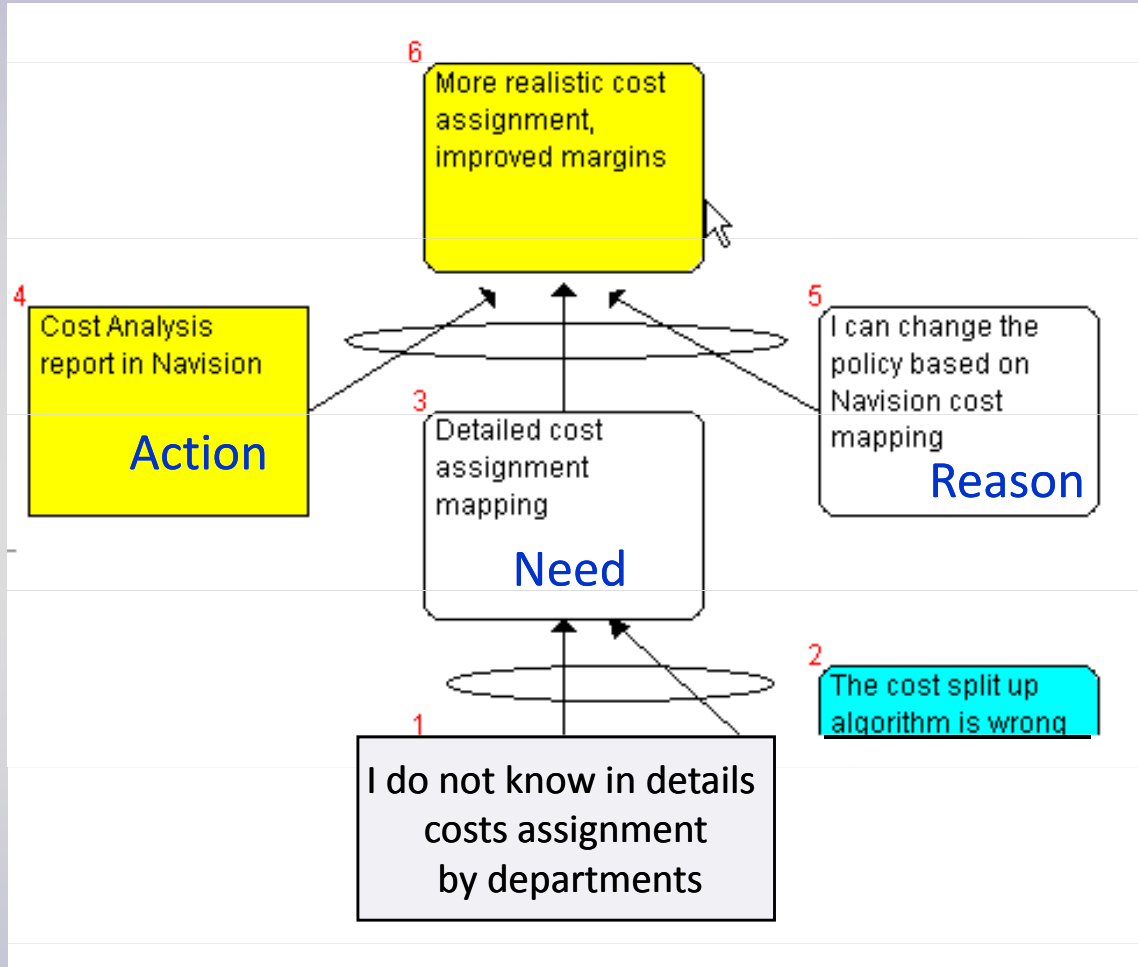
- detailed schedule of change implementation process
- what actions have to be taken in order to reach intermediate objectives using sufficiency logic (IF-THEN-ELSE)

# We cannot implement it, because.....

(Transition Tree) <http://www.thedecalogue.com/Tools/trt/TREE.html>:

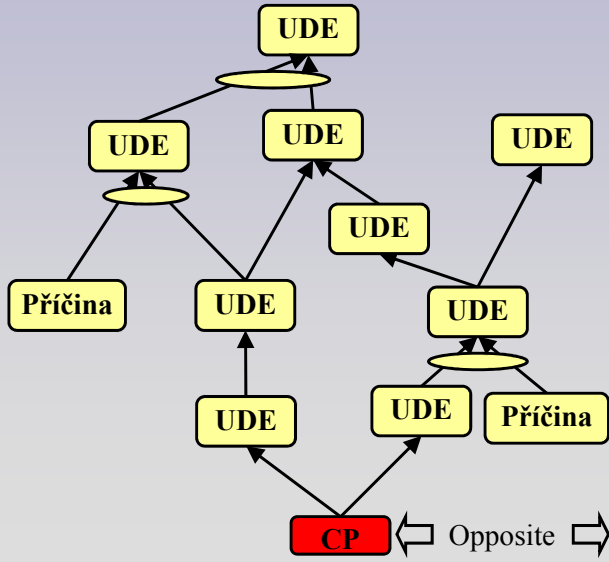


# We cannot implement it, because.....

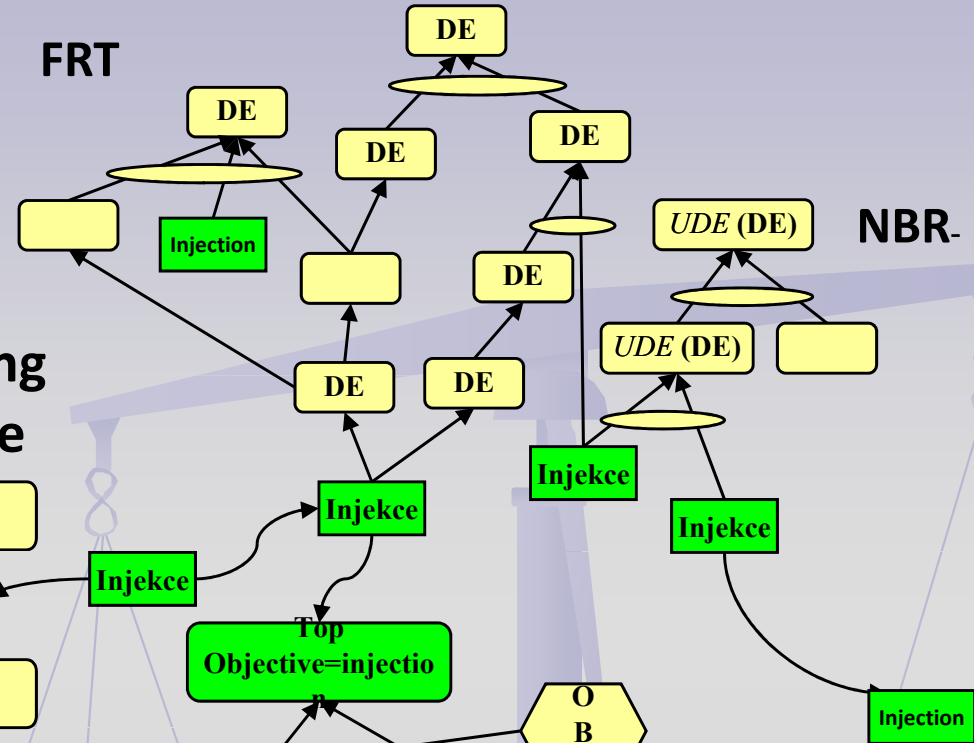


# Thinking Process Tools Relationships

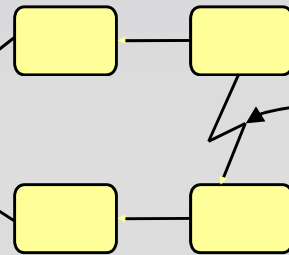
CRT



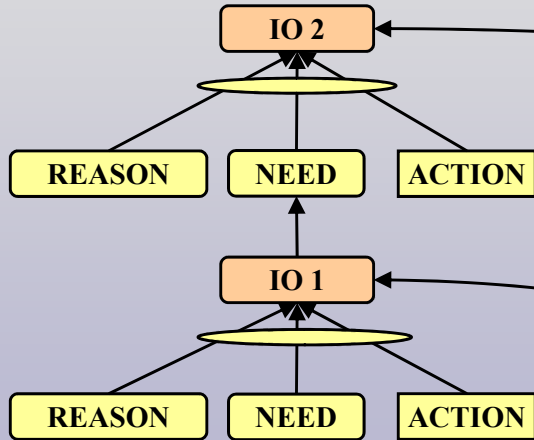
FRT



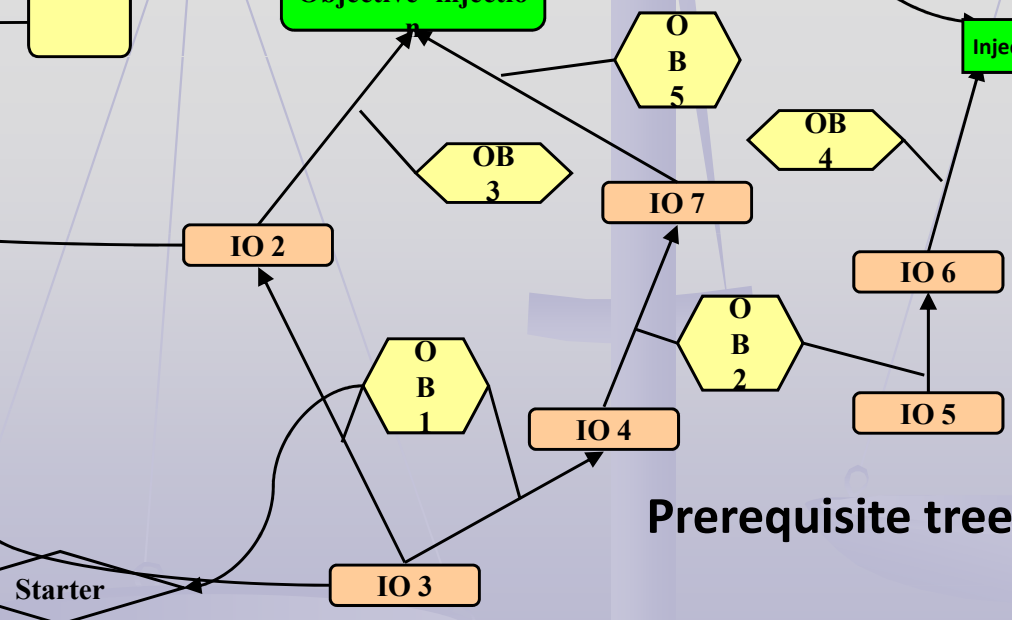
Evaporating cloud tree



TT



Prerequisite tree



# Additional metrics of TOC (appendix 1)

- **Inventory dollar days (IDD)**
- A measure of the effectiveness of a supply chain – i.e., did it do things that it shouldn't have done and as a result is the supply chain holding inventory of products the customer doesn't want? IDD accounts for two things: 1. the time from when a unit is placed in stock until it is actually needed by a customer; and, 2. the monetary value of the inventory being held. IDD is calculated by multiplying the monetary value of each inventory unit on hand by the number of days since that inventory entered the responsibility of that link. The system should strive for the minimum IDD necessary to reliability maintain zero throughput dollar days.
- NOTE: The resulting unit of measure is "dollar-days". It is neither monetary nor time based. Attempts to compare dollar-days to other monetary measures are invalid. IDD's can be compared only to other IDD levels.



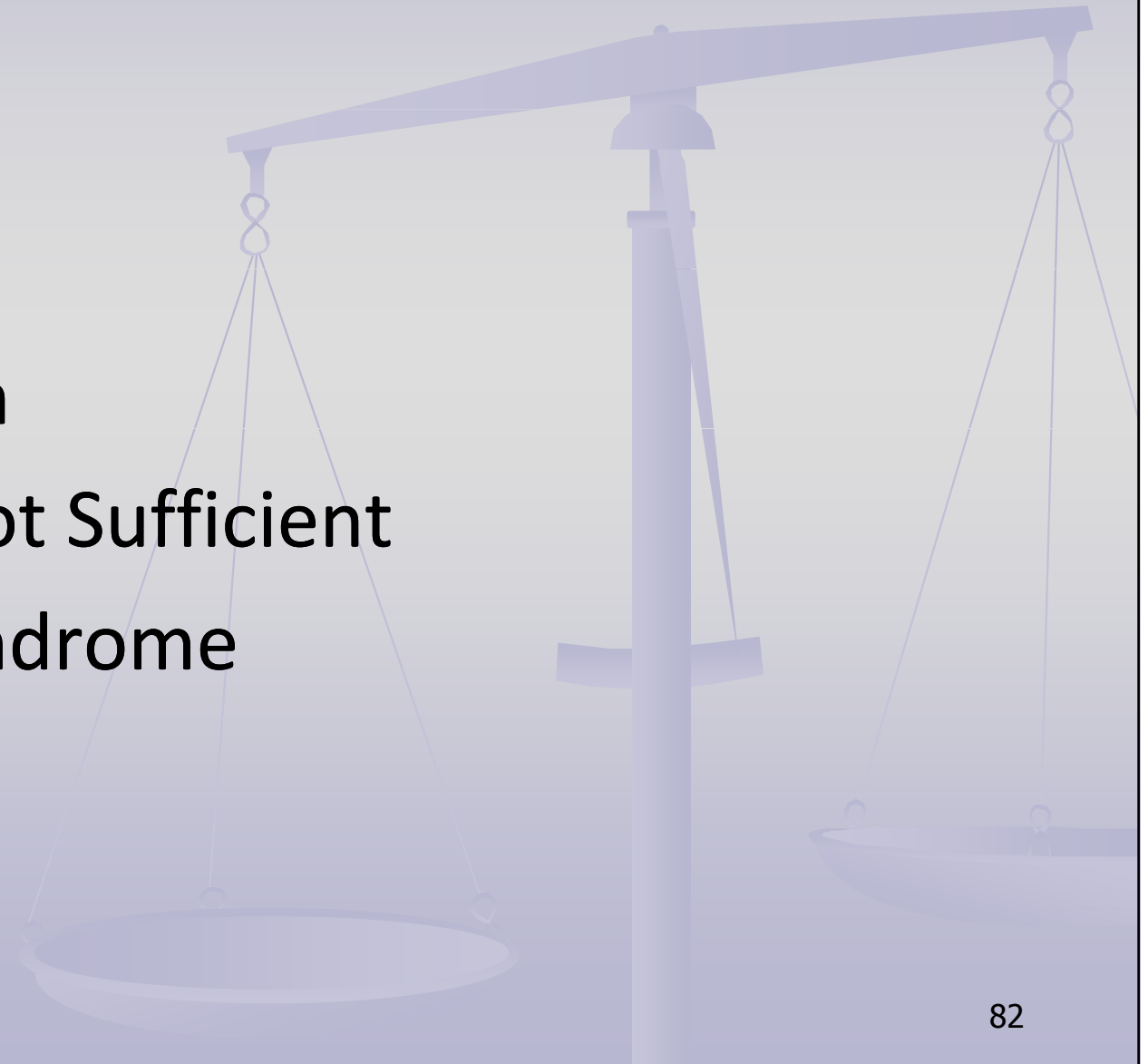
# Additional metrics of TOC (appendix 2)

- **Throughput dollar days (TDD)**
- A measure of the reliability of a supply chain. TDD considers two things: 1. the monetary value of the things a link is committed to deliver but does not; and, 2. the number of days by which the link misses its commitment to deliver. TDD is the summation of the commitments not delivered on time during the chosen time period. The TDD value of individual missed commitments is calculated by multiplying the dollar value of the end product times the number of days the commitment is/was overdue. The system should strive for zero throughput dollar-days.
- NOTE: The unit of measure "dollar-days" is neither monetary nor time based. Attempts to compare dollar-days to other monetary measures are invalid. TDD levels can be compared only to other TDD levels.

# Literature

## Goldratt, E., M.:

- The Goal
- The Race
- The Critical Chain
- Necessary But Not Sufficient
- The Haystack Syndrome
- It is Not Luck



# Internet

- [www.goldratt.cz](http://www.goldratt.cz)
- [www.goldratt.com](http://www.goldratt.com)
- [www.toc-goldratt.com](http://www.toc-goldratt.com)
- [www.focusedperformance.com](http://www.focusedperformance.com)
- [www.tocc.com](http://www.tocc.com)
- [www.tocca.com.au](http://www.tocca.com.au)
- [www.ciras.iastate.edu/toc/](http://www.ciras.iastate.edu/toc/)
- <http://www.ciras.iastate.edu/library/toc/measurements.asp>
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