Simulation Team

Modeling & Design of Complex System

Liophant Simulation

M&S Net

McLeod Institute of Technology and Interoperable M&S Genoa Center

Agostino G. Bruzzone

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www.itim.unige.it/cs/strategos/edu/complexsystems

DIPTEM
University of Genoa

Simulation Team

Who's Who
Agostino G.Bruzzone

- Basic Engineering Studies in Italian Naval Academy, Pisa and Genoa University
- Mechanical Engineer
- Expert in Modelling & Simulation, Project Management, Operation Management, AI & IA, Industrial Plants &Logistics
- Expertise as Freelance Consultant for Industries, Companies, Ports, etc.
- Experience in Projects with Major Companies (i.e. IBM, LMC, Boeing, FCA, Ansaldo, Leonardo, Solvay) & Agencies (i.e. EDA, NASA, NATO, DGA, DoD, Navy, etc.).
- Full Professor in DIME, University of Genoa
- Visiting Professor in Several Universities in North & Latin America, Europe, Australia, Africa and Asia
- World Director of the M&S Net (34 Centers worldwide) & Director of McLeod Institute of Simulation Science Genoa
- Founder & former Leader of the Simulation Program of the NATO STO CMRE
- Project and Program Manager in R&D Initiatives & Joint Ventures with Industries & Agencies for several MUSD along last years
- Director of the Master Program in Industrial Plants & MSc STRATEGOS in Strategic Engineering of Genoa University
- President of Liophant and Simulation Team
- General Chair of major conferences (e.g.I3M)

Simulation Team
www.simulationteam.com

Strategy & Challenges

www.itim.unige.it/strategos

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STRATEGOS:
Master Science in Engineering

A new Educational Degree in Engineering Technologies for Strategy in Defense, Industry, Government & Homeland Security in Companies

- **STRATEGOS** is the new International MSc (Master Science) in Strategic Engineering (Laurea Magistrale in Italia, 2 anni)
- **STRATEGOS** promotes Quantitative Modeling to Support Decisions by developing a new generation of Engineers able to deal with Strategic Thinking & Decision Makers
- **STRATEGOS** prepares Engineers for Decision Making providing strong foundation in Modeling, Simulation, Scenario Analysis as well as in Enabling Technologies

DITEN

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STRATEGOS: ***the International MSc in Engineering Technology for Strategy & Security***

夫未戰而廟算勝者，得算多也；
未戰而廟算不勝者，得算少也；
多算勝，少算不勝，而況於無算乎？
吾以此觀之， 勝負見矣。

STRATEGOS…

…wins battles by making many calculations in his temple ere the battle is fought, while the general who loses makes few calculations beforehand

Sun Tzu, Art of War, Laying Plans, 7, 500 B.C.

STRATEGOS…

ἡ Στρατηγία κάλλιστα προμηθεῖται τά
τε ἄλλα καὶ περὶ τὸ μέλλον ἔσεσθαι,
οὐδὲ τῇ μαντικῇ οἴεται δεῖν ὑπηρετεῖν
ἀλλὰ ἄρχειν, ὡς εἰδυῖα κάλλιον τὰ περὶ
τὸν πόλεμον καὶ γιγνόμενα καὶ γενησόμενα

…is able in the Art to Know better what is Happening or is Likely to Happen

Socrates in Laches, 198 E, 423 B.C.

Loosely Translated

Quisque Faber suae Fortunae

STRATEGOS...

… is artifex of his own fortune

Appius Claudius Caecus, 279BC

Loosely Translated

STRATEGOS...

Hanc not reprimere,
sed augere
Strategi debend

...don't have to repress people, but strengthen them

Gaius Iulius Caesar, De Bello Civili, III-92, 48 B.C.

Loosely Translated

…uatem aspicies,
quae rupe sub ima
fata canit
foliisque notas et nomina
mandat

STRATEGOS…

…visit the Sibyl who sings the future
and provides names and notes from the deep caves

Publius Vergilius Maro, Aeneid, III, 443-444, 19 B.C.

Loosely Translated

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STRATEGOS: *the International MSc in Engineering Technology for Strategy & Security*

STRATEGOS...

era questi infra i piú industri ingegni
ne' mecanici ordigni uom senza pari,
e cento seco avea fabri minori,
di ciò ch'egli disegna essecutori

T.Tasso, Gerusalemme Liberata, XVIII, 42

...should be among most talented & ingenious people, peerless in machine invention and using hundred assistants to execute his directions

Ghigærmo de ri Embrieghi, aka "Caputmallei", July 1099 A.D.

Loosely Translated

STRATEGOS...

Lê o conscidera e mirë comme di senplici strumenti pe focalizâ a seu energia, cöse che peuan ese cangiæ quande cangian e prioritæ: de neuve peuan azonzise e de atre peuan ese eliminæ

...looks at goals as to simply tools to focus positively the energy, these can be changed as his priorities change, new one added & others dropped

Christopher Columbus, Memorial, 1501 A.D.

STRATEGOS…

… has as principle to acquire one thing to know ten thousand others

Miyamoto Musashi, 五輪書, 地, *1645 A.D.*

STRATEGOS…

…should have the temper and the spirit of the good cause to carry him through difficulties with satisfaction and credit

Thomas Stamford Bingley Raffles, Letters, 1823 A.D.

STRATEGOS…

Aber auch bei diesen sind die Geistesverwicklungen und die große Mannigfaltigkeit der Größen und Verhältnisse nur in den höchsten Regionen der Strategie

…knows that, in the highest realms of Strategy, intellectual complications and extreme diversity of factors and relationships occur

Carl Von Clausewitz, Vom Kriege, III, 1, 1832 A.D.

Loosely Translated

STRATEGOS…

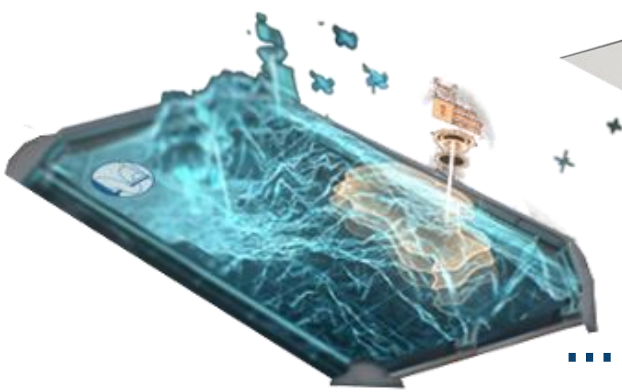
…il differire di tempo in tempo sui modi d'antivedere l'avvenire non ci toglieva d'essere intesi sulle condizioni presenti e sulla scelta dei rimedi.

… despite occasional different approaches to predict the future, is able to develop a common awareness on actual situation and critical decisions

Giuseppe Mazzini, Pensiero ed Azione, 1858 A.D.

STRATEGOS...

La Stratégie est l'art de bien diriger



... has the capability to direct all effectively

Gen.AntonJomini, Prècis de l'Art de la Guerre, 1838 A.D.

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STRATEGOS: *the International MSc in Engineering Technology for Strategy & Security*

Erfolg gedeiht nur in Ausdauer, ununterbrochener, unruhiger Ausdauer

STRATEGOS...

… Success flourishes only in Perseverance. Ceaseless, Restless Perseverance

Manfred von Richthofen, 1918 A.D.

STRATEGOS…

la scelta dei bersagli dipenderà da complesse circostanze di fatto, circostanze d'ordine materiale, morale e psicologico non facilmente ponderabili, e la genialità dei Comandanti delle future Armate Aeree si dimostrerà appunto in questa scelta.

…of future Air Wings should be genial in properly selecting targets based on complex factors dealing with operations, moral, psychology

Gen. Giulio Douhet, Il Dominio dell'Aria, 1921 A.D.

Loosely Translated

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STRATEGOS: *the International MSc in Engineering Technology for Strategy & Security*

STRATEGOS…

Strategie ist ein System von Notbehelfen… kein Operationsplan reicht mit einiger Sicherheit über das erste Zusammentreffen mit der feindlichen Hauptmacht hinaus

… is used to apply a system of expedients while… no plan of operations extends beyond the first contact with the main hostile force

Helmuth Karl Bernhard von Moltke, Über Strategie, 1871 A.D.

Loosely Translated

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STRATEGOS…

2018: Personal Net Worth 42.2 GUSD;
23.8GUSD Alibaba Revenues 6.2GUSD Profits,
56% Net Revenues Growth, Stocks +15% in 1 month

…to make a great company today, have to think about what Social Problem he could solve

Ma Yun, Alibaba Executive Chair, 2018 A.D.

www.simulationteam.com

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STRATEGOS & Genoa University

Genuense Athenaeum

STRATEGOS is led by Genoa University, founded in 1471 AD and located in middle of Italian Riviera, covering all disciplines and counting around 40,000 students in total. The Engineering School of the Genoa University was created in 1870 AD and is among most prestigious worldwide (ranked 1st in Italy during 2018 and usually on podium) and it provides BE, MSc and PhD Programs to 7,500 students.

STRATEGOS promoters in Genoa University are active In International projects with major Agencies and Companies at International Level, as well as in co-operations with Prestigious Universities and Institutes all around the world.

www.itim.unige.it/cs/strategos

Genoa Republic Skyline in XVIII, 250 years ago and 3 centuries after the establishment of the Genuense Athenaeum

Decision Theory within a *Dynamic & Competitive World*

<u>Decision Theory</u> (with two or more decision makers) requires to understand the reality as well as opponents so to understand well the related fundamental concepts it is necessary to develop create Models able to guide us in Analyzing the Scenario

Joint Researches on Decision Making by Agostino G Bruzzone & Lucia Pusillo

Winston Churchill
UK PM during WWII

Doug McMillion
Wall Mart CEO 2020

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Decision Maker Attitude

To play address Complex Systems usually we need to consider our attitude in Decision Making as well as our Opponents and boundary conditions potential evolution

It's never too early to start winning
It is always too early to start losing

J.Fleming, 007 Goldfinger

Identify Goals & Objectives

Decisions fill up our life and the Capacity of Choosing and Expressing our Whishes are the points which make the difference between the Life of an Intelligent Being from an Inferior Life Forms.

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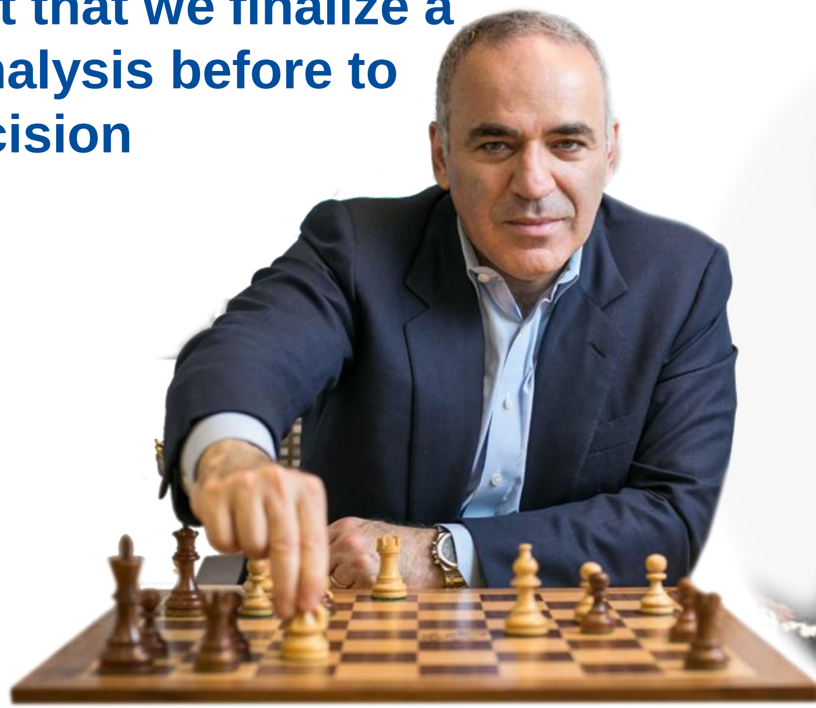
Different Decisions & Tools over Different Times

Every Day we make Decisions, but some of them have so small importance that we forget them within a few minutes, while others are so important that we finalize a Very Accurate Analysis before to take the Final Decision



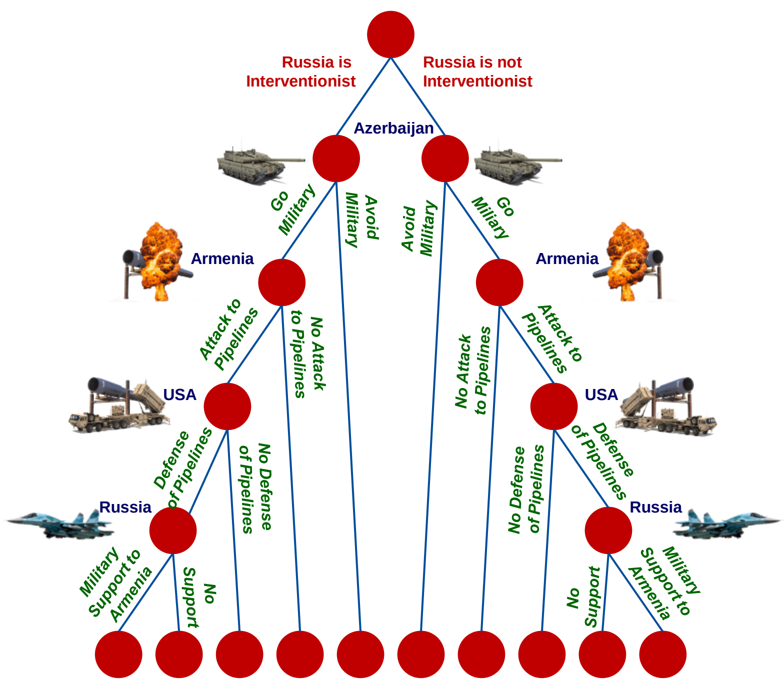
Garry K.Kasparov, Legendary World Chess Champion
…defeting IBM Deep Blue in 1996 (2 victories with white, 1 defeat with black, 3 draws)
and being defeated by it in 1997 (2 defeat with black, 1 victory with white, 3 draws)… today good chess engine could beat Deep Blue

Joint Researches on Decision Making
by Agostino G Bruzzone & Lucia Pusillo
DIME
Genoa University

Analysis & People for the Decision Making: Game Theory

What is an accurate Analysis?

Who is a good *Decision Maker*?



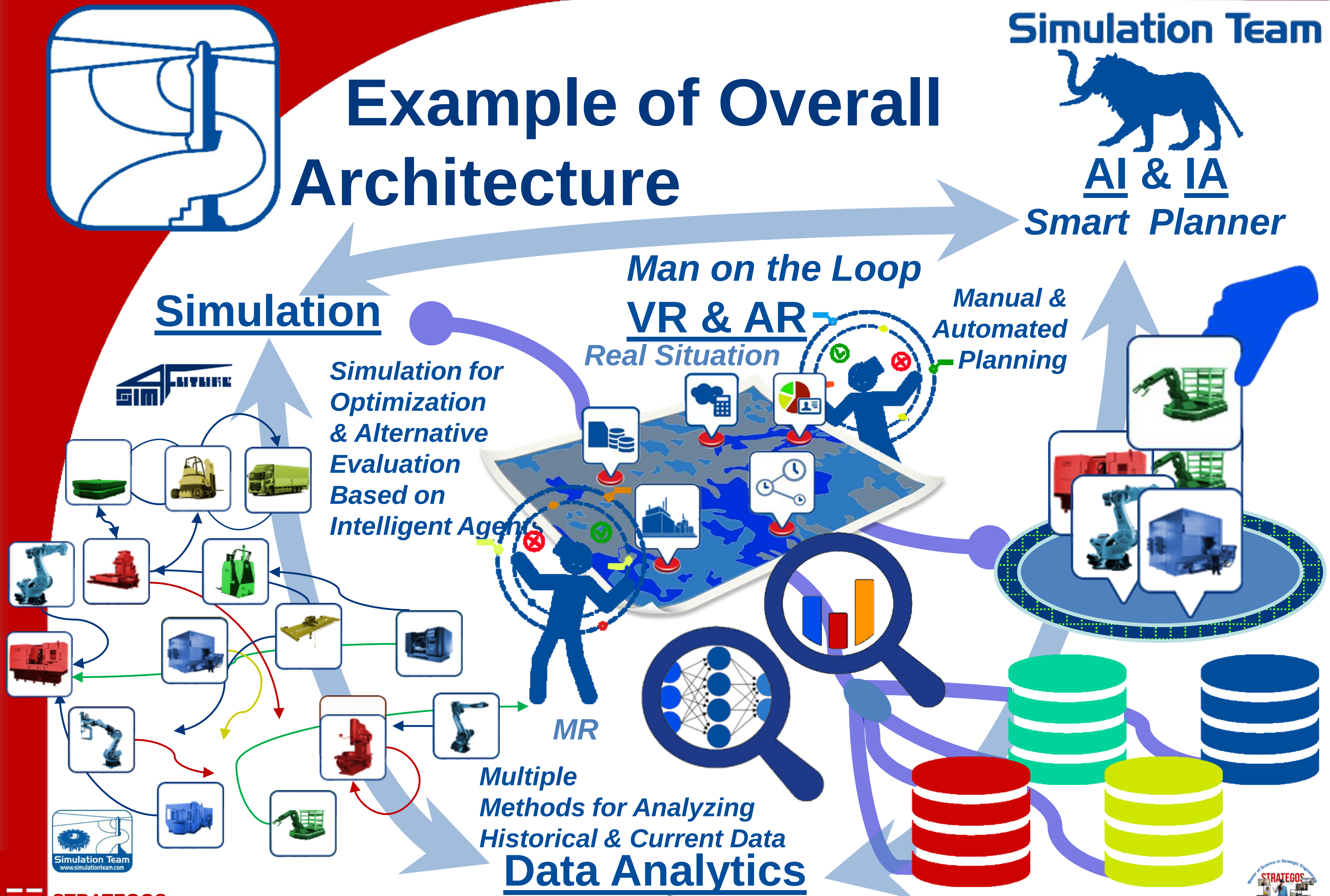
	Campaign	No Campaign
Campaign	2.5;2.5	4.0;2.0
No Campaign	2.0;4.0	3.3;3.3

Jeff Bezos
Amazon Founder

Joint Researches on Decision Making by Agostino G Bruzzone & Lucia Pusillo

DIME
Genoa University

Example of Overall Architecture



Modeling Excellence Networks

Simulation Team

Who Are We?

Universities, Research Centers and Companies operating worldwide in synergy for developing Innovative Solutions with a particular focus in Modelling and Simulation

DIME
Università
di Genova

Genoa

Liophant
Simulation

CentraLabs
Cagliari

CRiCS
Centre for Research
In Complex Systems

CSU
Australia

CIREM
Università di Cagliari

etea SICUREZZA

Blizzard Srl

MSC-LES

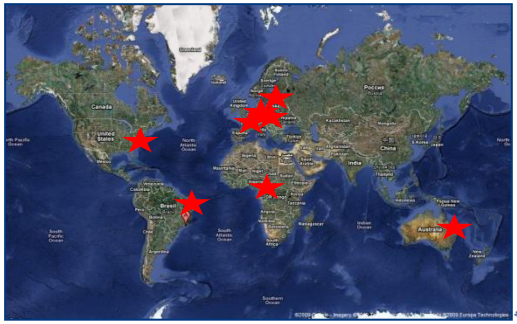
Mik
Riga TU

Universidad
de la Rioja

UNICAL

SimCenter Universitat
Autonoma de Barcelona

LOGIXTICA



Rio de Janeiro
Brazil

Università di Perugia

LSIS
Marseille

IMS-LAPS
Univ.Bordeaux

MITIM
Simulation Team
Genoa Center

McLeod Institute of
Technology & Interopeable
Modeling Simulation Genoa

VIRTUALY

Simulation Team

McLeod Institute of Technology and M&S M&S Net Genoa Center

Simulation Team Genoa Center

Email: agostino@itim.unige.it URL: www.mcleodinstitute.org
www.m-s-net.org

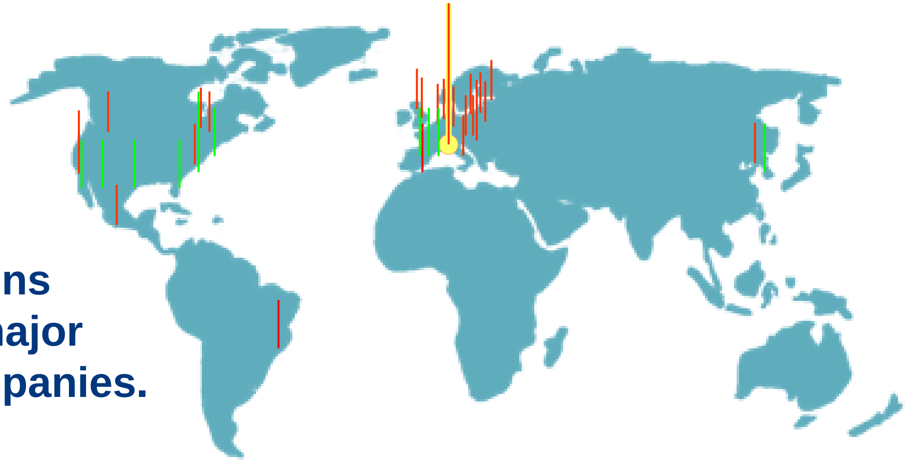
M&SNet

The research group of DIME of *Genoa University* is active from '60 in Simulation applied to Industrial Engineering and is cooperating with M&S Net and MITIM

The activities involve modeling, simulation, VV&A and analysis of Industrial Applications and Services (design, re-engineering, management, training etc.) as:

as:	Chemical Facilities	Power Plants	PM
	Harbor Terminals	Public Services	Environment
	Manufacturing	Assembling	Logistics
	Public Transportation		

The Department staff is in touch world-wide with the simulation community and is present actively to conferences, exhibitions and working meetings with the major Associations, Agencies and Companies.



34 M&S Net Centers World-Wide

Simulation Team

Simulation Team MITIM DIME

The Simulation Team - MITIM DIME of *Genoa University* carries out many industrial projects in cooperation with the large corporations and Small and Medium sized Enterprises; some example of recent industrial simulation project are following:1

ENI	**Fleet Management Planning & Scheduling**
Group Chemical Plant Logistics Optimization	
Ansaldo	**Plant Service Management and Optimization**
LAMCE Petrobras	**Oil Platform Simulation and Augmented Reality**
EDA	**Decision Support for Country Reconstruction Activity Planning**
Ford Motor	**New Production Line Design Based on Simulation**

Members of MISS are appointed in several positions in simulation community such as:

- General Director M&S Net (34 M&S Centers Worldwide)
- President Simulation Team (20 Centers Worldwide
- Chairman of Technical Chapter in SCS and Past Associate VP
- Member of NATO SAS, MSG, and NIAG, Project Leader for Marine M&S

DIME - University of Genoa

www.itim.unige.it

DIPTEM was founded in 1997 as evolution of the *Institute of Technology and Industrial Management* (ITIM) that was operative from ’60. In 2011, DIPTEM evolved in DIME and it is currently composed by about 80 faculty members, 15 technicians and administrative, plus several PhD Students, external Researchers and Consultants. DIME teachers are involved in Undergraduate, Postgraduate and Professional activities in Engineering, Management. DIME active in R&D Projects for major Institutions, Companies and Governmental Organisations. DIME co-operates actively with major Excellence Centers in all Continents

University of Genoa: an Overview

The University of Genoa is one of the oldest in Italy and in the World (founded in 1471 AD), it is located in middle of Italian Riviera.
The students are about 40,000 (about 8,000 new entries),
and the engineering departments has about 7,500 students (12% in Savona Branch Departments); in effect the Savona Campus Savona holds about 1,000 Engineering Students.
That campus is located about 2 km from Savona Downtown, in an old complex of barracks recently converted into new University Buildings (over an area of 200,000 m²).

For further Information about the University of Genoa:
http://st.itim.unige.it
http://www.unige.it

Simulation Team

Partners & Spin-Off

Former Students and Researchers from MISS DIPTEM Simulation Team created over the years start up companies that currently cooperate in M&S (i.e. MAST srl, Cal-Tek srl, Virtuality, LioTech ltd, DLM Solutions, Etea, etc); these companies are devoted to drive Innovation to Success in a wide spectrum of Application for different Business Sectors, Companies, Corporations, Agencies, Societies and Governmental Services and to put *Modeling and Simulation* to work by creating Outstanding Solutions Essential to a Better, Safer, Healthier and Wealthier Life operating worldwide.

These Partners offer a wide range of innovative products and services for M&S markets including:

- Aerospace
- Defense
- Electronics
- Engineering
- Safety and Security
- Retail
- Environment
- Logistics
- Service to the Society (nutrition, health care)
- Petrochemical
- Energy and Power
- Shipping & Transportation

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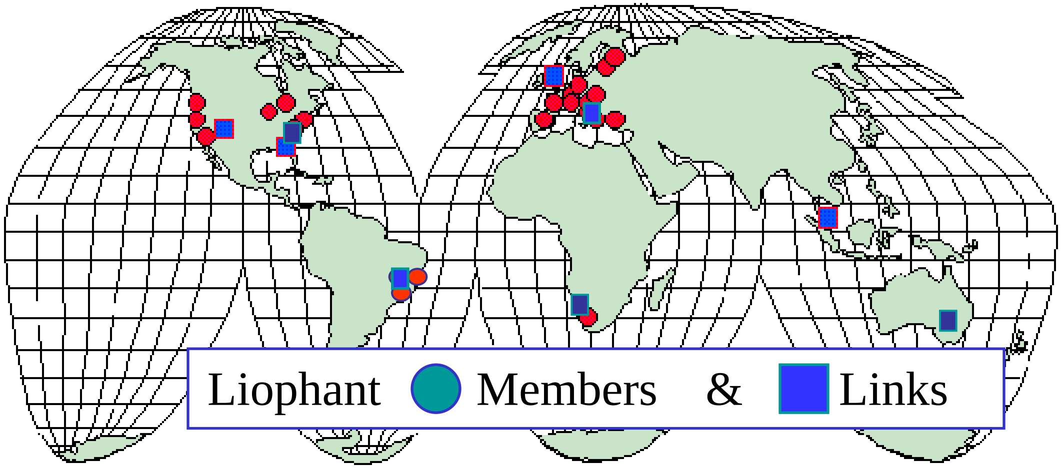
Liophant Simulation

Email: info@liophant.org

The *Liophant Simulation* involves World-Wide Scientists and Technicians working in Companies and Academia.
The *Liophant* promotes Advanced R&D Projects using M&S for Real Applications in challenging frameworks (e.g. Space, Industry, Business, Defence, Service of Society)

The *Liophant Simulation* promotes international Cooperations and exchanges with Excellence Centers World-Wide (i.e. NCS, KSC, VMASC, KPI)



www.liophant.org

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International Liophant Student Exchanges along 2017

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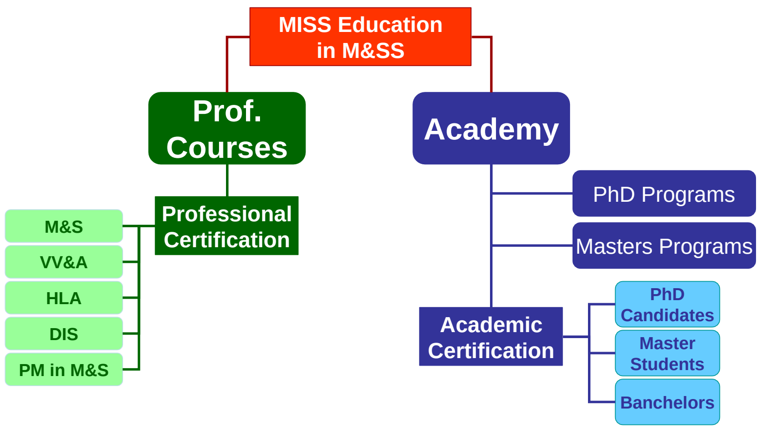
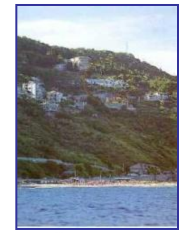
Simulation Technology Transfer

Since 2000 Simulation Team - DIPTEM support Professional and Academic MITIM International M&S Certification Program:



The Lecturers included experts from major excellence centres (i.e. Boston College, Genoa University, NASA, DMSO, National Center for Simulation, SAIC, Aegis, CSY., Riga TU, UCF , McLeod Institute of Technology and Inter.M&S). The Professional course attendance (PM >100, M&S 60, HLA 40, VV&A 20) included Companies (i.e. Piaggio Aero Industries, Alenia Aeronautica, Alenia Marconi, SIA, Fincantieri, COOP), Academia (Pol.Torino, TU Delft, Univ.Marseille, Pol.Milano, Univ.Firenze, Univ.Bari, Univ.L'Aquila, etc.) and National and International Services (i.e. Army, Navy, Air Force, Joint Forces)




Course Location

Lecturing

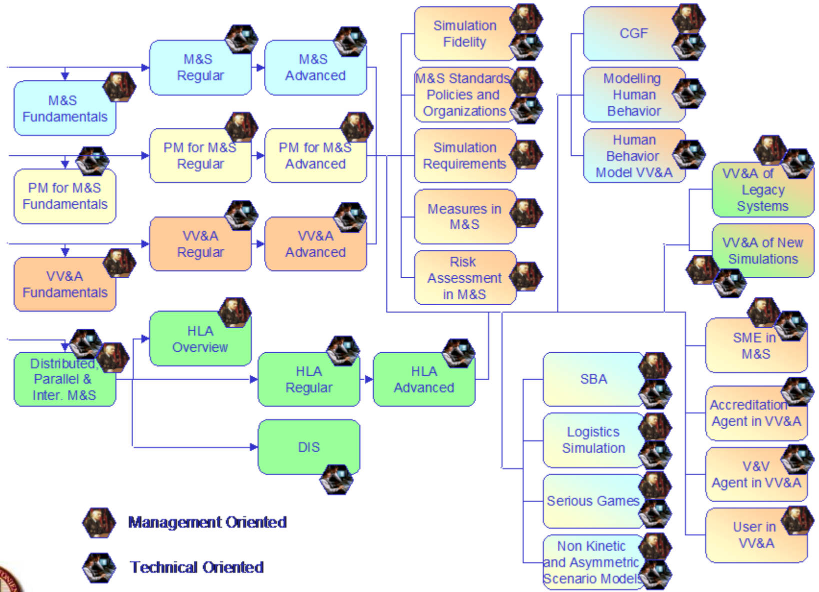
Team Working & Exercises

Simulation Team

SIREN Professional Courses

The professional courses have been organized since 2000 for World-Wide professional experts and technicians, in English, Italian and French, including:

- PM: Project Management for M&S
- M&S: Modeling & Simulation
- Interoperability M&|S
- HLA: High Level Architecture
- VV&A: Verification, Validation & Accreditation
- RCM: Reliability Centered Maintenance



The courses include lecturing and exercises; teachers are usually world wide experts from major excellence centers (i.e. Boston College, MITIM Genoa University, NASA, DMSO, National Center for Simulation, SAIC, Aegis Technologies, CSU, Riga TU, UCF, M&S Net, etc.).

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Systems of Systems & Complexity

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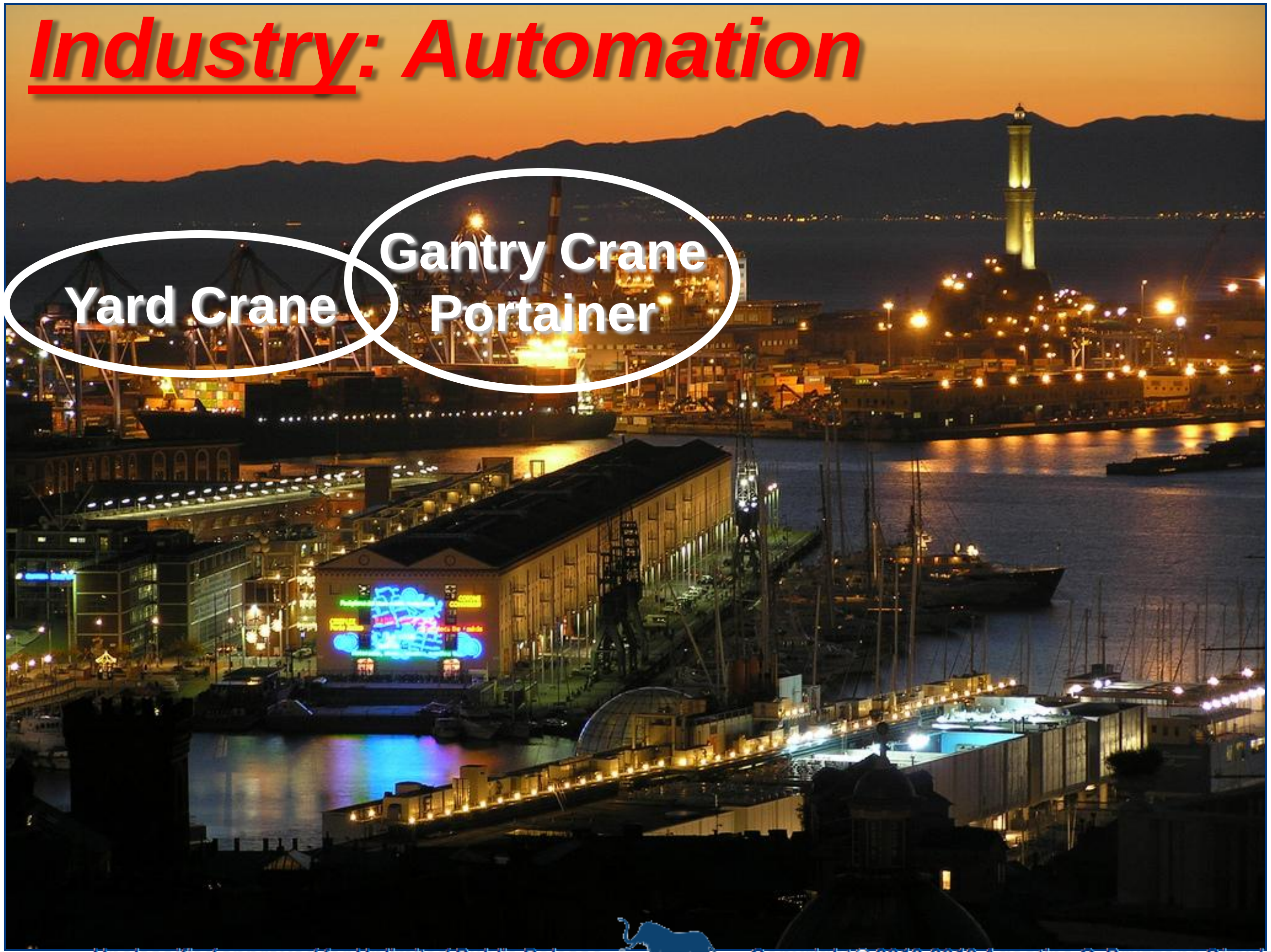
Good Afternoon from Genoa

Good Afternoon from Genoa

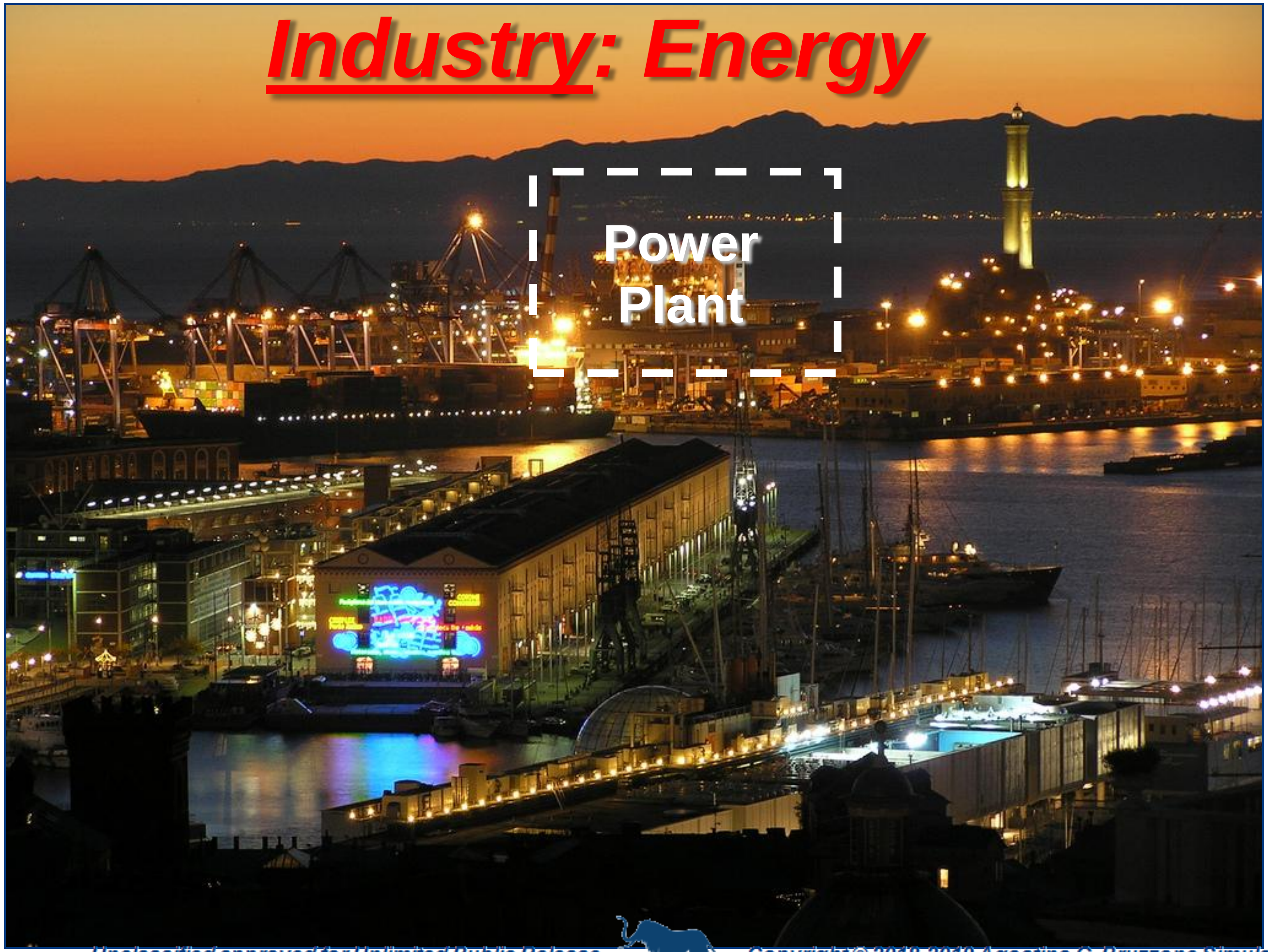
Good Afternoon from Genoa

Good Afternoon from Genoa



Good Afternoon from Genoa

Good Afternoon from Genoa



Good Afternoon from Genoa

Good Afternoon from Genoa

Good Afternoon from Genoa

Good Afternoon from Genoa

Good Afternoon from Genoa

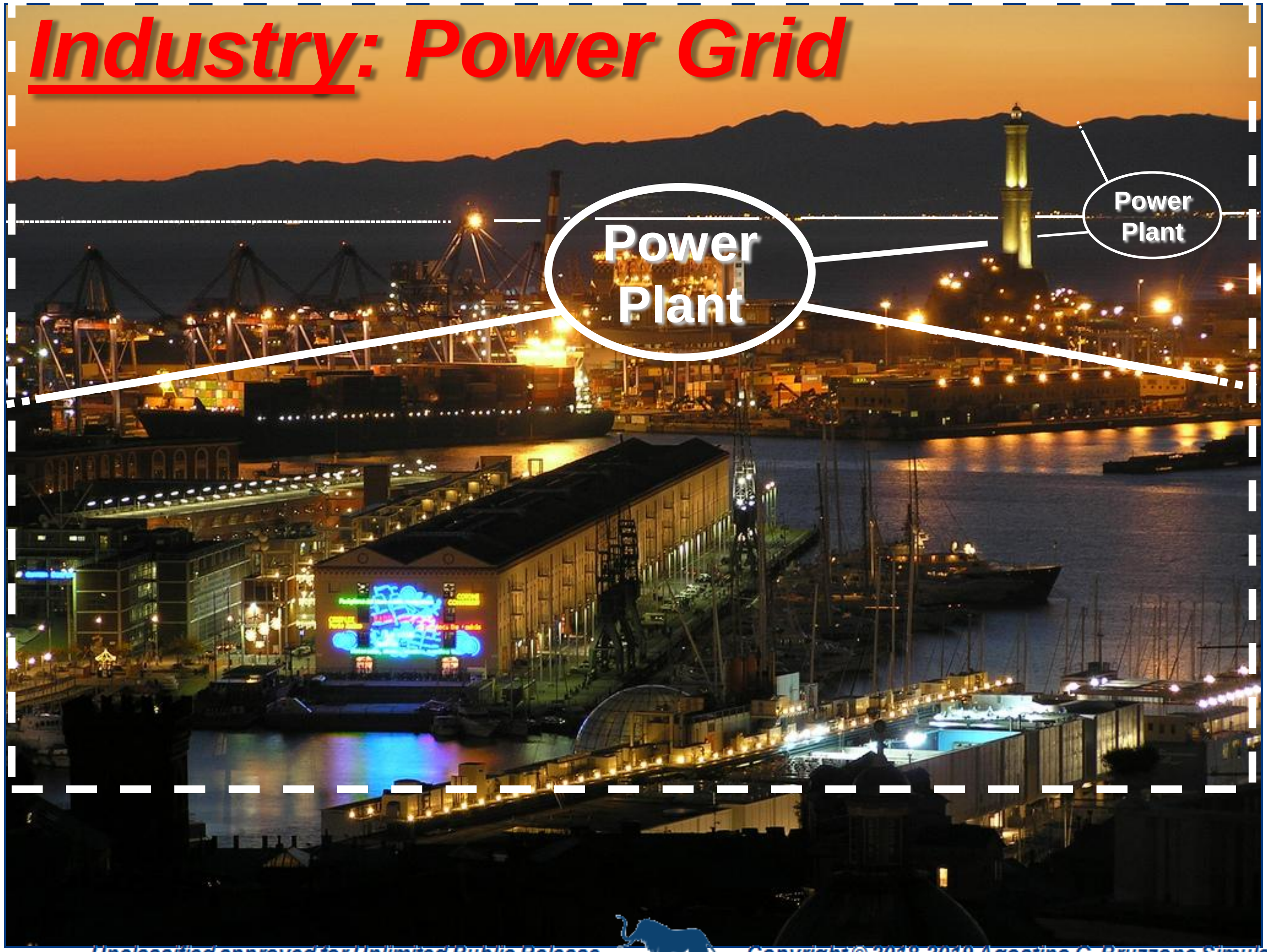
Good Afternoon from Genoa

Industry: Shipping & Shipbuilding

Fincantieri
Ship Yard Construction

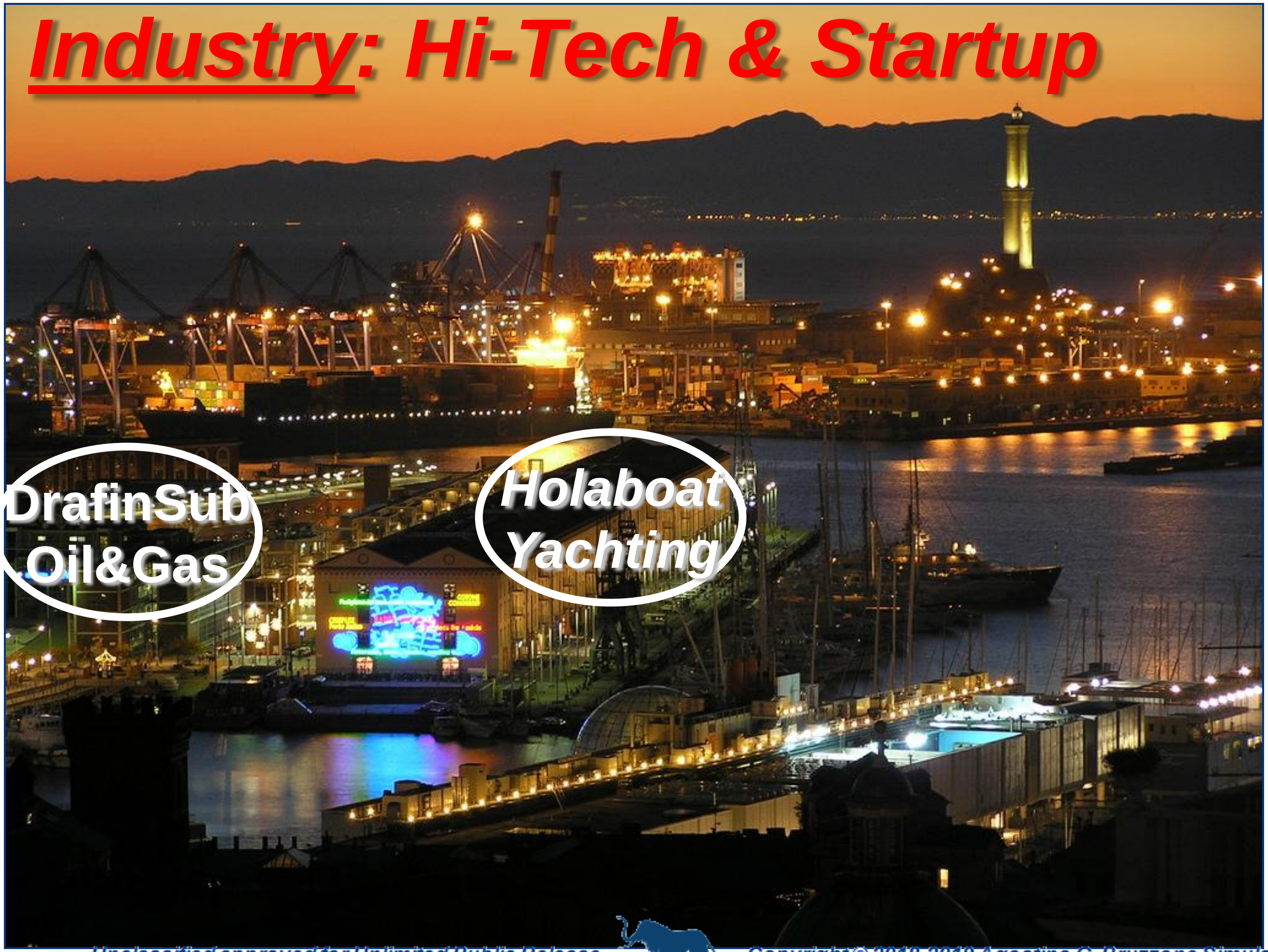
Genoa Port
Shipping, Shipbuilding, Intermodal & Logistics Solutions

Good Afternoon from Genoa



Good Afternoon from Genoa

Good Afternoon from Genoa



Good Afternoon from Genoa

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Complex Systems

What is a Complex Systems?

A Complex System is an entity obtained as composition of interconnected elements, able to exhibit one or more properties and or behaviors not obviously deriving from the properties of its individual parts.

What is Meant by a Complex System?

Many contrasting views

Biology, Computer Science, Engineering, Economics, etc.

Complex System: two pertinent definitions

A system composed of interconnected parts that as a whole exhibit one or more properties (behavior among the possible properties) not obvious from the properties of the individual parts[1] (Reductionism vs. Holism)

A system having many interrelated, interconnected, or interwoven elements and interfaces[2]

Physical Domain: Simple	Physical Domain: Complex	Functional Domain
Simple System Very Predictable. Traditional engineering methods apply.	**Complicated System** Satisfies functional requirements, but cannot ensure under all possible conditions/ states	Simple
Chaotic System (Non-Deterministic) Random perturbations give appearance of complexity. Solved using Robust Design	**Complex System** Must architect system to behave correctly by tailoring the emergent behaviors	Complex

Simple Complex
Physical Domain

Functional Domain: Simple / Complex

- **Architecture[3]:**
  - Structure of components
  - Relationships (Complex information exchanges, system interfaces, functional interoperation, etc.)
  - Principles & guidelines governing evolution over time

1. Joslyn, C. and Rocha, L. (2000). *Towards Semiotic Agent-Based Models of Socio-Technical Organizations, 2000.*
2. Crawley, Edward. System Architecture – course notes. MIT, 2005.
3. IEEE Std 610.12

Source Mavris, ASDL, GATECH

Figure adapted from Balestrini-Robinson, Santiago. "A Modeling Process to Understand Complex System Architectures," 2009.

Fundamental Properties of a Complex System

- Self Organization
- Non-Linear Interactions
- Adaptation
- Heterogeneity

Emergent Behaviors

Complex System properties lead to Emergent Behaviors

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Emergent Behavior

- A Behavior that arises out of the interactions between parts of a system and which cannot easily be predicted or extrapolated from the behavior of those individual parts.
- A Behavior that is not directly hardcoded into an algorithm.
- A Behavior that emerges from the characteristics of Complex Systems and Patterns to arise out of a multiplicity of relatively simple interactions.

Chinese People is very poor, Local Aristocracy is confused Many Nations exploit China. Hate on Christians & Foreigners

Boxer Movement appears starting to kill people: Western Visitors and Chinese that are their friends

Empress & Aristocracy support Boxer to be free from West

UK, USA, Italy, Japan, Russia, France, Austria Hungary are under Siege for 55 days In Beijing

After Western Victory China is forced to opens to West: Tianjin Port serves as gate under Italian & Austrian Control

New Cultural Elements enters in China and are accepted Accelerating local development

New Technologies enters in China and spreads around

China Economy explodes… Now Tianjin Port is the 9th Worldwide

Boxer Rebellion, 1899-1901 (very simplistic view)

IGI Global PUBLISHER of TIMELY KNOWLEDGE

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Computational & Kolmogorov Complexity

Computational Complexity **represents the amount of resources required to run an Algorithm.**

Kolmogorov Complexity **is the length of the shortest computer program (by a specific language) that reproduces an object as output, for instance defining as object a string, a piece of text or a sequence of bit**

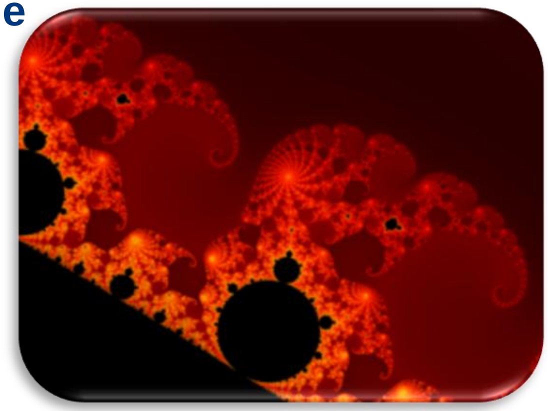
In practice it represent the measure of the computational resources needed to specify the object (aka Algorithmic Complexity) and it dates back to 1963.

Kolmogorov Complexity is also a support to check limitations in Algorithmic Capabilities to deal with some problems such as

Incompleteness Theorem

No consistent system of axioms whose theorems can be listed by an effective procedure (i.e., an Algorithm) is capable of proving all truths about the arithmetic of natural numbers

1st Theorem of Incompleteness
by Kurt Gödel



Halting Problem

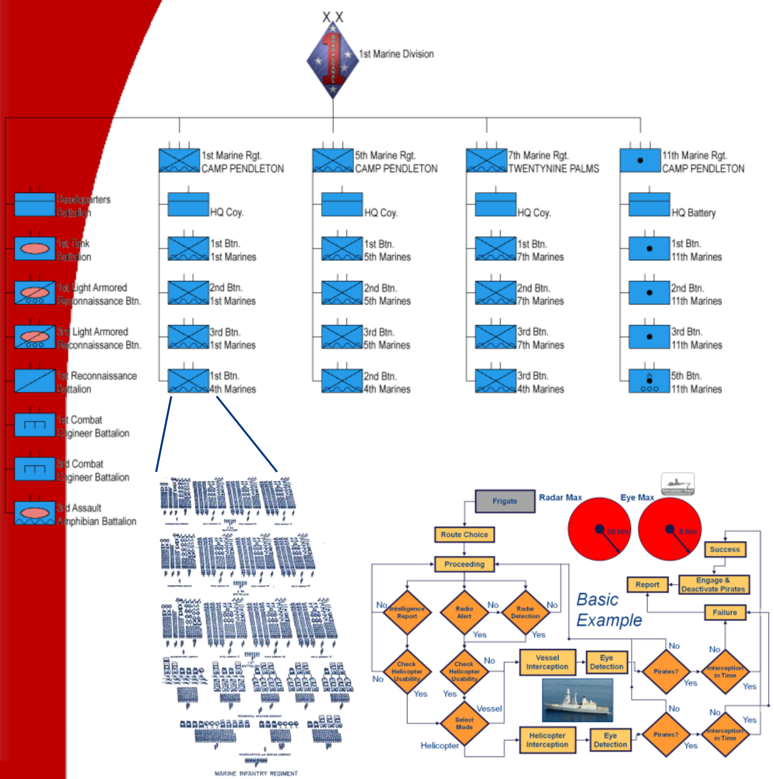
Problem of determining, from a description of an arbitrary computer program and an input, whether the program will finish running, or continue to run forever. No program can exist that handles this case perfectly

by Alan Turing

aka also know as

Krohn–Rhodes Theory

Krohn–Rhodes Theory, called also Algebraic Automata Theory is an approach to study Automata as Algebraic Finite Objects (semigroups).



In practice this Theory states that for all systems for which we can give a Finite State Automata Description it is possible to generae Automatically a Hierarchical Model

By Hierarchical Approach:

- **The Information Flow between elements and levels are restricted and this approach enables the modularity, including the simplified case of a single level characterized just by parallel components**
- **The system could be replicated by using Generalization & Specialization as natural operations realized by taking subsets of different elements and levels, up and/or down, the hierarchy**

Simulation Team

Dynamic Structures & Complex Dynamics

French Revolution…
… many Aristocrats guillotined…
…Navy Officers mostly from Noble Families

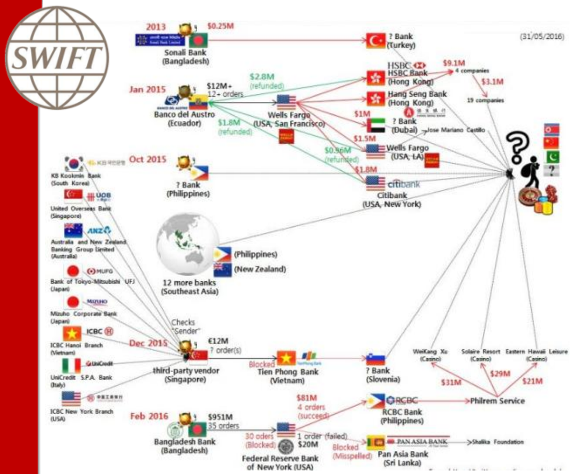
The dynamic behavior of a System is a consequence of its own structure. So, the Structure of a System could be designed or focused on in order to generate different behaviors.
Normally, in order to improve a Process, it is necessary to understand and change the related Structures affecting it.
These Structures should be represented in models to compare the differences, costs, benefits, criticalities & vulnerabilities at least between "*as-is*" and "*to-be*" configurations

In addition the Dynamics is strongly dependent on process feedback, indeed the Elements of a System interact each other and even through feedback loops, where a change in one variable affects other variables over time, potentially with some latency back to influence even the original one.
The capability to understand and manipulate the feedback effects represents a crucial way to improve or degenerate a System and it requires modeling to be effective.

Simulation Team

Complexity & Security

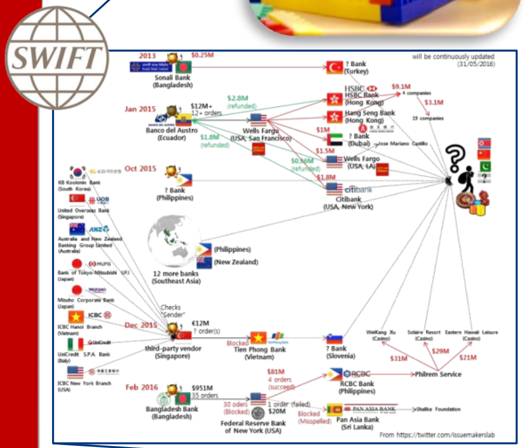
Usually “complexity is the enemy of security".
In a complex network, Security Rules are derived from many different inputs so, for instance, if within an organization is likely to have a Corporate Security Policy… in case each Department have Specific Security Rules, Human Resources may apply Access Rules for Classes of Users, therefore within the overall network, all these rules have to be combined and this introduces high probability of inconsistencies & conflicts.

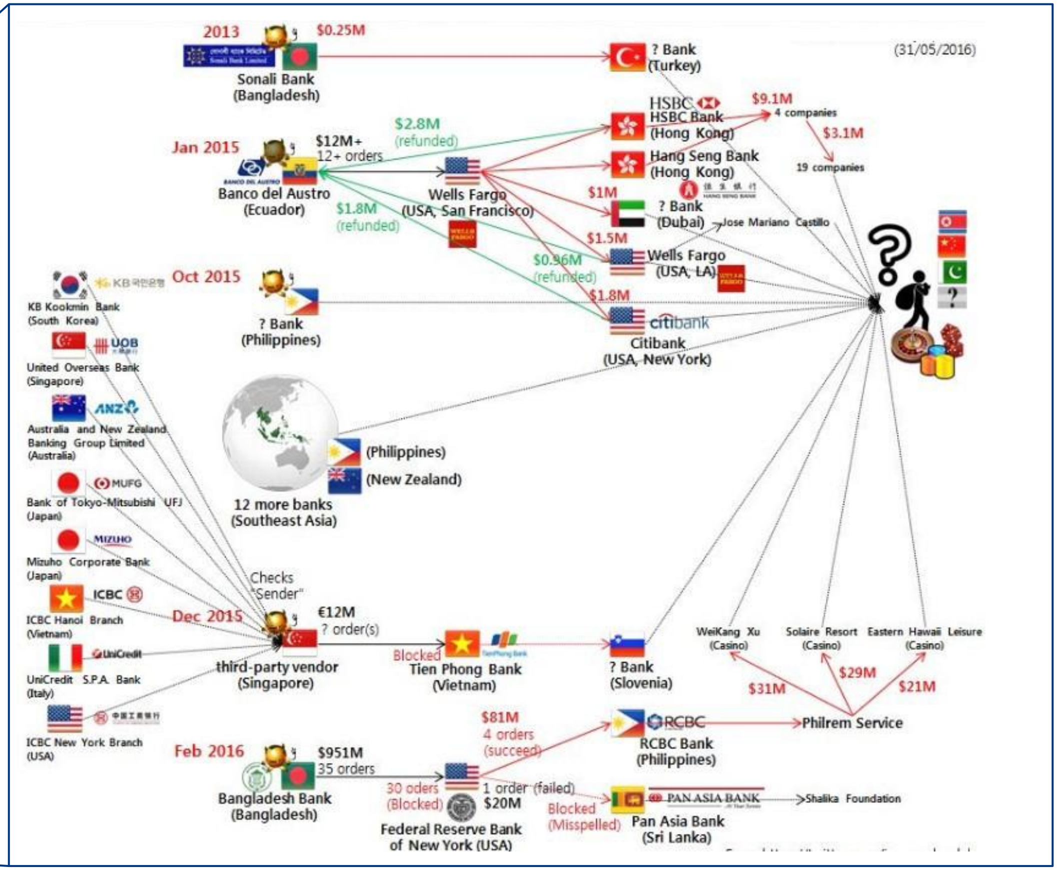


Predictability is a very important characteristics to promote Security. Creating a Secure Network is the real key, not the idea of Classified Network, but intrinsic Security.
Therefore, as more complex a network results as less predictable it becomes and this introduces normally major Security Vulnerabilities. So usually a certain level of complexity is inevitable, but it results possible to guarantee a reasonably Secure Level, while too much complexity is expected to produce a unsecure network.

Simulation Team

Network Complexity & Hierarchical Complexity





Hierarchies introduce the necessity coordinate the work

Number of Nodes & Links create the need to check more connections

So all these elements could add capabilities and increase flexibility, but they also increase the risky to loose Control, increase Vulnerabilities and reduce Awareness

Complex Systems and Multi Scale Aspects

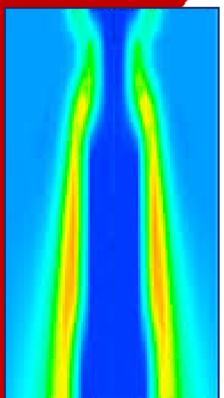
Even more classical systems are heavily affected by Complexity

For instance the Multi-Scale Nature of Complex Systems affects many Systems where changes on the behavior appear when a large number of heterogeneous elements interacts respect few ones

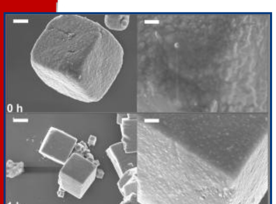
In Complex Systems often Micro, Meso and Macro scales interact generating different dominant mechanisms that act respect stability, therefore in not linear systems this is strongly dependent on boundary conditions so to investigate these cases is required proper Modeling and Simulation

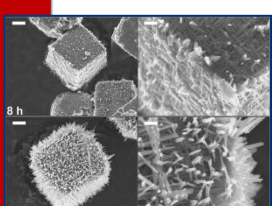
Simulation Team

Chemical & Physical Complex Systems



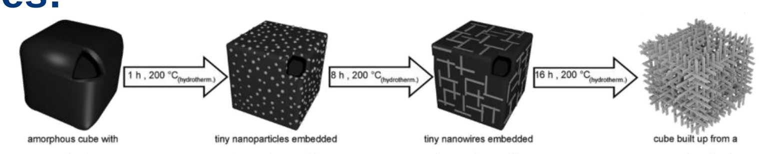
Chemical Complex Systems such as Flue Gas Treatment require, at particle-size scale, to keep temperature below 900°C to satisfy the deSOx and deNOx requirements; therefore at the cluster-size scale, the alternative change of the solid-rich dense phase and the gas-rich dilute phase is favorable to additioanl reduction of NOx, due to the creation of alternative reducing and oxidizing conditions, so at the unit scale, staged re-circulating air could further reduce the emission of NOx





Physical Complex Systems Complex related to geometric lattice like structures have interactions depending typically only on effects propagated from nearest neighbors. Even if each follow fixed element does not change and it is ruled by fixed differential equations (e.g. Newton's Laws & gravity, Maxwell's laws), due to the change in position is affected by a different number of element creating new properties:

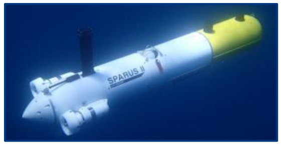
self-organized criticality, self-similarity, scaling, and power laws as it happens in snowflakes curves and fractals



Multidisciplinary Nature of the Complex Systems





Complex systems are addressed by multiple competences, multiple backgrounds, multiple technical languages

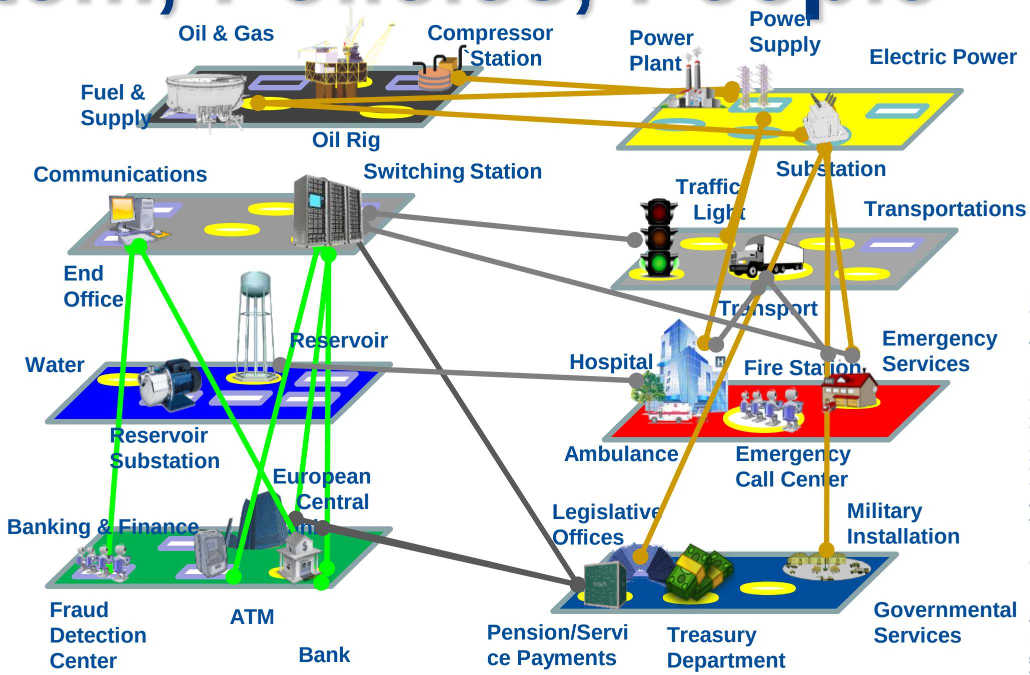
Simulation Team

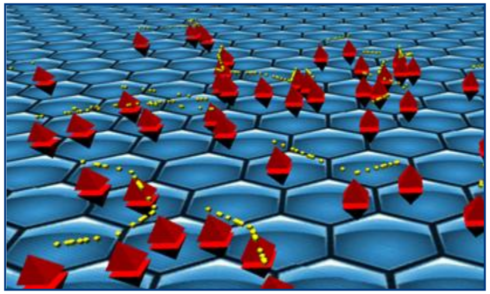
Multi-Layer Simulation for New System, Policies, People

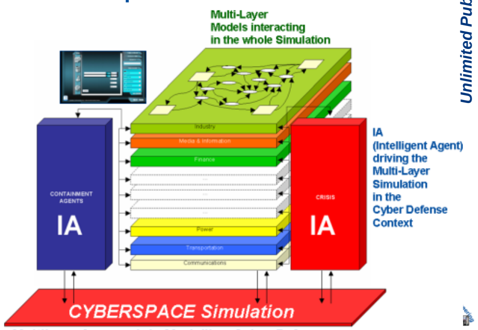
The Modern Systems are usually addressing Multiple Layers and requires to consider multiple aspects for developing

- New System Design
- New Policy Definition
- Table Top Exercise in order to raise Top Management awareness
- Training in procedures and Operations
- Personnel Training and education

The use of Intelligent Agent is crucial to automate Simulation







Multilayer Approach in Modelling Cyber Defense as Fifth Dimension interacting with Strategic Assets

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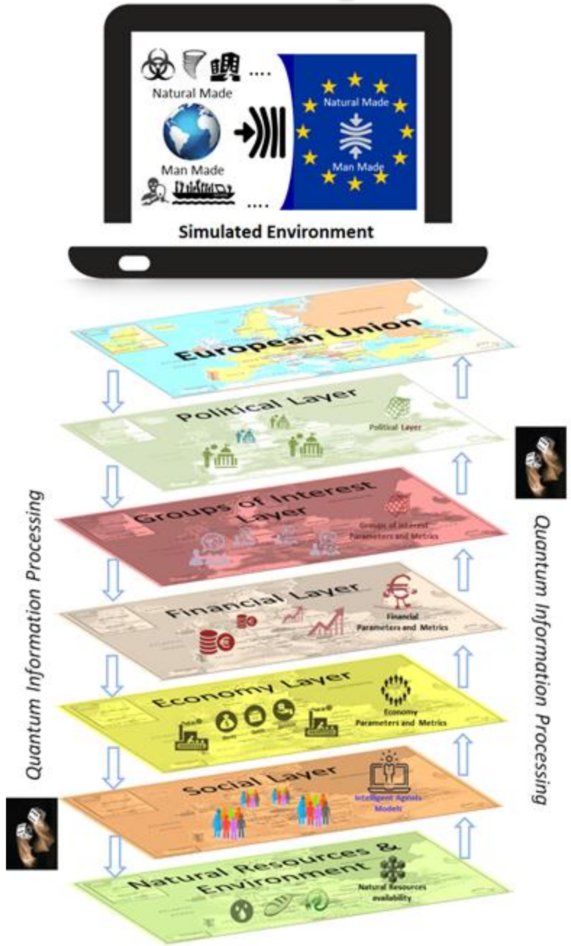
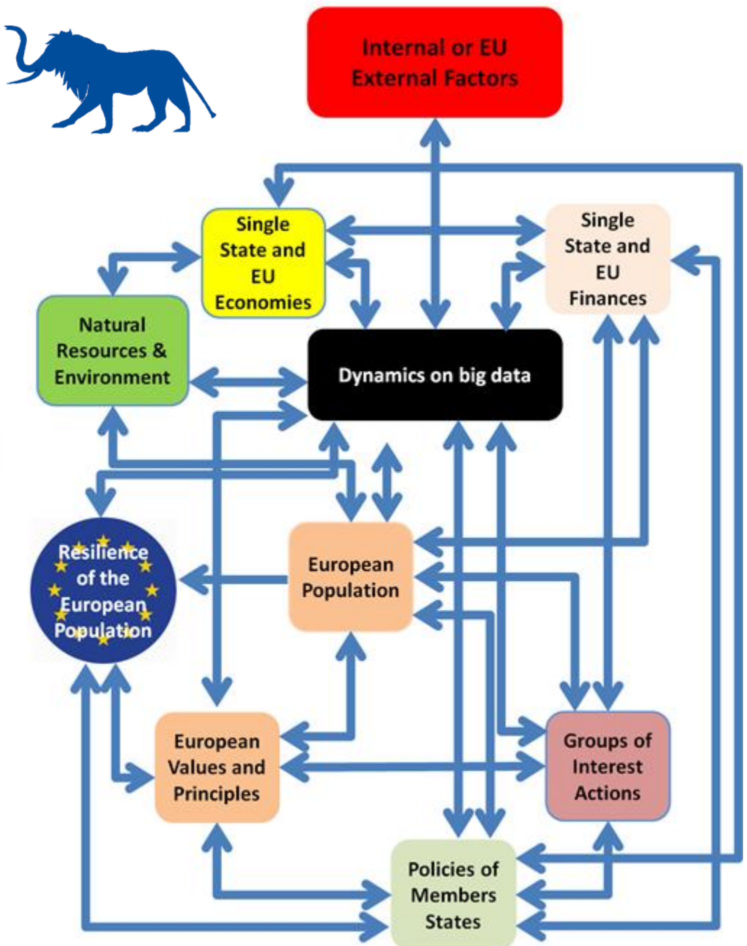
Multi Layers in Complexity: an Example

QuAMRE is an initiative for promoting Analysis of *"European Resilience"* combining Interoperable Simulation and Quantum Computing





Some Open Questions?

- How it is Changing the Industry & World?
- How Simulation enables to survive?
- Way Ahead, Challenges and Opportunities

← 2016! →

Vs.

Game

Reality

Perish in a Game or in War?

- How it is Changing the Industry & World?
- How Simulation enables to survive?
- To Perish in Game Industry… it is just a Game, or it is Real?

Vs.

Game

War!

Something that could Perish

- 1995 Mercedes from Munich to Denmark, 1600 km
- 1996 Parma University follow lane marks, 1900 km
- 1997 NAHSC, 20 vehicles in I7 San Diego
- 2004 DARPA, failure on running in the Desert
- 2005 Parkshuffle near Rotterdam
- 2007 DARPA, urban challenge won by Chevy CMU

.

.

- 2014 Vislab 20' in Rush Time →30M$ by Ambarella
- 2016 Tesla first Casualty
- 2016 Nutonomy in Singapore, Self Taxi Service
- 2016 Uber testing in Pittsburgh

18 millions of Taxi Drivers Worldwide

900'000 Truck Drivers In Italy

200'000 Uber Drivers Worldwide

CMU	Carnegie Mellon University
DARPA	Defense Advanced research Projects Agency
NAHS	National Automated Highway System Consortium

2015 Statistics

The Art for Winning Competition

L'Art de la Guerre se divise en cinq branches purement militaires; la stratégie, la grande tactique, la logistique, l'art de l'ingénieur, et la tactique de détail.

Antoine Henri Jomini, Precis de l'Art de Guerre

1836 AC

Industrial Competition: It is a Game or it is War?

夫未戰而廟算勝者，得算多也；
未戰而廟算不勝者，得算少也；
多算勝，少算不勝，而況於無算乎？
吾以此觀之， 勝負見矣。

Now the general who wins a battle makes many calculations in his temple ere the battle is fought. The general who loses a battle makes but few calculations beforehand.

Thus do many calculations lead to victory, and few calculations to defeat: how much more no calculation at all! It is by attention to this point that I can foresee who is likely to win or lose.

Sun Tzu, Art of War,

Laying Plans, 7, 500 BC

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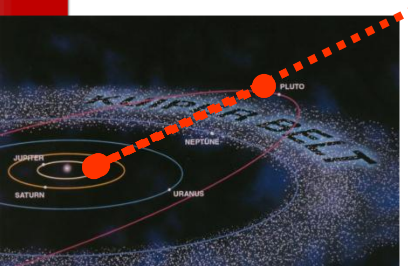
Challenges along Millennia…

… Corresponding Today to...

…Science Fiction!

10’000 times more than that!
70’000 Space Shuttles!

3 times more Far Away than this Distance!
7 Days To Communicate!



Over 20’000 times more Expensive than the full Gross World Product!

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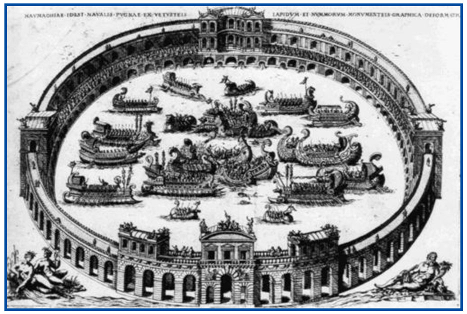
Simulation Origin?

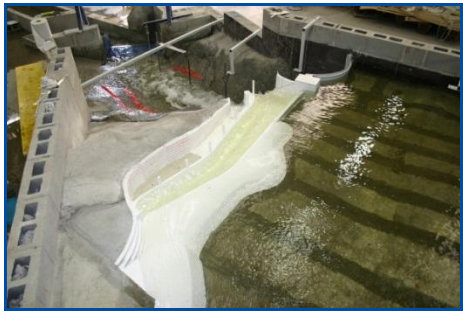
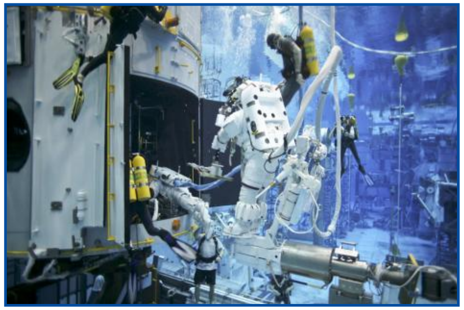
Simulator

Simulator Figurae

Ovid's Metamorphoses, 11, 634, 8 AD

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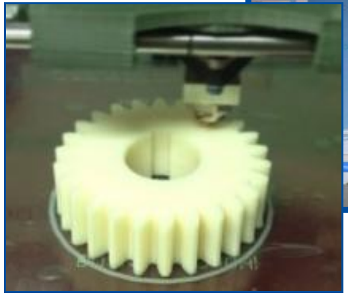
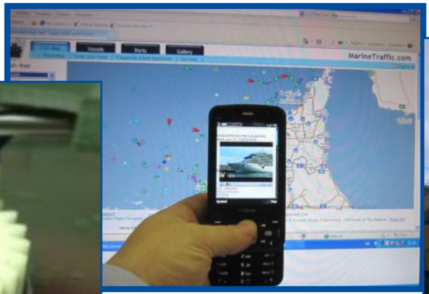
Looking Forward for new decade Technologies

Some of major issues arising will be focused on following issues:

- Serious Games & Simulation for Training
- Mobile Solutions
- Virtual Worlds & Augmented Reality
- Cloud Technologies
- New Industrial Paradigms





Industry

Industry: ***a group of productive Enterprises or Organizations that produce or supply goods, services, or sources of income***

Encyclopedia Britannica

Magna Industria Bellum Apparavit

Cornelii Nepotis, (55 BC), De Viris Illustribus

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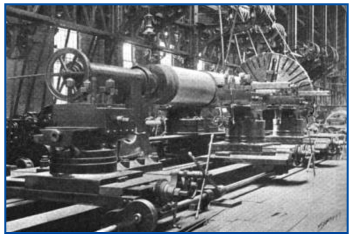
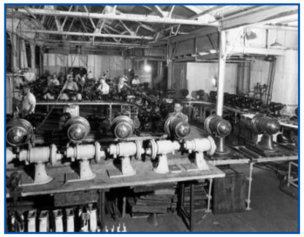
Industrial Evolution



Bethlehem Steel Co.
1899

Ford Motor Company
1910

General Motors
1921



IBM Dayton
1930

Douglas A-20
1943

Ford Motor Co.
1955

IBM 1401
1960

Philips TVs
1970

Toyota
1980

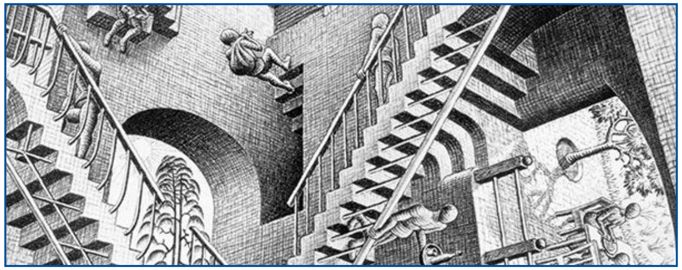
Cocacola Eritrea
1995

Hangzhou Jinding
Aluminium Group
1997

Shanghai Zhonglei
Industry Company
2001

Foxconn
2011

Today: Living in a Paradox



in 2020:

Uber, the world's Largest Taxi Company,… owns no Vehicles

Facebook, the most popular media owner,… creates no content

Alibaba, the most valuable retailer,… has no inventory

Airbnb, the largest accomodation provider,… owns no real estate

New Locations…

Freetown, Sierra Leone

Ashgabat, Turkmenistan

Asunction, Paraguay

..New Opportunities..

Macau, China

Simulation Team

…within Challenges

Kiev

Kobane

Simulation Team
www.simulationteam.com

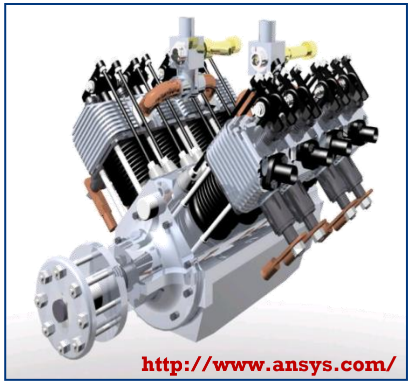
System Engineering & Complex Systems

System Engineering

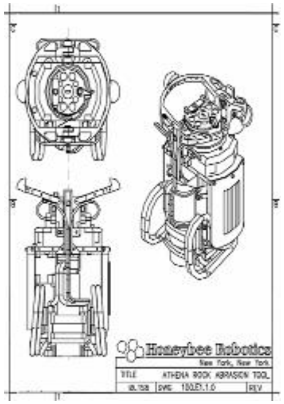
- ***Systems Engineering*** **is an Interdisciplinary Field of Engineering that focuses on the design and management of Engineering Systems over their whole Life Cycles.**

- **System Engineering includes**
  - ***Systems Engineering Technical Processes*** **assessing available information and defining effectiveness measures to develop define behavior and develop models for trade-off analysis, as well as to design production & test plan**
  - ***Systems Engineering Management Processes*** **devoted to organize the technical efforts all over the lifecycle**

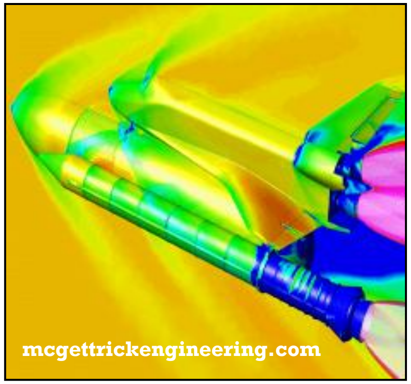
Engineers use many types of models...



CAD Models



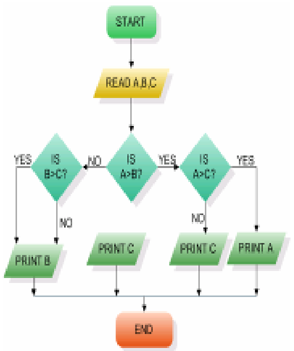
Drawings



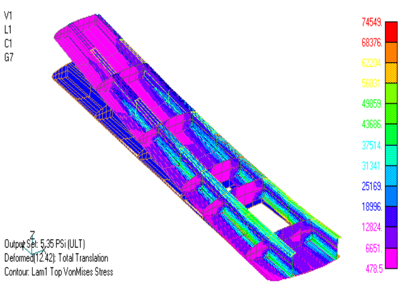
Physics-Based Models

```
Clear[T, U, V, x, y, w, W];
Clear[f, cont];
f[z_] = i (1 - z) / (1 + z);
W = ComplexExpand[f[x + i y]];
U = Together[ComplexExpand[Re[W], TargetFunctions→{Re, Im}]];
V = Together[ComplexExpand[Im[W], TargetFunctions→{Re, Im}]]; ;
T[x_, y_] = 100 - 100/π ArcTan[V/U];
Print["w = ", f[z], " = ", U + i V];
Print[" "];
Print["u = ", U];
Print["v = ", V];
Print[" "];
Print["T[x,y] = 100 - 100/π ArcTan[v/u]"];
Print["T[x,y] = ", T[x, y]];
```

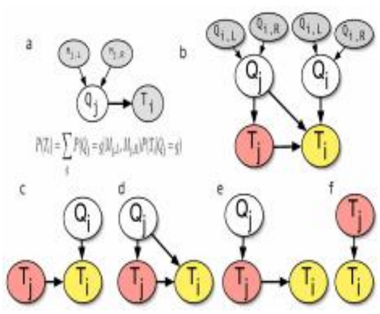
Software Models



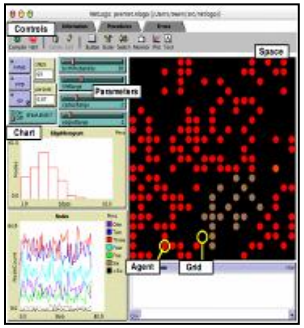
Conceptual Models



Structural Models



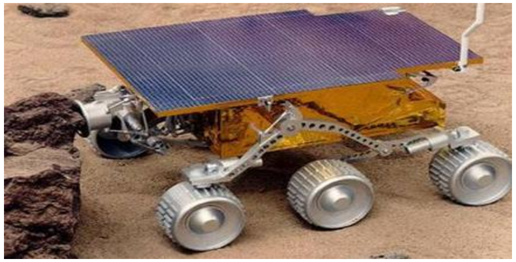
Mathematical Models



Constructive Models

Source Mavris, ASDL, GATECH

Some definitions of System?



- **IEEE1220-1994**: *"An interdisciplinary approach to derive, evolve, and verify a life-cycle balanced system solution that satisfies customer expectations and meets public acceptability"*
- **ISO 15288.2008**: "A combination of interacting elements organized to achieve one or more stated purposes."
- **NASA Systems Engineering Handbook**: "The combination of elements that function together to produce the capability to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. The end product (which performs operational functions) and enabling products (which provide life-cycle support services to the operational end products) that make up a system."

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Some definitions of System?

- **IEEE1220-1994**: *“An interdisciplinary approach to derive, evolve, and verify a life-cycle balanced system solution that satisfies customer expectations and meets public acceptability”*
- **IEEE1220-1998 (2005)**: "A Set or Arrangement of Elements and Processes that are related and whose behavior satisfies customer/operational needs and provides for life cycle sustainment of the products."
- **ISO 15288.2008**: "A combination of interacting elements organized to achieve one or more stated purposes."
- **NASA Systems Engineering Handbook**: "The combination of elements that function together to produce the capability to meet a need. The elements include all hardware, software, equipment, facilities, personnel, processes, and procedures needed for this purpose. The end product (which performs operational functions) and enabling products (which provide life-cycle support services to the operational end products) that make up a system."

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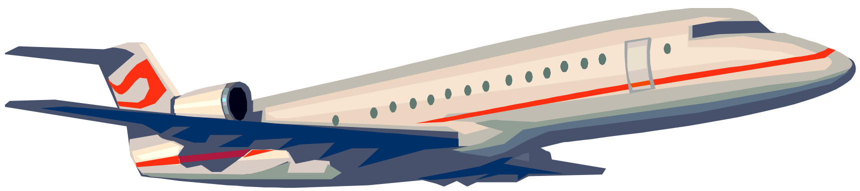
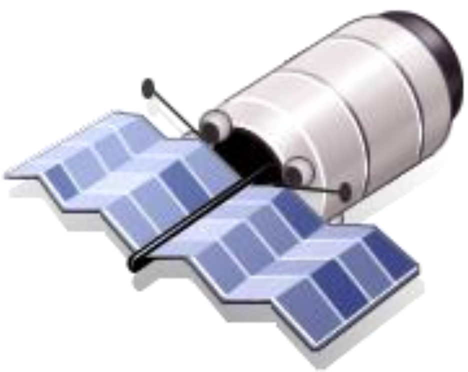
What is a System?

INCOSE, the International Council of System Engineering, adopts this definition:

- "A ***System*** is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected."

What is a system?





Source Mavris, ASDL, GATECH

Issues in System Engineering

System Engineering is addressing Products along their Life Cycle including:

Development | *Design*
Implementation | *Manufacturing*
Service | *Decommission*

So System Engineering has to consider among others:

Requirements | *Logistics*
Maintainability | *Reliability*
Team Coordination | *Testing and Evaluation*

System Engineering

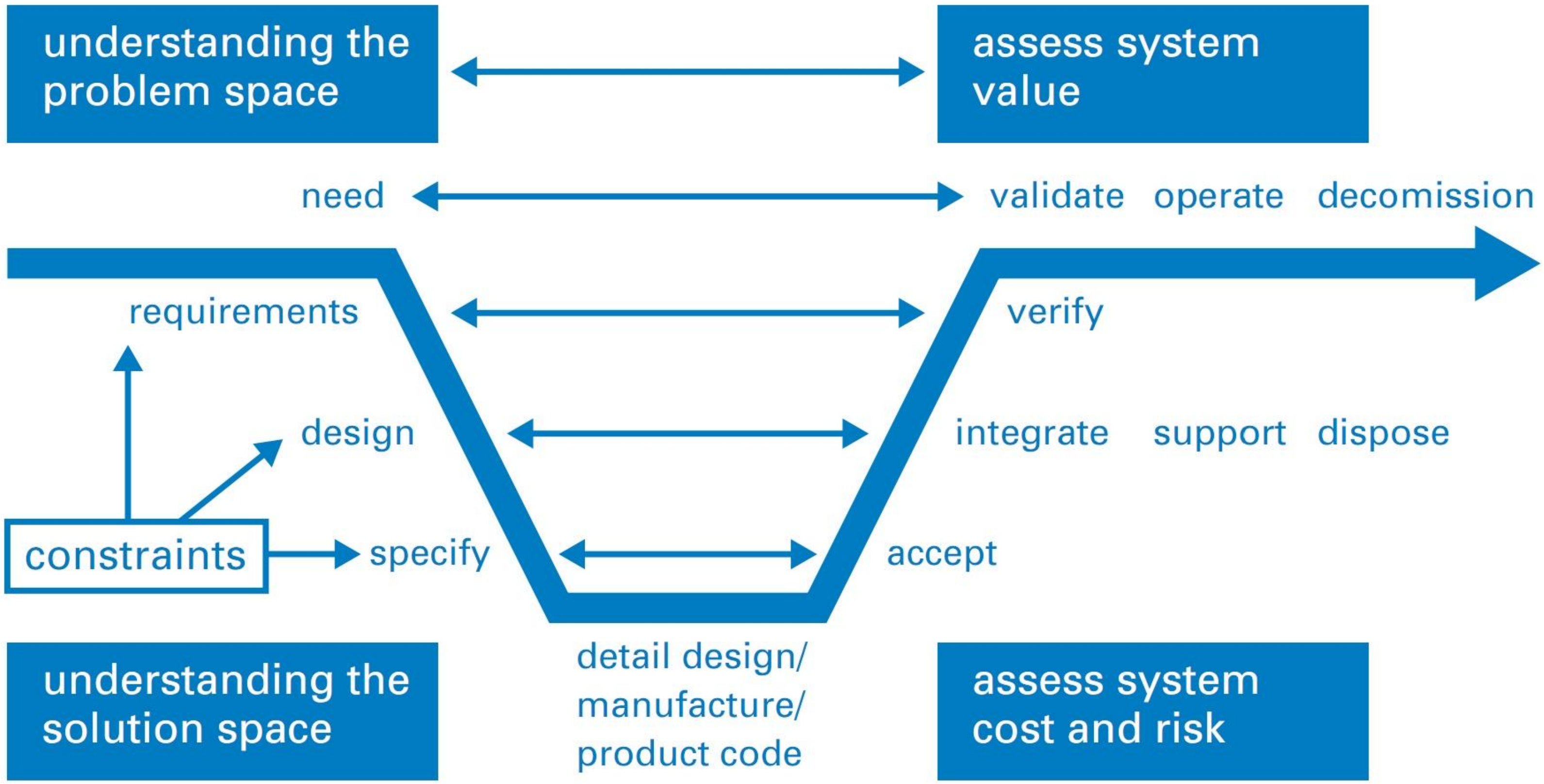
- The Systems Engineering involve to activate several process for analyzing real problems, identify the needs, formally defining the functions and requirements for solving them, choosing most effective and efficient feasible solutions, considering constraints and opportunities (e.g. producibility,
- costs, time, people, knowledge, technologies), guaranteeing its operations along the life cycle.
- This is strongly dependent of human resource capabilities due to its complexity

System / Product Life Cycle

A Product, or System, *Life Cycle* is the cycle through which it goes through from its initial introduction to the withdrawal or eventual demis and includes among others:

Requirements Definition
System Definition
Development
Commissioning
Production
Deployment
Operation & Service
Decommissioning

System Engineering within the Product Life Cycle



Source incoseonline.org.uk

Life Cycle Representation

An Example is the American DoD Acquisition System that includes the life cycle, phases, deliverables of each milestone

Life Cycle for Defense Acquisition US DoD 5000.2 (rev 2/26/93)

	Phase 0	Phase I	Phase II	Phase III e Phase IV	
Needs Mission Identification	Concepts and Ideas Exploration and Definition	Demonstration and Validation	Engineering Development and Manufacturing	Production and Deployment	Operations and Support

Milestone 0	Milestone I	Milestone II	Milestone III	Milestone IV
New Concepts Study Approval	Demonstration Approval	Technical Project Approval	Production Approval	Main Required Changes Approval

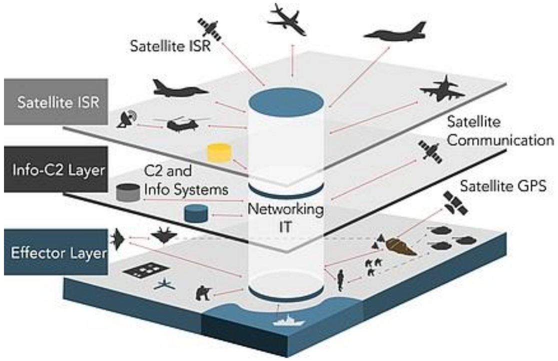
Different Approaches within System Engineering

- Systems engineering goal is to address a system as a whole integrating all aspects of the project
- Systems engineering deals with ***processes design***, ***optimization methods***, and ***risk management***.
- System Engineering uses both ***technical*** and ***human centered disciplines*** such as:
  - Industrial engineering
  - Control engineering
  - Software engineering
  - Organization
  - project management.

Techniques supporting System Engineering

- System Architecture
- Modeling & Simulation
- Optimization
- System Dynamics
- Systems Analysis
- Statistical analysis
- Reliability analysis
- Decision making

Architecture & Systems



Historically an Architecture is:

- The art or practice of designing & constructing buildings (Oxford Dictionary)
- Formation or construction resulting from or as if from a conscious act able to unify or coherent form or structure (Merriam-Webster Dictionary)
- …
- Common Themes: Structure, Utility, Aesthetics

In Systems Engineering… Architecture is :

- The fundamental organization of a system, embodied in its components, their relationships to each other and the environment, and the principles governing its design and evolution. (*ANSI/IEEE 1471-2000*)
- The ***fundamental organization of a system***, embodied in its components, their relationships to each other and the environment, the principles governing its design and evolution, its ***purpose***, and its ***attractiveness*** (e.g. functionality, cost). (Dimitri Mavris, GATECH)

Including the utility and the value into the architecture development phase requires the ability to estimate and evaluate these components of the architecture, thus driving a need for architecture frameworks to be integrated with systems engineering and modeling and simulation

Source Mavris, ASDL, GATECH

Techniques supporting System Engineering

- ***System Architecture***
- **Modeling & Simulation**
- **Optimization**
- **System Dynamics**
- **Systems Analysis**
- **Statistical analysis**
- **Reliability analysis**
- **Decision making**

A system architecture is the conceptual model that defines the structure, behavior, and components of system.[
An architecture description is a formal description and representation of a system, organized to support understanding its structure and behaviors.

A system architecture comprises usually system components, externally visible properties of the components, the relationships between them. There Architecture Description Languages (ADL)in use to address it especially in Software Engineering

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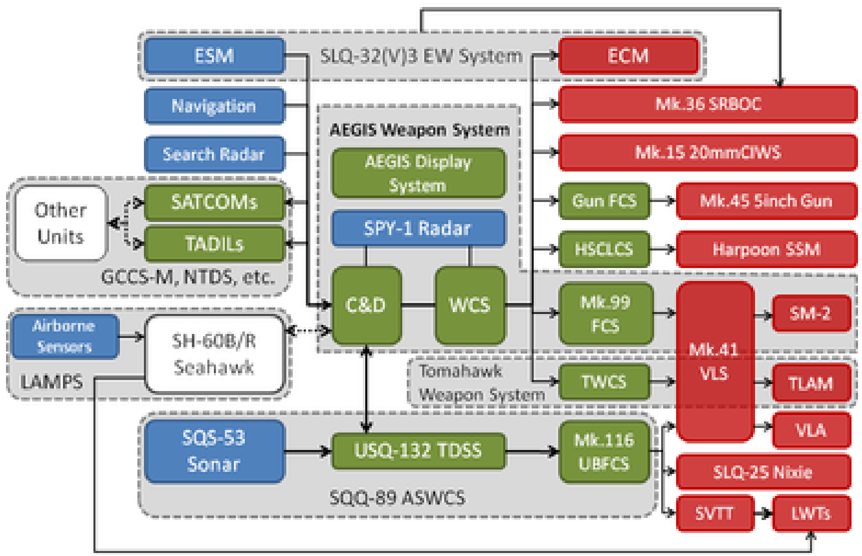
Techniques supporting System Engineering



AEGIS US Navy phased array radar-based combat system (Shield in Greek)

- **Statistical analysis**
- **Reliability analysis**
- **Decision making**

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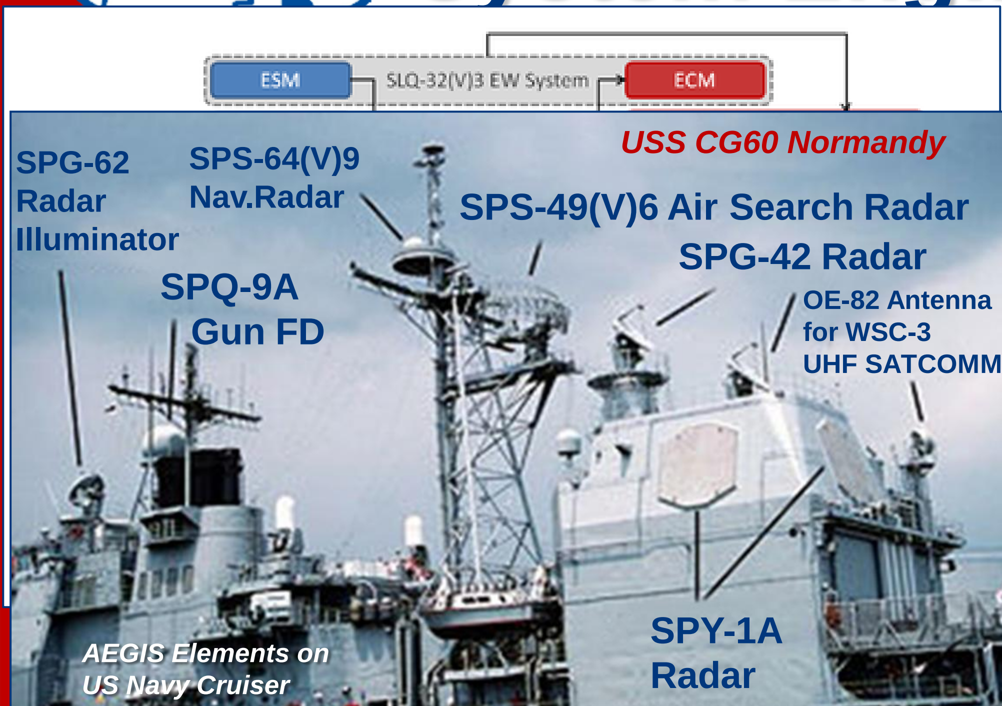
Techniques supporting System Engineering



- **Reliability analysis**
- **Decision making**

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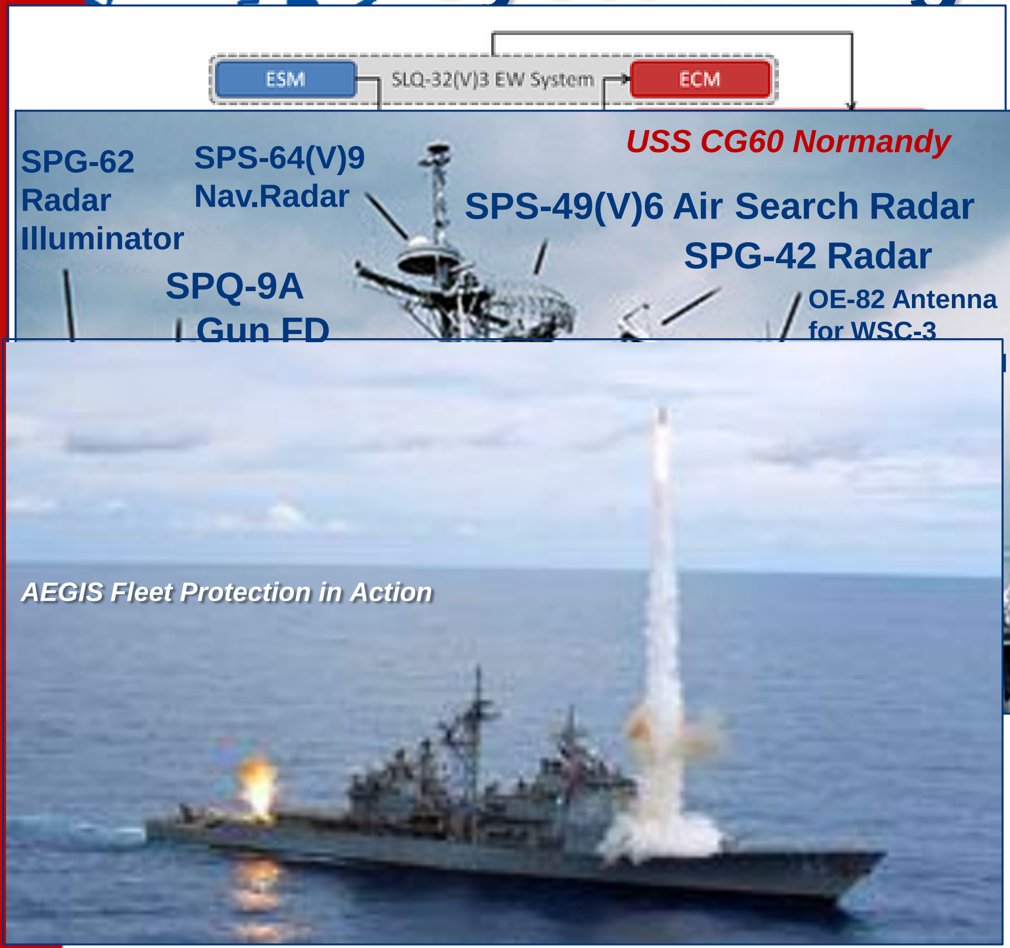
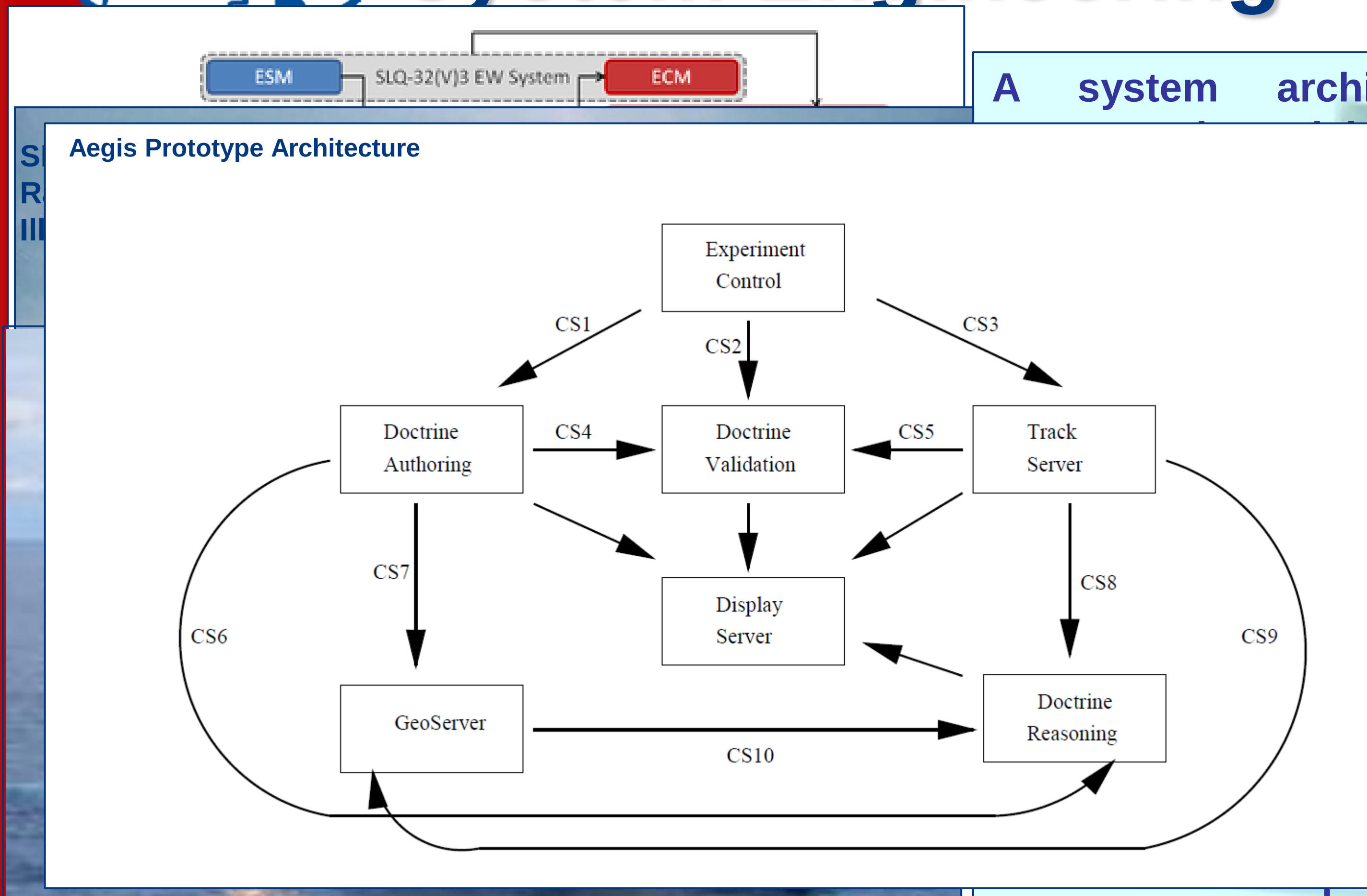
Techniques supporting System Engineering



A system architecture is the conceptual model that defines the structure, behavior, and components of system.[
An architecture description is a formal description and representation of a system, organized to support understanding its structure and behaviors.

A system architecture comprises usually system components, externally visible properties of the components, the relationships between them. There Architecture Description Languages (ADL)in use to address it especially in Software Engineering

Techniques supporting System Engineering



A system architecture is the ... that defines the ... and components ...

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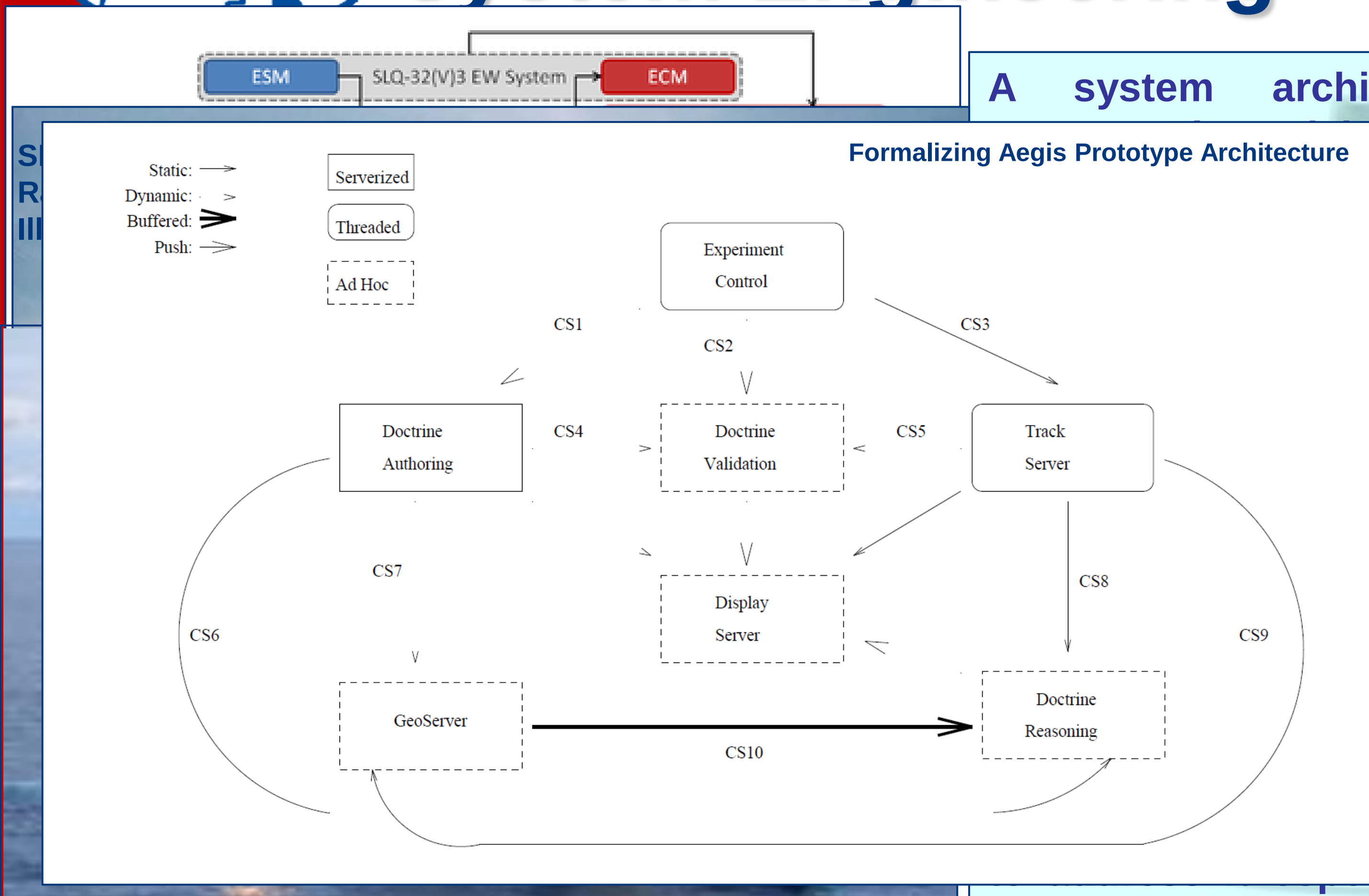
Source R.Allen (1997), CMU on Wright ADL

Techniques supporting System Engineering



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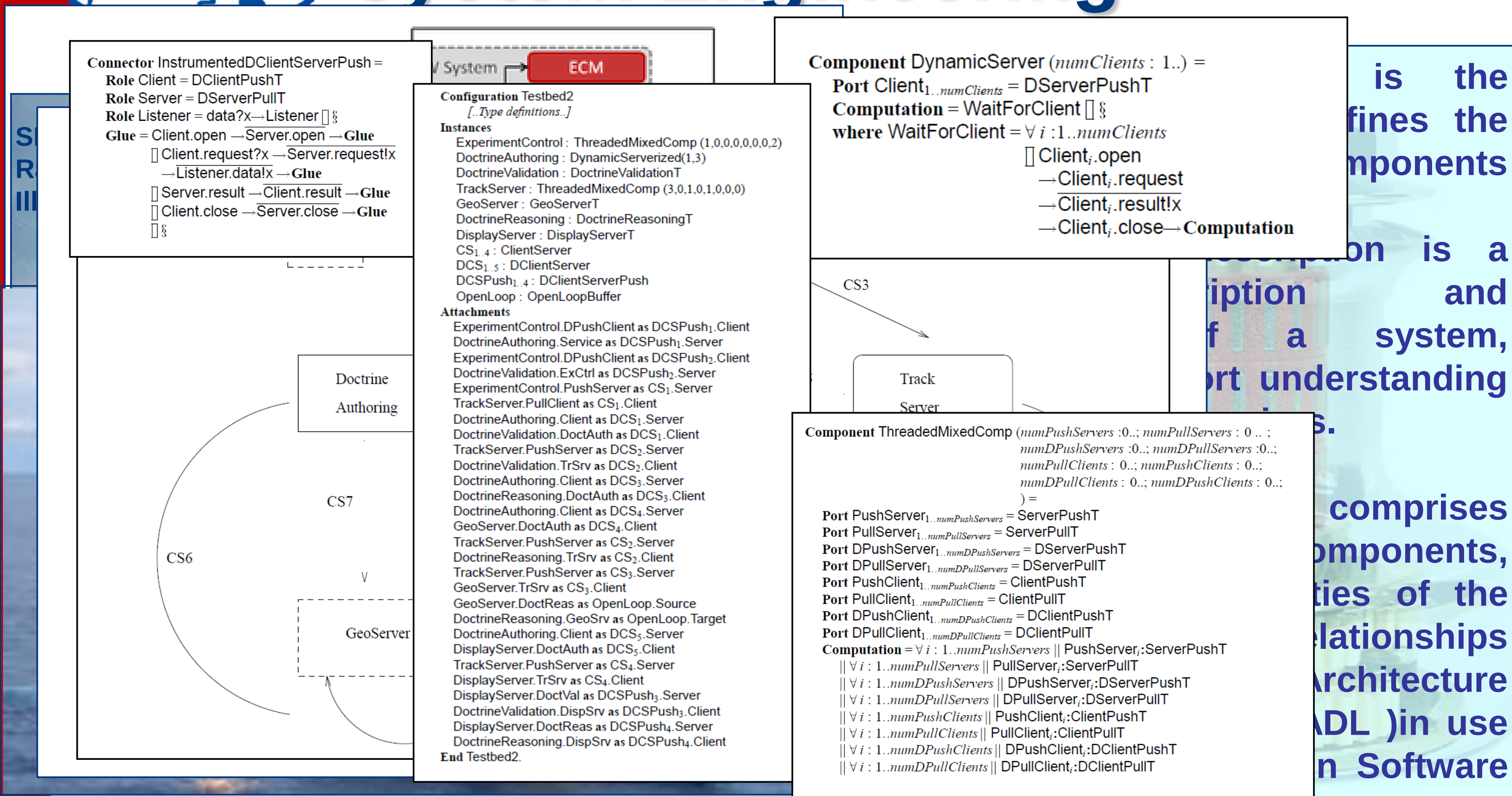
Techniques supporting System Engineering



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Techniques supporting System Engineering

- System Architecture
- ***Modeling & Simulation***
- Optimization
- System Dynamics
- Systems Analysis
- Statistical analysis
- Reliability analysis
- Decision making

Modeling & Simulation (M&S) allows to reproduce the System in a virtual framework. Different models could be developed to simulate the product/system all over its life cycle allowing to test and experiment it virtually, quickly, safely and at low cost.
The use of interoperable simulation allows to integrate the System Simulation with other equipment or components that need to interact with him at low level (e.g. emulation to test automation system) or at high level (e.g. high level architecture to design a new C4I2 system)

Simulation Team

Techniques supporting System Engineering

- Statistical analysis
- Reliability analysis
- Decision making

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Techniques supporting System Engineering


C-17 Transport Plane

- Statistical analysis
- Reliability analysis
- Decision making

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Techniques supporting System Engineering


Parachuting Service on C-17

- Statistical analysis
- Reliability analysis
- Decision making

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Techniques supporting System Engineering


Critical Activity that involve multiple interactions

- **Reliability analysis**
- **Decision making**

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Techniques supporting System Engineering

Simulation of C-17 and Parachuting solved the problem

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Techniques supporting System Engineering

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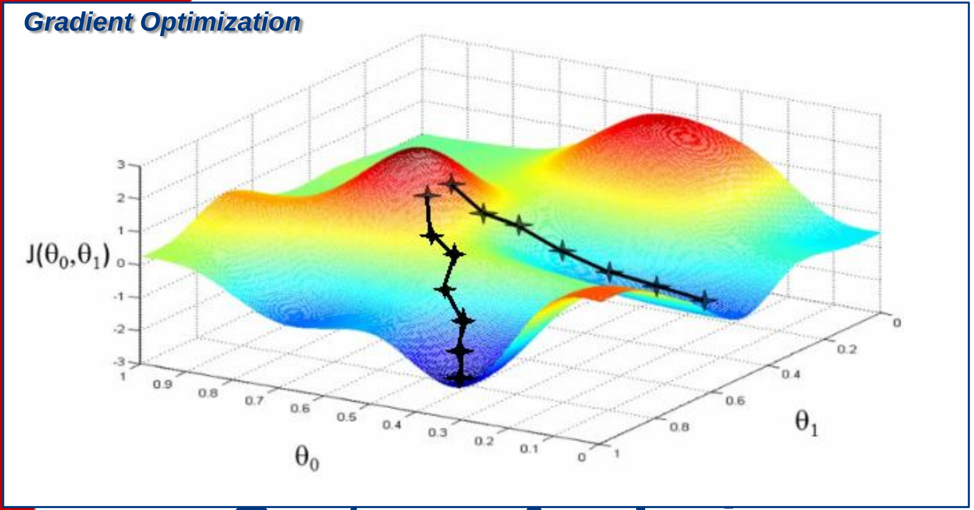
Simulation Team

Techniques supporting System Engineering

- System Architecture
- Modeling & Simulation
- *Optimization*
- System Dynamics
- Systems Analysis
- Statistical analysis
- Reliability analysis
- Decision making

Optimization Techniques related to parameters and functions introduced into a product or system could enhance its performances up to the maximum related to the existing constraints
In this field it is particularly critical to avoid Local Optimization that leads to limited optimization; this phenomena is particularly critical in case of not-linear behaviors and high number of variables.
Optimization techniques include Gradient Techniques, Metamodelling, Heuristics, Artificial Intelligence Techniques

Techniques supporting System Engineering



- Systems Analysis
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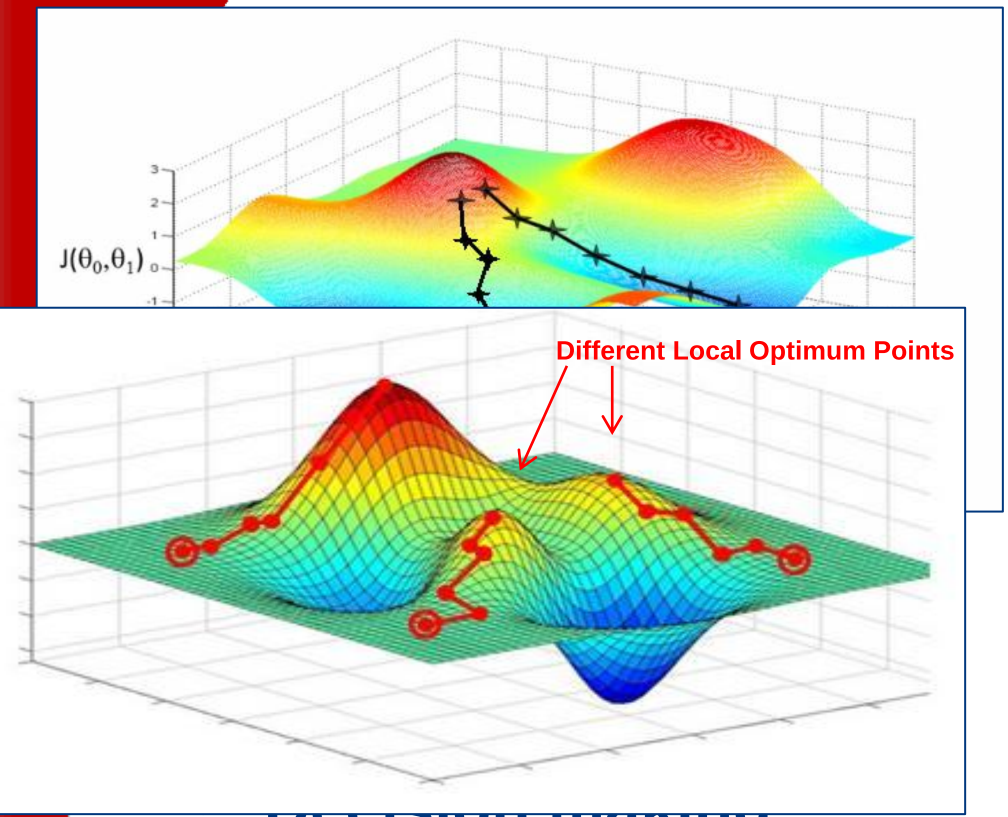
Techniques supporting System Engineering



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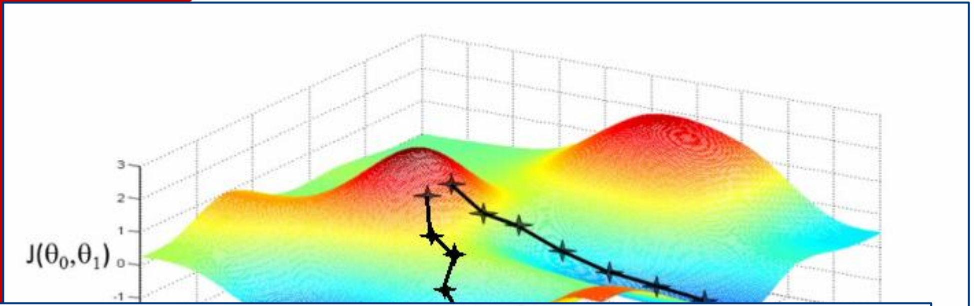
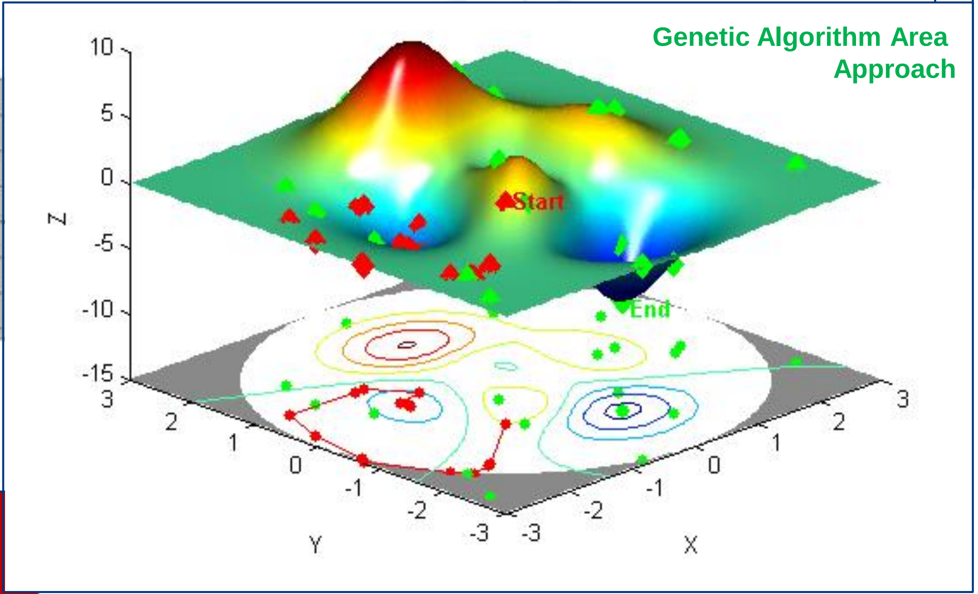
Techniques supporting System Engineering





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Techniques supporting System Engineering

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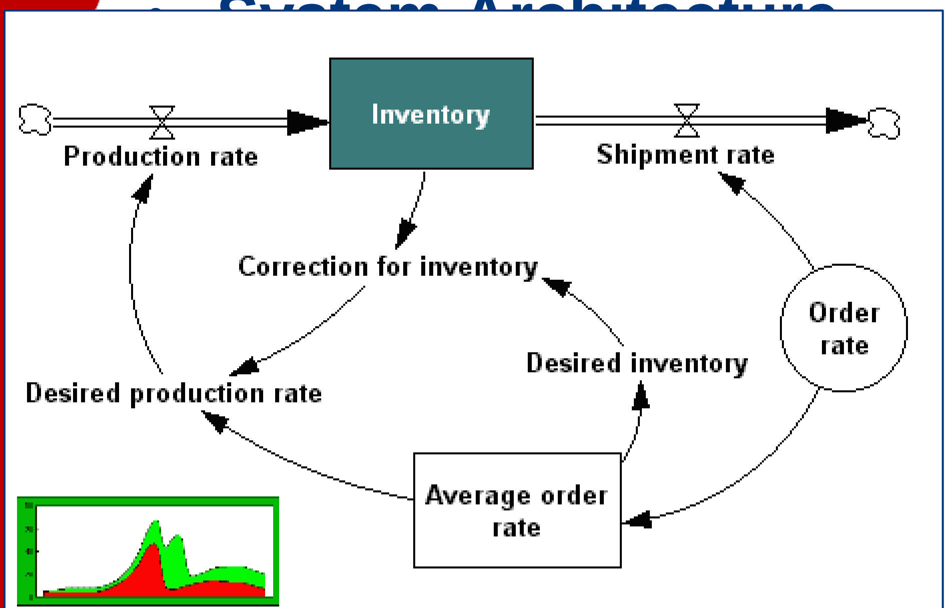
System Dynamics was introduced in middle of last century by Prof.Forrester of MIT and it is an approach devoted to understanding the nonlinear behaviour of complex systems over time using stocks, flows, internal feedback loops, and time delays.[
This represent a special simplified kind of simulation that animates the flow diagrams and there are several tools (e.g. (JDynSim, Pyndynamics, Sphinx SD, SSD, System Dynamics, Venisim) to create this models and reproduce the systems

Techniques supporting System Engineering

- System Architecture



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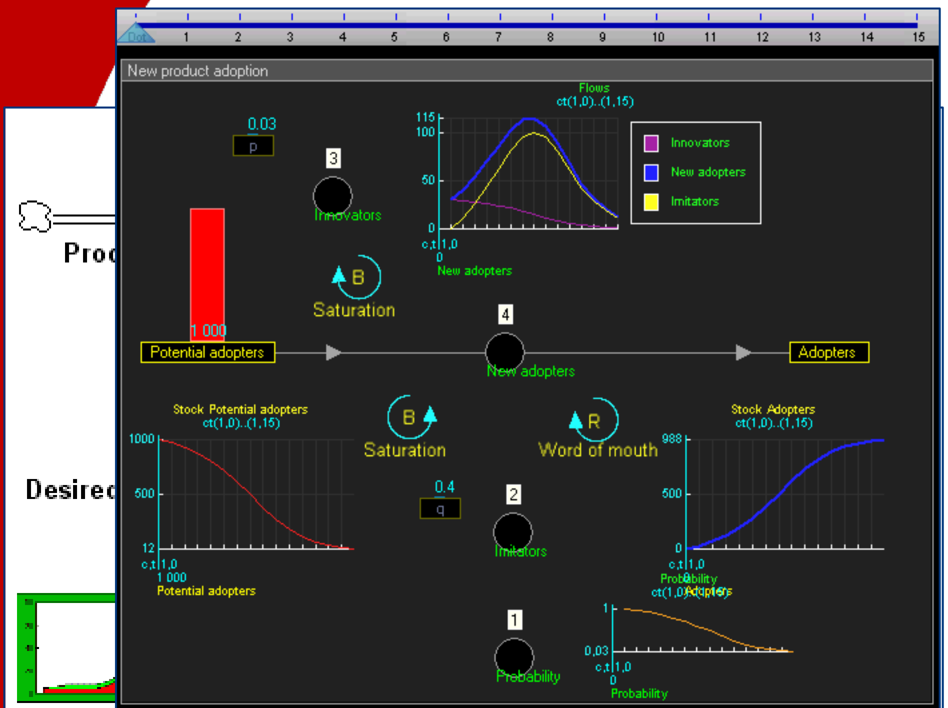
Source Wikipedia

Techniques supporting System Engineering



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Source Wikipedia

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Techniques supporting System Engineering

- System Architecture
- Modeling & Simulation
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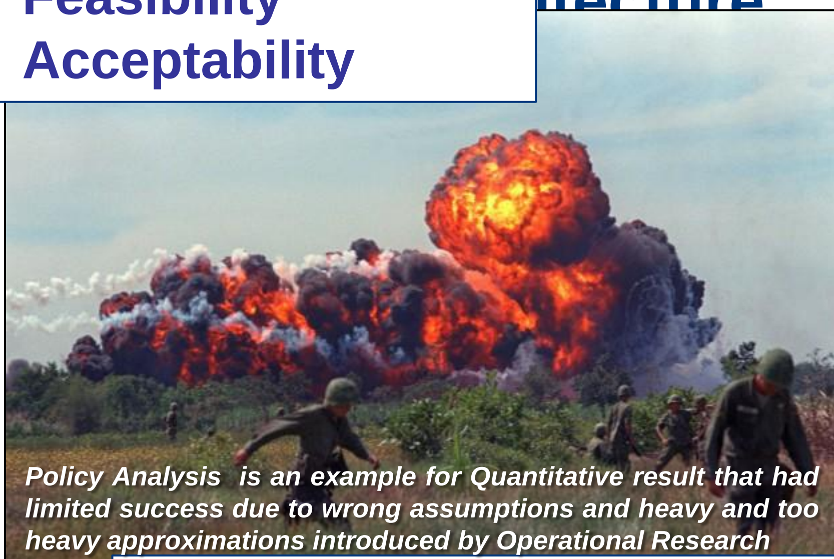
System Analysis represent an approach for engineering and it consists into the process of studying a problem; this lead to identifying objectives & functions, creating systems and procedures In order to solve the problem in an efficient way. Indeed systems analysis is a problem-solving technique based on decomposing a system into its components for the purpose of the studying how well those elements work and interact to accomplish the global objectives. System Analysis is often related with Requirement Analysis. In part System Analysis and Operational Research were sometime improperly combined due to wrong assumptions

Techniques supporting System Engineering

- Cost
- Feasibility
- Acceptability

itecture



Policy Analysis is an example for Quantitative result that had limited success due to wrong assumptions and heavy and too heavy approximations introduced by Operational Research

- Effectiveness
- Unintended Effects
- Equity

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Techniques supporting System Engineering

- System Architecture
- Modeling & Simulation
- Optimization
- System Dynamics
- Systems Analysis
- ***Statistical analysis***
- Reliability analysis
- Decision making

Statistics is based on the systemic study of the collection, analysis, interpretation, presentation, and organization of data.
In statistics it is crucial to define the samples as well as to identify the statistical model of the whole population. The Populations represent the whole set of the cases under analysis (e.g. products, events, etc.)
Statistics was originated to study Taxes and Country Economics and Demographics and to address relevance of stochastic factors over a large set of data. In statistics for engineering it is crucial to planning the data collection in terms of the Design of Experiments .

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Techniques supporting System Engineering

Aleatory Systems

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Stochastic Systems

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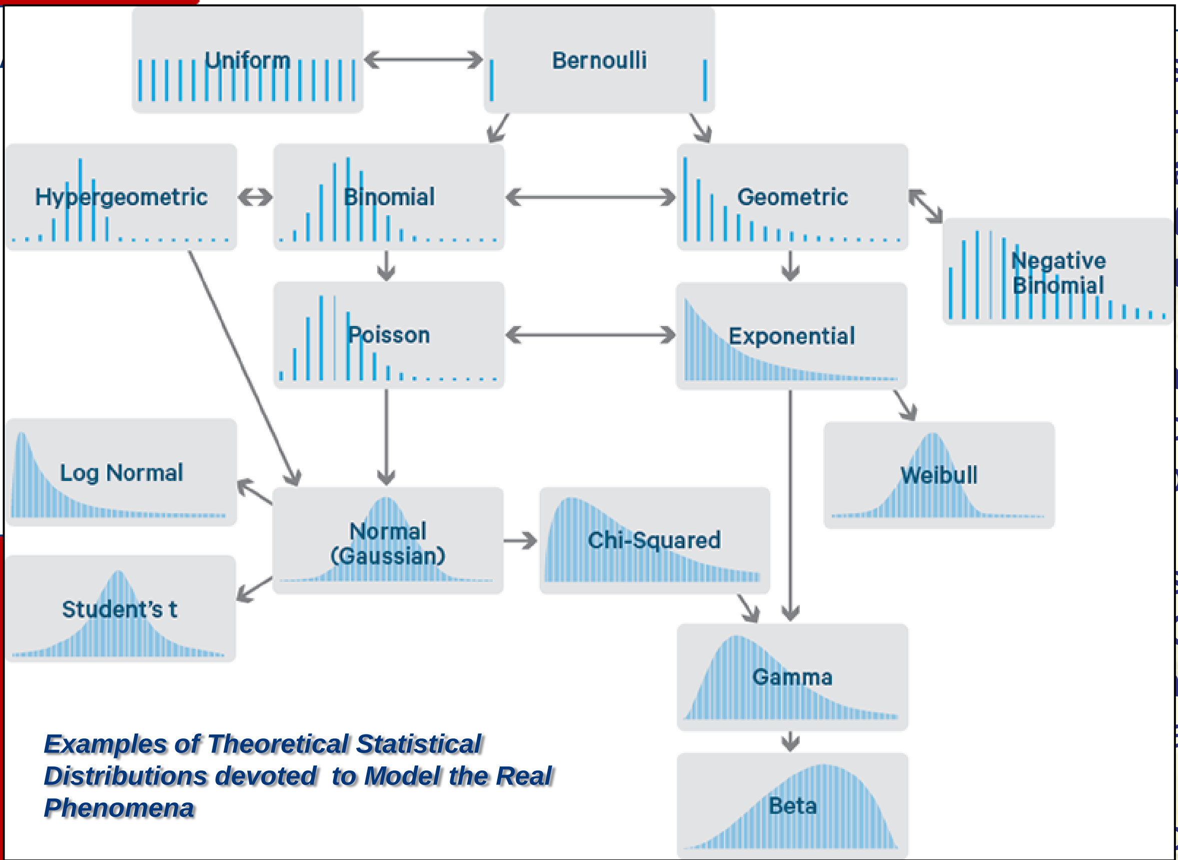
Techniques supporting System Engineering



Examples of Theoretical Statistical Distributions devoted to Model the Real Phenomena

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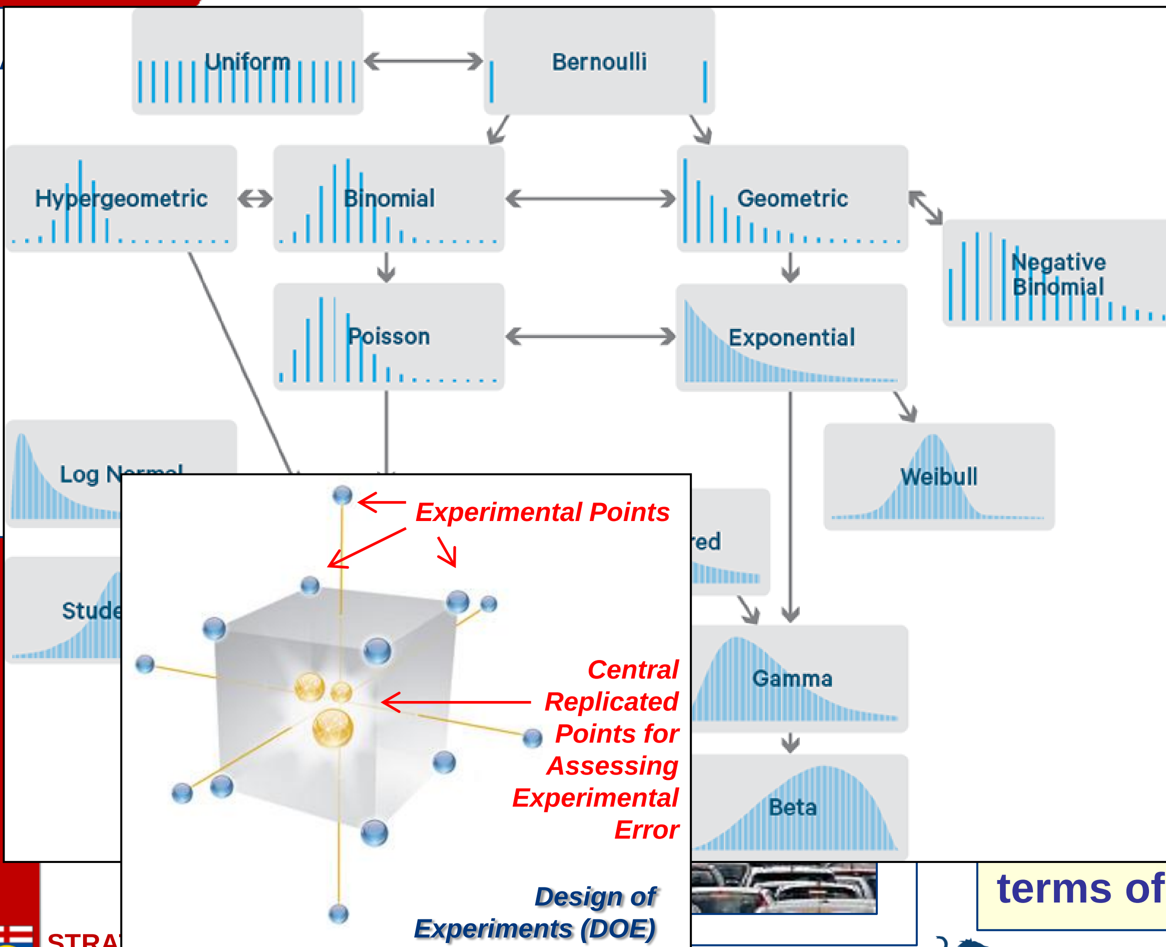
Source Web

Techniques supporting System Engineering



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Source Web

Techniques supporting System Engineering

- System Architecture
- Modeling & Simulation
- Optimization
- System Dynamics
- Systems Analysis
- Statistical analysis
- ***Reliability analysis***
- Decision making

Reliability Engineering analyzes the product dependability over its lifecycle. Reliability, describes the ability of a system or component to function under stated conditions for a specified period of time. Reliability Analysis improve also the Availability (system ability to function at a specified moment or along an interval of time). Reliability Engineering consider the degenerated capabilities based on component failures as well as preventive management and breakdowns. During Engineering Phase this analysis allows to improve these parameters through optimization of Product Design

Simulation Team

Techniques supporting System Engineering

$$Av = \frac{MTBF}{MTBF + MTTR}$$

MTBF Mean Time between Failures
MTTR Mean Time to Repair
Av Availability

- Statistical analysis
- ***Reliability analysis***
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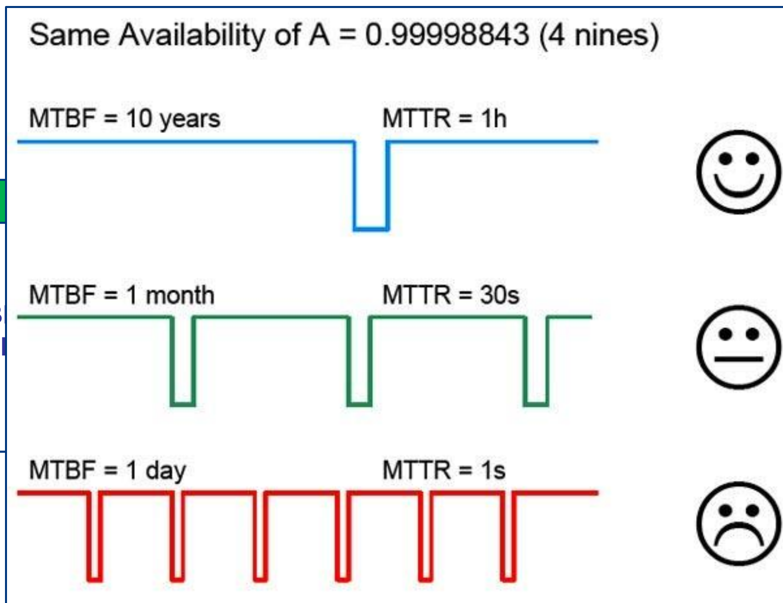
Techniques supporting System Engineering



MTB
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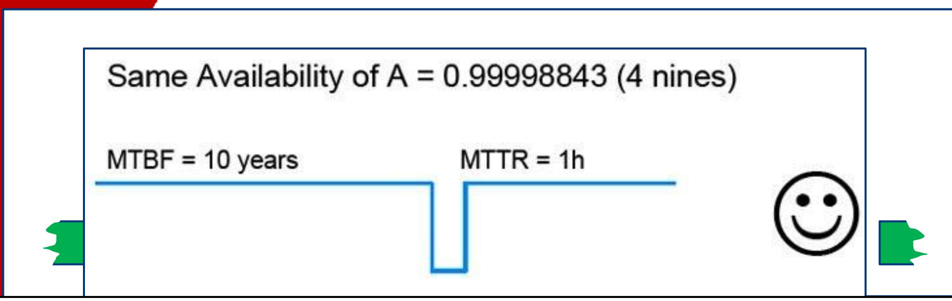

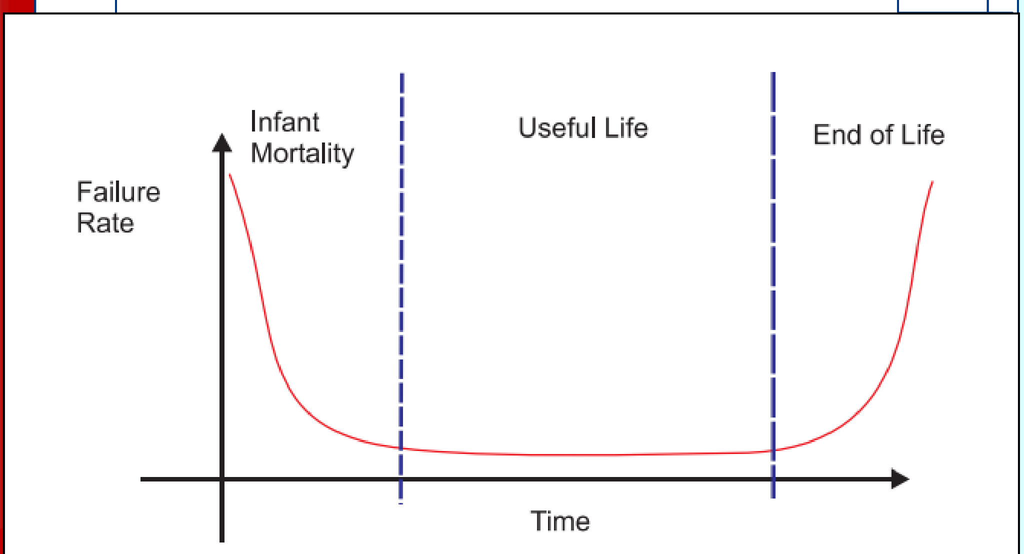

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Techniques supporting System Engineering

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- Modeling & Simulation
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- System Dynamics
- Systems Analysis
- Statistical analysis
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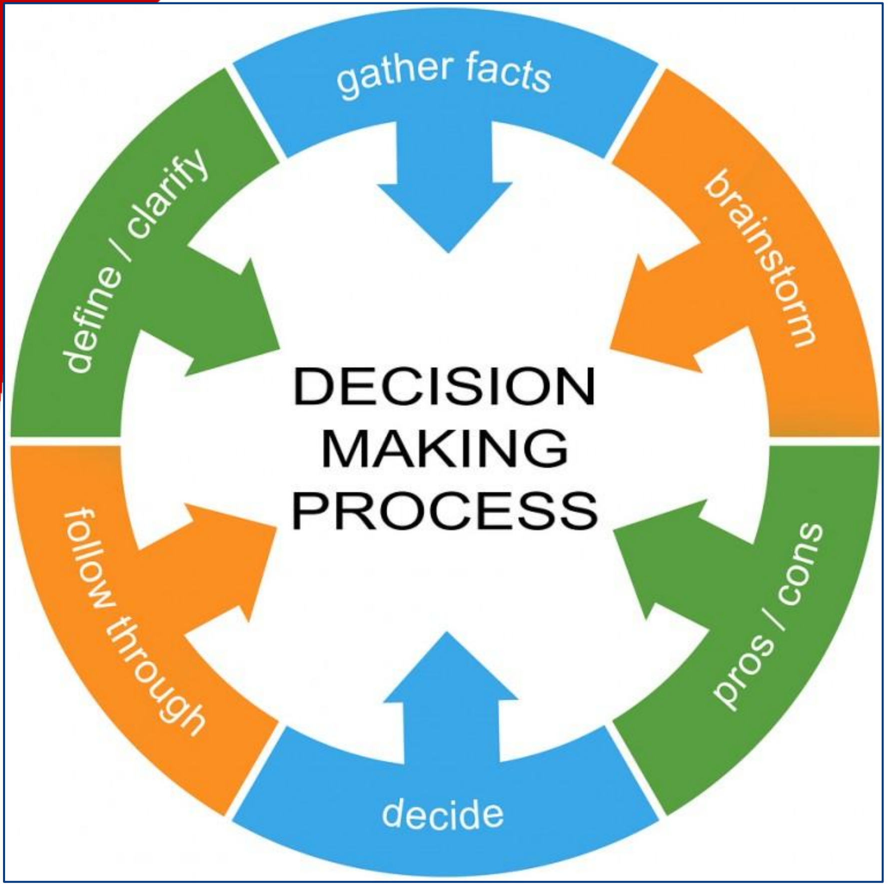
- *Decision making*

Decision Making is the Cognitive Process devoted to the selection of a Course of Actions (COA) or Solution among several alternative possibilities. Decision Making address both the necessity to finalize the decision within limited resources such as time, knowledge and people as well as the capability to identify the most effective solution.

Decision Making is the process of identifying and choosing the best Course of Actions from many alternatives based on their characteristics, evaluated performance and even considering the preferences of the Decision Maker.

Techniques supporting System Engineering



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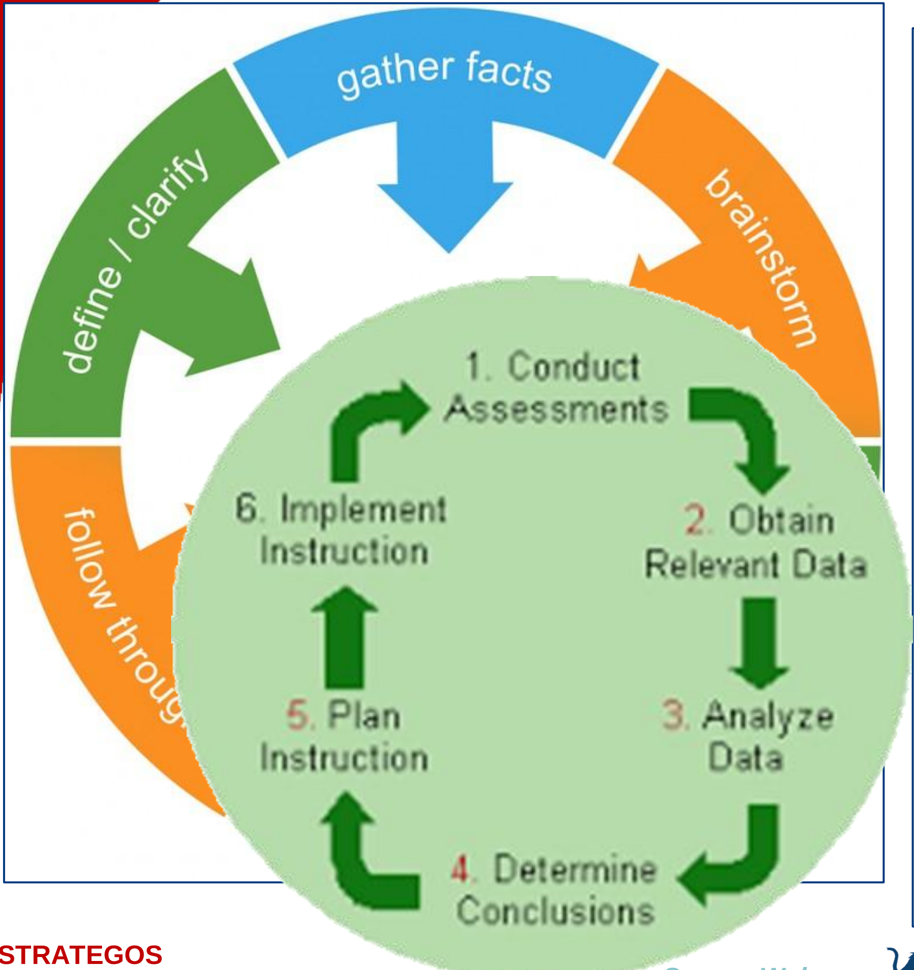
Techniques supporting System Engineering



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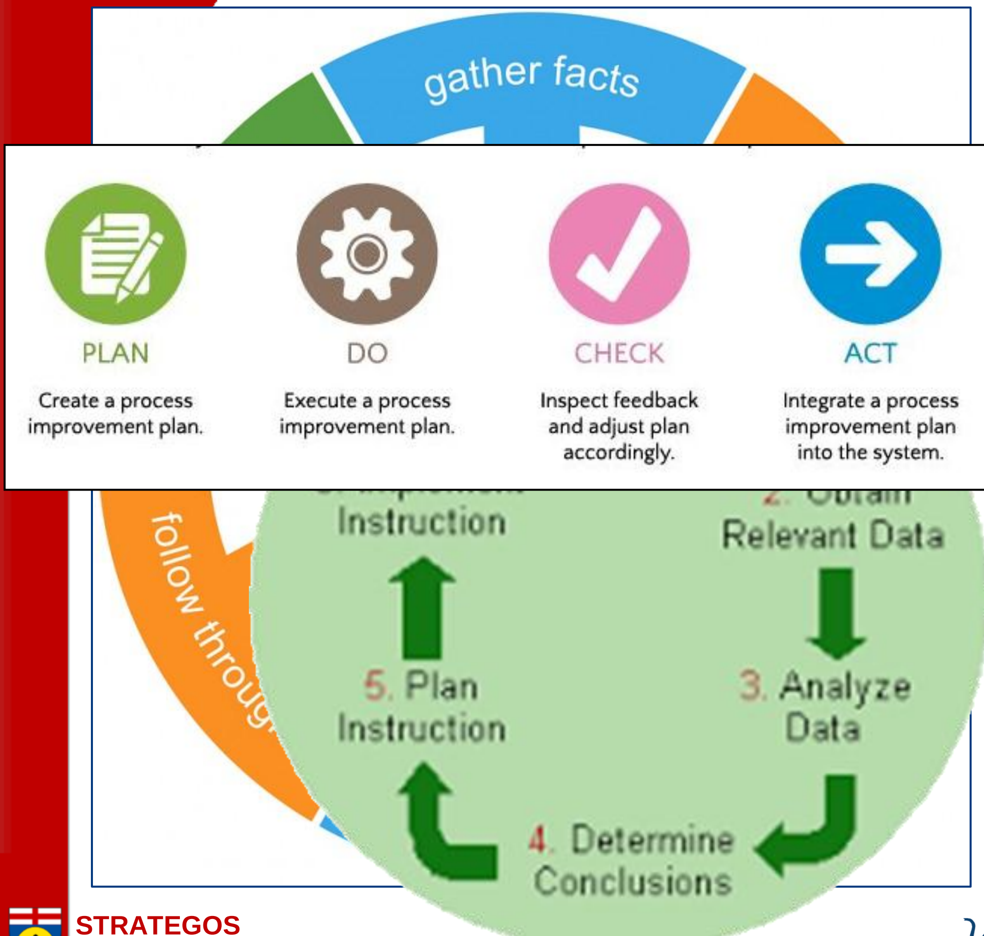
Techniques supporting System Engineering



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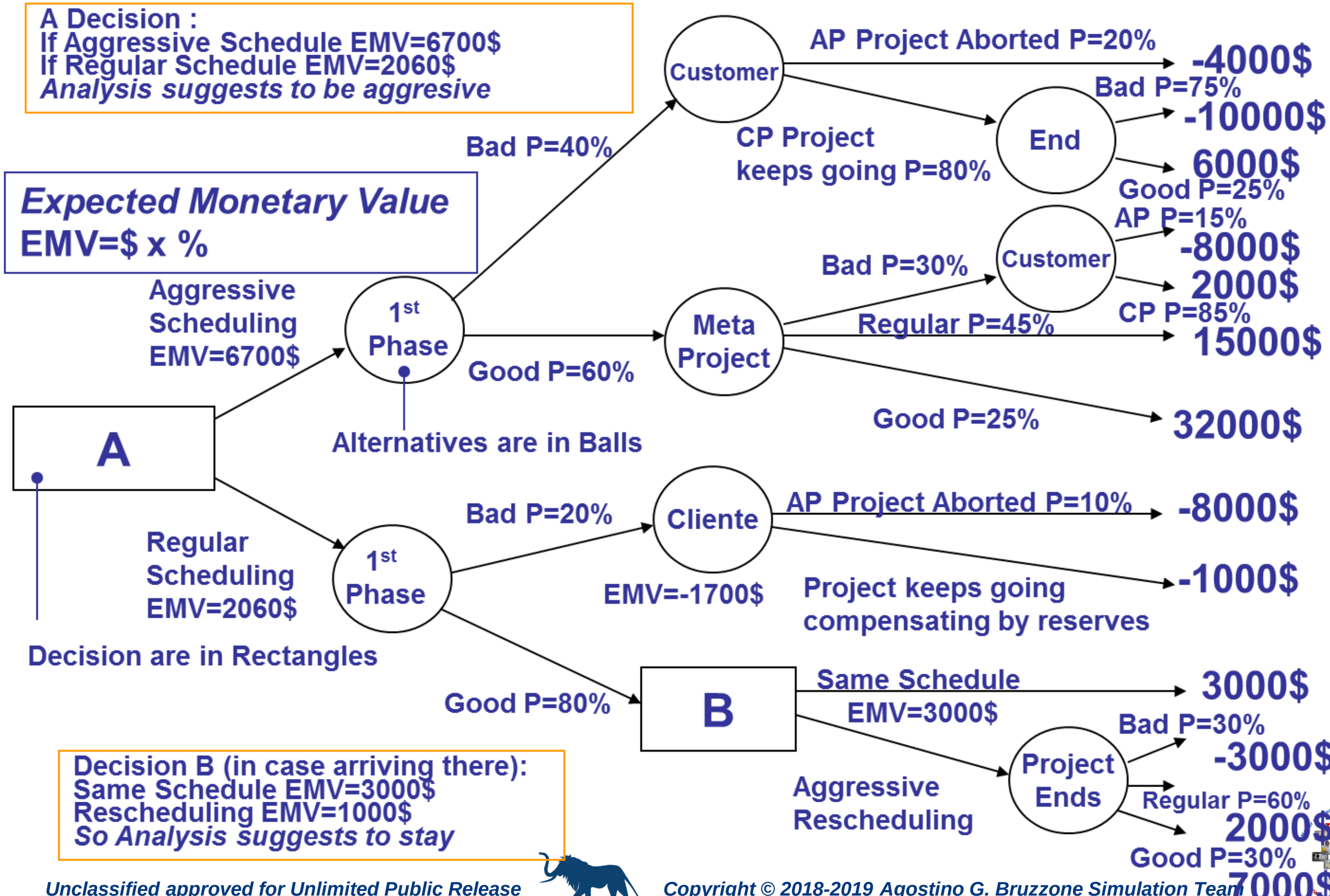
Simulation Team

Decision Tree for EMV & Risk Analysis

A Decision :
If Aggressive Schedule EMV=6700$
If Regular Schedule EMV=2060$
Analysis suggests to be aggresive

Expected Monetary Value
EMV=$ x %



Decision B (in case arriving there):
Same Schedule EMV=3000$
Rescheduling EMV=1000$
So Analysis suggests to stay

From System Engineering to Complex Systems

- **Today Engineering is mostly focused on creating systems that aggregate many different functions and components, with high degree of interactions and often including interoperability issues…**

e.g. we are moving from designing

… a phone…

… to a smartphone

Modeling Tools for System Engineering

- Several tools and methodologies have been developed to support Systems Engineering including
  - **USL**
  - **UML**
  - **QFD**
  - **IDEF0**

Modeling Tools for System Engineering

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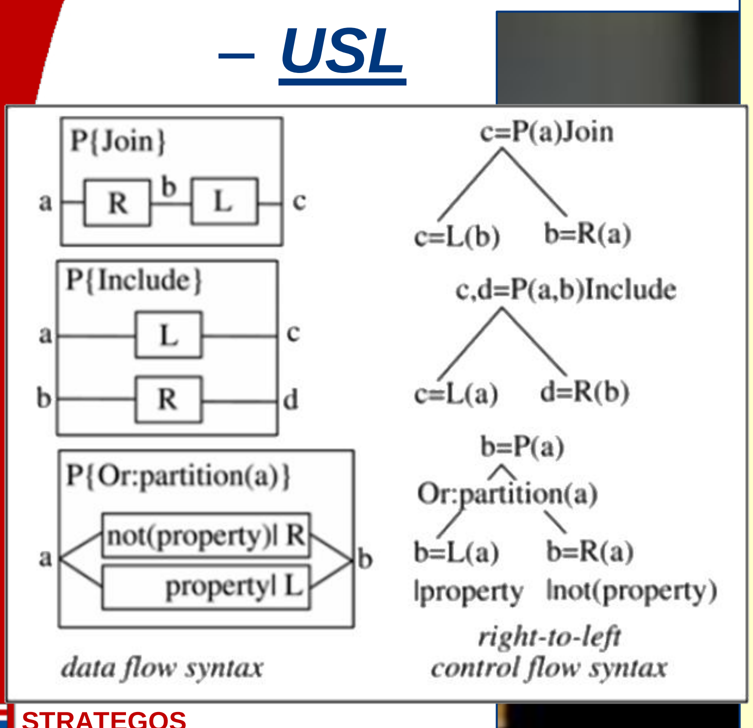
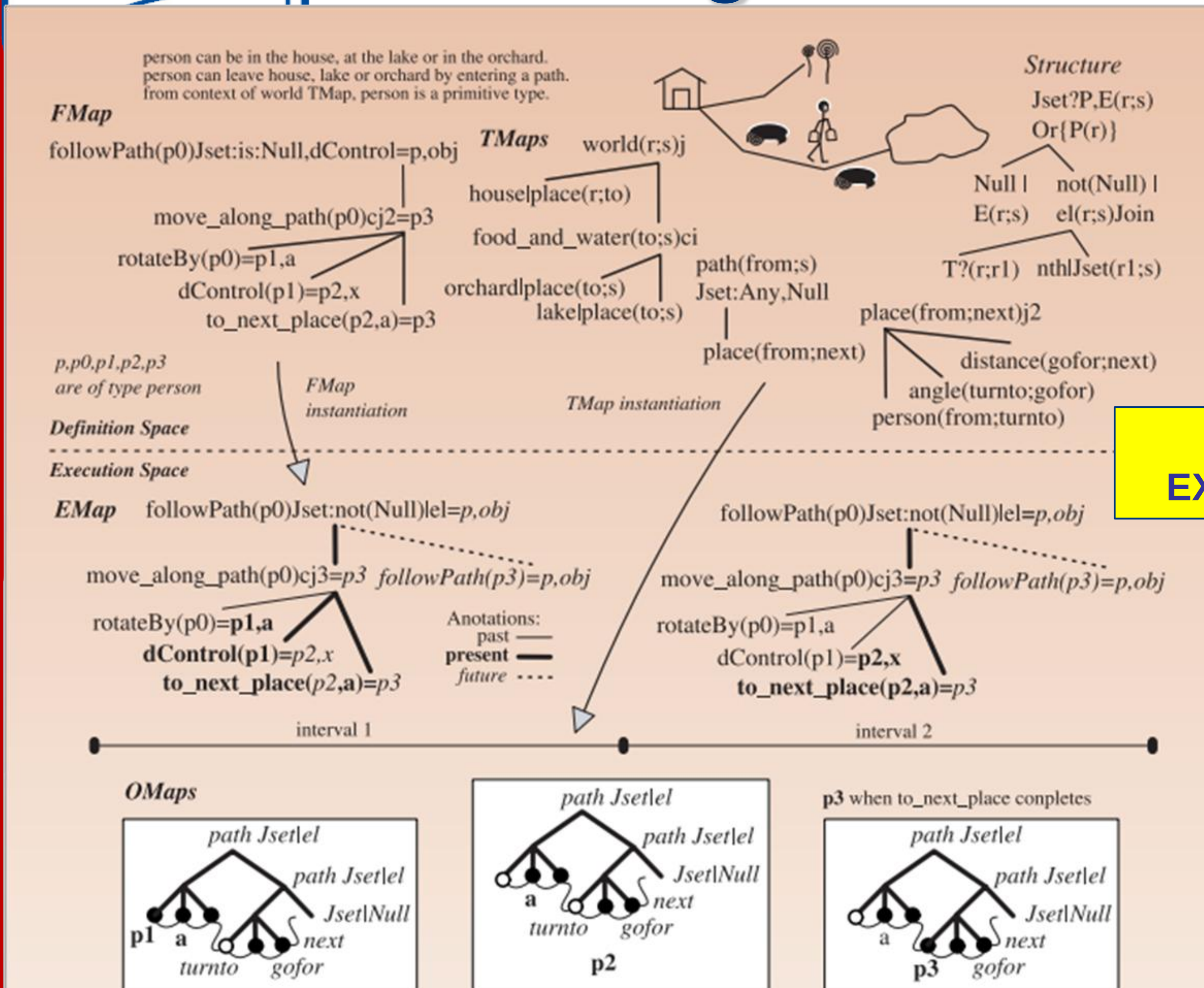


USL, the Universal Systems Language (USL, is a computer system language based on a preventive instead of a curative paradigm developed my Margaret Hamilton based on lessons learned from the Apollo onboard flight software effort. USL diffused over multiple domains as a systems engineering approach since it called by its computer language name (001AXES)

USL is an innovative way to think about systems: instead of object-oriented and model-driven systems, the designer thinks in terms of system-oriented objects (SOOs) and system-driven models.

Modeling Tools for System



Source http://letslearn2015.blogspot.it/2015/04/hamilton-technologies.html

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Language (USL, is a
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hink about systems:
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in terms of system-
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USL EXAMPLE

Simulation Team

Modeling Tools for System Engineering

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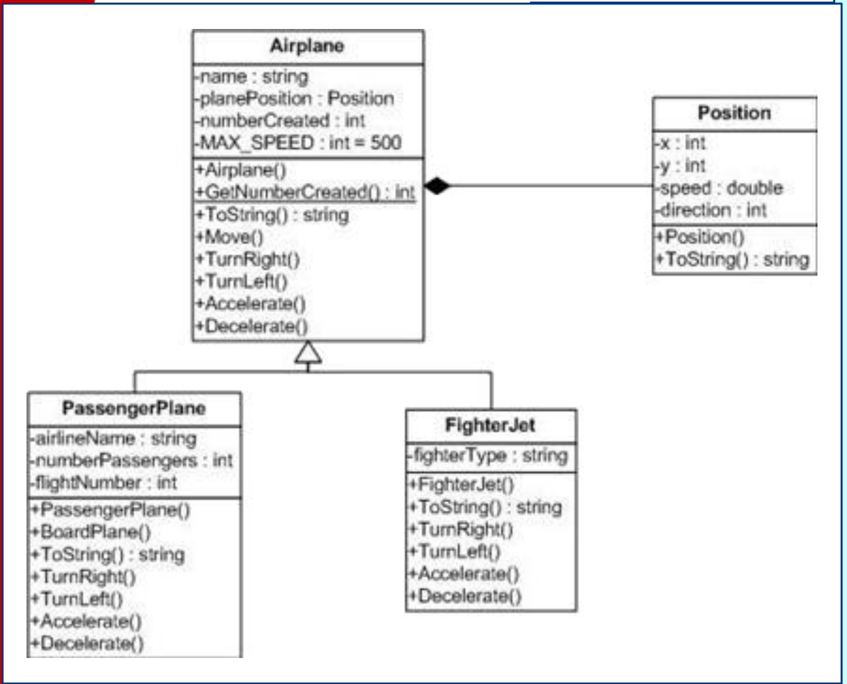
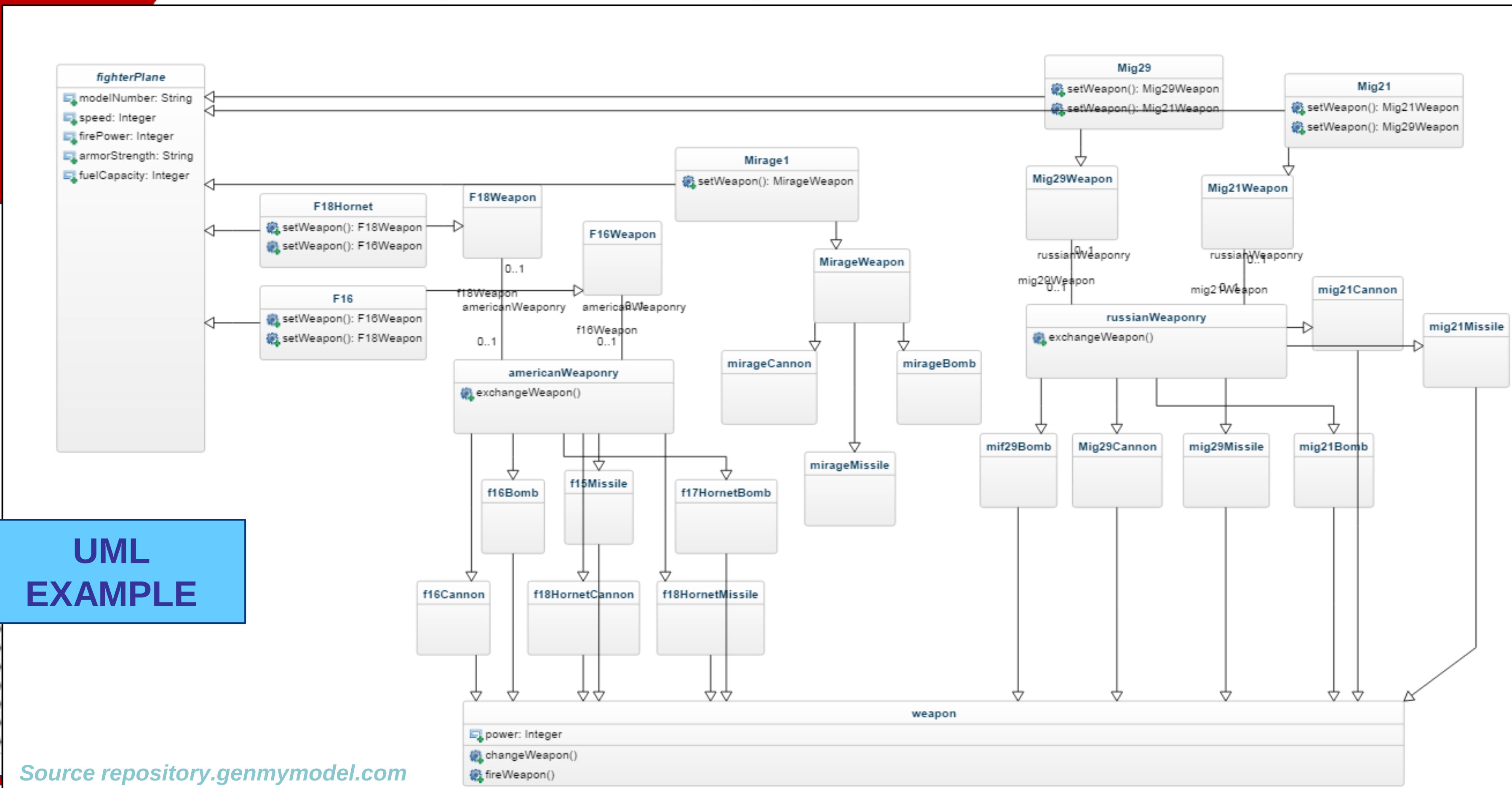


UML, the Unified Modeling Language, is a general-purpose, developmental, modeling language in the field of software engineering, that is intended to provide a standard way to visualize the design of a system.

UML was originally motivated by the desire to standardize the disparate notational systems and approaches to software design (Grady Booch, Ivar Jacobson, James Rumbaugh at Rational Software 1994–95).

In 2005 UML was adopted by ISO (International Organization for Standardization) as an approved standard and then it has been periodically revised.

Modeling Tools for System Engineering



UML EXAMPLE

Source repository.genmymodel.com

Modeling Tools for System Engineering

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Modeling Tools for System Engineering

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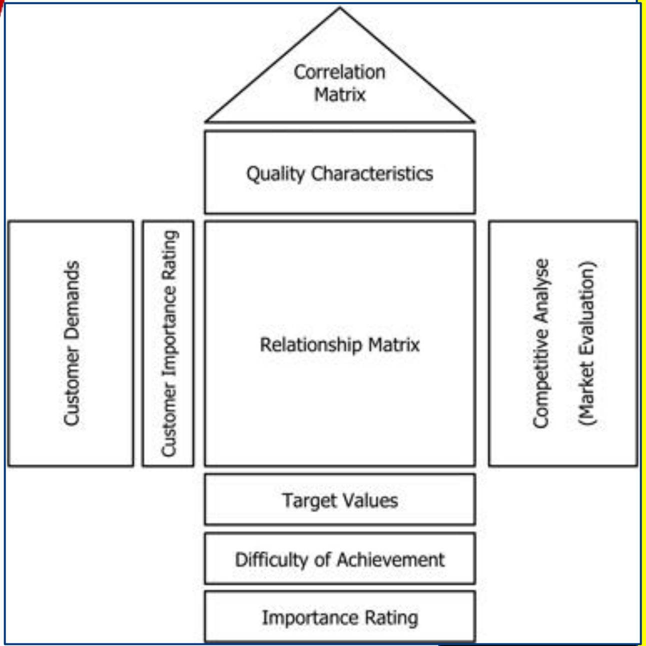

QFD, the Quality function deployment, is a method transforming customer needs (the voice of the customer, VOC) into engineering characteristics (and appropriate test methods) for a product or system. QFD creates operational definitions of the system requirements and prioritizes its characteristics as well as development targets.
It was introduced by Dr. Yoji Akao (Japan 1966) to transform qualitative user demands into quantitative parameters, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process.

Modeling Tools for System Engineering

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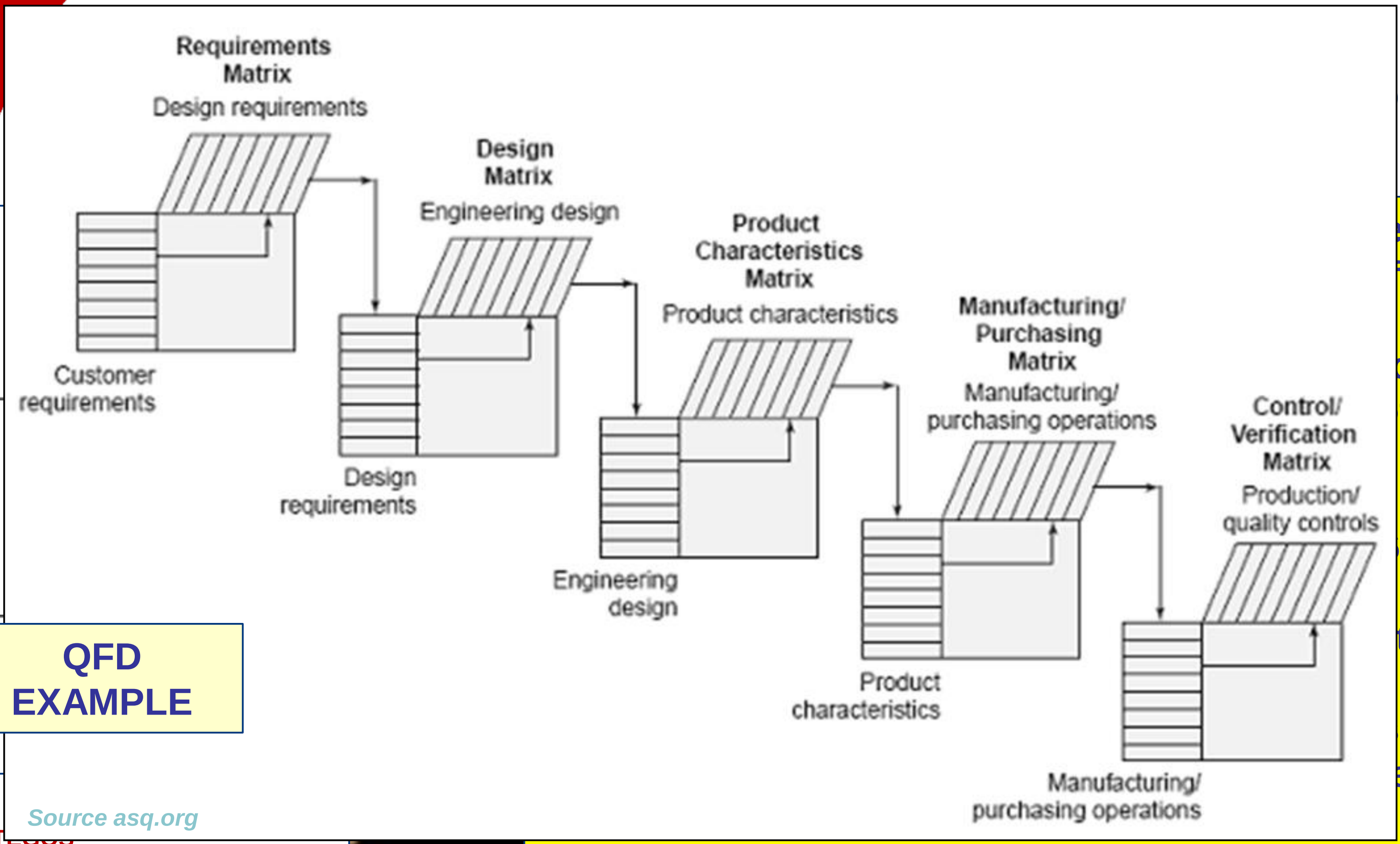

QFD EXAMPLE

Modeling Tools for System Engineering

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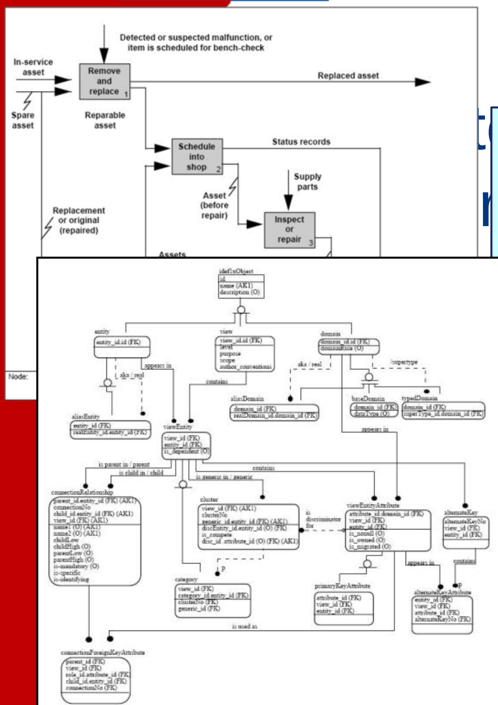
  - ***IDEF0***

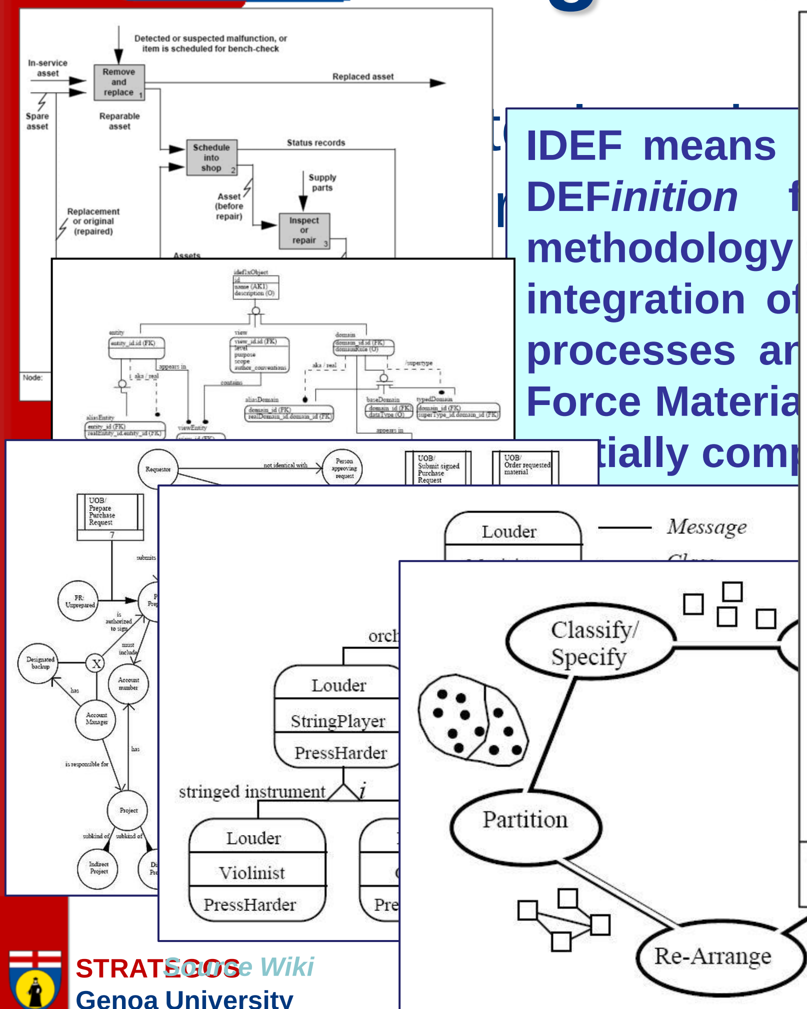
Modeling Tools for System Engineering



IDEF means I*CAM (Integrated Computer Aided Manufacturing)* DEF*inition* for F*unction* M*odeling* and is a modeling methodology for the analysis, development, reengineering, and integration of information systems, manufacturing & business processes and software. IDEF appeared in '70 within the Air Force Material Lab deeloping several IDEF languages (most just partially completed and adopted):

IDEF0 (Function modeling), IDEF1 (Information Modeling), IDEF1X (Data Modeling), IDEF2 (Simulation Model Design), IDEF3 (Process Description Capture), IDEF4 (Object-Oriented Design), IDEF5 (Ontology Description Capture), IDEF6 (Design Rationale Capture), IDEF7 (Information System Auditing), IDEF8 (User Interface Modeling), IDEF9 (Business Constraint Discovery), IDEF10 (Implementation Architecture Modeling), IDEF11 (Information Artifact Modeling), IDEF12 (Organization Modeling), IDEF13 (Three Schema Mapping Design), IDEF14 (Network Design)

Modeling Tools for System Engineering



IDEF means
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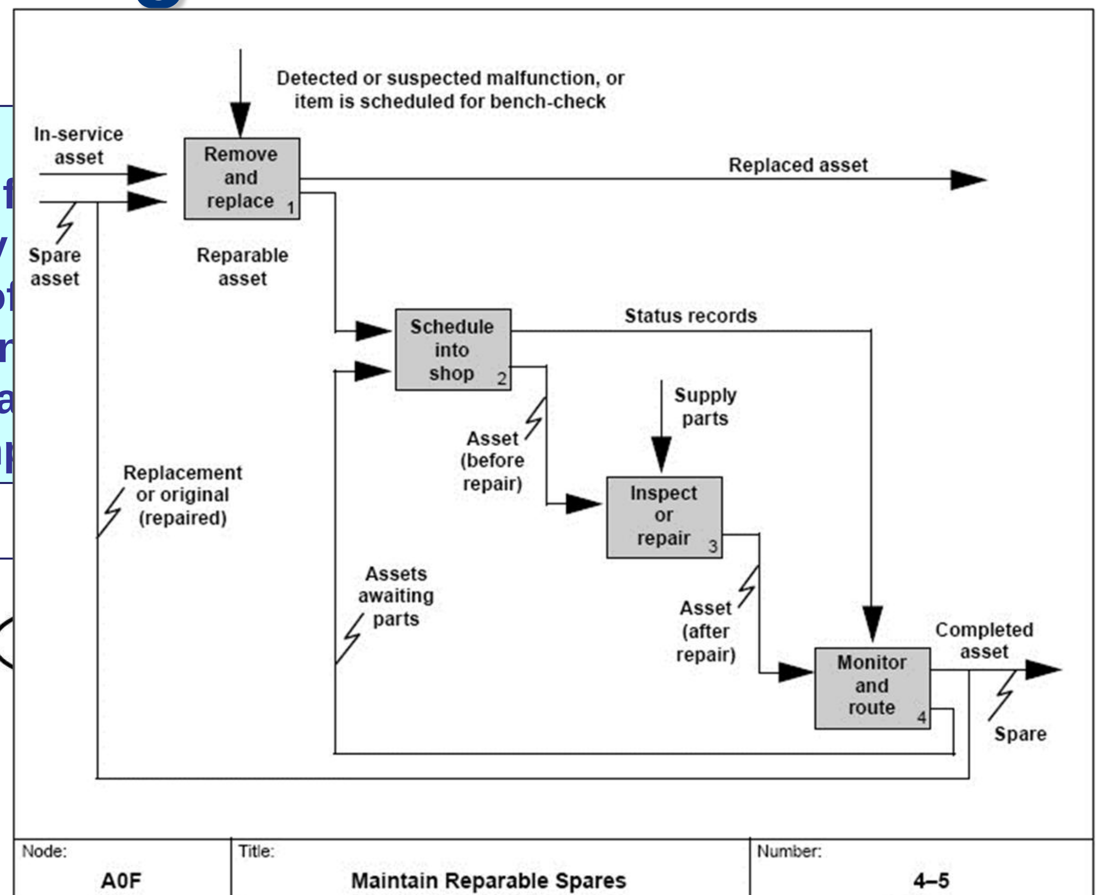

e Schema Mapping Design), IDEF14

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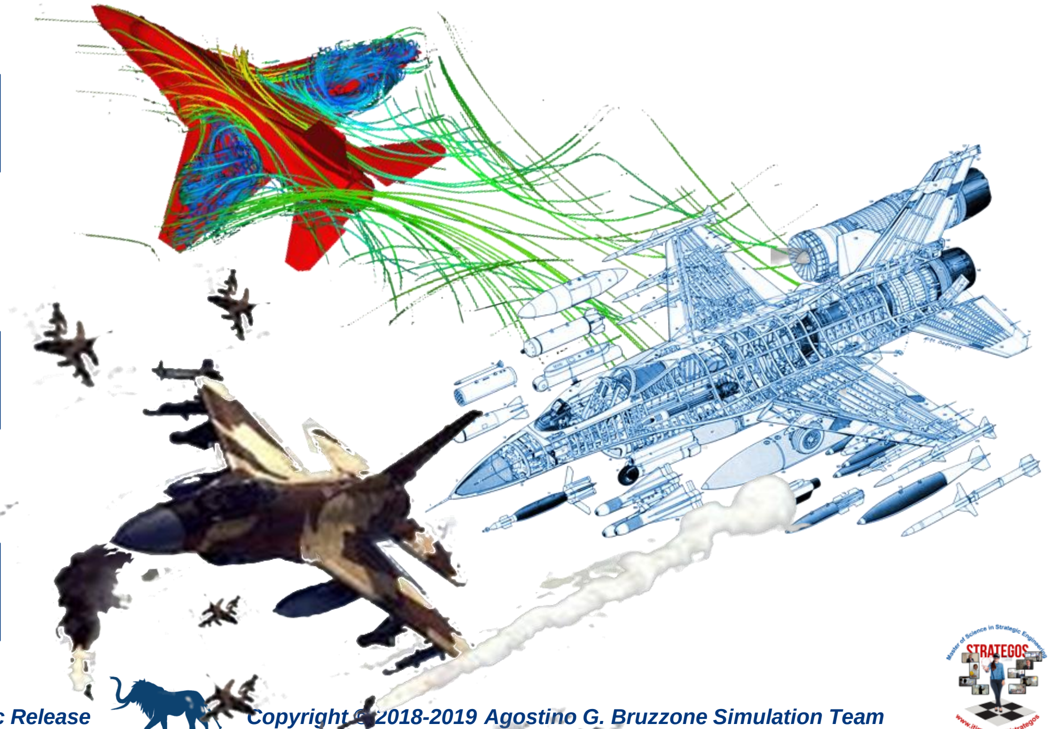
Complexity Concepts in System Engineering

There are different kind of complexity affecting the Products and Systems to be addressed:

Internal Complexity

Integration Complexity

External Complexity



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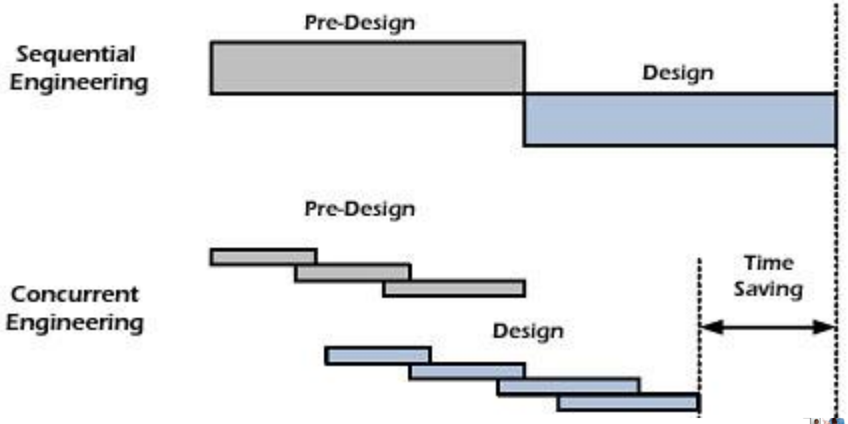
Complex Systems/Products for Aerospace & Defence

- **Weapon Systems represent examples of Complex Systems often devoted to interoperate among each others**

Simulation Team

Concurrent Engineering: a Definition

A Systematic approach to the integrated concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, costs, schedule, and user requirements

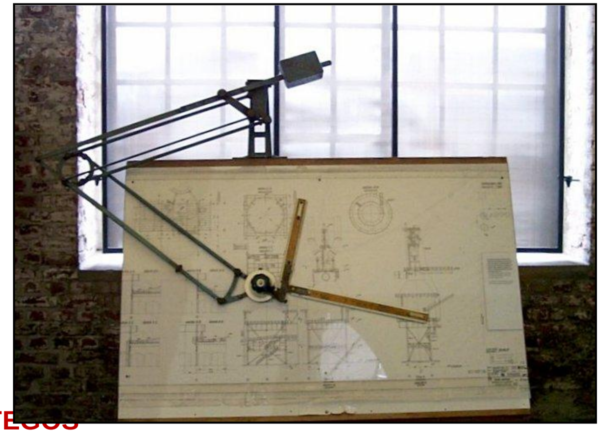


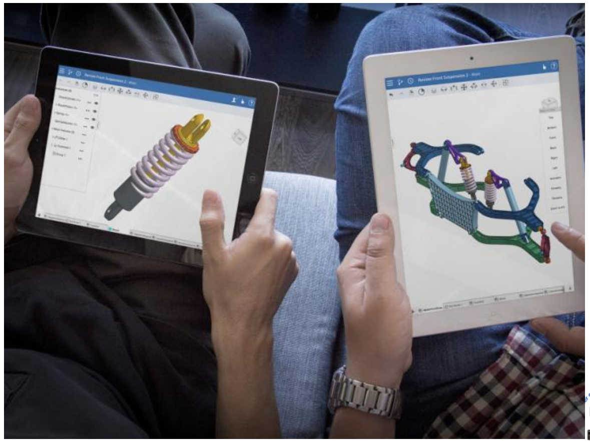
Concurrent Engineering vs. Traditional approach (Old Way)

Traditional Approach

Product Requirement							
Product Design	Prototyping	Re-Design	Development	Test	Manifacturing		
Customer Specifications		Design Process	Production Plans	Revise Production plans	Production		

Time Line





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Concurrent Engineering vs. Traditional approach (New Way)

Product Requirement

Product Design

Customer Specifications

Prototyping

Process Design

Production Plans

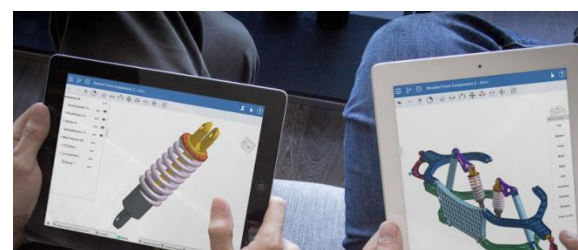
Production

Concurrent Engineering

New Tools

New Communications

New Teams

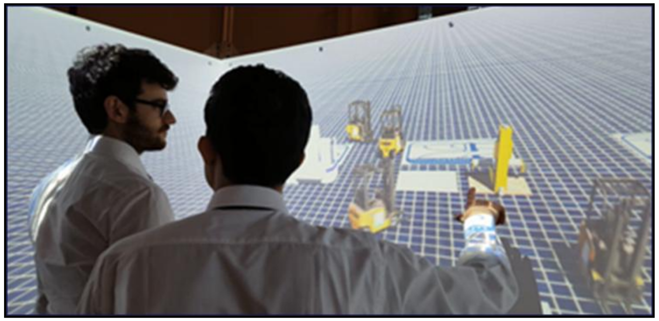


Need of interoperable distributed analysis tools allowing instantaneous data exchange between teams

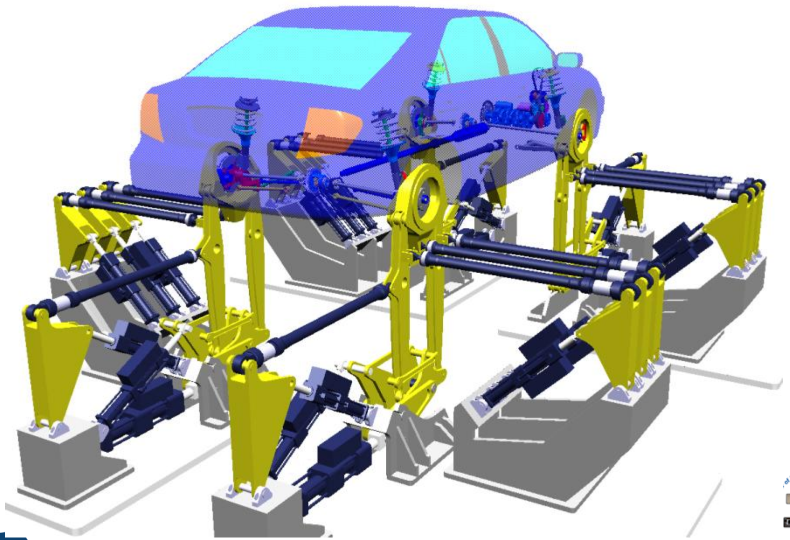
Concurrent Engineering in Project Management

- Multidisciplinary Team
- Enphasis on process more than on operative functions
- Active participation of customers as team members
- Multiple activities in parallel
- Ehnanced informative sistem

Concurrent Engineering key factors



- People should be adequately prepared to work in this environment
- Develop adequate interactive distributed support tools and models
- Prepare companies for Business Process Reengineering



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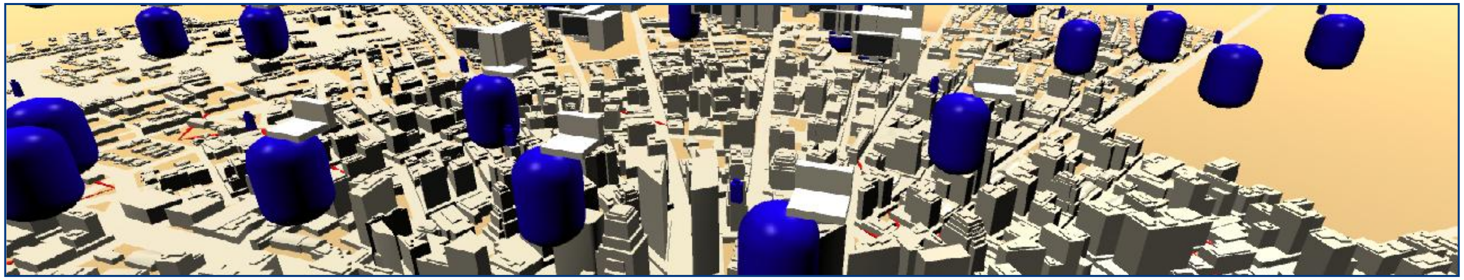
Trandisciplinary Engineering

The number of complex problems for new Engineers has increased, and the technical knowledge required to address and mitigate them continues to evolve rapidly. These problems include not only the design of engineering systems with numerous components and subsystems, but also the design, redesign, and interaction of social, political, managerial, commercial, biological, medical, and other systems. These systems are likely to be dynamic and adaptive in nature. Finding creative solutions to such large-scale, unstructured problems requires activities that cut across traditional disciplinary boundaries.



Transdisciplinary vs. Multidisciplinary Approach

Modern projects require to combine different backgrounds from technical to managerial. Therefore it is critical to avoid multidisciplinary teams that are just a mix of different professionists unable to understand each other and to share common concepts.

It is crucial to create transdisciplinary team with common language and capability to to interoperate effectively in the development of new projects over common goals.

Simulation Team
www.simulationteam.com

SoSE for Complex Systems

Need for more interoperable, Cost Effective Systems

- Defense Systems are more and more ***increasingly complex*** due to ICT and connectivity evolution
- Distribution of Joint operations is creating a need for Defense Systems to be ***increasingly interoperable***
- Despite their complexity, Defense Systems budget constraints force to be more and more ***cost effective***

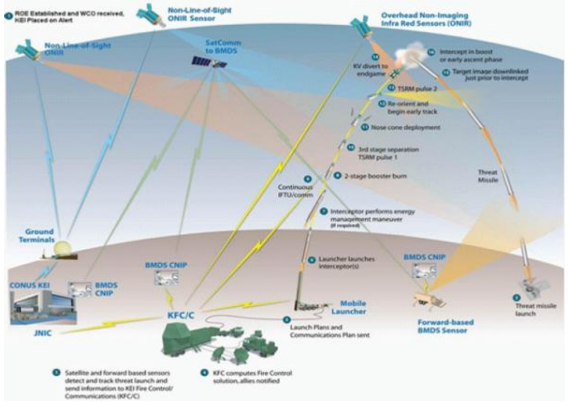
Source Mavris, ASDL, GATECH

Simulation Team

SoSE:
System of Systems Engineering

- Technology related to military and space systems increases, increasing systems **complexity**
- Distributed operations require systems to become increasingly **interoperable**
- Eventhough complexity arises, defence and aerospace systems must be **cost effective**

What is SoSE?



- **System of Systems (SoS) Engineering is an emerging interdisciplinary approach focusing on the effort required to transform capabilities into SoS solutions and shape the requirements for systems. SoS Engineering ensures that:**
  - **Individually developed, managed, and operated systems function as autonomous constituents of one or more SoS and provide appropriate functional capabilities to each of those SoS**
  - **Political, financial, legal, technical, social, operational, and organizational factors, including the stakeholders' perspectives and relationships, are considered in SoS development, management, and operations**
  - **A SoS can accommodate changes to its conceptual, functional, physical, and temporal boundaries without negative impacts on its management and operations**
  - **A SoS collective behavior, and its dynamic interactions with its environment to adapt and respond, enables the SoS to meet or exceed the required capability.**

Source: System of Systems Engineering Center of Excellence, Sponsored by the Office of the Under Secretary of Defense for Acquisition, Technology, & Logistics, Defense Systems, Systems and Mission Integration, Joint Force Integration (USD-AT&L)

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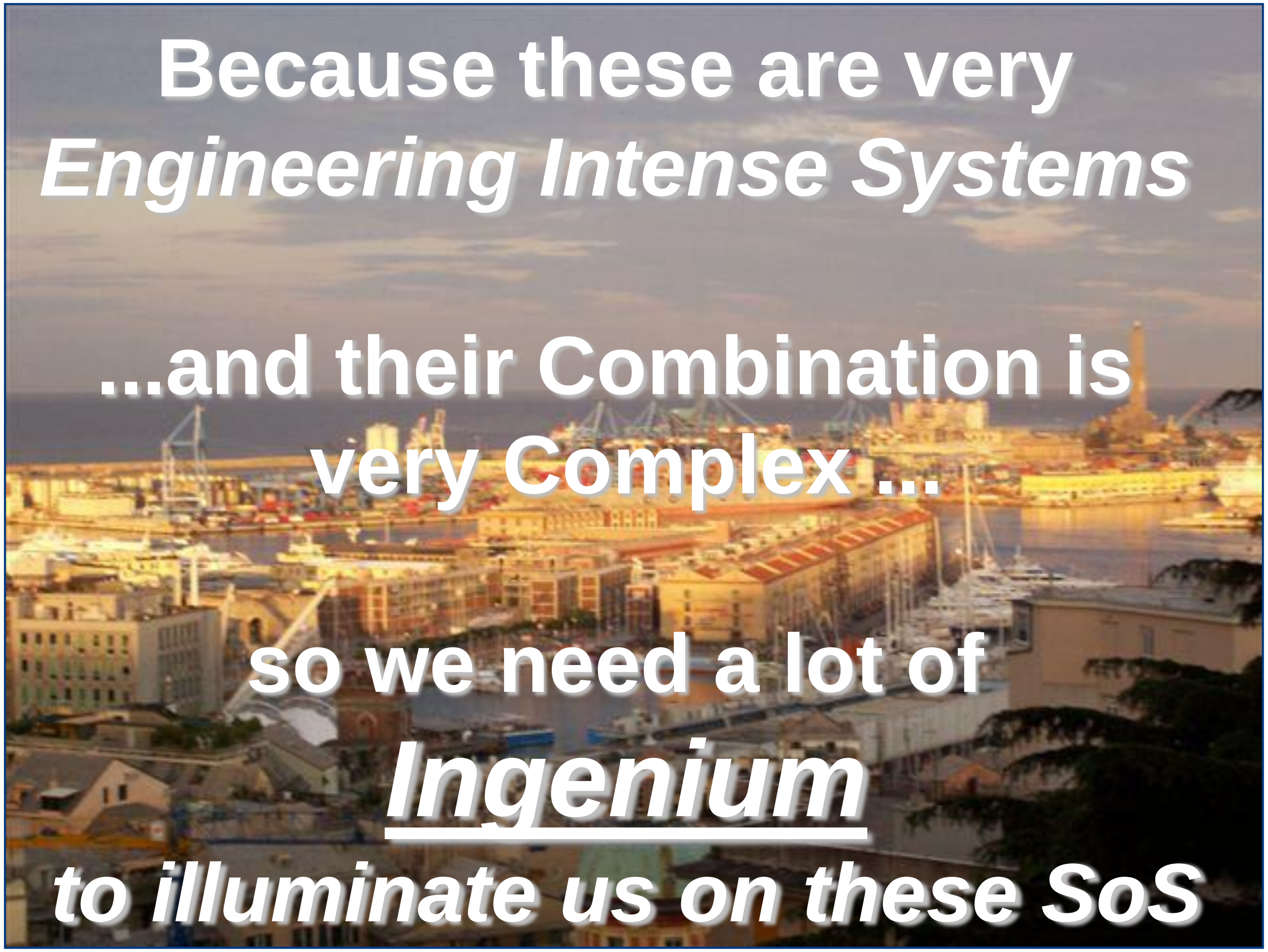
System of Systems Engineering: Why Engineering?



Because these are very *Engineering Intense Systems*

...and their Combination is very Complex ...

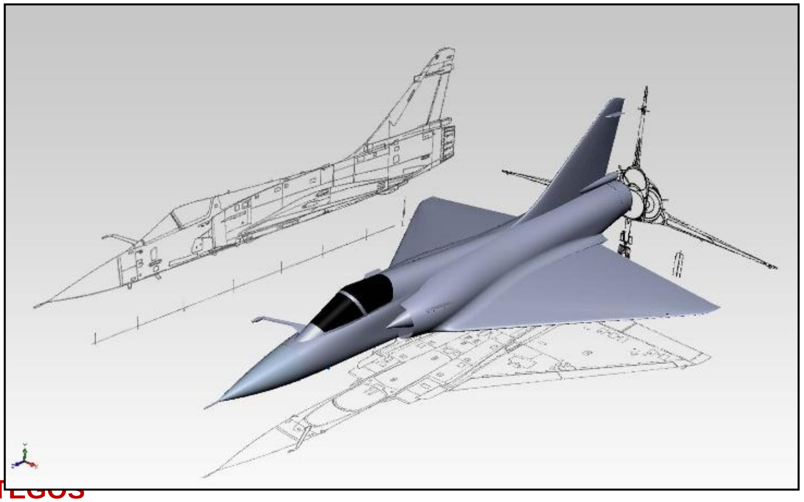
so we need a lot of *<u>Ingenium</u>* *to illuminate us on these SoS*

Why SoSE?
Background Context

- Technology related to military and space systems increases, increasing systems **complexity**
- Distributed operations require systems to become increasingly **interoperable**
- Eventhough complexity arises, defence and aerospace systems must be **cost effective**

Why SoSE in Early-Phases of the Project?

Fundamentals decisions, strongly affecting costs, are made during the Early Phases of Project, the system design & during architecture definition?

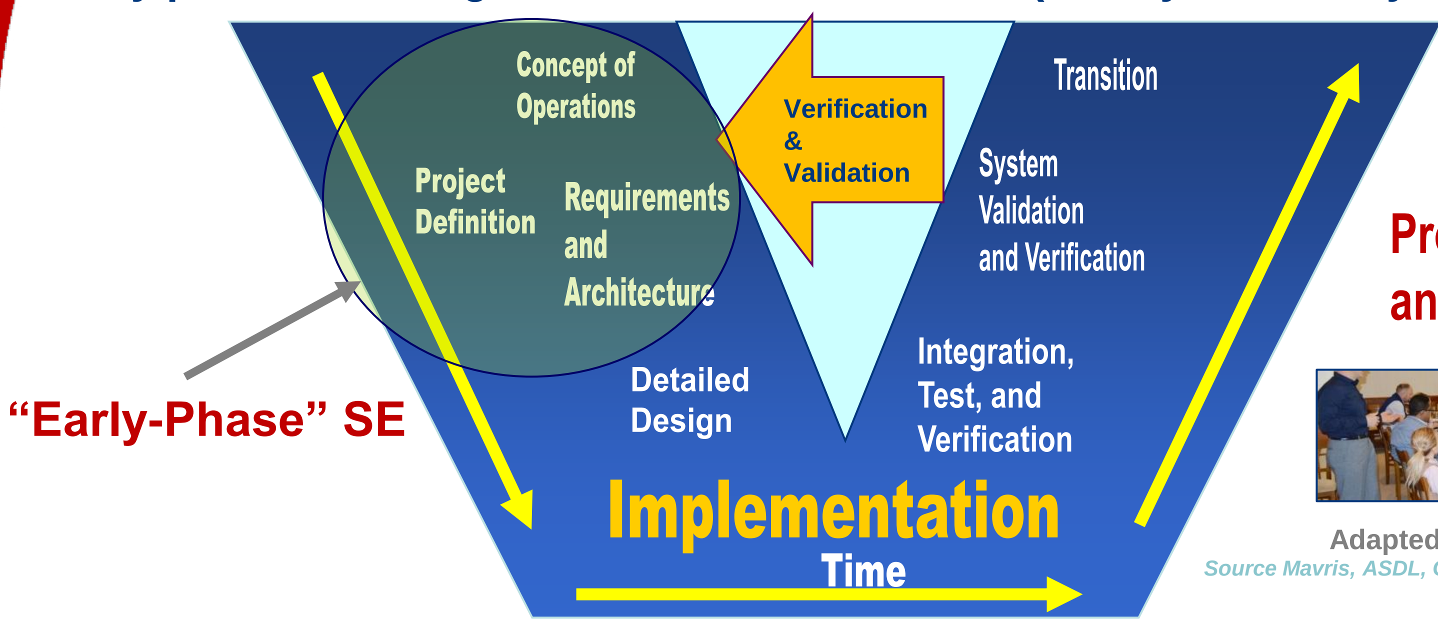


SoSE: Emphasis on "Early-Phase" SE

Systems Engineering (SE)

– An *interdisciplinary* approach to *derive, evolve, and verify* a life-cycle balanced *system solution* that *satisfies customer expectations* and meets public acceptability (IEEE 1220-1994)

The most fundamental (and most difficult and costly to reverse) decisions are made in early phases of design & architecture definition (doubly true for System of Systems



Adapted From INCOSE Handbook

Source Mavris, ASDL, GATECH

Whey SoSE is focusing on Capability-Based Design?

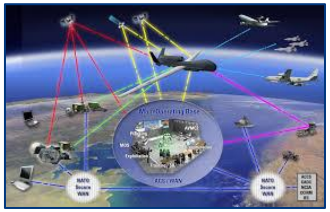
- New and diverse challenges related to defence
- Challenges addressed acquiring new capabilities
- Capabilities embedded in system of systems rather than in a single system

Shift new Systems to a “Capability-based” Focus

“In the past 15 years, the Department of Defense (DOD) has faced a constant stream of new challenges…the United States must be prepared both to deal with a larger number of more diverse threats with varied attributes and to do so in circumstances involving complex and uncertain risks.”

-Naval Analytical Capabilities: Improving Capabilities-Based Planning, **Committee on Naval Analytical Capabilities and Improving Capabilities-Based Planning, National Research Council**

- Customers want to acquire capabilities, particularly in military applications
  - New acquisition paradigms attempt to be more “top-down” & avoid stove-piping
- New capabilities are often not enabled by single systems, but by SoS (Systems of Systems)
  - The supporting systems (such as ships and aircraft) are typically multi-mission
  - Systems cannot be studied in isolation, but must be examined in the context of operational scenarios, environments, and interactions
- High-quality System of Systems Engineering is a key component to success in capability-based design



Source Mavris, ASDL, GATECH

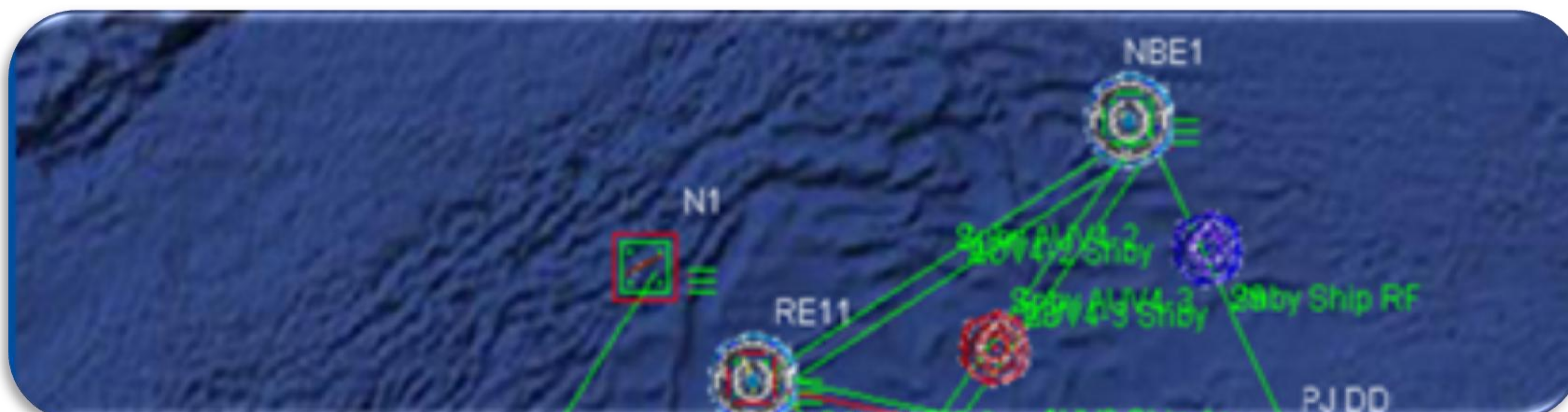
System of Systems

- **“A set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities.”**
  - *DoD Defense Acquisition Guidebook 2004*
- **"System of systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems."**
  - *INCOSE-TP-2003-002-03, Systems Engineering Handbook V3*
- **“Groups of systems, each of which individually provides its own mission capability, that can be operated collectively to achieve an independent and usually larger, common mission capability “**
  - *Pre-Milestone A and Early-Phase Systems Engineering: A Retrospective Review and Benefits for Future Air Force Systems Acquisition. National Academies Press, 2008*

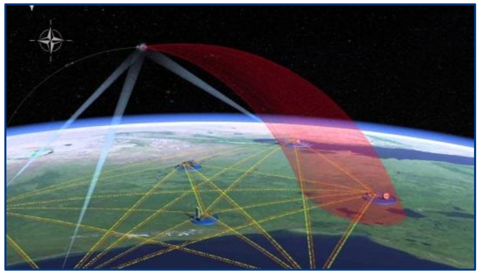
Source Mavris, ASDL, GATECH

Why SoSE instead of SE?

- Single component of complex systems are usually multi-mission
- Systems are to be studied contextualized to the operational scenarios considering interactions
- High quality SoSE is foundamental to develop succesful capability-based design



What makes *Systems of* *Systems* (SoS) Different?



Compared to a *System*, a *SoS* might:

- *Be larger in scope*
- *Have more complex integration*
- *Be often subject to higher degree of uncertainty and risk*
- *Evolve continuously despite differing element lifecycles*
- *Lack a single management/acquisition entity and have a broader range of stakeholders*
- *Have elements which are not designed to fit the whole, and which are integrated post-design and deployment*
- *Exhibit emergent behaviors*
- *Have more ambiguous requirements and fuzzy boundaries*
- *Adopt continuous a SE approach which never ends*

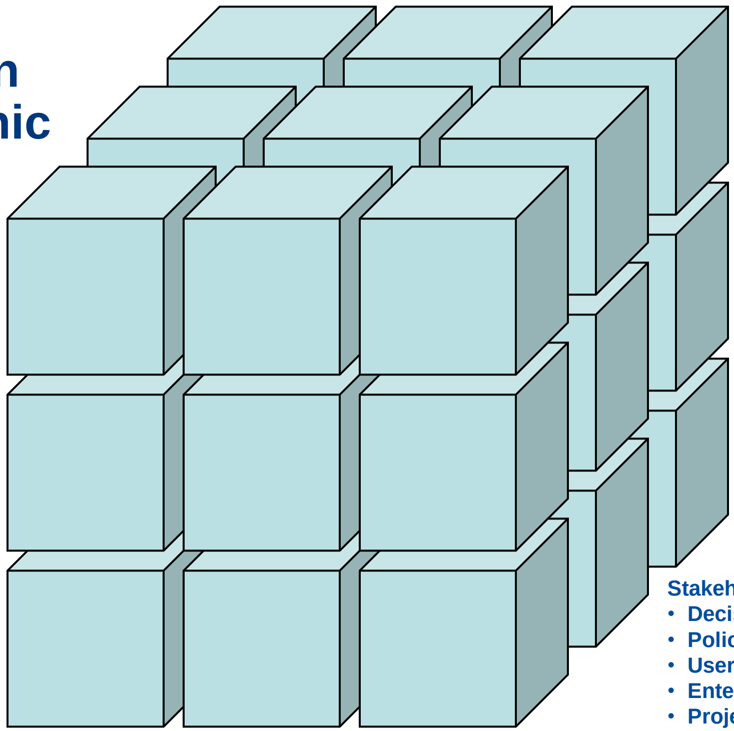
Sources: INCOSE SE Handbook v3, "Architecting Principles for Systems-of-Systems" by Mark W. Maier, DoD SE Guide for SoS

Source Mavris, ASDL, GATECH

System of Systems

The principal differences between a very large, complex, but monolithic System and a System of Systems is related to the following issues:

- A System of Systems is expression of many Systems that have their own capability to operate technically independently
- Managerial Independence of each System
- Geographically Distributed Systems
- Evolutionary Development
- Emergent Behaviors



Most Contemporary Challenging Issues on SoS are Human Components

SoS Characteristics are Very close to those of a Complex Systems

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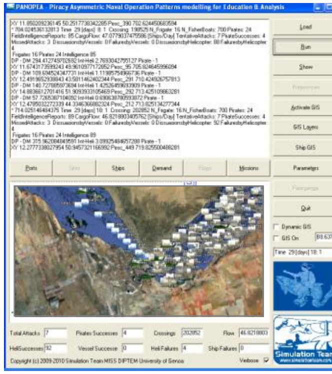
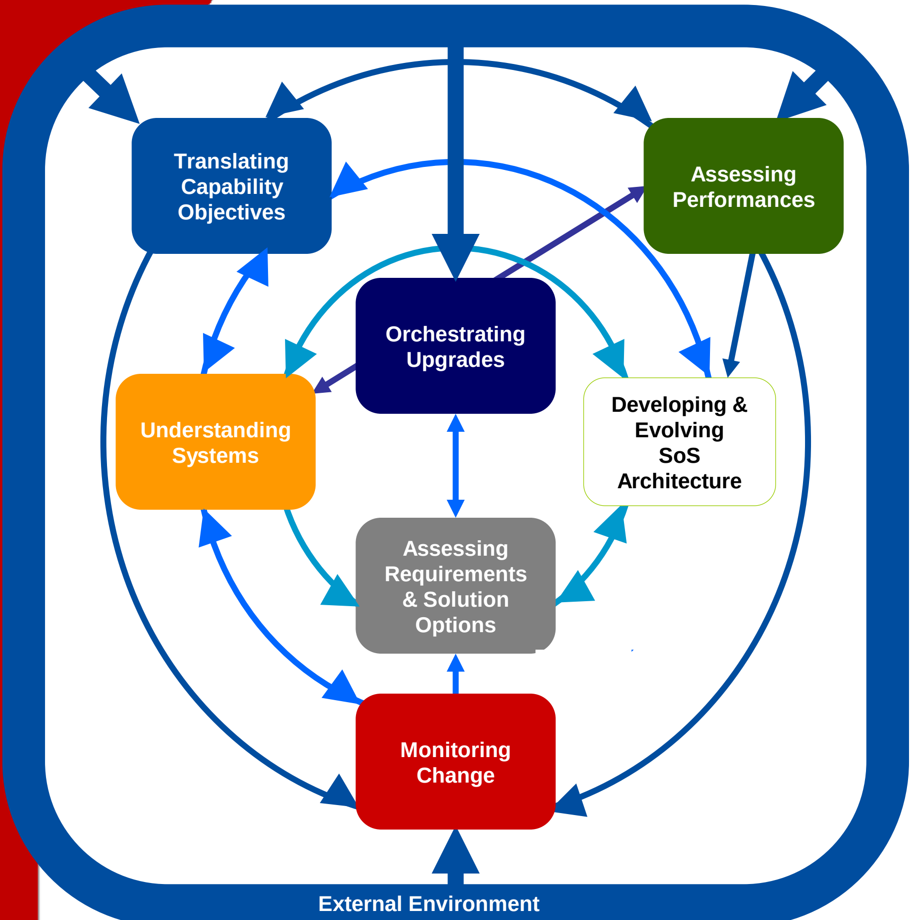
System of Systems as Challenging Framework

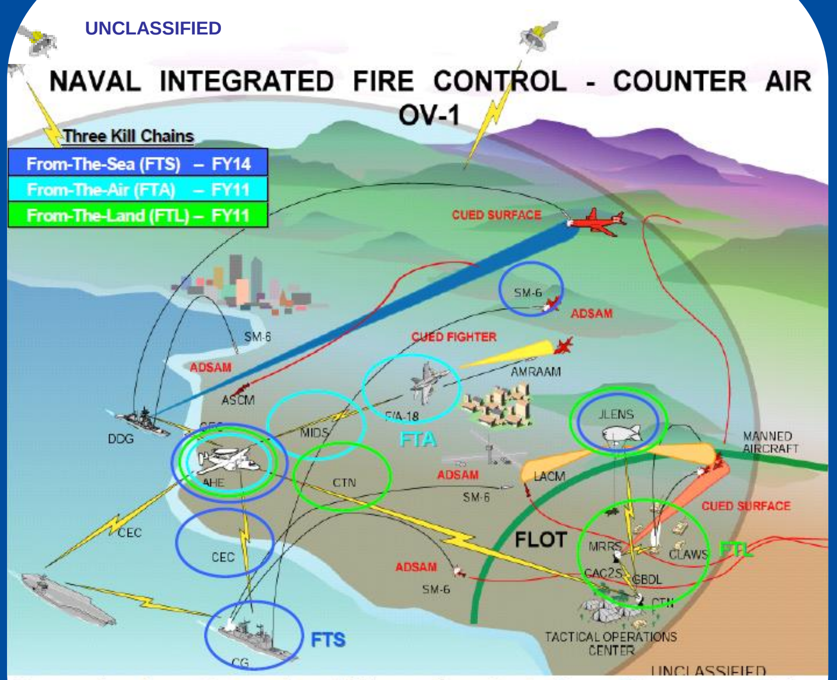


To succeed in applying SoS Engineering it is necessary to deal with challenges such as

- **Clearly Defining SoS Boundaries, Ranges of Validity and Requirements**
- **Keeping under Control the SoS development environment to guarantee that the requirements are satisfied in optimal way considering technical, economic and operative issues**
- **Considering the Constraints related to the use of Legacy Systems as SoS Components and their possible impact in term of functional and implementation inefficiencies and inconsistencies**
- **Defining SoS solution considering that the Component Systems have independent ownership, funding, and development processes in addition to the operational and technical elements**
- **Paying attention to Emergent Behavior and Development Changes and on their possible overriding effect on SoS Capabilities**

SoS SE as guideline for DoD Acquisitions





Example of an Operational View of an SoS: Naval Integrated Fire Control Counter Air [Source: Navy Chief Engineer's Office]

SoS System of Systems
SE System Engineering DoD US Department of Defense

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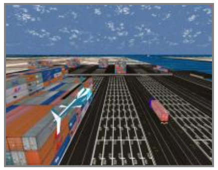
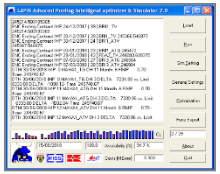
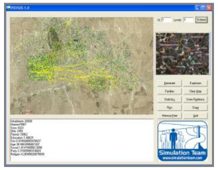
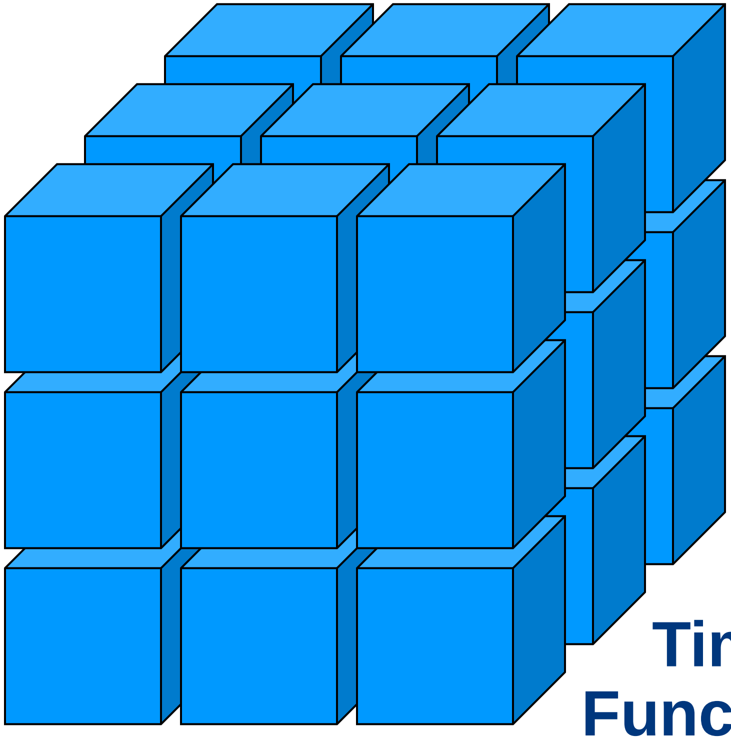
Engineering in SoS as a Paradigm

System of System Engineering is an approach able to be applied to SoS created in multidimensional environments









Disciplines & Areas

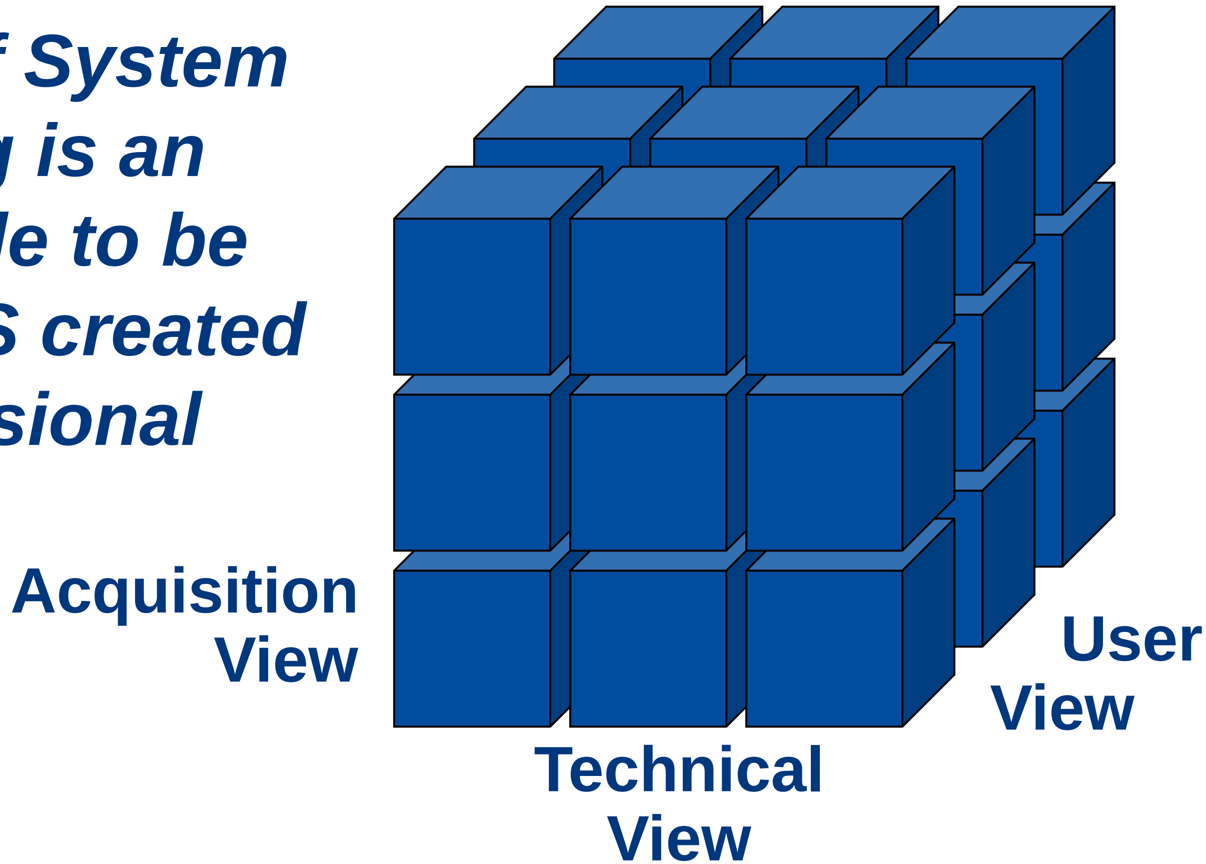
Time & Functions

Space and Configuration

Strong need to combine Social and Technical Networks

Engineering in SoS as a Paradigm

System of System Engineering is an approach able to be applied to SoS created in multidimensional environments



Strong need to combine Social and Technical Networks

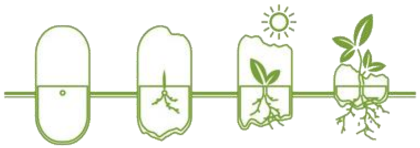
What is a System of Systems?

System-of-Systems Engineering is an emerging discipline in the aerospace community and new methods and techniques are required to address SoS challenges, but these should be based on proven Systems Engineering methods

Source Mavris, ASDL, GATECH

Challenges in New SoS Engineering

- Complexity is a major issue
- Management can overshadow engineering
- The initial requirements are likely to be ambiguous
- System elements operate independently
- Fuzzy boundaries cause confusion
- System elements have different life cycles
- SoS engineering is never finished



New methods &techniques are required to address these challenges

Source Mavris, ASDL, GATECH

The Evolution of New Ideas

All truth passes through three stages. First, it is ridiculed. Second, it is violently opposed. Third, it is accepted as being self-evident.
Arthur Schopenhauer, German philosopher (1788 - 1860)

New Ideas need Simulation for being early accepted

Organizational Barriers against new Methodologies

New methods go against the grain of established paradigms that are well defined and accepted by the practicing community and thus are always viewed with skepticism, criticism, or cynicism

Criteria to facilitate the introduction and acceptance of new methods :

- The underlying theories, methods, mathematics, logic, algorithms, etc. upon which the new approaches are based must be well understood, accepted, scientifically sound and practical
- Familiarity is needed with the underlying theories and the material needed for someone to understand the method itself must be readily available
- Availability of training material written on the overarching method, tutorials, etc. with relevant examples
- Tools automating the proposed method and making it practical for every day use to take the method beyond the academic level
- Relevant examples and applications within a given field of study

Proposed methods which are grounded in, or are complimentary to, established practices have a better chance of succeeding

Source Mavris, ASDL, GATECH

What is needed for this New Paradigm Shift to Occur?

- Transition from single-discipline to multi-disciplinary analysis, design and optimization to handle concurrently *different aspects*
- Easy integrative environments supporting combinatorial nature of the SoS problems
- Automation of the resultant integrated design process
- Transition from a reliance on historical data to physics-based formulations, especially true for unconventional concepts
- Means to perform requirements exploration, technology infusion trade-offs and concept down selections during the early design phases (conceptual design) using physics-based methods
- Methods which will allow us to move from deterministic, serial, single-point solutions to dynamic parametric trade environments
- Probabilistic methods to quantify and assess risks

- Transition from single-objective to multi-objective optimization
- Need to speed up computation to allow for the inclusion of variable fidelity tools so as to improve accuracy, from macro-level to meso- to micro-level representations
- Means to facilitate data and knowledge creation, storage, versioning, retrieval and mining
- An integrated knowledge based systems engineering and management framework
- Dynamic visualization of the results in a team-centered, real-time analysis environment

Source Mavris, ASDL, GATECH

Synthesis of Established Techniques for the New Methods

Established Techniques

- Response Surface Methodology *(Biology, Operations Research)*
- Neural Networks *(Artificial Intelligence, Image Processing)*
- Design of Experiments *(Agriculture, Manufacturing)*
- Design for Computer Simulation *(Geo-statistics, Physics, Nuclear)*
- Quality Function Deployment, Pugh Diagram *(Automotive, Electronics)*
- Morphological Matrix or Matrix of Alternatives *(Forecasting)*
- Multi-attribute decision making (MADM) techniques *(U.S Army, DoD)*
- Uncertainty/Risk Analysis *(Control Theory, Finance, Mathematics)*
- Agent based Models, System Dynamics, Network Theory *(Business, Entertainment, etc.)*
- Visual Analytics *(Homeland Security, Visualization, Video Gaming)*

Customized Methods Synthesized from Established Techniques

- Feasibility/Viability Identification
- Robust Design Simulation (RDS)
- Technology Identification, Evaluation, Selection (TIES)
- Joint Probabilistic Decision Making (JPDM)
- Unified Trade-off Environment (UTE)
- Inverse Design using Filtered Monte Carlo Simulation
- The Architecture-based Technology Evaluation and Capability Tradeoff (ARCHITECT)

Source Mavris, ASDL, GATECH

SoSE: Analisys of the trend

- The increased level of complexity, interoperability and cost effectivness resulted in an increased focus on System of Systems Engineering

An Architecture-based Approach to SoSE

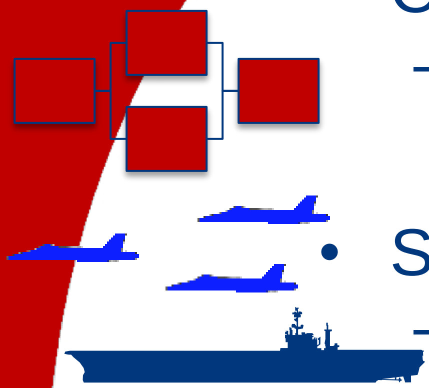
- "*The initial stages of architecture design are where the most fundamental design decisions are made*; these are the decisions which are most difficult to correct when they are in error"
  - Felix Bachmann, Software Engineering Institute (SEI) at Carnegie Melon

- "To *effectively acquire complex systems-of-systems in a capability-based acquisition environment requires that we increase the use of integrated architectures* to identify inter-relationships and resolve issues with system integration and interoperability that impact the operational effectiveness of warriors; platforms; command and control; networks; and weapons."
  - Phillipp Charles, Chief Engineer of SPAWAR Systems Center

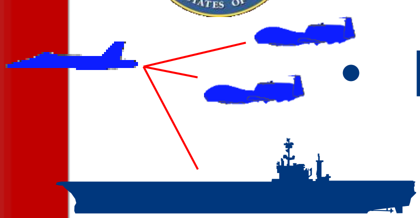
- "Degradation in combat effectiveness can be caused by…poor or non-existent integration or interoperability. Because integration and interoperability are so critical to combat effectiveness, *the entire Family of Systems must be considered in the engineering and acquisition process if decision makers are to choose the most operationally sound, technically feasible, and effective program investments*"
  - Dickerson, Soules, Sabins, Charles in "Using Architectures for Research Development and Acquisition"

Source Mavris, ASDL, GATECH

SoS Architecture Alternative Space



- Operational Alternatives (HOW and WHEN)
  - Changing the ways things are done (for example, the communication structure, or the order in which activities are performed)
- System Alternatives (WHAT and HOW MANY)
  - Changing the elements (physical systems, the means) of the architecture
- Organizational Alternatives (WHO)
  - Changing who is responsible for certain elements, activities, facilities, etc



- Network Alternatives (HOW)
  - Changing the network architecture that enables the information flow required by the SoS
- Combinations of the above

Source Mavris, ASDL, GATECH

The System Alternative Space

- The Interactive Reconfigurable Matrix of Alternatives (IRMA) is used to explore the alternative space for a new system
- The IRMA is an example of this approach

Interactive Reconfigurable Matrix of Alternatives (IRMA)

Engagement Model Inputs

Platform	Presets	B-52	B-1B	B-2	F-16	F/A-18E
		F/A-22	New Design			
	Cruise Speed	Subsonic	Supersonic	Hypersonic	Orbital	
	Engine Type	Turbofan	Turbojet	Ramjet	Turboramjet	Scramjet
		Pulse Detonation	Combined Cycle	Other		
	Number of Engines	1	2	4	Other	
	Ferry Range	<1000 nm	1000-3000nm	3000-5000 nm	>5000 nm	
	Refuelable	Yes	No			
	Piloting	Manned	Unmanned/Remote	Unmanned/Autonomous		
	Stores	External	Internal Exposed	Internal Enclosed		
	Wing Morphing	None	Variable Sweep	Variable Camber		
	Body Style	Blended Wing	Flying Wing	Conventional		
Missile	Presets	Air Launched Tomahawk	JASSM	ASDL Parametric Model	Traditional ICBM	New Design
	Primary Engine Type	Turbofan	Turbojet	Ramjet	Turboramjet	Scramjet
		Rocket	Airbreathing Rocket	Pulse Detonation	Combined Cycle	Other
	Inlet Position	Chin	Nose	Bottom	Top	Twin Offset
		Twin Symmetric	None			
	Flight Speed	Subsonic	Supersonic	Hypersonic	Orbital	
	Range	< 300nm	300-600nm	600-1200 nm	>1200 nm	
	Wings	Subsonic Wings	Supersonic Wings	Hypersonic Wings	None	
	Trajectory	Terrain Following	Low Altitude	High Altitude	Climb and Glide	Ballistic
	Controls	Tail	Canard	Thrust Vectoring	Other	
	Seeker/Guidance	Laser	Infrared	RADAR	GPS	INS
Missile Engine	Number of Spools	1	2	None		
	Compressor Style	Axial	Centrifugal	None		
	Nozzle Type	Converging	Converging-Diverging	Variable		
	Blade Fabrication	Equiax	Directionally Solidified	Single Crystal	Other	N/A
	High-Temp Material	Titanium	Nickel-Alloy	Carbon Composites	Metal Composites	Ceramic Composites
	Cooling Scheme	Convection	Impingement	Film	Transpiration	Liquid

TOPSIS

Possible Combinations

1,500

Computational Analysis Time

One Run per Second:	0.02 Days
One Run per Minute:	1.04 Days
One Run per Hour:	62.50 Days

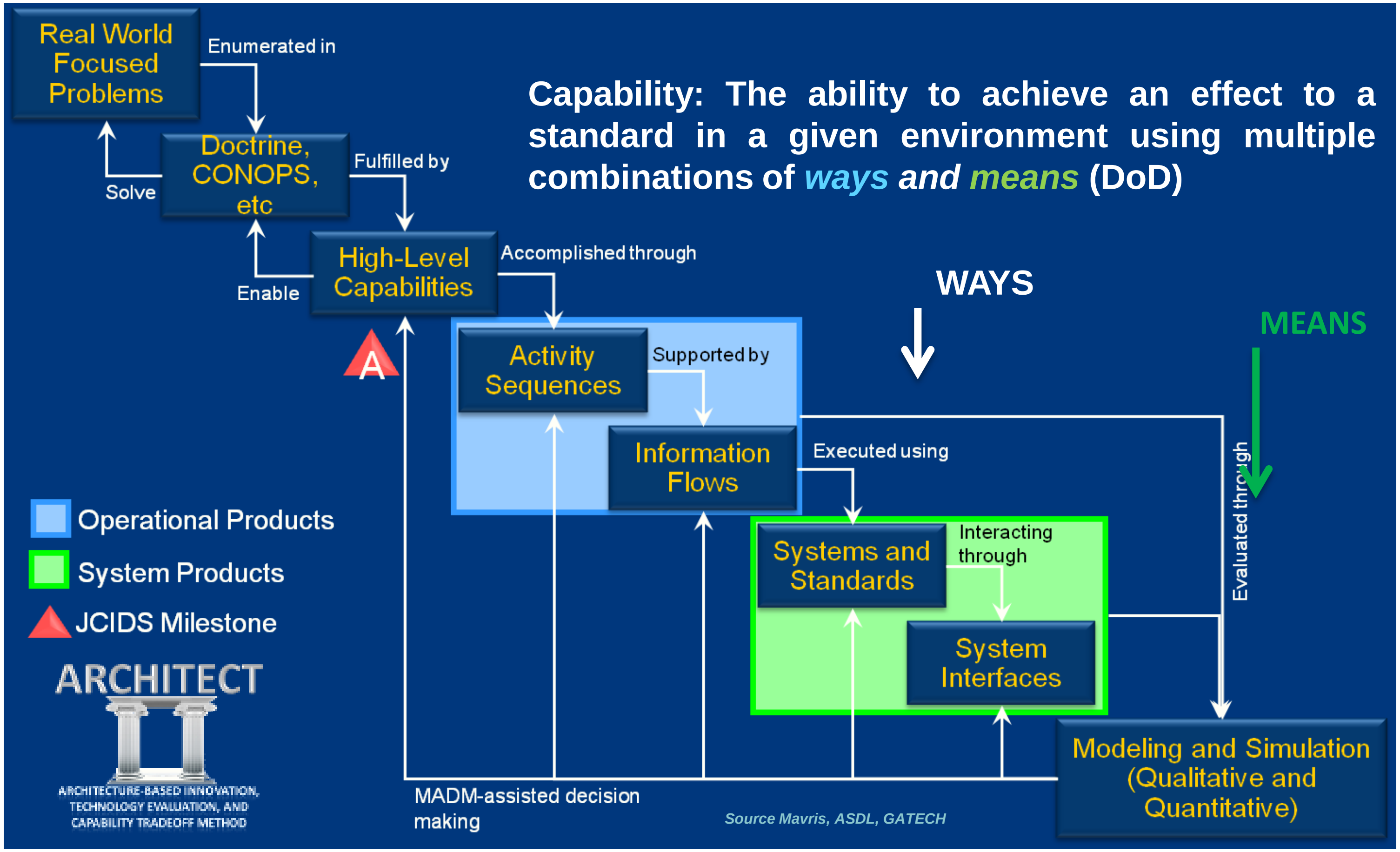
Minimum TRL: 1

Air Force Asset Only: No

ASDL

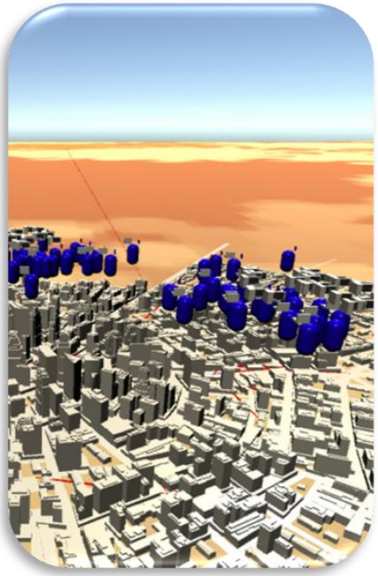
ARCHITECT Method

The Architecture-based Technology Evaluation and Capability Tradeoff Method



Modeling and Simulation Challenges in SoS Engineering

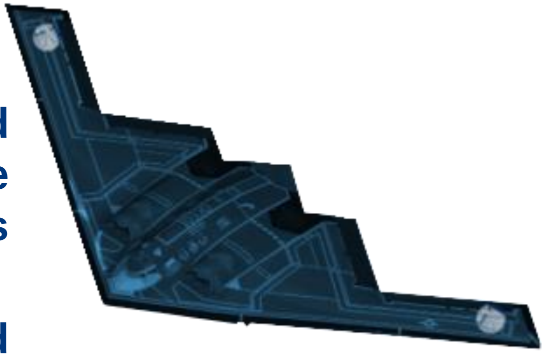
- Physical experiments are typically infeasible or limited
  - Computer simulations are required, and are often computationally intensive and time consuming
  - Verification and Validation is a challenge
- SoS are complex
  - Limits available modeling techniques
  - Often results in high dimensionality
- SoS have a large and diverse alternative space
  - Unfathomable number of combinations
  - Need to speed up modeling and simulation
  - Can be challenging to visualize results
- SoS are stochastic in nature
  - For a given set of inputs, the results are a distribution
  - Behavior is often modal in nature

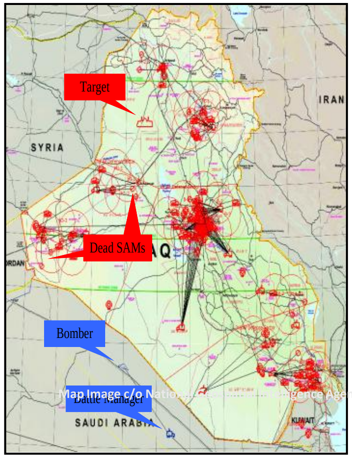


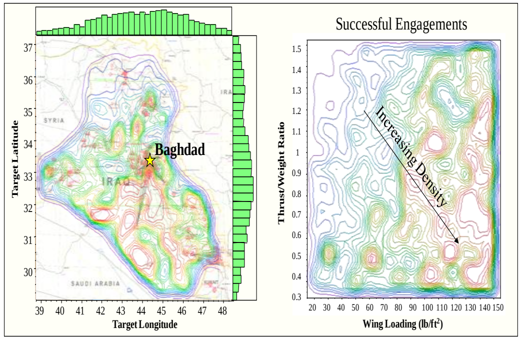
Source Mavris, ASDL, GATECH

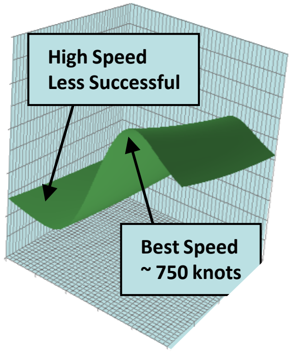
Extension to Systems of Systems Analysis

- The DoD shift to capability based acquisition is merging the operations research and systems design communities
- The impact of systems and subsystems is often negligible when compared to tactics, doctrine, and strategy
- Methods for efficient scenario construction, surrogate creation, and optimization for SoS are needed





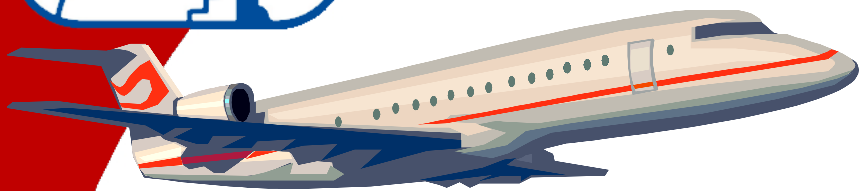


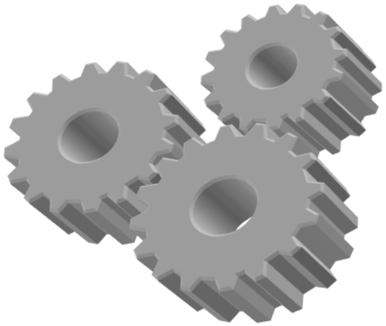


The Complexity of the Systems-of-Systems Analysis Problem Often Confounds Analysts

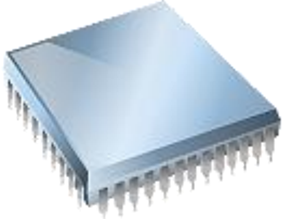
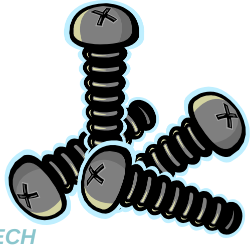
Source Mavris, ASDL, GATECH

Which of these are systems?



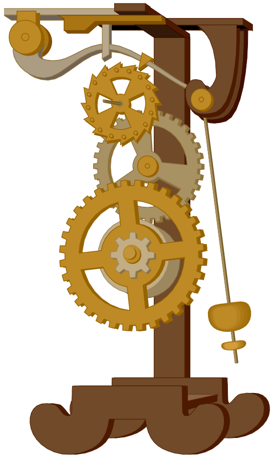



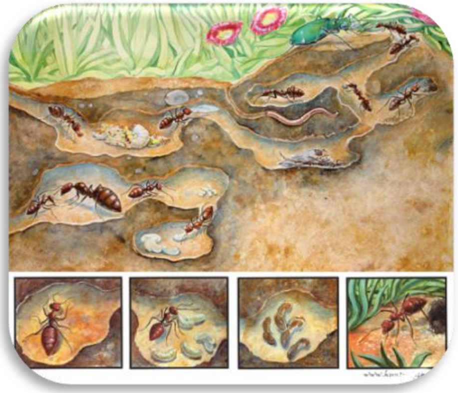


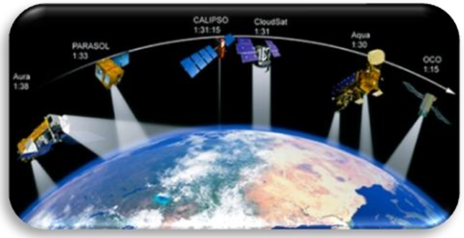




Source Mavris, ASDL, GATECH

Which of these are a SoS?

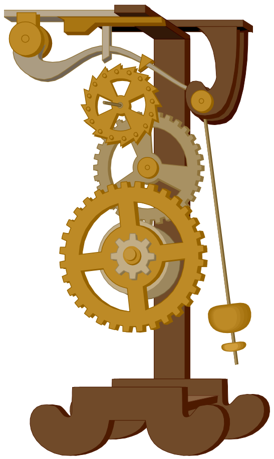




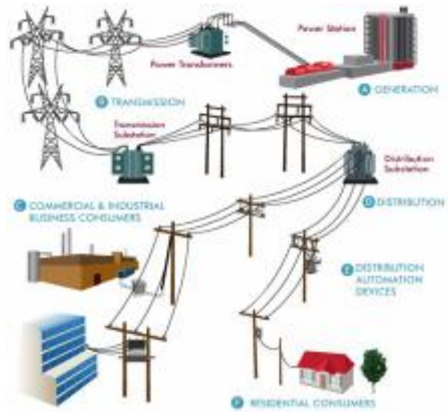


Source Mavris, ASDL, GATECH

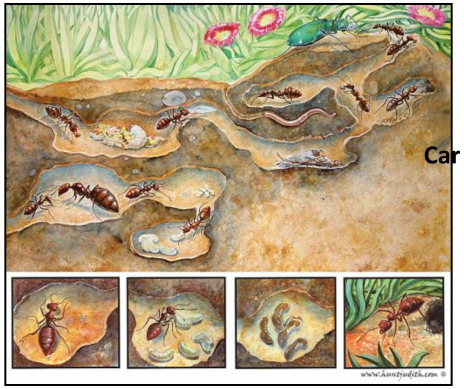
Which are simple?
Which are complex?



Pendulum

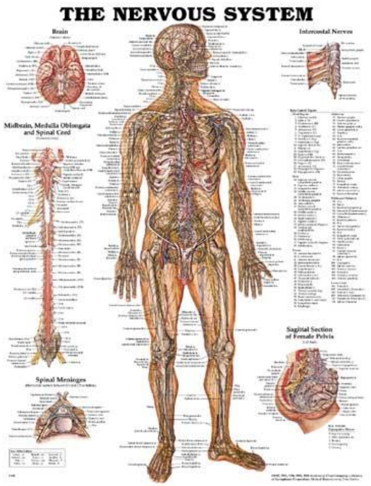


Electricity Grid



Car

Ant Colony

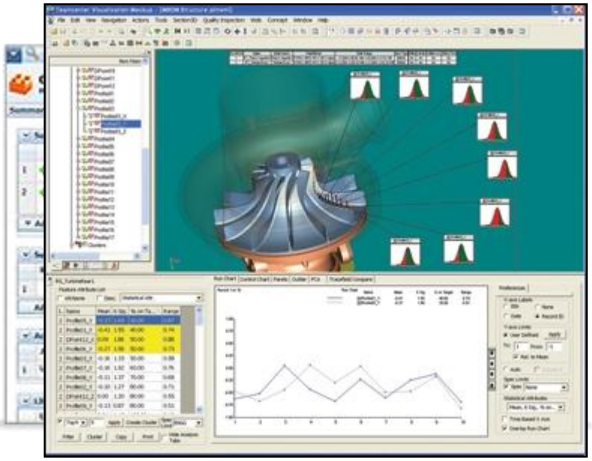


Aircraft

Pen

Car

PLM as evolution of PDM



Original Data were "simple" Design files, parts lists and specifications. At the time, engineering data management software (EDMS) and later PDM allowed users to organize their product data, and apply rules for item identification and revision control. An associated electronic data library contained 2D CAD files and other design files.
Currently, due to additional complexity in product design, engineering data management present two separate solutions:

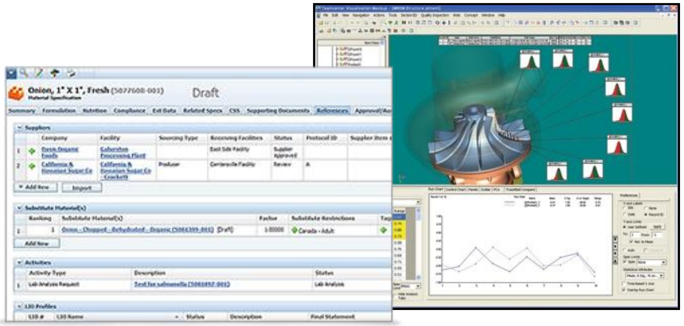
Product data management combining CAE/CAD softwares as "design environment" it has as design object mostly CAD files. The **PDM** tool manages sets of linked files (e.g. CAD) in hierarchical real or virtual folders.

Product lifecycle management is a cross-organizational tool for collecting, controlling and publishing approved product configurations. In PLM, part and document objects are represented in a database, and managed by change forms. Unlike PDM, part and document records exist independently of files.

Source Web

Simulation Team

PLM & PDM Main Features



PDM **software provides engineers and designers with tools for managing linked multi-file CAE/CAD models**

PLM software provides all disciplines (design, product management, quality, production, test engineering, marketing, etc.) with a complete, approved and locked-down product configuration.

The normal CAD/PDM/PLM interaction consists of:

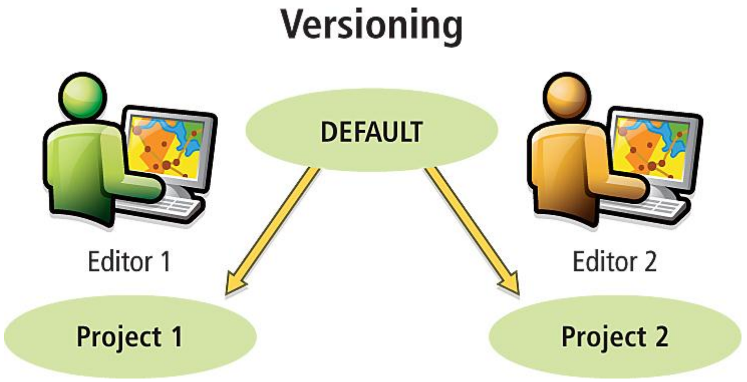
- **creating part numbers within the PLM system**
- **using the part numbers during CAD/PDM model development**
- **exporting the BOM from CAD for import into PLM**
- **attaching models (file sets) as approved, controlled snapshots of the 3D model.**

The file set (and related specifications and procedures) is approved within the PLM system and released to your production and supply chain.

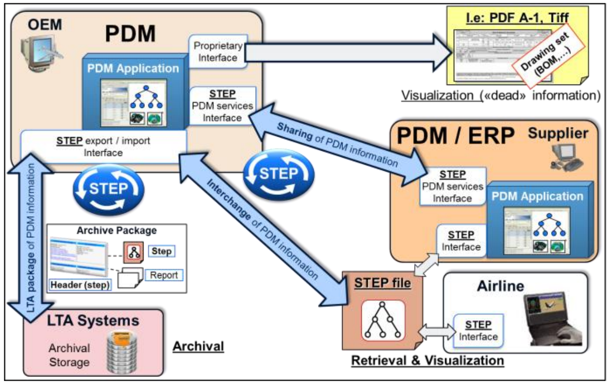
PDM: Product Data Management

Product Data Management (PDM) is the business function responsible for the management, storage and publication of product data. PDM support versioning and configuration evolution. PDM is often part of Product Lifecycle Management (PLM). The management of version control ensures that everyone is on the same page and that there is no confusion during the execution of the processes and that the highest standards of quality controls are maintained.

PDM sofware supports Product Coniguration Management



PDM Services



PDM allows to:

- Enter and review the Bills of Material (BOM)
- Define Work Centers and related costing and accounting information, routing instructions and lead times
- Set up Shift Information and Kanbans in manufacturing
- Enter and review processes, operations, components, and sub system within process assembling & manufacturing
- Set up, review, approve, and print Engineering Change Orders
- Set up Calendar and Start dates, managing overlapping and concurrent operations and calculating combined lead times.

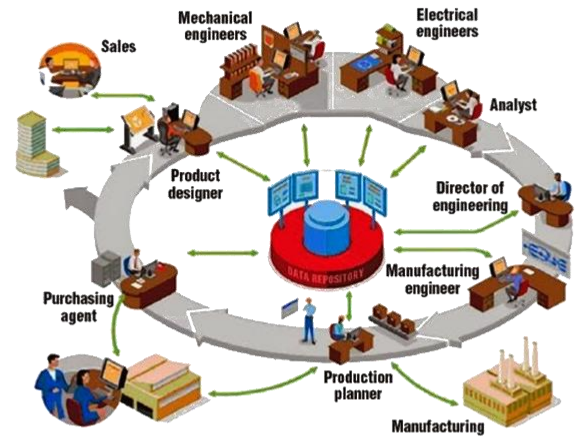
BOM Setup → Calendar Setup → Work Center Setup → Routing Setup → Product Costing Setup

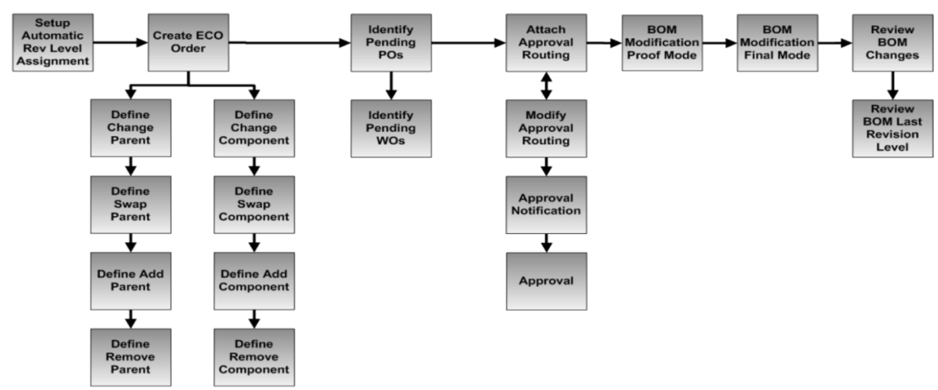
BOM	Bill of Materials
ERP	Enterprise Resource Planning
LTA	Long Term Archiving
OEM	Original Equipment Manufacturing
STEP	Standard for the Exchange of Product model data (ISO10303)

Engineering Change Order & Engineering Change Notice

PDM Features for EOC/EON:

- **BOM Change Management**
- **Remove, Add, Swap, Change Components & Parents on the BOM**
- **Automatic BOM Population**
- **BOM revision & changes**
- **ECO creation from ECR**
- **ECO/ECR approval routing**
  - **Add-on approval routing**
  - **Approval notification**
  - **Pending Order**
- **Item Flash Message**





EOC/EON Definition → Approval → Change Implementation

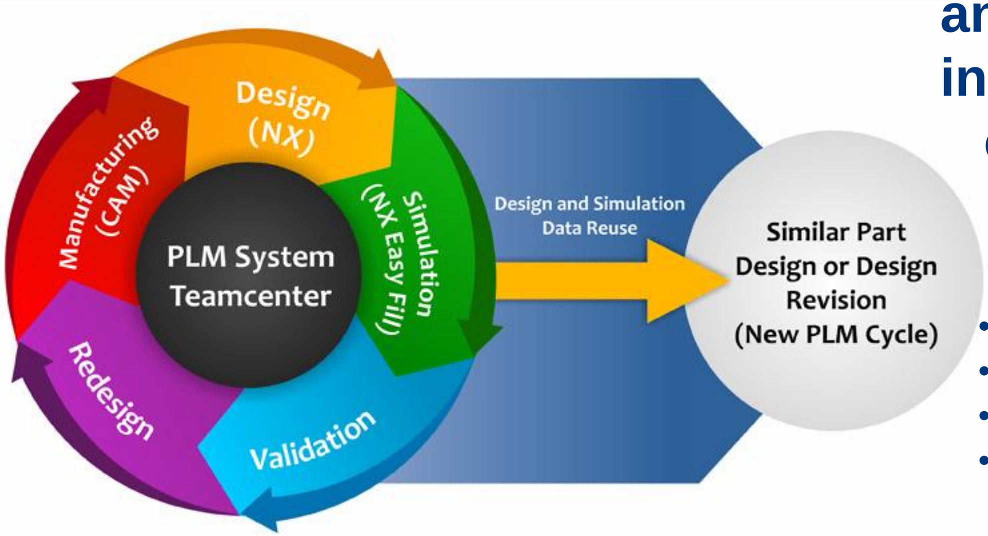
Source Web

ECO	Engineering Change Order
ECN	Engineering Change Notice
ECR	Engineering Change Request

PLM: Product Lifecycle Management

In industry, product lifecycle management (PLM) is the process of managing the entire lifecycle of a product from inception, through engineering design and manufacture, to service and disposal of manufactured products.

PLM integrates people, data, processes and business systems and provides a product information backbone for companies and their extended enterprise.



Source Web

PLM includes;

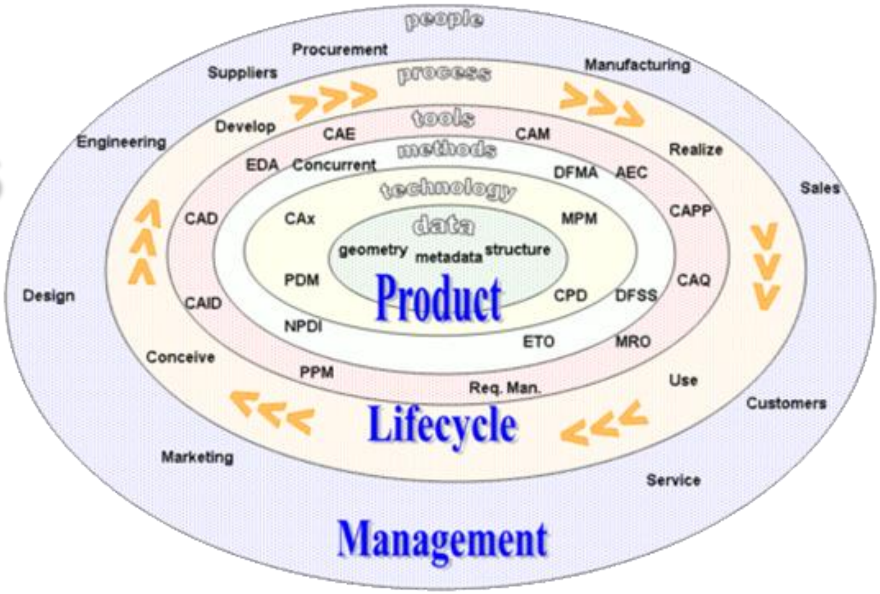
- Systems engineering (SE)
- Product Portfolio Mngt. (PPM)
- Product design (CAx)
- Manufacturing process management (MPM)
- Product data management (PDM)

Simulation Team

PLM Components

PLM Addresses different main phases such as:

- Conceive
  - Specification
  - Concept design
- Design
  - Detailed design
  - Simulation, Validation & Analysis
  - Tool design
- Realise
  - Plan manufacturing
  - Manufacture
  - Build/Assemble
  - Test (quality check)
- Service
  - Sell and deliver
  - Use
  - Maintain & support
  - Dispose



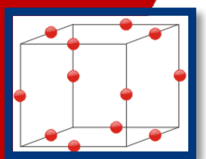
- AIC Application Interpreter Construction (STEP)
- CAID Computer Aided Industrial Design
- CAD Computer Aided Design
- CAE Computer Aided Engineering
- CAM Computer Aided Manufacturing
- CAPP Computer Aided Process Planning
- CAQ Computer Aided Quality Control
- CAx Computer Aided Technologies (|e.g. CAD, CAM)
- CPD Collaborative Product Development
- DFMA Design for Manufacturing and Assembly
- DFSS Design For Six Sigma
- ETO Engineering To Order
- MRO Maintenance, Repair & Overhaul
- MPM Manufacturing Process Management
- NPDI New Product Development and Introduction
- PDM Product Data Management
- PPM Product Portfolio Management
- STEP Standard for the Exchange of Product model data

Source Web

Configuration of New Complex Products: Bradley M2

- New Products are characterized by evolving requirements… it could result pretty dangerous and expensive.
- Missing SoSE it is possible to loose control of the configuration as in the case of Bradley M2 US Army

Enablers for Complex SoS

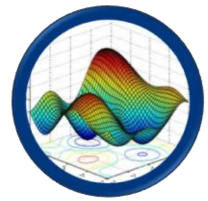


Design of Computer Simulations

– Space Filling Designs
– Adaptive DoE

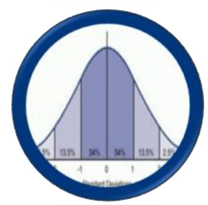
Modeling and Simulation Techniques

– Agent-based modeling and constructive simulations
– System Dynamics Modeling
– Discrete Event Simulation
– Mathematical Modeling Techniques



Non-linear Surrogate Modeling

– Neural Networks
– Kriging/Gaussian
– Stepwise RSE



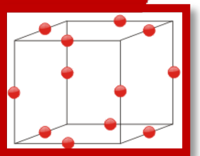
Probabilistic Theory

– Stochastic Modeling
– Surrogate modeling of Stochastic Processes
– Monte Carlo Simulation

Visual Analytics

Source Mavris, ASDL, GATECH

Enablers for Complex SoS



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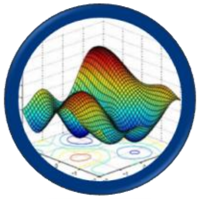

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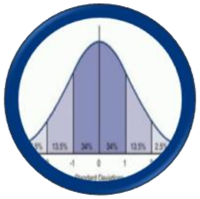

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Source Mavris, ASDL, GATECH

Design of Experiments

① Factor Assignment

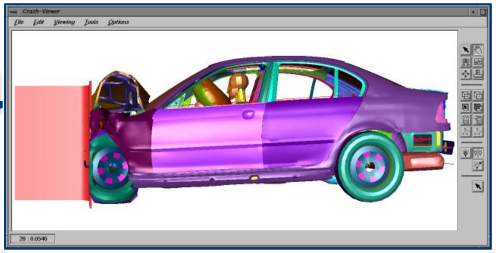
② Tests	Main Effects ③			Interactions ④			
	A	B	C	D (A-B)	E (A-C)	F (B-C)	G (A-B-C)
1	–	–	–	+	+	+	–
2	+	–	–	–	–	+	+
3	–	+	–	–	+	–	+
4	+	+	–	+	–	–	–
5	–	–	+	+	–	–	+
6	+	–	+	–	+	–	–
7	–	+	+	–	–	+	–
8	+	+	+	+	+	+	+

Design Of Experiments (DOE)

- Design of Experiments (DoE) was developed for physical experiments
  - Effect of fertilizers on crops
  - Effect of food and environment on bacteria growth
  - Variations in weld strengths
- Design of Experiments has historically focused on how to devise screening techniques and sampling strategies for physical experiments that are aimed at mitigating the effects of the *random error*

Source Mavris, ASDL, GATECH

Physical vs. Virtual Experiments



Physical Experiments

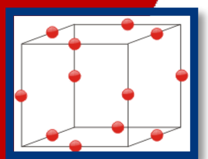
- Often a limited number of factors
- Data collection must often be done in "one shot" (for example, one growing season)
- Types of Error
  - Human Error: Experimenter makes a mistake
  - Systemic Error: Flaw in philosophy of the experiment adds a consistent bias to result
  - Random Error: Measurement inaccuracies due to the instruments being used

Virtual Experiments

- Often have a larger number of factors than real world experiments
- Data collection is sequential in nature
- Types of Error
  - Human Error: Bugs in the code, incorrectly entered boundary conditions, etc
  - Systemic Error: Consistent errors due to approximations in the code
  - Random Error: Does not exist in computational experiments

Source Mavris, ASDL, GATECH

Enablers for Complex SoS



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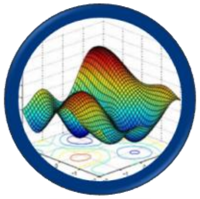

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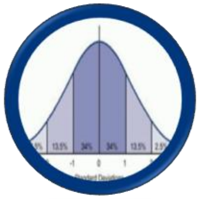

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Visual Analytics

Source Mavris, ASDL, GATECH

Design of Computer Simulation

- Computer simulation is a numerical technique for conducting experiments on certain types of mathematical and logical models describing the behavior of a system (or some component thereof) on a digital computer over extended periods of real time. (*Burdick & Naylor, 1966*)

- Design of Computer Simulation (DoCS) is geared toward developing sound experimental design practices foe experiments performed on computational simulations

Source Mavris, ASDL, GATECH

Agent Driven Simulation

Netlogo Agent-Based Simulation Tool
http://ccl.northwestern.edu/netlogo/

SIMCJOH VIC Agents
www.liophant.org/simcjoh

CAPRICORN Agents
www.liophant.org/capricorn

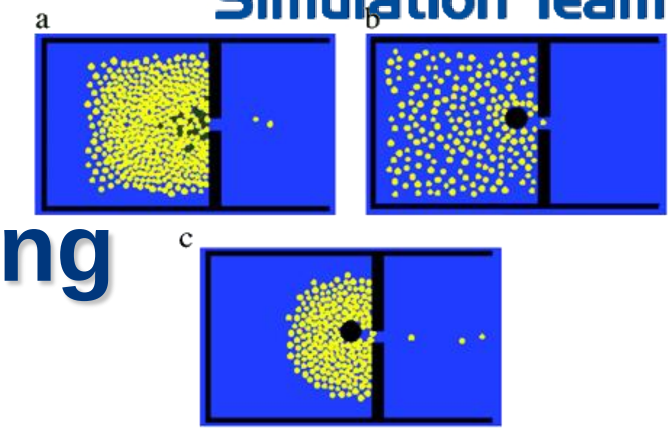
Massive Software
www.massivesoftware.com

Image:
http://www.vfxtalk.com/forum/massive-software-used-create-visual-t5617.html

- Agent driven simulation is a multi evel **bottom-up** approach to modeling phenomena assigning agents to drive entities and units over time and space
- Each agent interacts with its environment and with each other
- Simulation let emeerge "the properties of the whole system from properties of the constituent elements"
  - Behavior of Population in a village are the result of the actions of soldiers and civilians
  - CIMIC and Psyops success is based on the actions carried out by the people, the Blue Coalition and the Insurgent
- In this context it is important the VV&A

Agent-Based Techniques model Behaviors and requires Verification & Validation

Agent-Based Behavioral Modeling

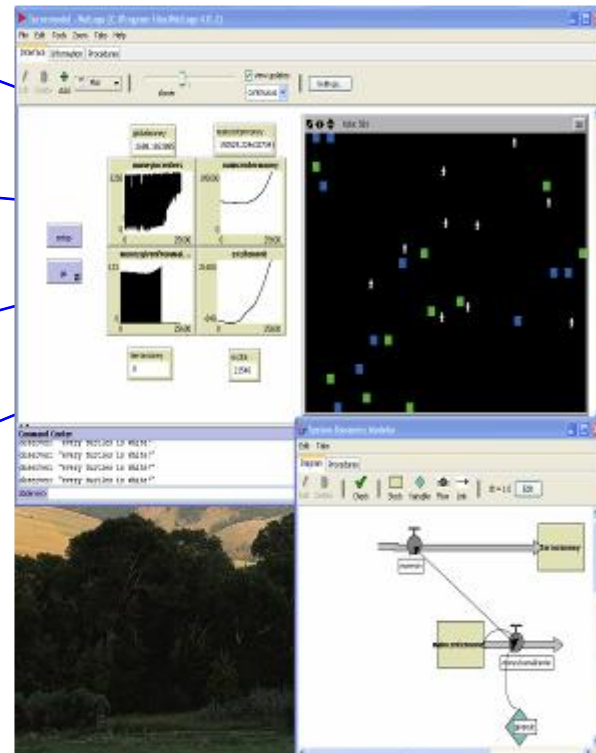


- **Conditions that make Agent Based Models (ABM) convenient includes among others** [Bonabeau 2002]:
  - Individual behavior is nonlinear and can be characterized by discrete decisions, thresholds, if-then rules, or nonlinear coupling
  - Describing discontinuity in individual behavior is difficult with differential equations. For example, if a logistics officer orders parts in batches, he may have a threshold for making parts requests (rather than continuously demanding replacements for parts used)
  - History matters. Path-dependence, lagging responses, non-Markovian behavior, or temporal correlations including learning and adaptation are applicable to the system.
  - Averages are not good enough. Under certain conditions, small fluctuations in a complex system can be amplified, so that the system is stable for incremental changes but unstable to large perturbations

Source Mavris, ASDL, GATECH

System Dynamics Modeling

- System Dynamics (SD) is a macro-level **top-down** approach to modeling phenomena at high levels of abstraction and aggregation
- SD models portray the structure of interrelationships between variables with flows and stocks
  - Stocks are the variables in the system
  - Flows represent change
- Methods for rapid model construction and validation are needed

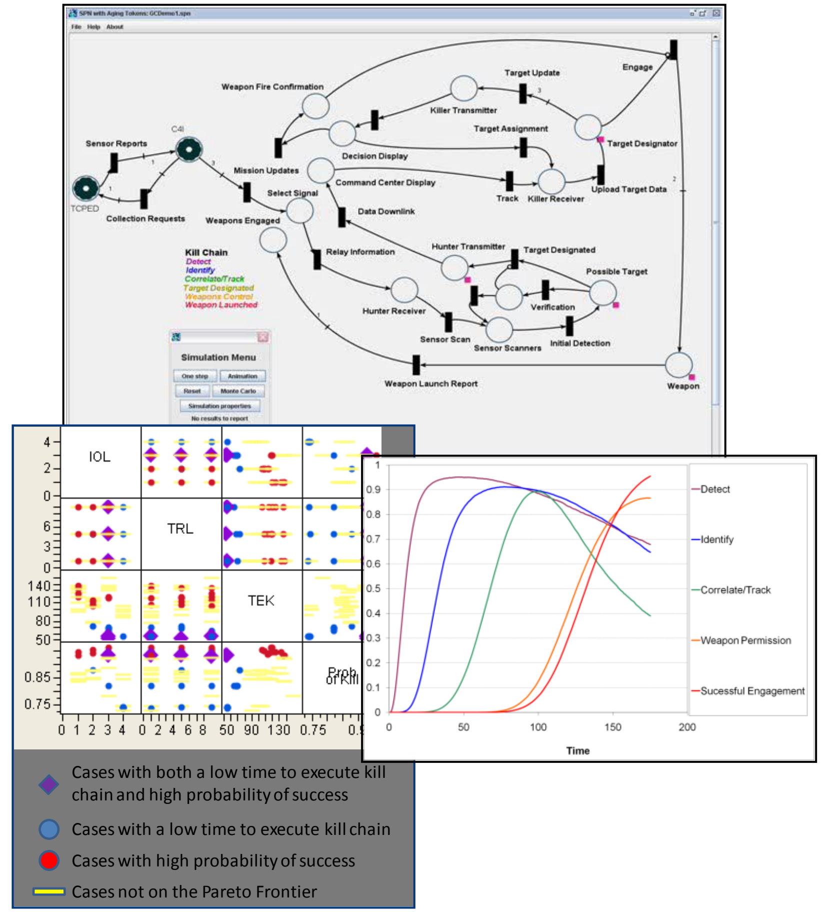


System Dynamics Handles Complexity with a Top-Down View of the World

Source Mavris, ASDL, GATECH

Discrete Event Simulation

- Discrete Event Simulation (DES) uses numerical analysis to analyze systems where the state variable(s) changes only at discrete points in time
- DES Paradigms
  - Activity Oriented
  - Event Oriented
  - Process Oriented
- DES models have the advantages of a relatively fast run time, flexibility, and modularity
- Useful for modeling queues and logistics



Source Mavris, ASDL, GATECH

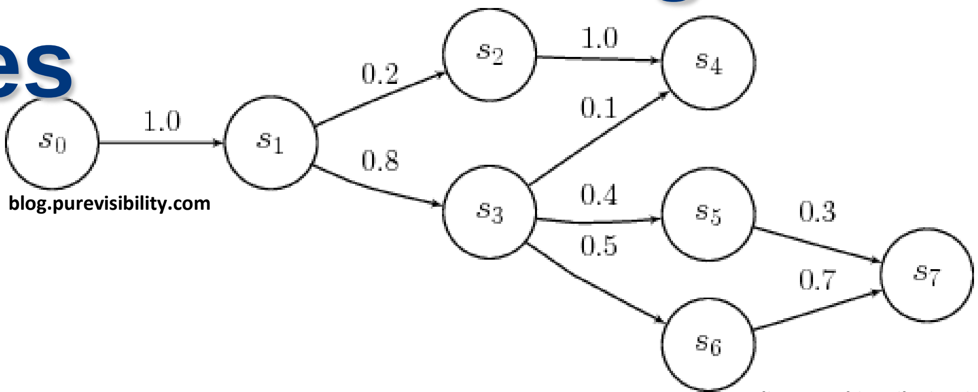
Discrete Event Simulations

- **Discrete event problems embody among the others the following concepts** [Fishman 2013]:

  - **Resources - provider of service**
  - **Performance - overall system measure**
  - **Routing - collection of required services**
  - **Scheduling - pattern of resource availability**
  - **Sequencing - order resources provide service**
  - **Buffers - waiting area for work awaiting service**
  - **Work - items, jobs, or customers seeking service**
- **DES has many types of applications and describes a broad class of simulations**
- **Queuing models are able to describe systems with resource allocation and sequences of operations** [Zimmermann 2008]

Source Mavris, ASDL, GATECH

Mathematical Modeling Techniques



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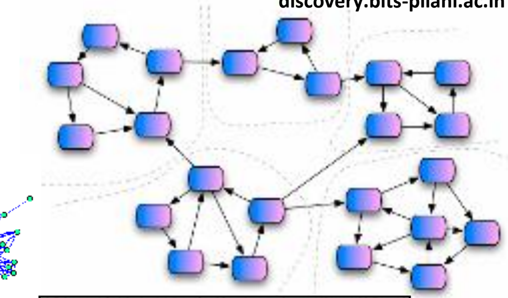
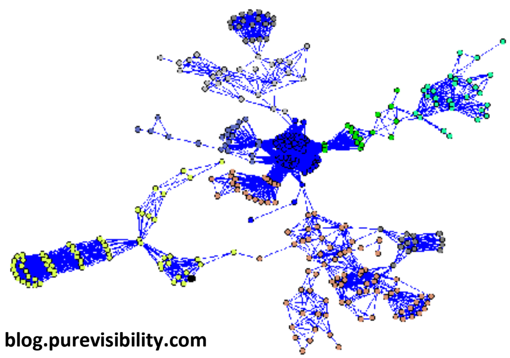
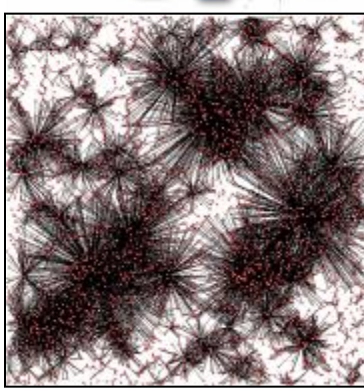


- There are a variety of mathematical modeling techniques that are applicable to SoS
- Markov Chains
  - Used to model stochastic processes which adhere to the Markov Property
- Graph Theory
  - Basis of many network models
  - Can also be used to study the complexity and structure of a SoS


blog.purevisibility.com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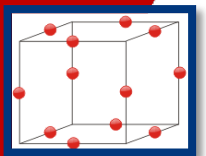
Enablers for Complex SoS

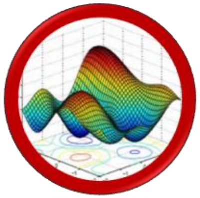


Design of Computer Simulations

- Space Filling Designs
- Adaptive DoE

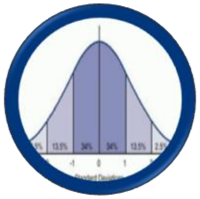
Modeling and Simulation Techniques

- Agent-based modeling and constructive simulations
- System Dynamics Modeling
- Discrete Event Simulation
- Mathematical Modeling Techniques



Non-linear Surrogate Modeling

- Neural Networks
- Kriging/Gaussian
- Stepwise RSE



Probabilistic Theory

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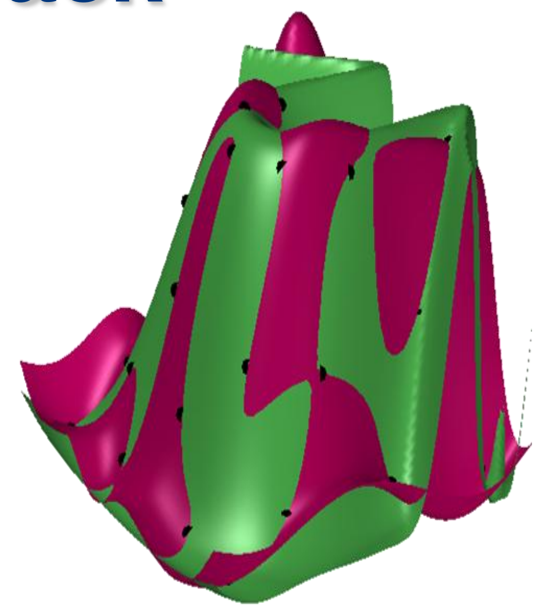
- Surrogate modeling of Stochastic Processes
- Monte Carlo Simulation

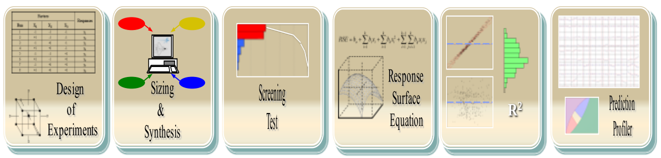
Visual Analytics

Source Mavris, ASDL, GATECH

Surrogate Modeling: Metamodelling is Back

- In the 1990s, ***surrogate models*** were seen as a mathematical curiosity in the design community
- **Response surface equations, Kriging models, and neural networks have been cross-fertilized and their use is now widespread**
- **Automated tools for creation and validation are needed**
- **A library of surrogates and the underlying assumptions for their use must be constructed**





Response Surface Methodology

Surrogate modeling for Systems Analysis is now a standard technique in the field

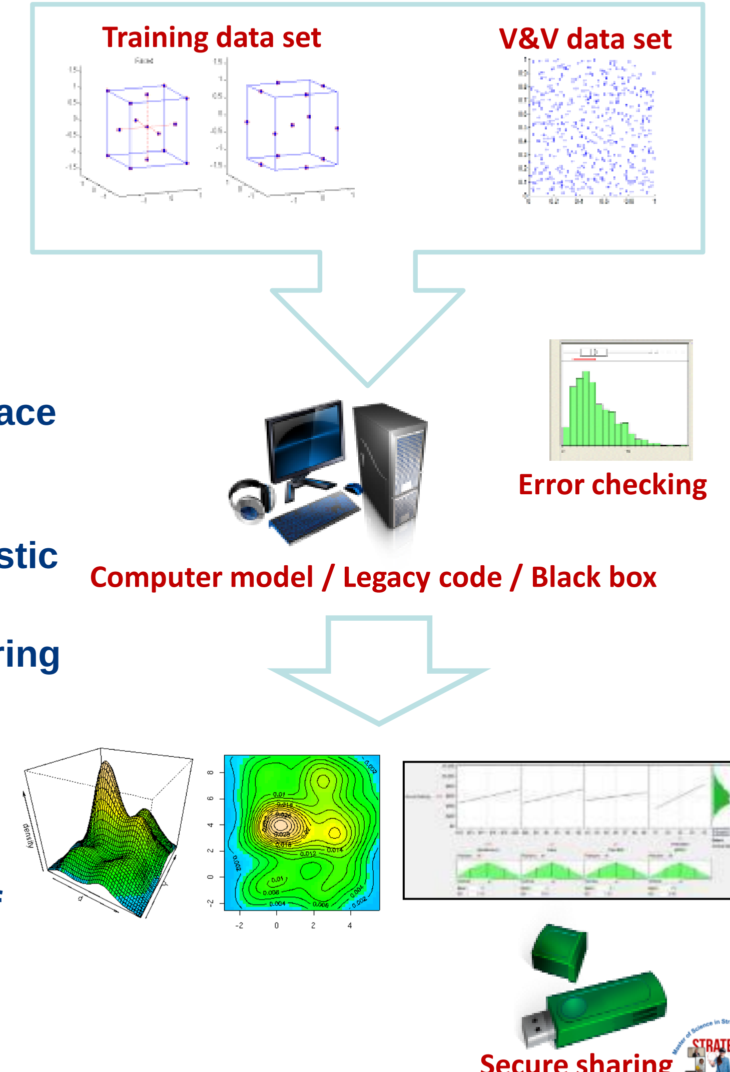
Why Surrogate Models?

Why do we use surrogate models?

- Statistical analysis of contributing factors, including interactions and high order effects
- Closed-form mathematical characterization of "black box"
- Dynamic / interactive visualization of model space
- Computer evaluation time is multiple orders of magnitude less than legacy "black box" codes, enables Monte Carlo simulations and probabilistic analysis
- Share model of systemic behavior without sharing sensitive tools and models.

What do we need to create surrogate models?

- A carefully selected data set for regression or "training", may imply a significant allocation of resources (Design of Experiments)
- A sufficiently broad data set for Validation & Verification (V&V) through and error checking



Surrogate Models

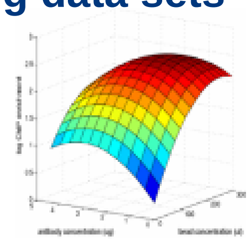
Are surrogate models the silver bullet?

No, because:

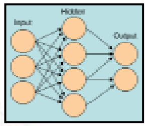
- They contain statistical error that may be significant
- Their applicability is limited by the domain range of the DoE
- The adequacy of a given surrogate model type depends on the nature of behavior it is meant to capture
- They carry implicit assumptions that can be overlooked
- …altogether, surrogates can be misused or abused for analysis
- Selecting the "right" type of surrogate (validation) is as important as constructing the surrogate "right" (verification)

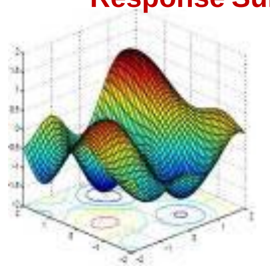
What kinds of surrogate models?

- Different surrogate models will capture varying levels of complex behavior with a given degree of accuracy/error using a corresponding regression & training data sets

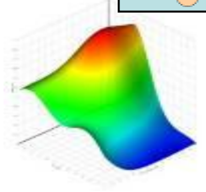


Response Surface Equations





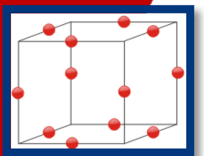
Gaussian Process Regression, Or Kriging



Artificial Neural Networks

Source Mavris, ASDL, GATECH

Enablers for Complex SoS



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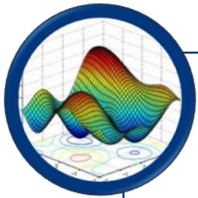

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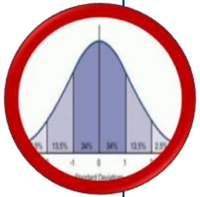

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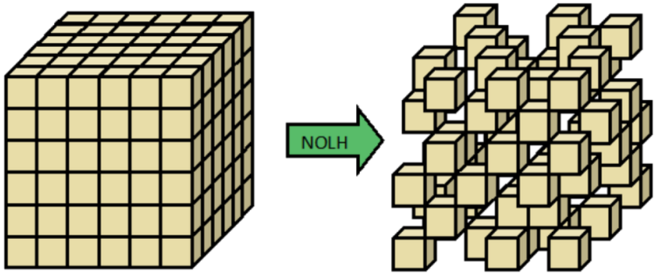
Visual Analytics

Source Mavris, ASDL, GATECH

Challenges in Stochastic Processes for Surrogate Models

- For a given set of inputs, the outputs are a distribution, not a single point
  - Repetitions of each DOE case are required to capture the distribution
  - If the variability is high, a large number of repetitions are required
- The distribution may be non-normal, or be modal in nature
  - More difficult to accurately model a non-normal distribution
  - In the case of modal behavior, must determine the drivers for the modes
- Multiple surrogates will be required for each response
  - The number of surrogates required will be dependant on the assumed distribution



Factorial Design:

Complete Cover

Nearly Orthogonal Latin Hypercube Design

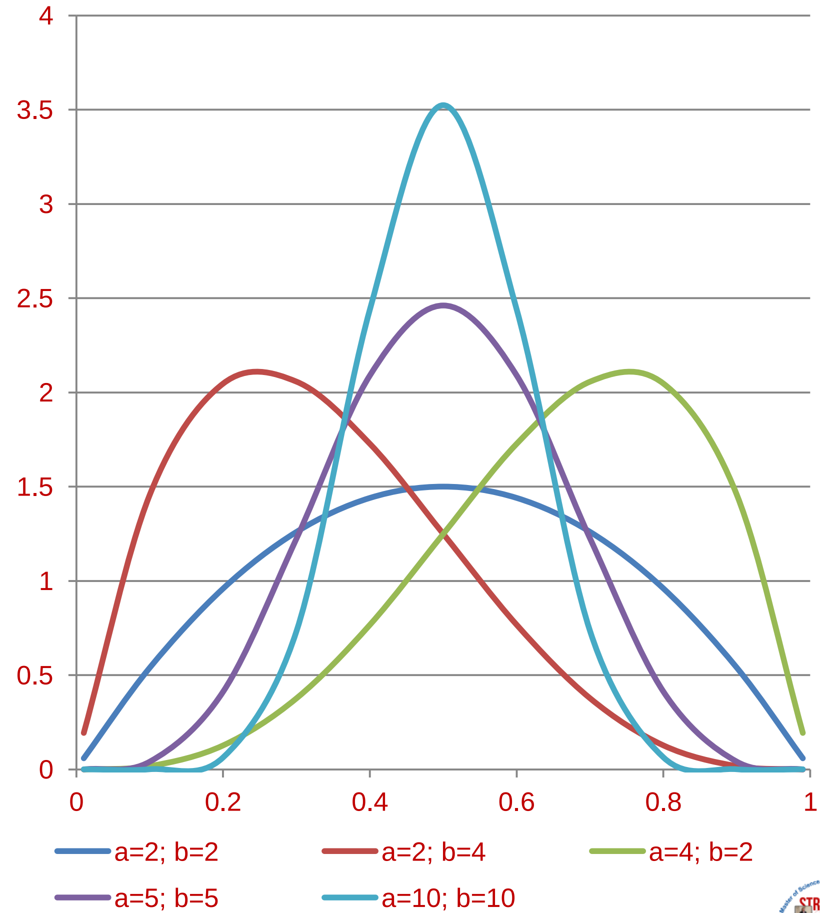
Statistical Cover

Source Mavris, ASDL, GATECH

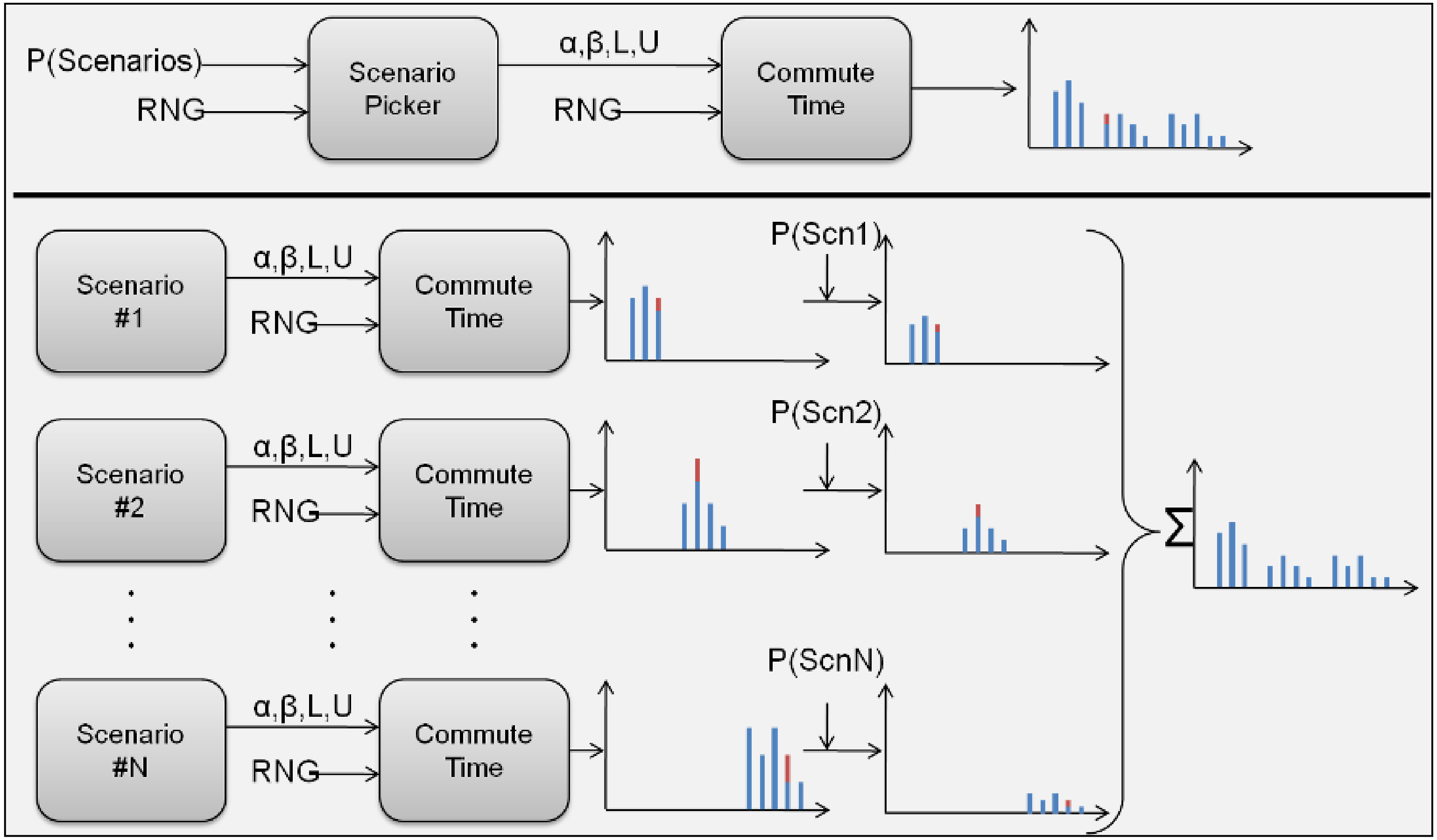
Beta Distribution for Stochastic Processes

Beta Distribution

- Beta distributions are extremely flexible functions
- Beta Distribution have four parameters:
  - α : Shape parameter
  - β : Shape parameter
  - min : Range parameter
  - max : Range parameter
- Beta Distributions could be model by adopting Optimistics, Pessimistic and Most Probable Values



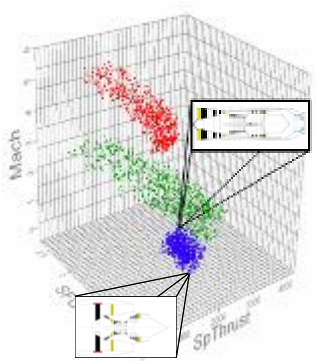
Fitting Modal Responses

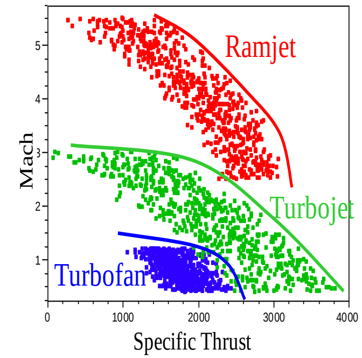


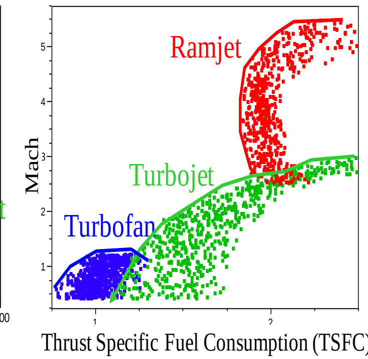
Source Mavris, ASDL, GATECH

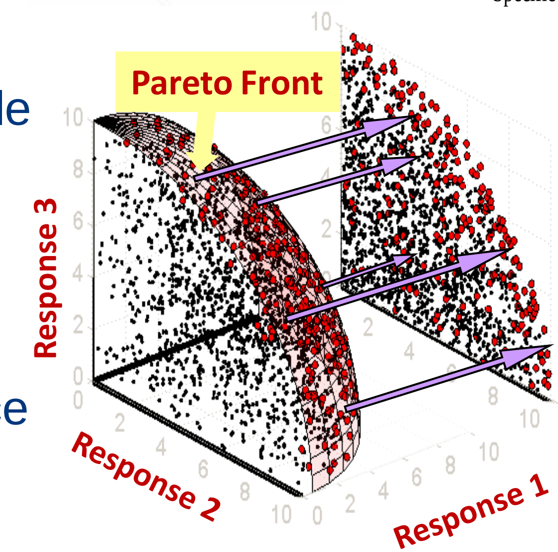
Pareto Optimal Solutions in Many Dimensions

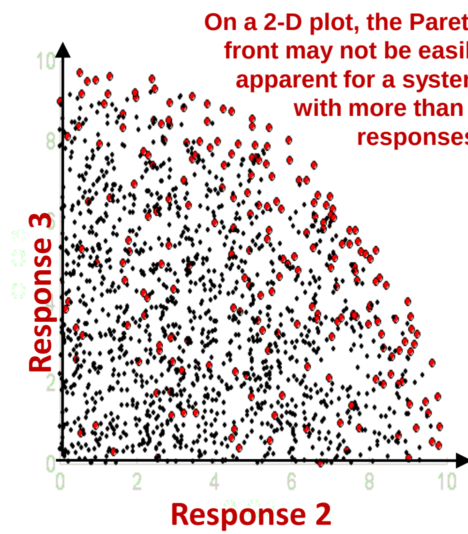
- The use of Genetic Algorithms to find ***Pareto Frontiers*** has become a common tool for multi-objective optimization
- When extended into multiple responses, the concept tends to break down as all solutions appear Pareto Optimal
- Methods are needed to slice the design space and visualize multidimensional tradeoffs







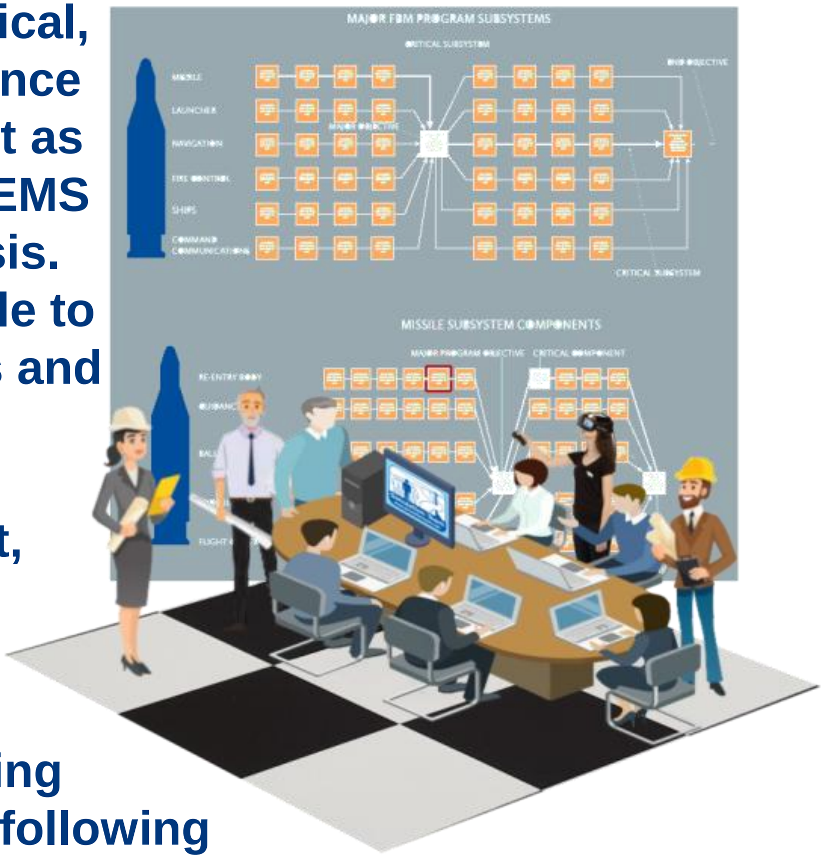




Visualizing Multi-Dimensional Optimality is Difficult for Human Decision Makers

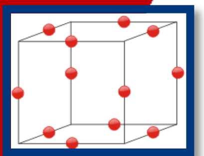
Project Management Methods & Risk Analysis

PM (Project Management) is very critical, including the use of PDM (Precedence Diagram Methods) for Time Management as well as EAC (Estimation at Completion), EMS (Equivalent Monetary Value) & Risk Analysis. These aspects are very important to be able to figure out the impact of uncertainty, risks and opportunities respect Complex Systems.



In general the capability to Manage a Project, corresponding to a *Temporary* and *Unique Initiative* devoted to achieve *Explicit Goals* with *Limited Resources* (e.g. Time, Money, People) is a very crucial element in addressing Complex Systems and it is described in the following as well as in a specific Module for assessing Student Capabilities.

Enablers for Complex SoS



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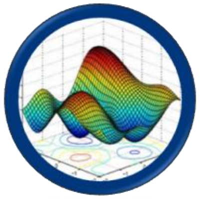

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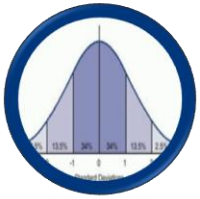

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- Monte Carlo Simulation

Visual Analytics

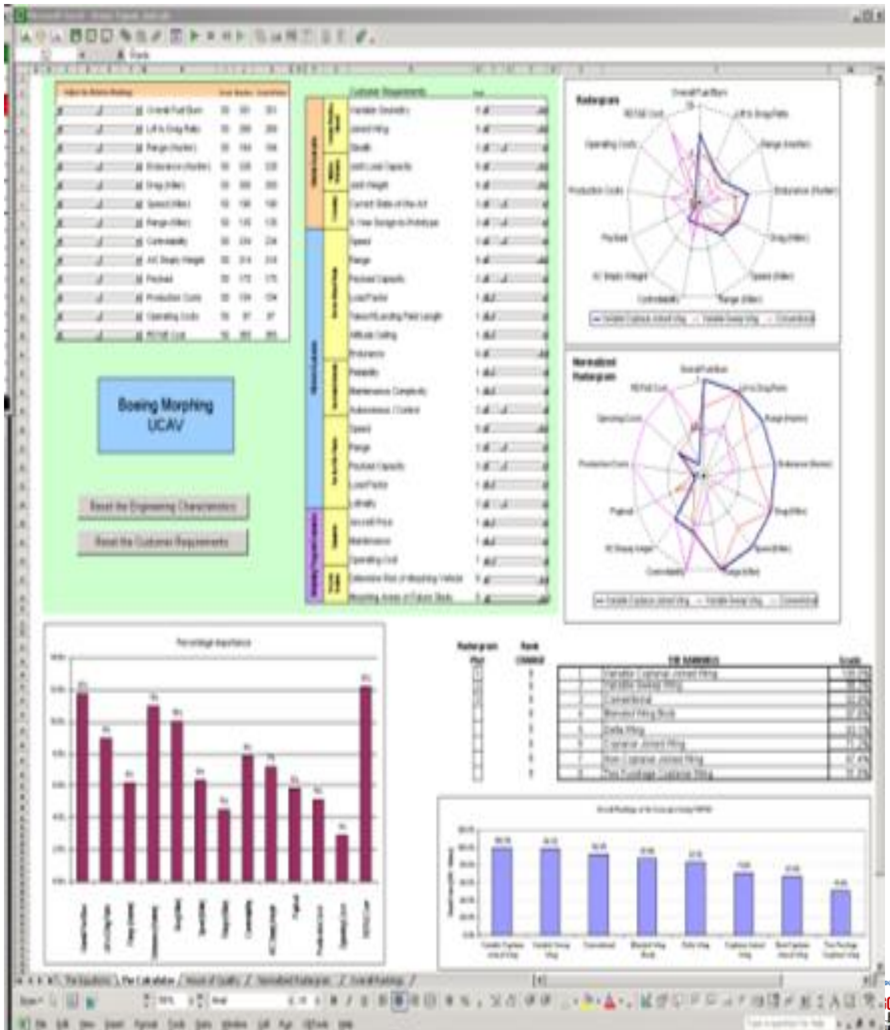
Source Mavris, ASDL, GATECH

Multi-Attribute Decision Making

How do we select among a plethora of alternatives in the presence of uncertainty or missing information?

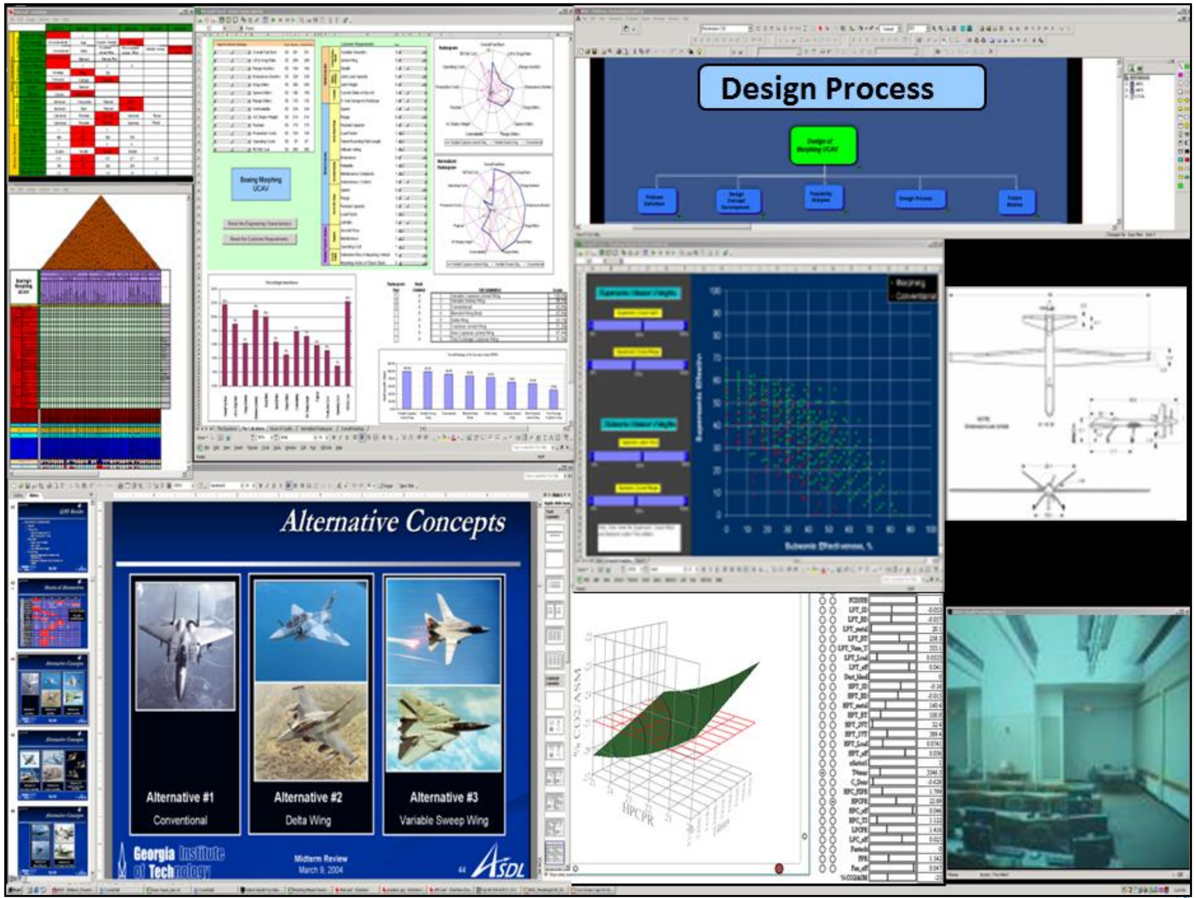
How do we support those making key decisions?

- Multi-Attribute Decision Making (MADM) techniques provide a mechanism for:
  - Structuring information about the alternatives
  - Capturing value systems
  - Capturing decision-maker preferences
  - Scoring alternatives in a traceable and repeatable fashion
- MADM techniques can be readily implemented in interactive, dynamic, and visual environments to support the pre-decisional assessment phase of decision-making



Source Mavris, ASDL, GATECH

Interactive Electronic Design Reviews



Interlinking data on a large format visualization wall allows decision makers to interact with engineers

Surrogate models, probabilistic techniques, and defined interface standards are required

In this way the speed of the decision making and design processes could be enhanced

Interactive Design Reviews are useful in SoS due to large amount of information and dynamic nature of data

Source Mavris, ASDL, GATECH
Unclassified approved for Unlimited Public Release

Collaboration and Integration in Design

- **Design is, by nature, a collaborative endeavor**
- **Facilities to support integrated design and visualization are becoming more affordable**
  - **ASDL has the Collaborative Visualization Environment (CoVE) and the Collaborative Design Environment (CoDE)**
- **Courses that encourage collaboration and the use of new web technologies are needed**
- **ASDL's Grand Challenges are a used to foster education in collaborative design methods**

ASDL's CoVE

- **Collaborative Visualization and Design Facilities are Becoming Affordable and Widespread**

Source Mavris, ASDL, GATECH
Unclassified approved for Unlimited Public Release

Collaborative Environments, M&S and Integration in SoSE

SoSE benefits of new technologies for immersive environments and simulation:

- Design is, by nature, a collaborative endeavor
- Facilities to support integrated design and visualization are becoming more affordable
- Universities should encourage collaboration and the use of new web technologies
- Design competitions are a good way to foster education in collaborative design methods

Source Mavris, ASDL, GATECH

Remarks on SoSE

- System of Systems Engineering is a young field with many exciting research opportunities
  - Systems-of-Systems Engineering requires new and novel approaches to improve the traditional SE process
- A wide range of methods is needed in order to address key SoSE challenges in both the military and the civil domain
- Additionally, increased effort is needed in training the technicians and engineers on how to approach problems from an SoS perspective and on the use of collaborative visual analytics design approaches

Source Mavris, ASDL, GATECH

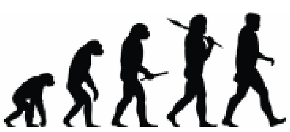
Simulation Team

Simulation Team
www.simulationteam.com

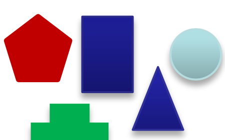
Modeling & Design for Complex Systems

Impact of Complexity on Modeling and Simulation

- Self Organization
  - Feedback and interactions must be captured
- Non-Linearity
  - Behavior is more than sum of the behavior of the components
  - Tiny change in a condition can eventually lead to a huge number of different possible results



- Adaptation
  - Complex systems continually adapt to their environment to improve performance
  - Adaptive agents are more robust but more difficult to create

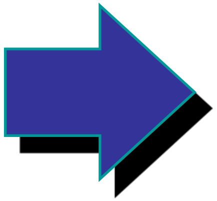


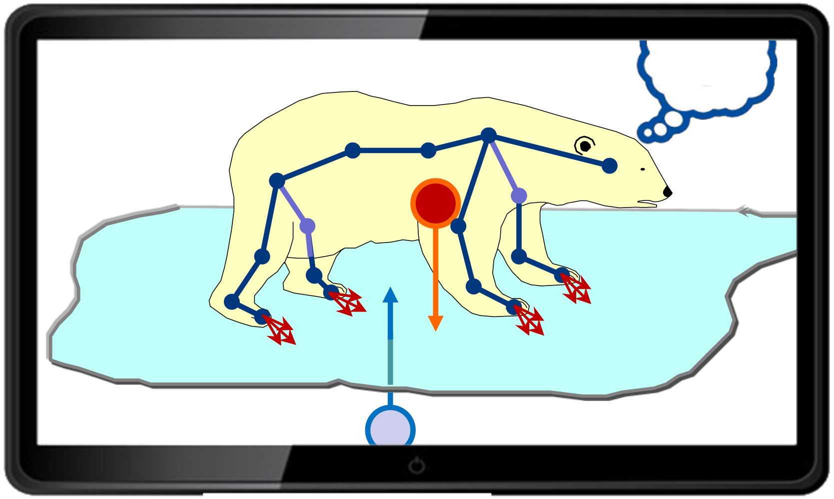
- Heterogeneity
  - Chance of emulating emergent behavior increases with more interactions of diverse agents

Source Mavris, ASDL, GATECH

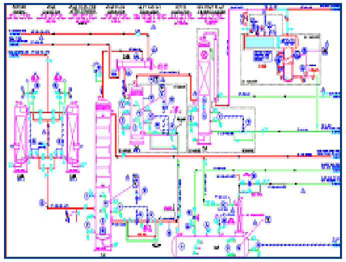
What are M&S and SG?

Simulation is the reproduction of the reality by using computer models. The Simulation allows to build up a *Virtual Environment* and to run dynamic scenarios in order to analyze or optimize the real system. A Serious Games allows to involve players in an learning experience through user Engagement .





System Complexity requiring Modeling & Simulation



Internal Complexity → Complex Behaviors

↓

Not Linear Systems

A reason to Simulate
More Efforts ←
More Capabilities
Reusable Model

Not valid Simplified Hypotheses
Boundary Conditions are Critical
No Generalization

↑

External Complexity → Many Interaction

Simulation Team

Simulation Types

Interoperable

Distributed

Parallel

Modelling & Simulation as a Service (MSaaS)

Deterministic

Stochastic

Man-in-the-Loop (MIL)

Hardware-in-the-Loop (HIL) &
Software-in-the-Loop (SIL) &

SIMULATION

Discrete Event

Continuous

Combined

Hybrid

Real-Time

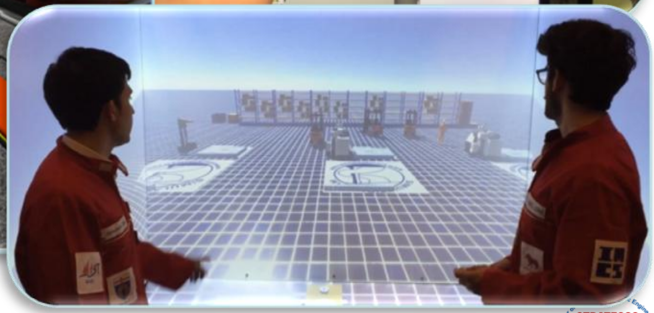
Slow-Time

Quasi-Real Time

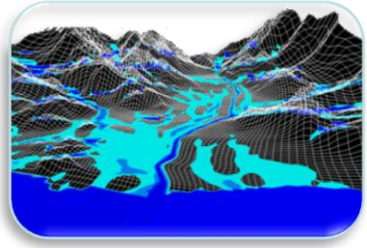
Fast-Time Reality

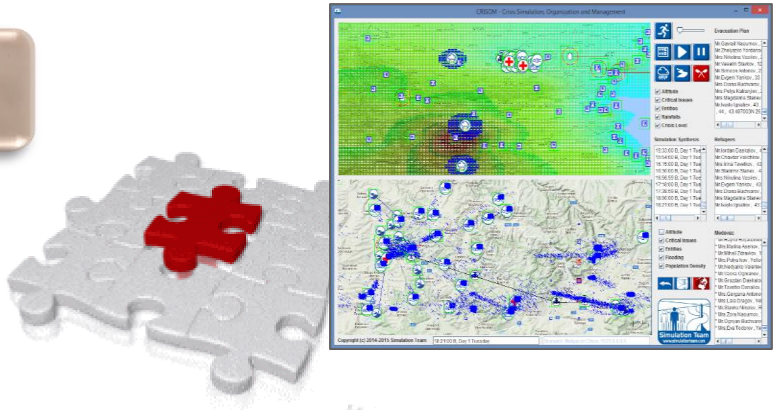
MS2G Paradigm as new Enabler

The innovative concept of ***MS2G*** (***Modeling, interoperable Simulation and Serious Games***) allows to develop interoperable scalable and reusable simulators with benefits of new Immersive Solutions. MS2G is very flexible and enable use from different platforms: regular laptops, computers, CAVE (Computer Automatic Virtual Environment) large enough to immerse 4-5 people in the Virtual World, HDM, HoloLens as well as Smartphones and Tablets



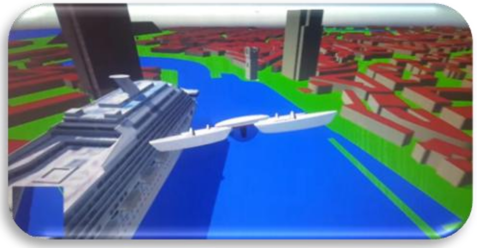
MS2G Paradigm what is inside…

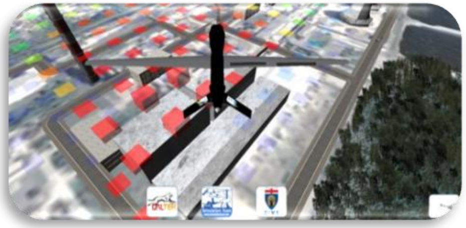




MS2G

- **Modeling**
- **interoperable Simulation**
- **Serious Games**

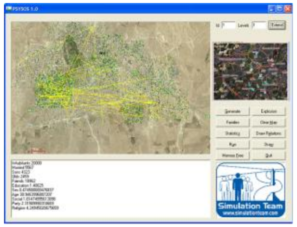




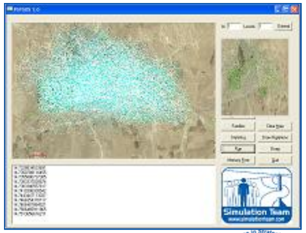
MS2G and IA

The MS2G (Modeling, interoperable Simulation and Serious Games) is a crucial new paradigm able to combine Interoperable Simulation fidelity with Serious Game engagement and intuitive approach for users. In this way the use of IA (Intelligent Agent) allows to simulate concurrently many actors, people and actions enabling to recreate and study very complex scenarios to improve trainee engagement

Agent Directed Simulation Benefits



- Simulation of Complex Behaviors related to People, Organizations, Entities and Resources
- Experimentation with a reduced workload thanks to the agents autonomous behavior able to replace man-in-the-loop and help in scenario setup
- Execution of large number of simulation runs and replications
- Allow collective training with limited Personnel
- Investigation of New Policies and Regulations on the Simulation
- Achieve a greater accuracy and reliability of simulation results in the case of experimental analysis and training
- Set-up a greater number of exercises given the same amount of available resources
- Support Expert Contributions and Creativity by operating over Realistic and Reactive Simulation Frameworks



Benefits from *IA-CGF*

Intelligent Agent Computer Generated Forces

- Introduction of Composable Elements in the Simulation Environment
- Reduction of Workload for Experimentation
- Speeding Up Scenario Preparation
- Supporting Data Farming and Experimental Analysis
- Simulate Complex Non-Conventional Scenarios
- New Capabilities to eva of Second Effects
- New Sparring Partners

Simulation and Virtual Reality

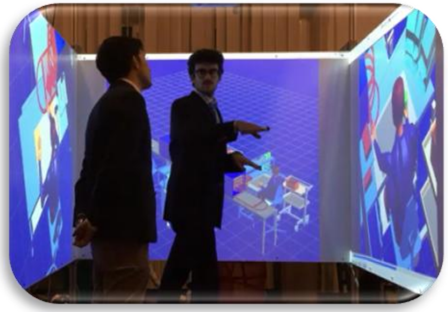
Simulation and Virtual Reality has a double utility in complex system analysis engineering:

During Project Development

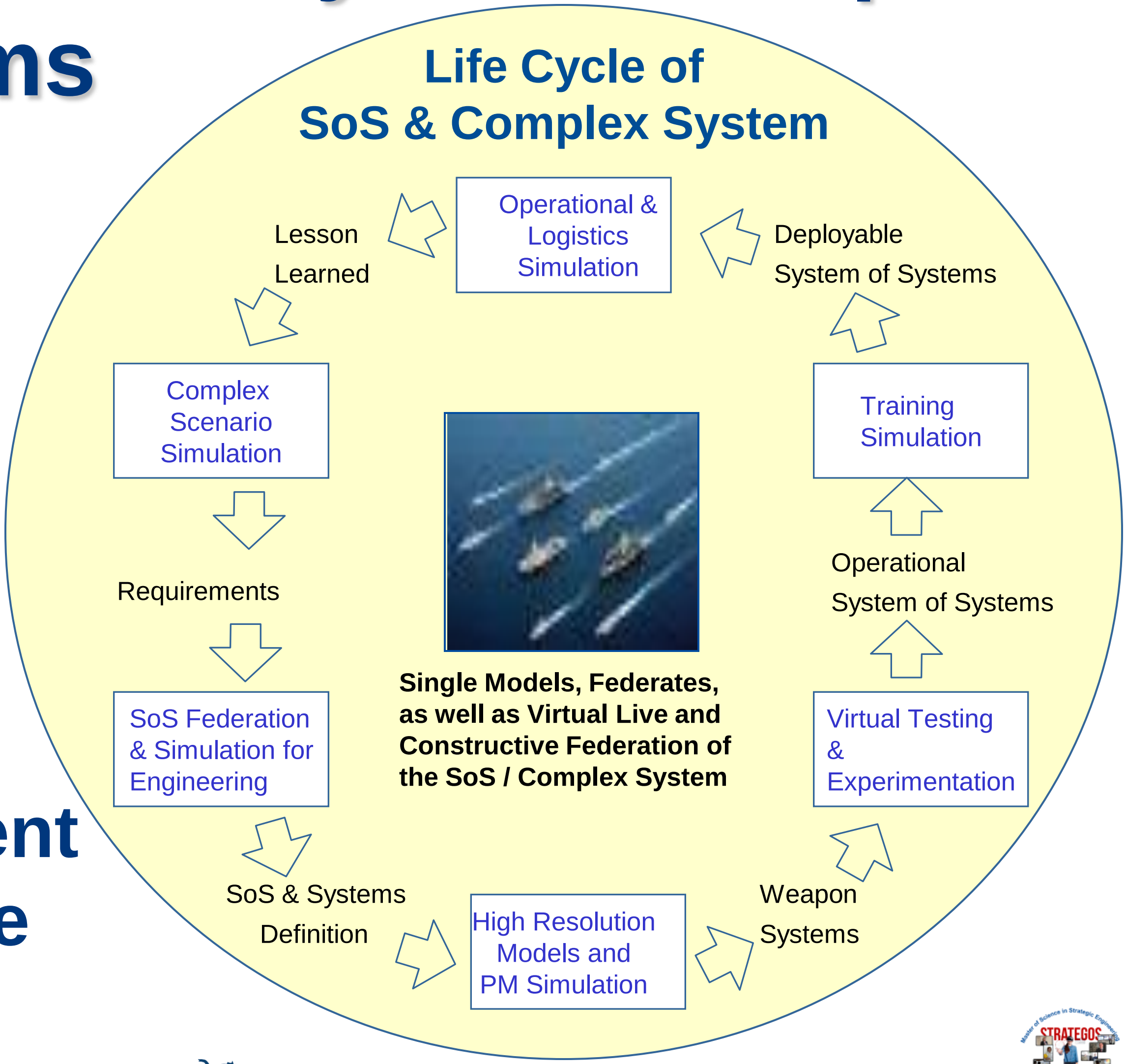
- System Logic short comes highlight
- Design short comes highlights
- Complex interactions between entities
- Emerging behaviors
- High involvement of personnel during V&V

Exposing results

- Direct results presentation
- Training tool for designers, maintenance crew, supervisors
- Direct representation of consequence of alternative choices
- Visual information easy to be valued



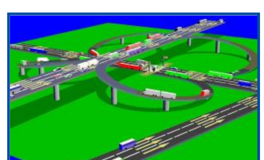
M&S in Life Cycle of Complex Systems

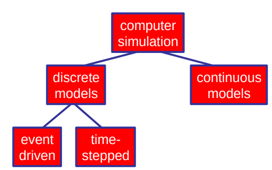


To support the whole Life Cycle of a System of Systems we need simulators able to federate the different aspects and to take care of Humans

Combined Discrete Continuous Models (Hybrid)

- The behavior of the model is simulated by computing the values of the state variables at small time steps and by computing the values of attributes and global variables at event times.
- Discrete change made to a continuous variable (i.e. vehicle efficiency after maintenance operations)
- A threshold value for a continuous variable may induce a new event (i.e. starting of vehicle maintenance operations after a certain time)
- Change in the analytical relationships between continuous variables at discrete time instants (i.e. change in the equation governing the acceleration of a vehicle when human being is in the vicinity of the vehicle





Different Time Concepts

- *physical system*: the actual or imagined system being modeled
- *simulation*: a system that emulates the behavior of a physical system

```
main()
{ ...
double clock;
...

}
```

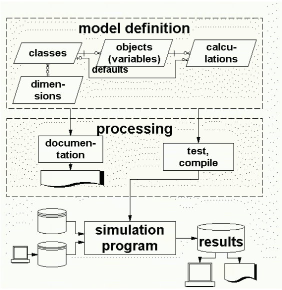
Important to distinguish among simulation time, wallclock time, and time in the physical system

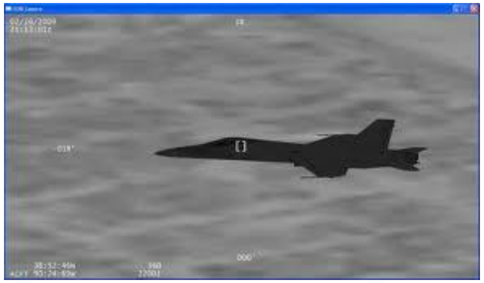
Physical System ***Simulation***

- ***physical time****:* time in the physical system
  - Noon, December 31, 2010 to noon January 1, 2011
- ***simulation time****:* representation of physical time within the simulation
  - floating point values in interval [0.0, 24.0]
- ***wallclock time****:* time during the execution of the simulation, usually output from a hardware clock
  - 9:00 to 9:15 AM on October 10, 2010

Object Oriented Simulation (OOS)

- An Object Oriented Simulation (OOS) models the behavior of interacting objects over the time.
- Object collections are called classes and can be used to create simulation models and simulation packages.
- The simulations built with these tools possess the benefits of an object-oriented design: encapsulation, inheritance, polymorphism, run-time binding, parameterized typing





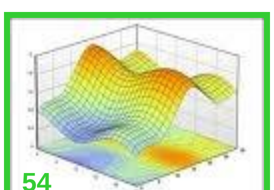

Classification Criteria for M&S in Military Applications

- Classification of Simulation for Military Applications:
  - **Live Simulation**
    - *A Simulation where real people are operating real systems*

  - **Virtual Simulation**

    - A simulation involving real people operating simulated systems (MIL)

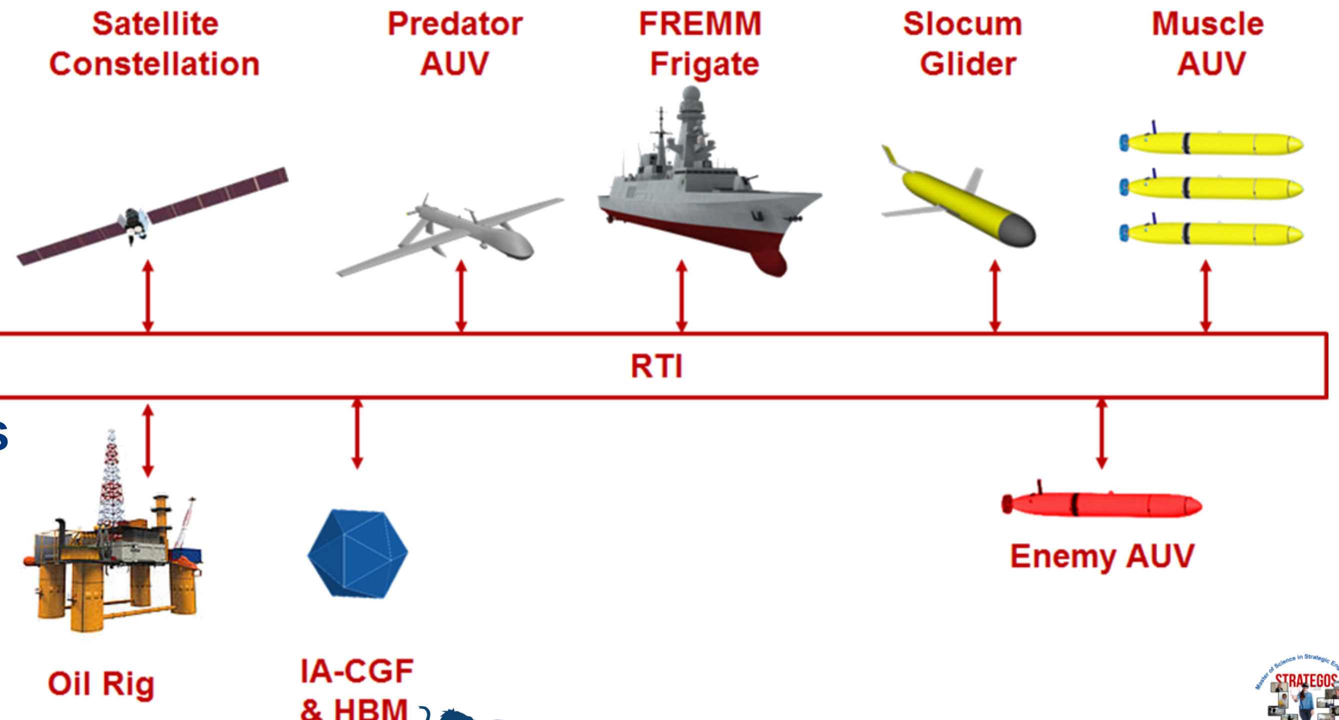
  - **Constructive Simulation**
    - A simulation involving Simulated people operating simulated systems



Interoperable Simulation for Extended Maritime framework

A first case for ISSEM Federation is devoted to protect an Off-Shore Platform by using AUV (Autonomous Underwater Vehicles) by adopting High Level Architecture Standard (HLA)

The simulation allows to model different Threats and assets.. Intelligent Agents Computer Generated Forces control the behavior of the entities



Human Modeling Challenges

- RATIONAL DECISION MAKING
  - Intelligent Individual Behavior
  - Organization & Hierarchies



- EMOTIONS & ATTRIBUTES
  - Psychology, Culture, Social
  - Crowd Behavior
  - Social Networks

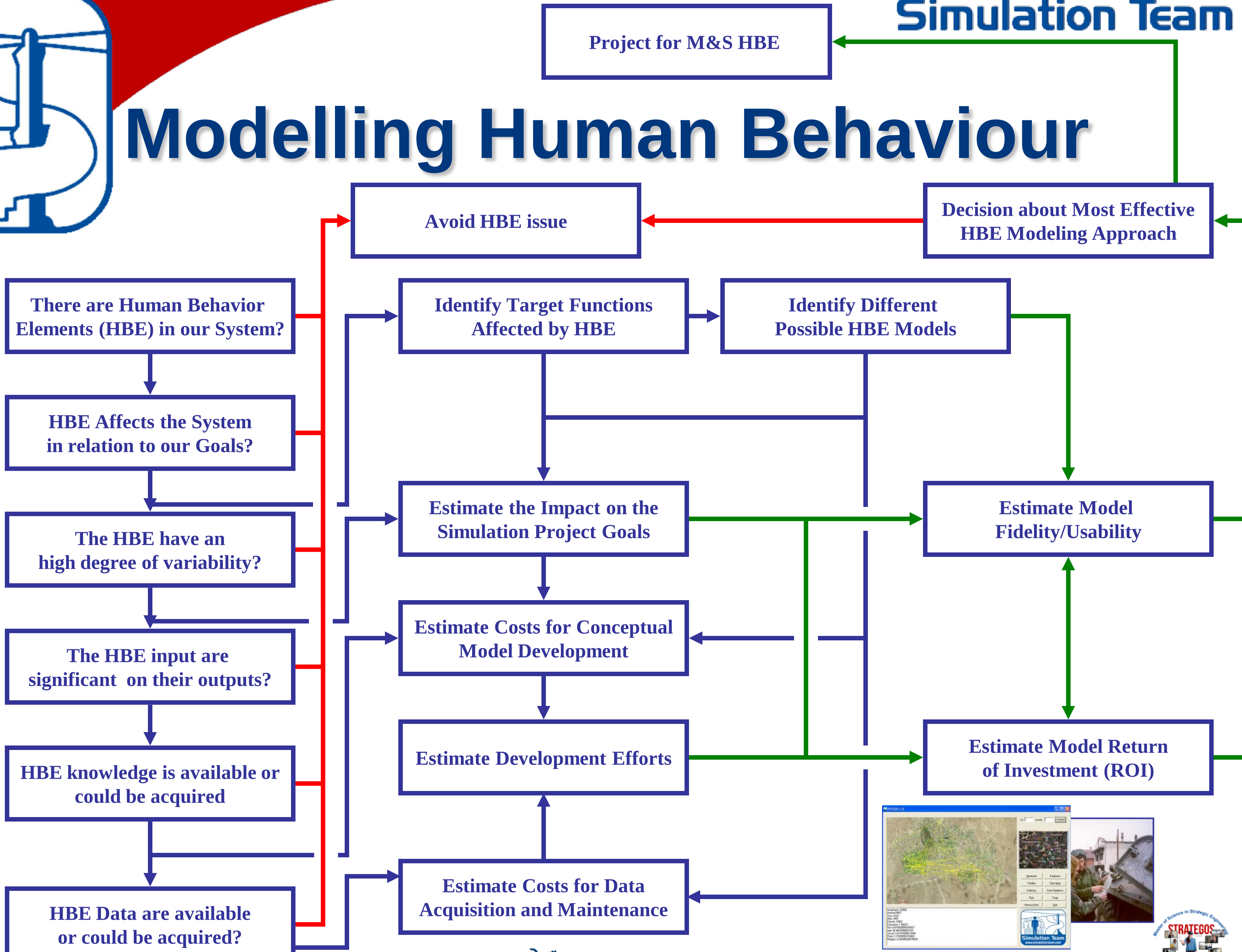
Simulation Team

Human Behavior & Simulation

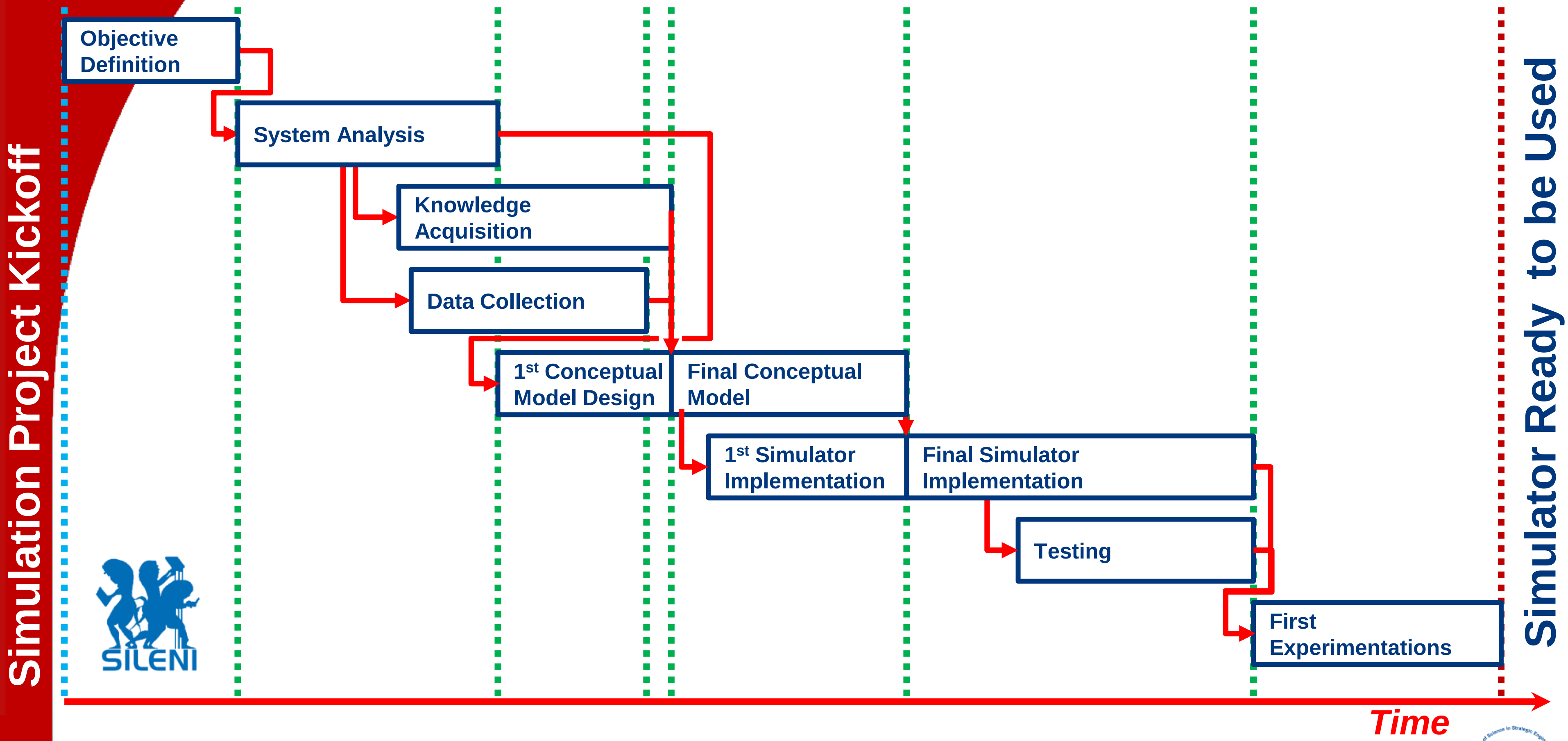
- The data flows, business processes are usual in use in current simulation. The human behavior models (HBM) are present in these aspects and have sometime have a very strong impact, so it becomes more and more important to properly consider these aspects.

Simulation Team

Modelling Human Behaviour



Development Time & Main Phases

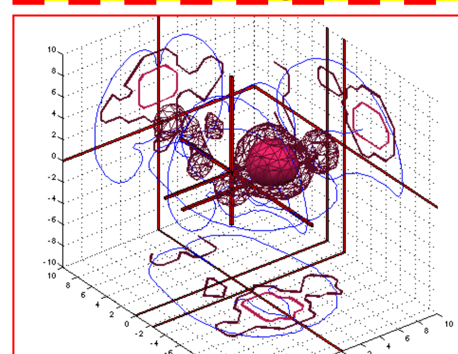


Open Issues in M&S Projects

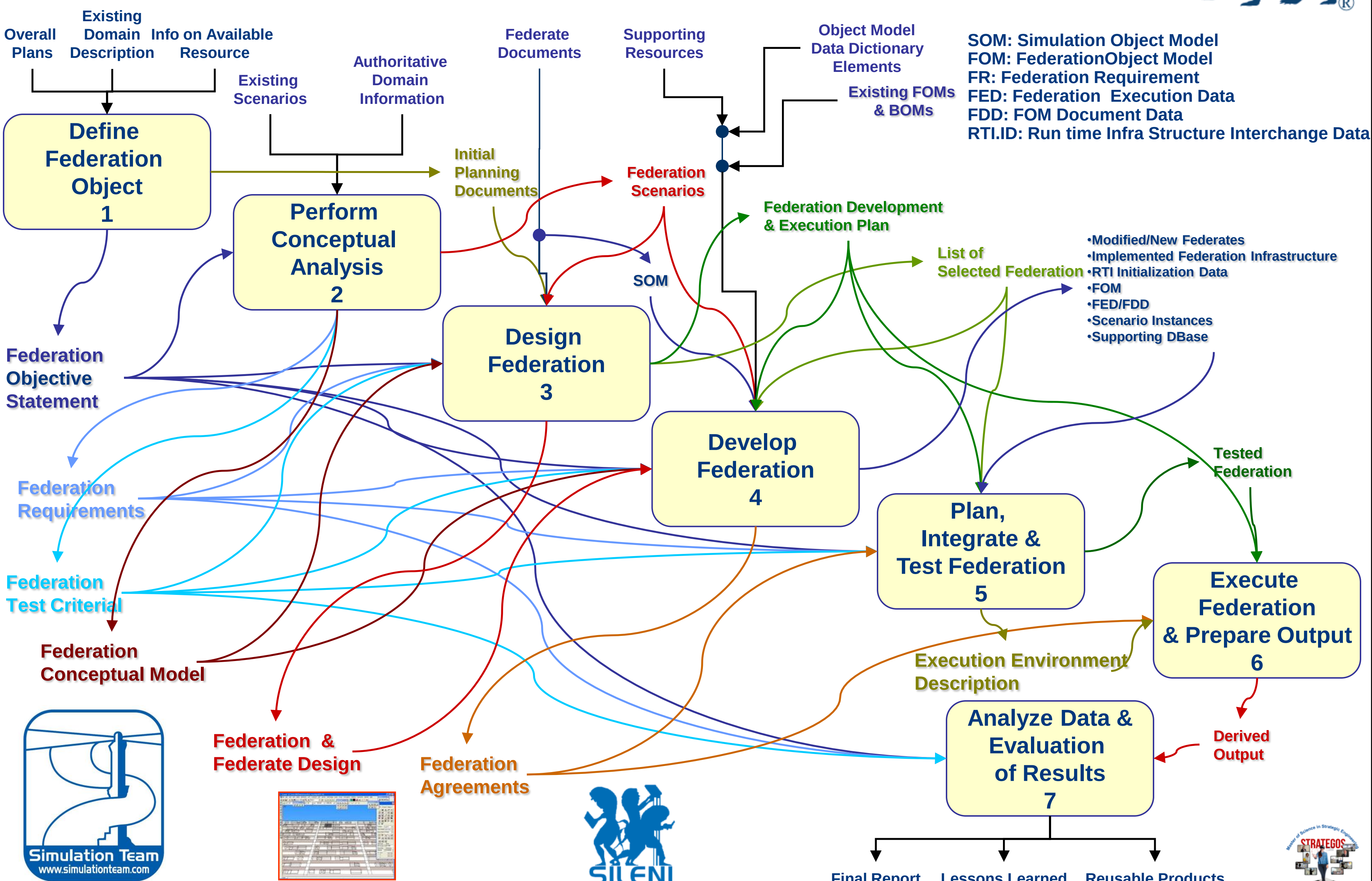
Problem Playground

- **Multidisciplinary Teams**
- **Distributed Teams**
- **Scenario Definition**
- **Skills & Experiences**
- **Legacy Dreaming**

- **Large Projects**
- **Ambitious Goals**
- **Complex RAM**
- **Development Bottlenecks**
- **Discovering the Real Models**

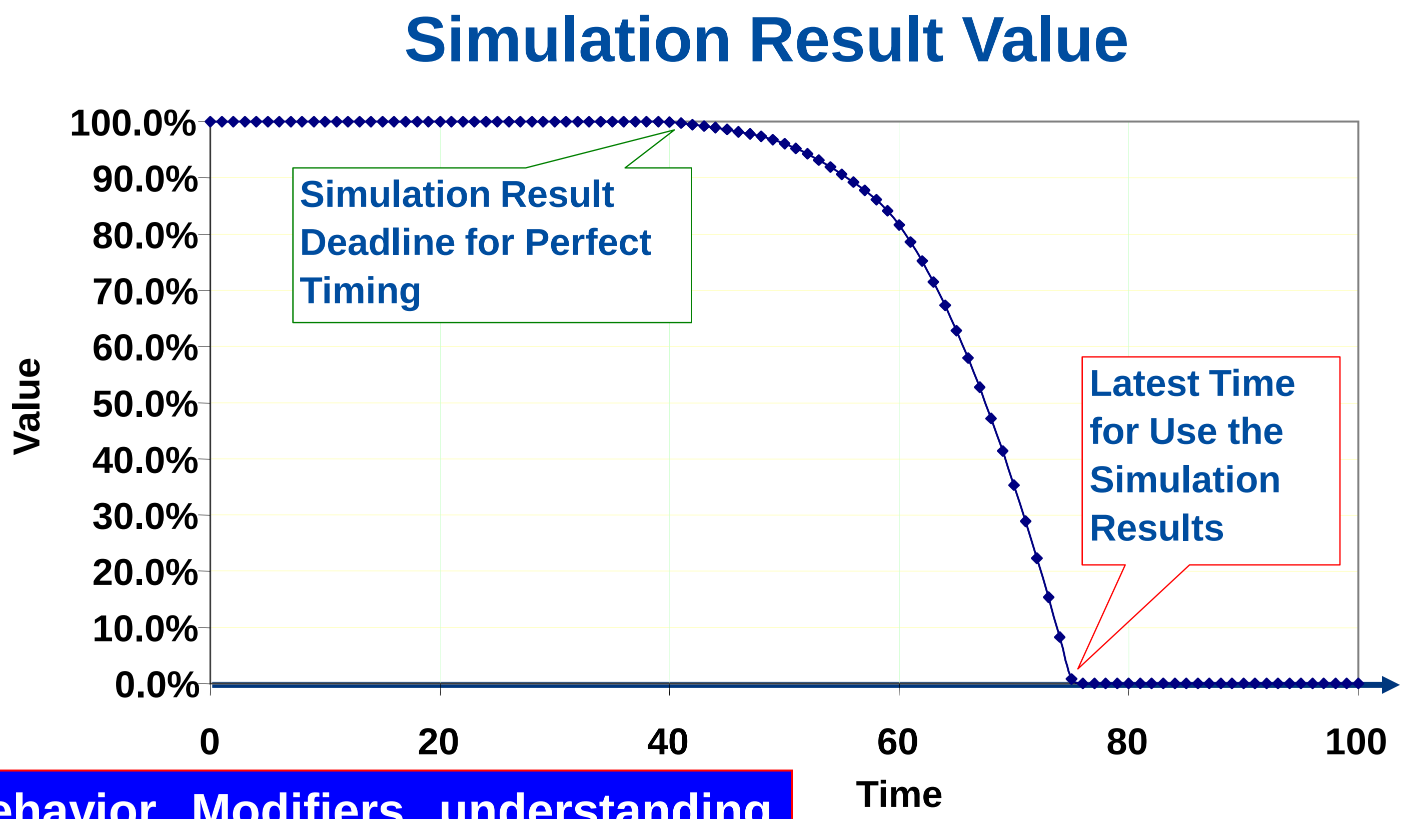


Simulation Projects vs.Fedep



Unclassified approved for Unlimited Public Release

Just in Time on Simulator Deliverables



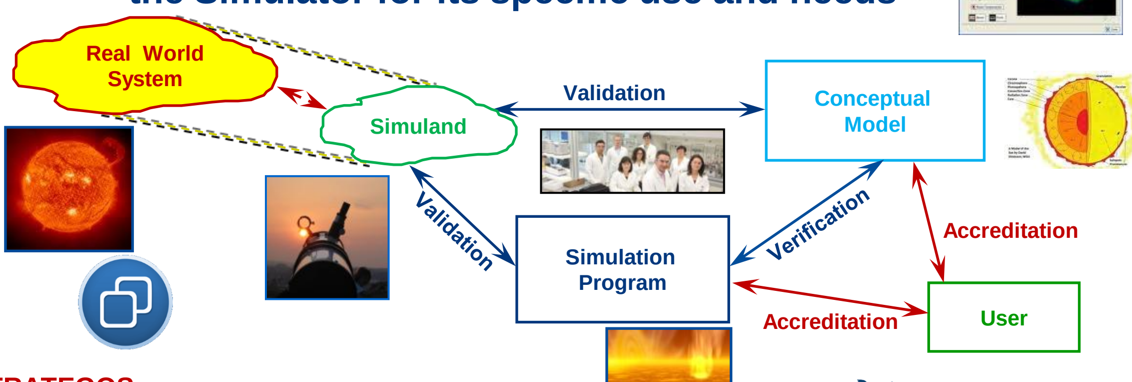
Human Behavior Modifiers understanding have an high risk to arrive too late

VV&A in M&S

Verification & Validation is critical in M&S and require to be followed all along the whole Simulation Development Process from Objective Definition to integration tests, experimentation and data analysis. Accreditation is the key to certify the Simulator satisfies User Requirements

Validation and Verification as Critical Issues

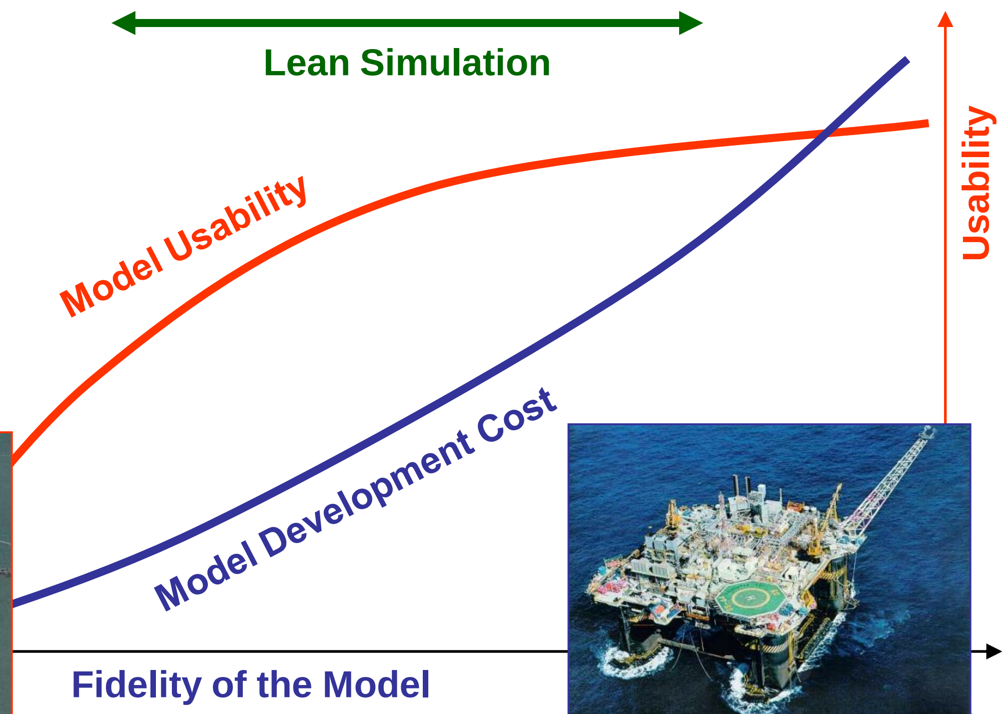
- **Validation is the process of determining whether the conceptual model is an accurate representation of the actual system being analyzed. Validation deals with building the right model.**
- **Verification is the process of determining whether a simulation computer program works as intended (i.e., debugging the computer program). Verification deals with building the model right.**
- **Accreditation certifies users is satisfied of the Simulator for its specific use and needs**

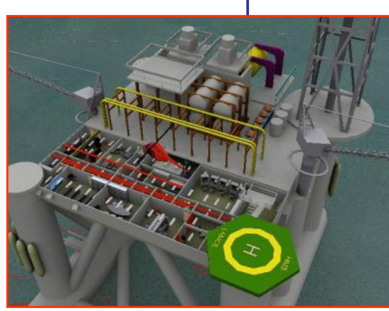


Usability vs. Fidelity in M&S

A model Output could be considered in relation to a credibility level. If correctness grows, development cost of the model grows; meanwhile usability of the model increases, but with a non-linear, and usually at decreasing, rate.

So Verification, Validation and Accreditation are critical issues





Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September

Simulation Team

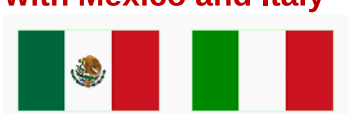
Lean Simulation

Lean Simulation relies on developing Smart Teams able to use fast Simulation Development Solutions, Methods for relaxed fidelity, but able to control Confidence to create quickly Solutions using Data from Digitalization & IoT/IIoT

The main scope is to support:

- Small & Medium Size Enterprises (SME) Competitiveness
- Early Stage Evaluation of Large Programs

- Projects carried out with major Corporations in Europe and USA
- International Cooperations with Mexico and Italy

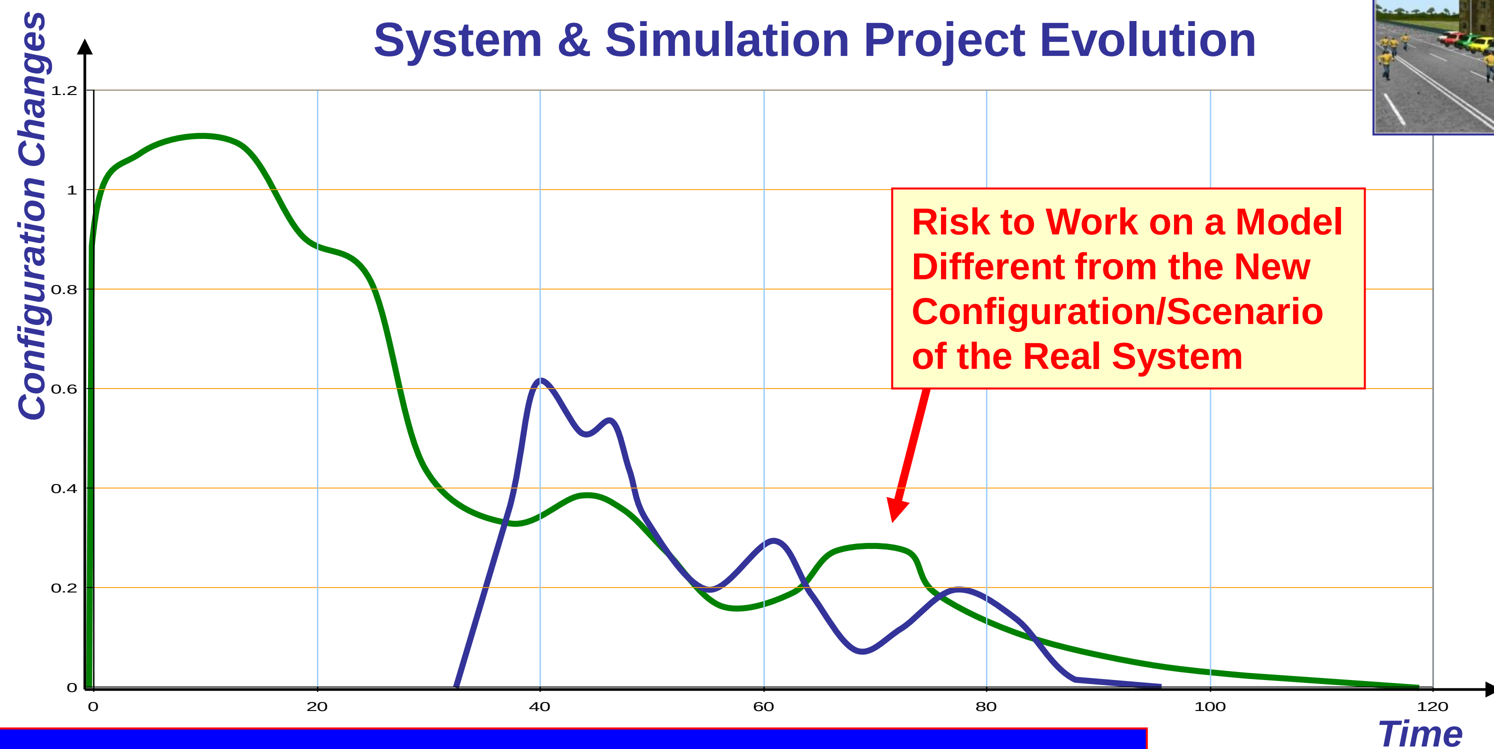


IIoT Industrial Internet of Things
IoT Internet of Tings

Project Evolution and Product Configuration

- In Projects related to System of Systems it usually very critical to keep control over the Product configuration that involve to control requirements and design of many systems and subsystem
- Along the Project the Product configuration could evolve (e.g. due to changes in requirements) so it is critical to control them

System Configuration Dynamics



Real System
Model

Human Behavior Analysis introduces Drastic Changes in the Model Infrastructure

Standards & Regulations: Examples for Complex Systems

Simulation Team
www.simulationteam.com

Standards and Regulation for Systems and Subsystems

ISO defines:

Standard: a document approved by a recognized institution, to be used repetitively and including commonly rules, guidelines and specifications for products, processes or services; for these is still not obligatory to respect these rules

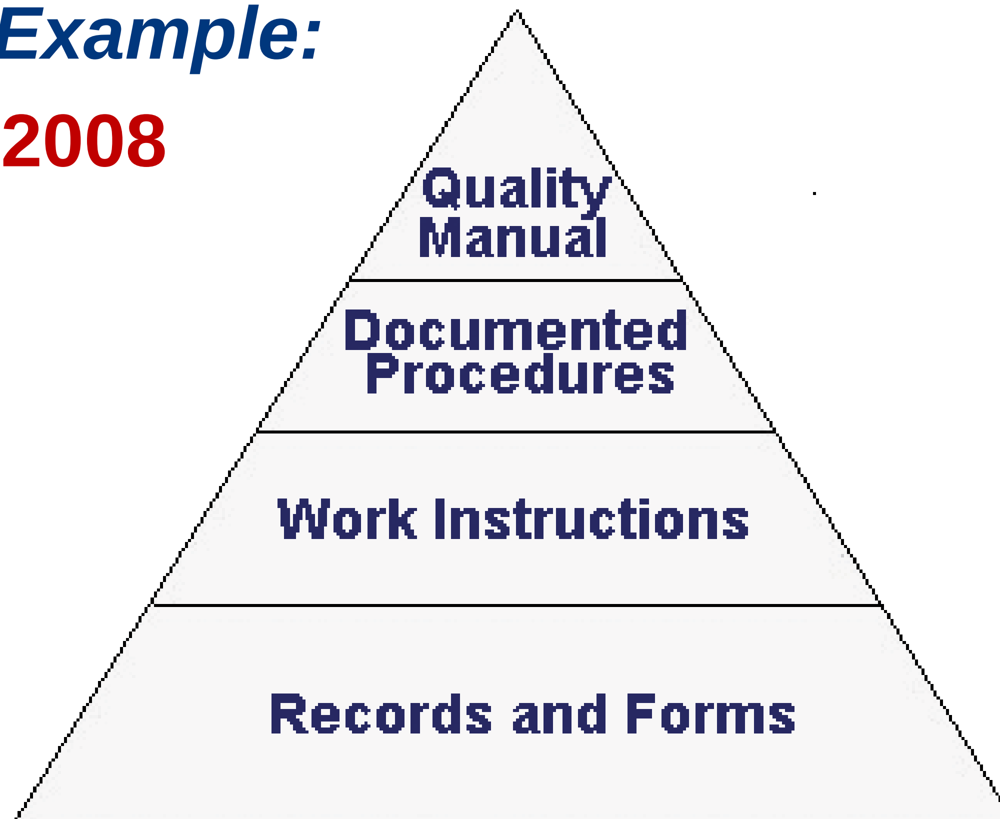
Regulation: a document presenting products, processes or services identified by characteristics, including the applicable administrative procedures, for which compliance is mandatory.

Obviously the discussions on standards and regulation are very important and affect project time, costs, resources and negotations. Fundamental questions therefore are whether the standards are de facto Regulations, if they are devoted to become mandatory for certification institutions requests, etc..

Multinational Standards & Regulations

Quality Assurance Example:

- **UNI EN ISO 9001:2008**
- **AS/EN 9100:2009**
- **AS/EN 9110:2012**



Multinational Agencies & Regulations in Aerospace

Quality Assurance Example:

- **CAA – Civil Aviation Agency**
- **FAA – Federal Aviation Agency**
- **EASA – European Aviation Safety Agency**
- **The agencies produce regulations (i.e. CAR, FAR)**

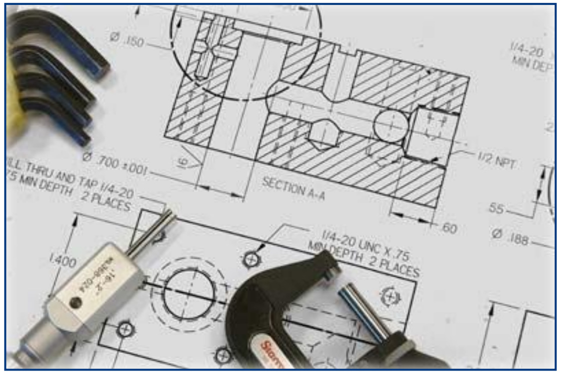
Civil Aviation Authority

FEDERAL AVIATION ADMINISTRATION

European Aviation Safety Agency

- EASA Part 21 Subpart J DOA - Design Organization Approval
- EASA Part 21 Subpart G POA – Production Organization Approval
- EASA Part 145 MOA – Maintenance Organization Approval
- EASA Part 147 (MTO)

National Standards & Regulations



- **AER-P-10, Italian National, Mantenimento dell’Aeronavigabilità**
- **AER-Q-2110 (AQAP-2110), Italian National, qualità Progettazione, Sviluppo, Produzione**

Simulation Team

Certificates by NADCAP


Nadcap

In accordance with SAE Aerospace Standard AS7003, to the revision in effect at the time of the audit, this certificate is granted and awarded by the authority of the Nadcap Management Council to:

Aero Dynamics

142 Batchelder Road
Seabrook, NH 03874
United States

This certificate demonstrates conformance and recognition of accreditation for specific services, as listed in www.eAuditNet.com on the Qualified Manufacturers List (QML), to the revision in effect at the time of the audit for:

Aerospace Quality System (AC7004)

Expiration Date: 31 July 2017

Joseph G. Pinto
Vice President and Chief Operating Officer

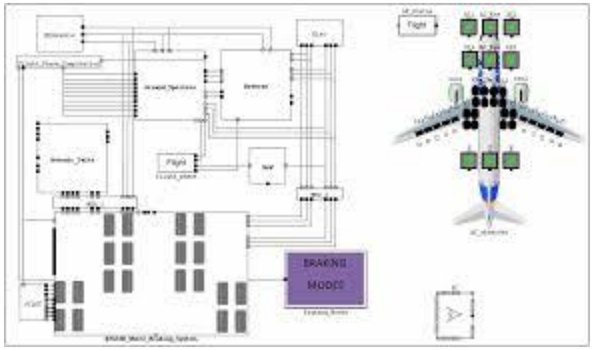
Performance Review Institute (PRI) | 161 Thorn Hill Road | Warrendale, PA 15086-7527

Certificate of Compliance to SAE-AS7003, issued by NADCAP

- *Aerospace Quality System, AQS*
- *Chemical Processing, CP*
- *Coatings, CT*
- *Composite Materials, COMP*
- *Conventional Machining as a Special Process, CMSP*
- *Elastomer Seals, SEAL*
- *Electronics, ETG*
- *Fluid Distribution Systems, FLU*
- *Heat Treating, HT*
- *Materials Testing Laboratories, MTL*
- *Measurement and Inspection, M&I*
- *Nondestructive Testing, NDT*
- *Nonconventional Machining and Surface Enhancement, NMSE*
- *Sealants, SLT*
- *Welding, WLD*

NADCAP (National Aerospace and Defense Contractors Accreditation Program)

Guidelines



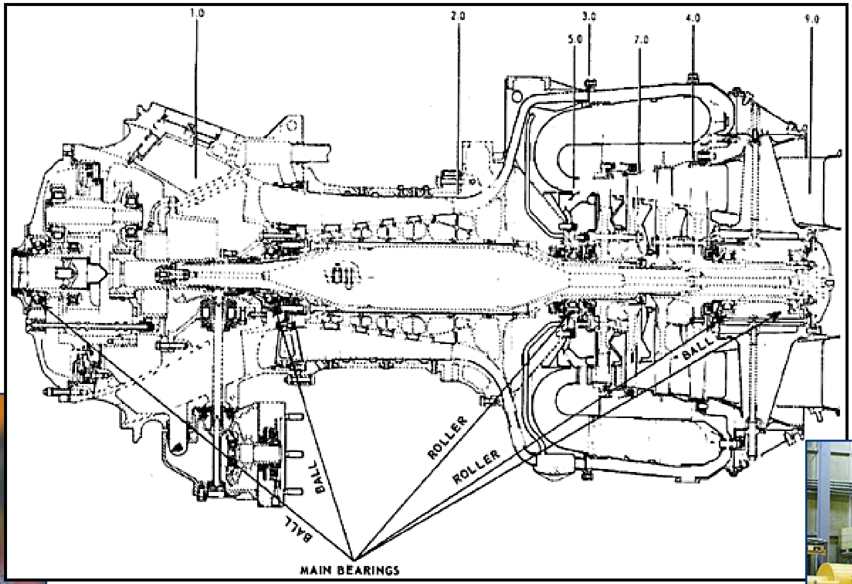
- **SAE-ARP4754A (Society of Automotive Engineering – Aerospace Recommended Practice)**

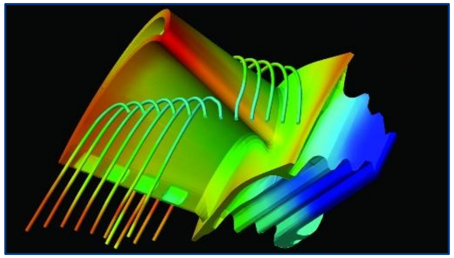
Document	Release date	Prior release	Focus
SAE ARP4754A	12/01/2010	11/01/1996	Aircraft Systems
RTCA DO-178C	12/13/2011	12/01/1992	Airborne Software
RTCA DO-254	04/19/2000	n/a	Airborne Electronic Hardware
RTCA DO-278A	12/13/2011	03/05/2002	Ground and Space Software
RTCA DO-330	12/13/2011	n/a	Software Tool Qualification Supplement
RTCA DO-331	12/13/2011	n/a	Model-Based Design Supplement
RTCA DO-332	12/13/2011	n/a	Object-Oriented Supplement
RTCA DO-333	12/13/2011	n/a	Formal Methods Supplement

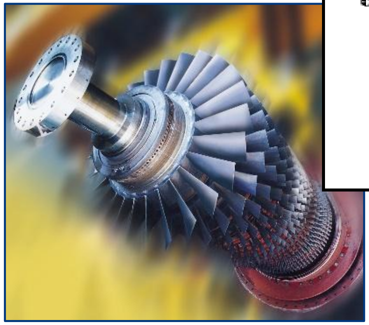
Aircraft certification documents and recent updates

Simulation Team

Case Study: Construction & Service for Complex Systems





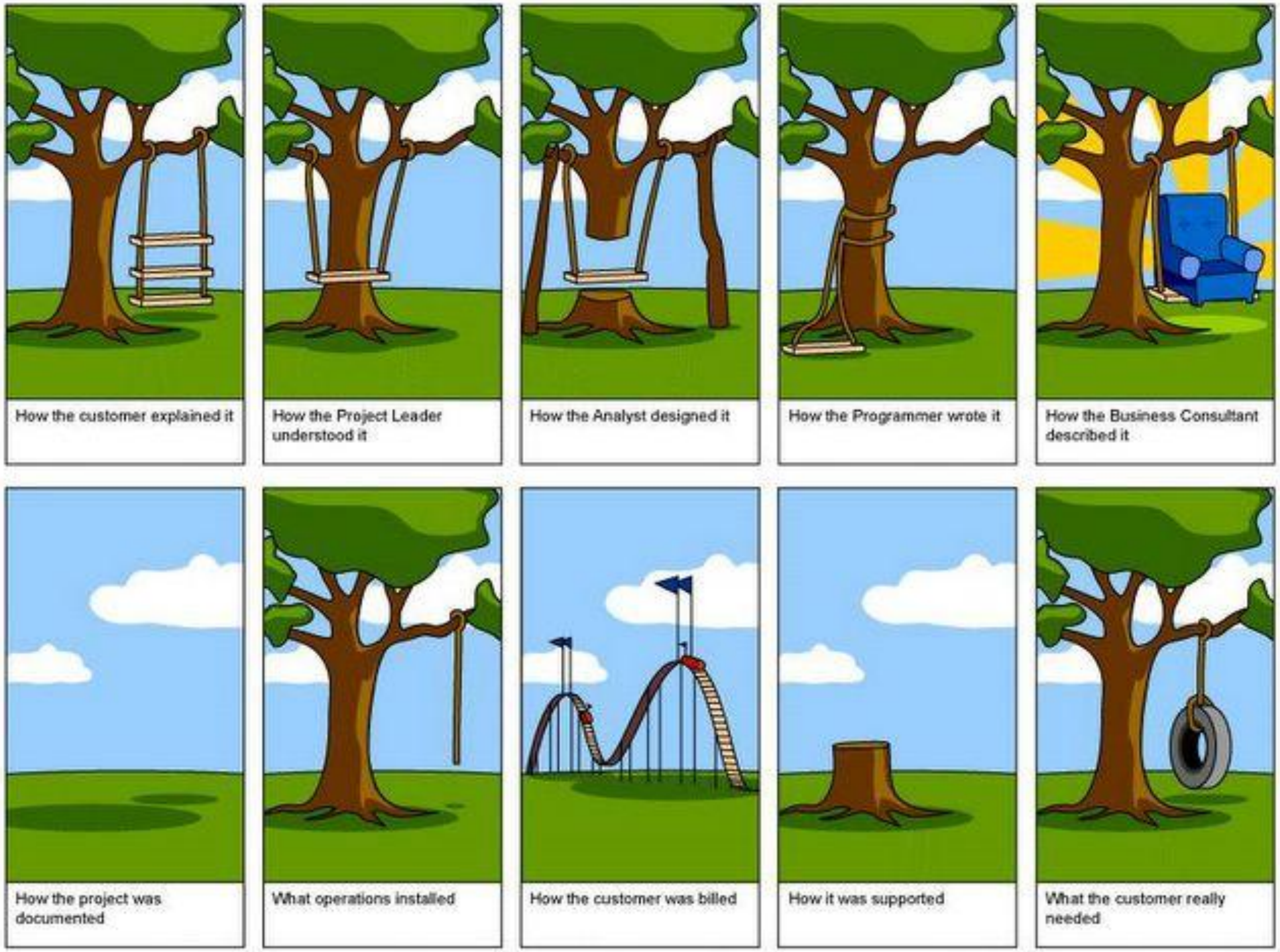


Project Management in Complex Systems

Project Management for Complex Systems

- Project Manager strongly rely on experience
- Project Management is based on Techniques and Methodologies
- Extended team working with proper Education & Training is crucial
- It is crucial to guarantee Coordination among People
- It is crucial to keep Aligned all different Players
- Research & Development are often a fundamental and risky part of the Project

Project Management & Different Views: Humour



Source Web

What is a Project?

Organizations make Works; these works generally are divided into:

- **Projects**
- **Operations**



They share resources constraints, need of planning, execution and control, people empowerment.
While Operations are in a such way continuative and repetitive, Projects are *exclusive* and *temporary*

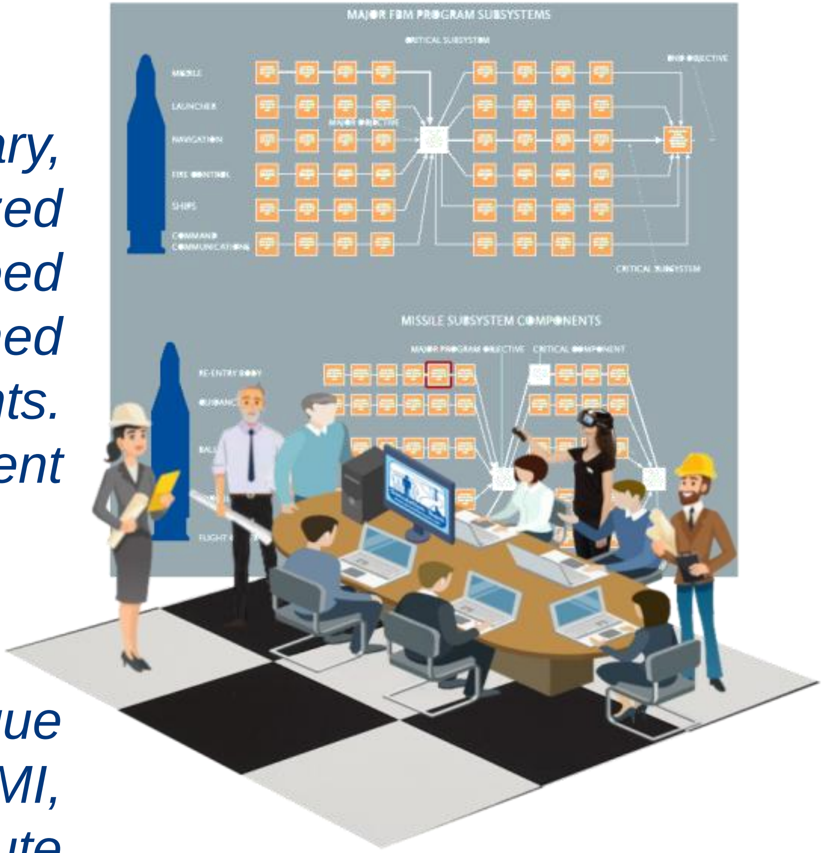
A Project is a sequence of temporary activities devoted to the creation of a single product/service.

Project Management Institute 1996

Main Project Definitions…

A "Project" is:

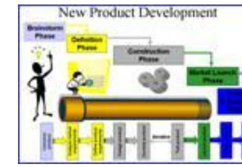
A) *A project is a "unique, temporary, multi-disciplinary and organized endeavor to realise agreed deliverables within predefined requirements and constraints. (IPMA, Int. Project Management Institute 2020)*



B) *It's a temporary endeavor undertaken to create a unique product, service or result. (PMI, Project Management Institute 2020)*

… other Definitions of Project





A "Project" is:

C) A set of all activities required for achieving a not continuous and not repetitive specific objective, obtained by coordinating specialized relationships, and by controlling the achievement of the objective at specific conditions during all the period of realization. (G.F.Aragozzini)

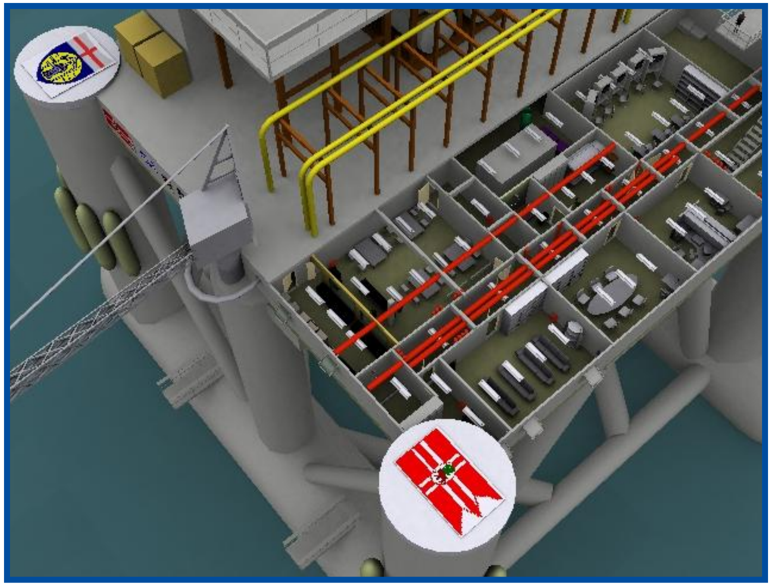
D) A combination of human resources not joined into a temporary organization in order to achieve a defined objective with limited resources (Project Management Institute 1987)

E) A temporary process devoted to the production of one or more units of a single product or service whose features are gradually elaborated (Project Management Institute 1992)

A Project is related often to System with Many Elements

The Project usually deals with the development of a Complex System (e.g. Offshore Rig, New Smartphone Development) that is usually characterized by a Systemic Vision of the different elements that are usually organized in terms of:

- Systems
- Subsystems
- Components



Projects involving Multiple Contractors and Stakeholders

Stakeholders are all the people actively involved in the project and their satisfaction influences the Project success. Among the others (i.e. Project Team families), there are:

- **The Project Manager**
- **The Customer** it is necessary to remark the presence of different types of customer (i.e. doctor and patient for a new medicine)
- The **Involved Structure in the Project**
- **Sponsors** (supporting the project in different ways)

It is difficult to satisfy their requirements and expectations:

- *The subjects are different and often the objectives are not clear for the subjects themselves, often they are in conflict, etc .*
- *Normally the requirements of the Customer have priorities, but it is not easy to disregard those from that ones of other subjects.*

Project Participants

User: using the product; it could be or not the customer (i.e. BASF commits desulphurization plant vs. Stuttgart City builds a Hospital); it is the reference for operational specifications

Customer: supporting an investment for an external project

Commissioner: announcing the proposal request; he is responsible of the Project during its duration and he is an interface to the contractor.

Contractor: company contracting for the project realization; generally, for big orders there is a *main contractor* and a set of contractors and sub-contractors. Sometimes the customer identifies directly a *managing contractor as* contractors coordinator.

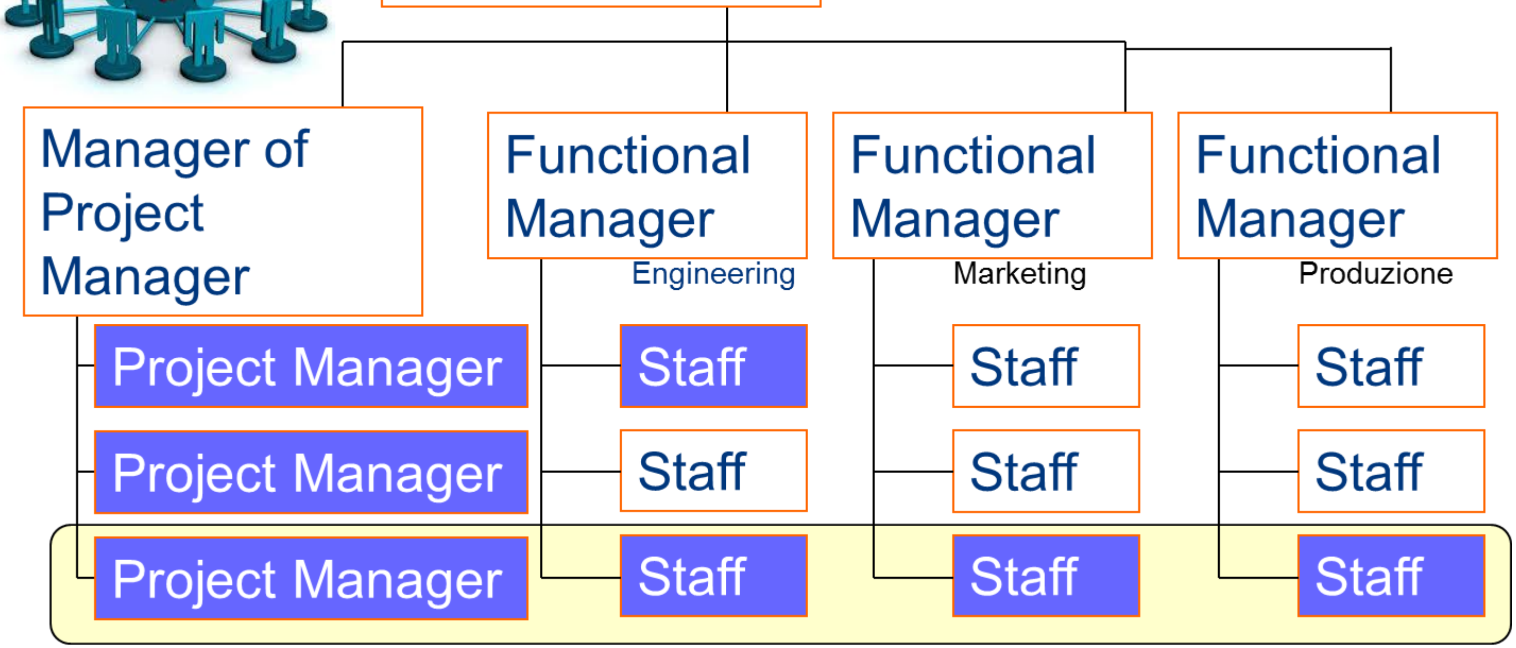
Licensee: who provides the license to use patents/ external technologies (i.e. Siemens to Ansaldo on Turbo Gas).

Supplier: supplying services, products, components or raw materials.

Regulation Institutions: all the institutions defining standards and regulations impacting on the project

Strong Matrix Organization

There are:
Project Manager Full Time
Project Manager Administration



Staff in colored boxes refer to Project Activities affiliation

Project Coordination

RAM: Responsibility Assignment Matrix

These Structures highlighting tasks and activities of Each Group or People

Project ASCI-SW	Workgroups				
	R&D	*Marketing*	*Engineers*	*SW*	*PM*
Specifications Definition	E	P	P	I	R
Project	P		E	V	R
Development	P	V	P	E	R
Preliminary Check	R	P	R	E	
Test			V	E	R

Staff Acquisition

They may be hierarchically structured by covering all the WBS phases

Project ASCI-SW	Personnel R&D					
	Francy	*David*	*Sandrosky*	*Sonny*	*Laitanasi*	*Nehislin*
Specifications Definition	S	P	P	P	A/V	R
Project	A	P	A/V	P		A/V
Development	A	P		P		A
Preliminary Check	R	A/V		A/V		
Test						

E Emission - P Participation - I Input Supplier - R Review - S Signature
A Attributable - V Observer

Complex Systems & Plants: What is an EPCC?

Plant Projects are very good examples to address the need of PM in Complex Systems: Project Management is fundamental activity and its basic criteria could be applied to many different sectors (e.g. Political Campaign, New Software Development, New Car Development, Space Mission, Smart City Initiative, etc.)

Engineering, Procurement, Construction and Commissioning (EPCC) are Projects covering the whole development process of an Industrial Plant.
Often these Projects are simply called EPC (Engineering, Procurement & Construction), while there are many other kind of contracts regulating Industrial Plant Construction and extending the life cycle (e.g. Operations & Management, Construct Build Operate and Transfer).



EPC Projects

- EPC Engineering Procurement & Construction: the contractor provides engineering, procurement and construction services. Think Design & Construct style contracts, where the project is largely Contractor managed and the cost risk and control are weighted towards the Contractor and away from the Owner.
- EPCC: Engineering Procurement Construction and Commissioning
- EPCI: Engineering, Procurement, Construction and Installation (e.g. off shore installations)
- EPCM: Engineering , Procurement , Construction, Manage: Contractor is responsible for total construction right from conceptual design to Final handing over to owner; Other companies are contracted by the Owner to provide construction services and they are usually managed by the EPCM contractor on the Owner's behalf.

Projects vs. Labels

- EPMC: Engineering, Procurement & Management of Construction; the executor will be someone else deputed in consultation with owner
- BOOT: build Own Operate Transfer (usually after 7 years or as contract with owner)
- DBOOT: Design Build Own Operate Transfer (usually after 7 years or as contract with owner)
- OM: Operation and Maintenance
- LSTK: Lump Sum Turnkey
- PFI: Private Finance Initiative
- PPP: Public Private Partnership
- PMC: Project Management Consultant: the manager of a project in behalf of the Client. The PMC handle the contracts issued by the Client to perform a project such as EPC's, Services.

Project Control in Complex Systems: Time, Costs, Quality

Project Management

Project Integration Management
Combine and Coordinate Different Aspects of the Project

Project Scope Management
Identification of all objectives and needs

Project Time Management
Guarantee Times Respect

Project Cost Management
Define and observe Project Costs

Project Quality Management
Guarantee Project Quality

Human Resource Management
Manage Project Personnel

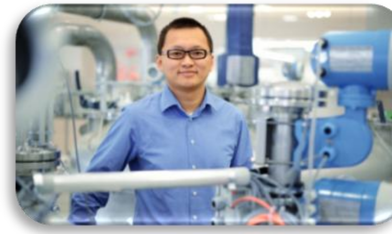
Project Communication Management
Manage Communications

Project Risk Management
Evaluate and Manage Risk

Project Procurement Management
Evaluate and Manage Suppliers

PMI (Project Management Institute) Structure

Complex Systems and Industrial Offsets



The contract varies from refundable to fixed cost:

Agreed Price

Contractor Margins

$$C_t = x\,P + (1 - x)\,C + M$$

Refundable Contract
x = 0

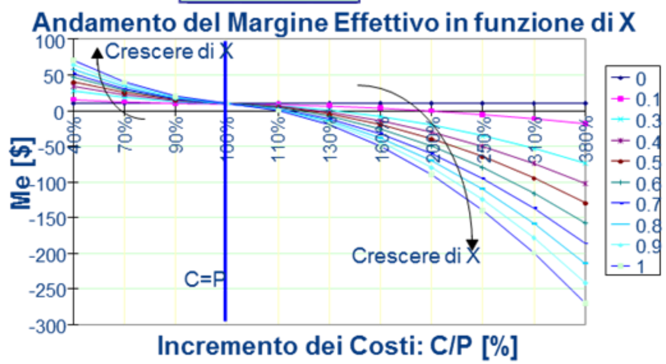
Lump sum Contract
x = 1

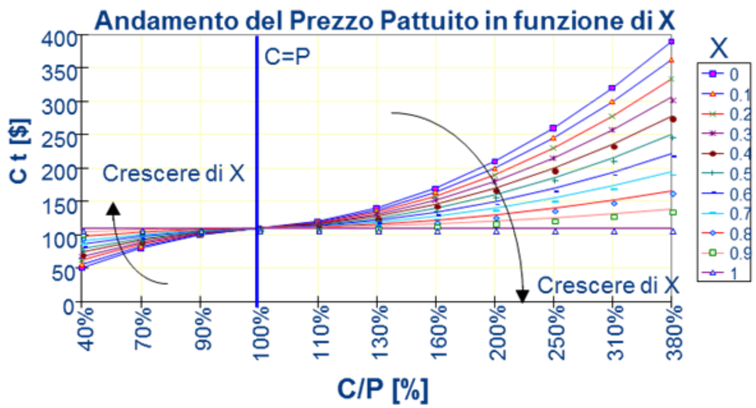
Risk Repartition Between Contractor and Commissioner

Final Cost

Effective Margin

$$Me = C_t - C = x\,(P - C) + M$$





General Project Development Output

Project General Plan (Project Plan)

It is a formal document that is approved and is the reference for the project execution management and control.

It should be distributed according to the scheme provided by the communications.

It include:

Project Contract

Objective (deliverables, objectives)

PMBs (Perf.Meas.Bas.) par costs-times

Staff (key or required people)

Open Points and on going decisions

PM strategies for the different areas

Work Breakdown Structure

Milestones and Main Target (times)

Critical Risks (hypothesis, constraints, reactions)

Connected Management Plans (i.e. Scope and Schedule Management Plan)

Costs Estimation, Starting Date & Responsibilities at the WBS level for the control

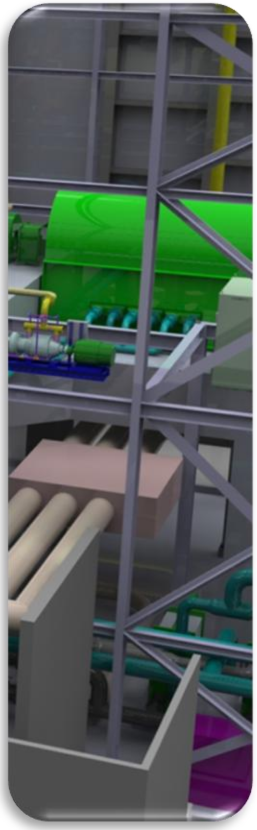
Support Details

Normally they include:

- Output for the planning processes not included in the Project Plan
- Additional Information or documents developed during the development.
- Technical Documentation (specifications, projects etc.)
- Fundamental Standards Documentation

This material must be reorganized in order to easy reference

Performance Measurement Baselines (PMBs) vs Project Plan

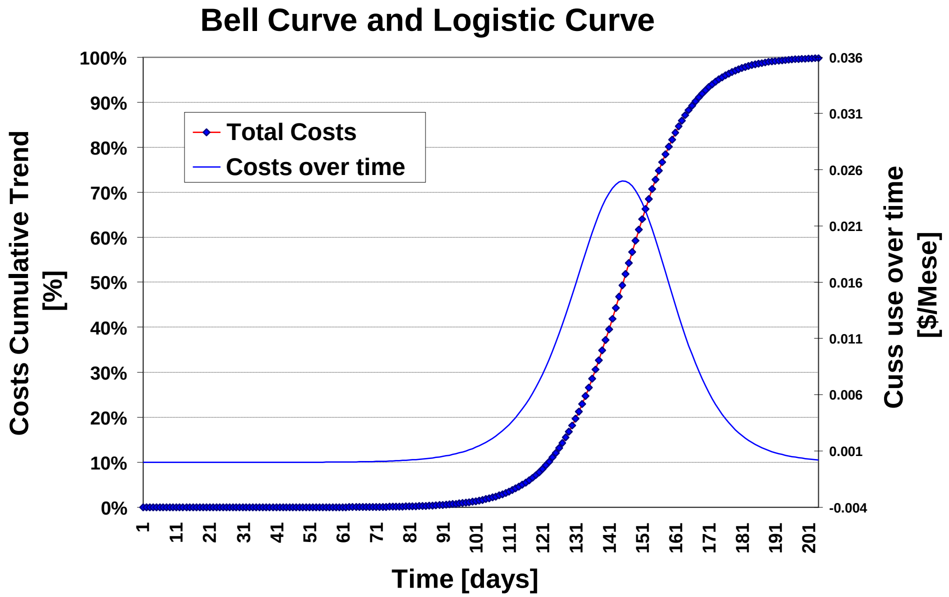


The Performance Measurement Baselines (PMBs) are key documents for the project control and the working progress evaluation.
It is therefore a Management Control which normally changes only occasionally and in front of officially approved changes in the project scope (in order to guarantee a solid reference for the project status evaluation).
The Project Plan is, as already said, a set of documents evolving during the project based on the new information incoming and it is a useful tool for the project overview.

Simulation Team

The Logistic Curve for Plant Projects

The Logistic Curve is the typical example of PMB and it may represent :
Physical Produced Quantities (i.e. Produced Pipe)
Performed Work Equivalent in Man/ Hours (i.e. Engineering)
Payed Costs (i.e. General Project progress)



The man-hours could be defined as *Actual Man Hour* (really used hours) or *Standard Man Hours* (measured under standard conditions).

From similar historical cases it is possible to create some *"regularity"* curves to be used as a reference and support for milestones definition

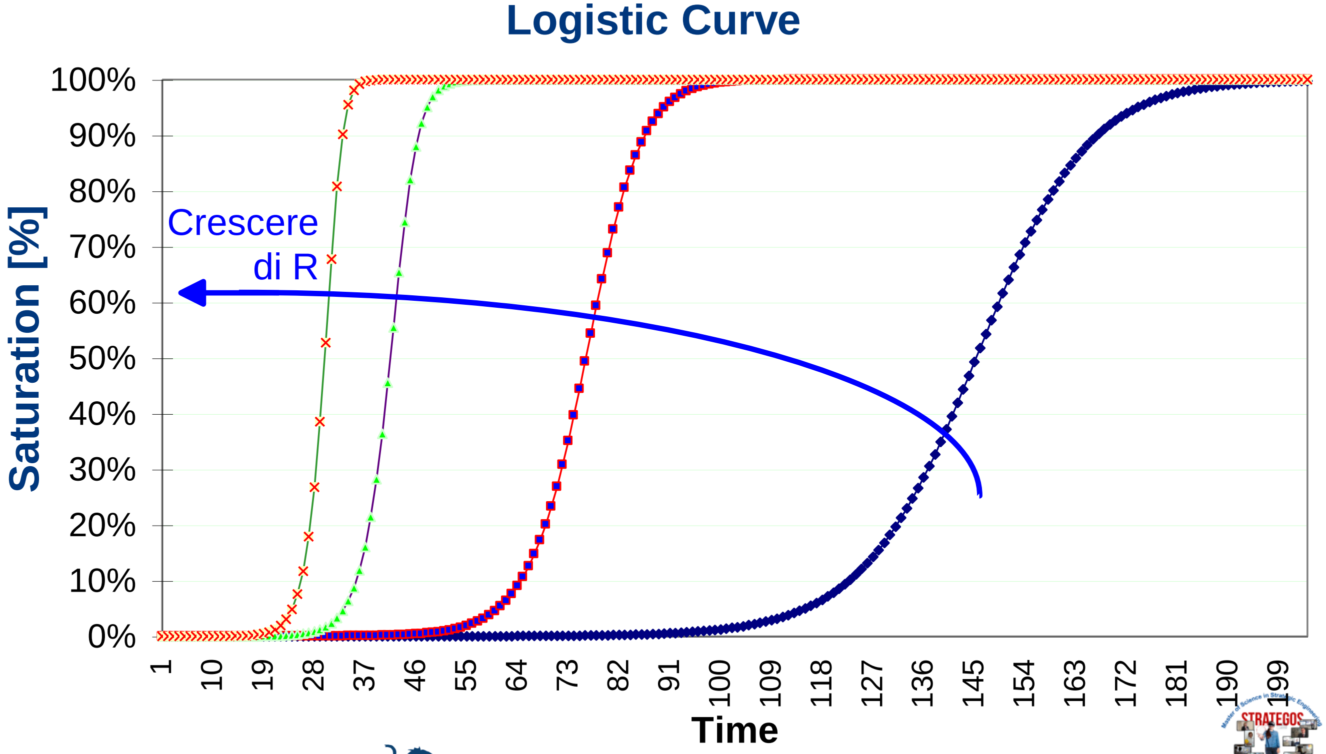
The Logistic Curve or "S" Curve

The ***"S"Curve*** or ***Logistic Curve*** reproduces the cumulative trend of the Plant Project (in term of costs, working progress, etc.). This obviously means to integrate resources employment curves in the time that correspond to instead bell curves..

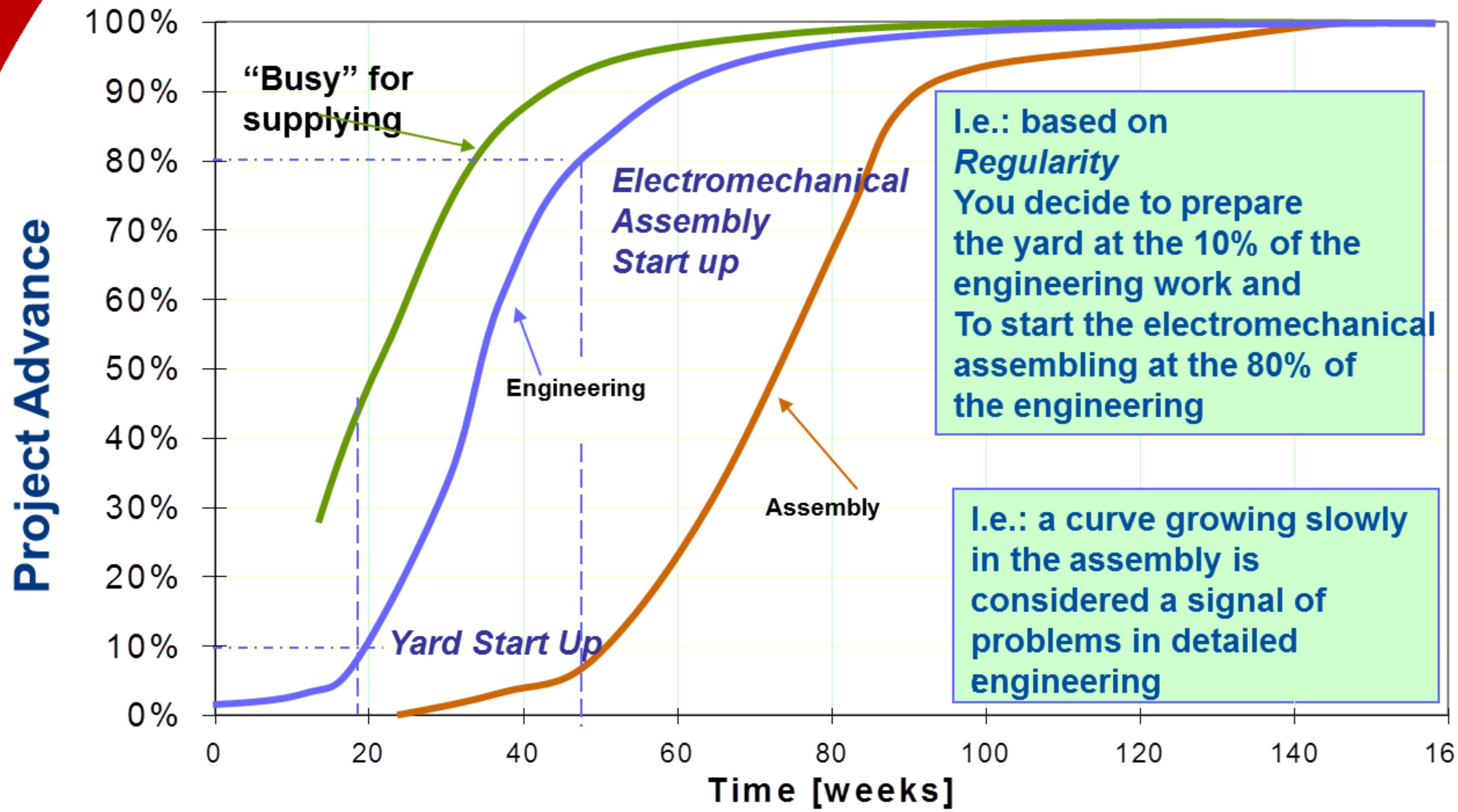
P.F. Verhulst (1845)

F(x) = R x (1 - x)

x(t+1) = x(t) + F(x)



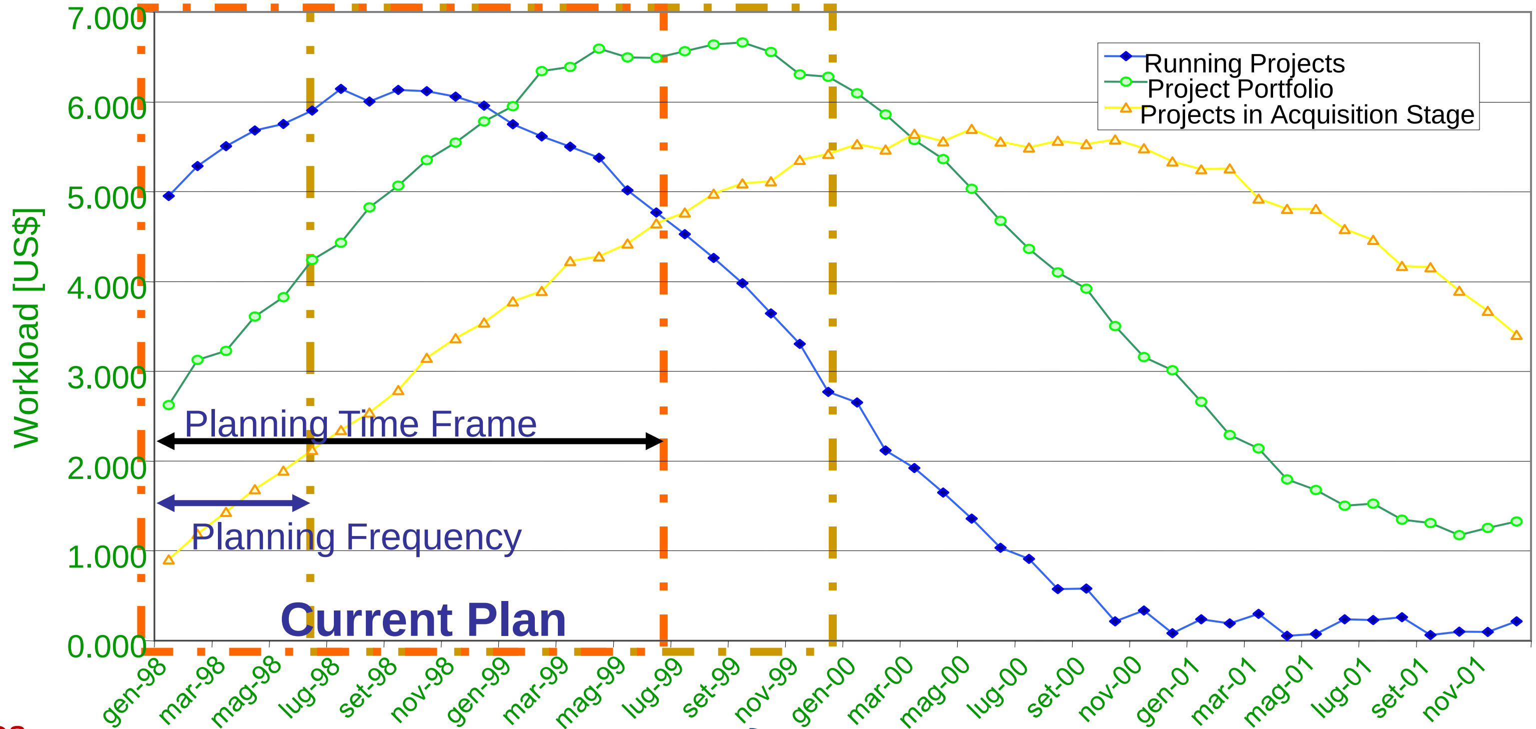
Correlations between Progress and Regularity Curves



Simulation Team

Rolling Wave for Strategic Analysis

Often more projects are managed in parallel; in the strategic planning it is possible to use a periodic technique operating in a limited temporal frame that allows constant updates ("rolling wave") so that it is possible to identify the different tasks of the different projects.



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Project Life Cycle Representation

An Example is the American Defence Minister Acquisition System that includes the phases and the deliverables of each milestone.

Life Cycle for Defense Acquisition US DoD 5000.2 (rev 2/26/93)

	Phase 0	Phase I	Phase II	Phase III e Phase IV	
Needs Mission Identification	Concepts and Ideas Exploration and Definition	Demonstration and Validation	Engineering Development and Manufacturing	Production and Deployment	Operations and Support

Milestone 0
New Concepts Study Approval

Milestone I
Demonstration Approval

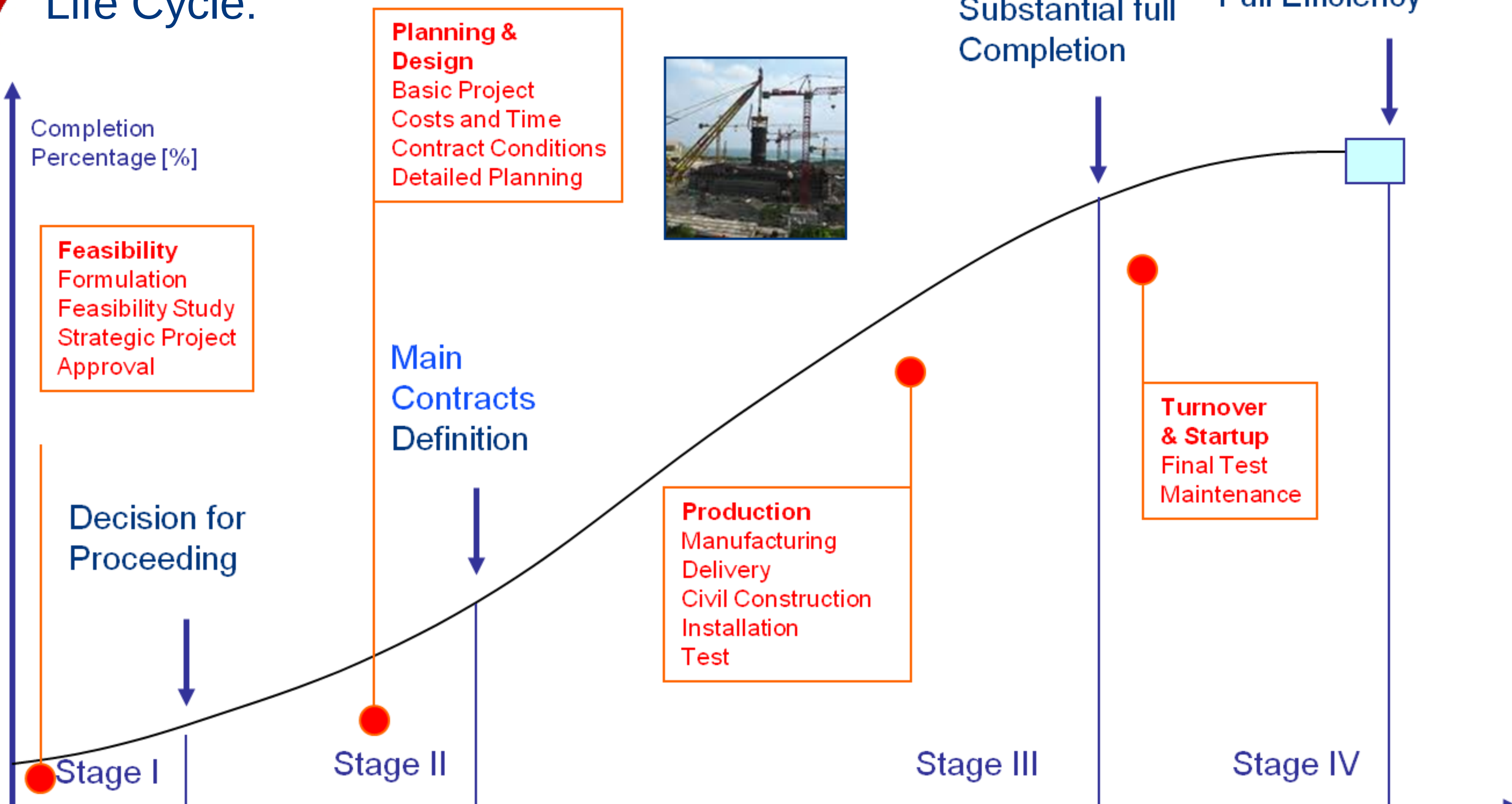
Milestone II
Technical Project Approval

Milestone III
Production Approval

Milestone IV
Main Required Changes Approval

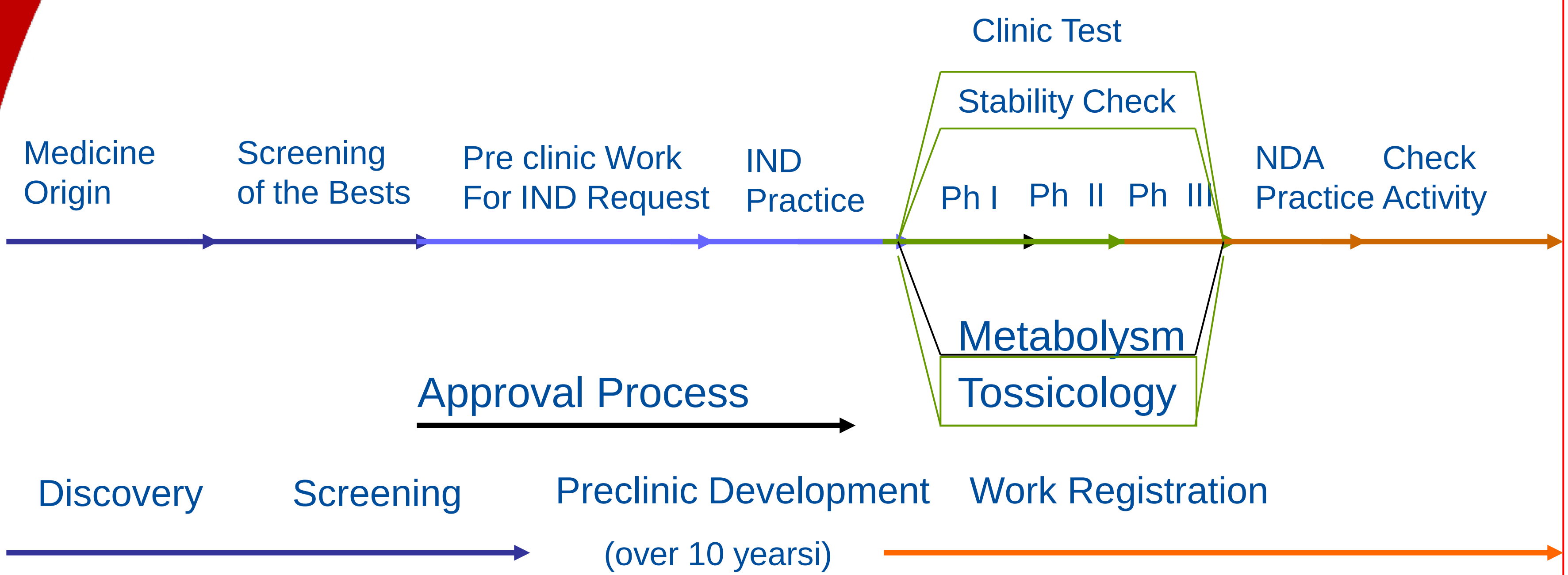
Morris Representation of the Project Life Cycle

For Construction Projects it is often proposed the Morris vision of the Project Life Cycle:



Murphy Representation

For Pharmaceutical Projects it is proposed the Murphy representation of the Project Life Cycle:

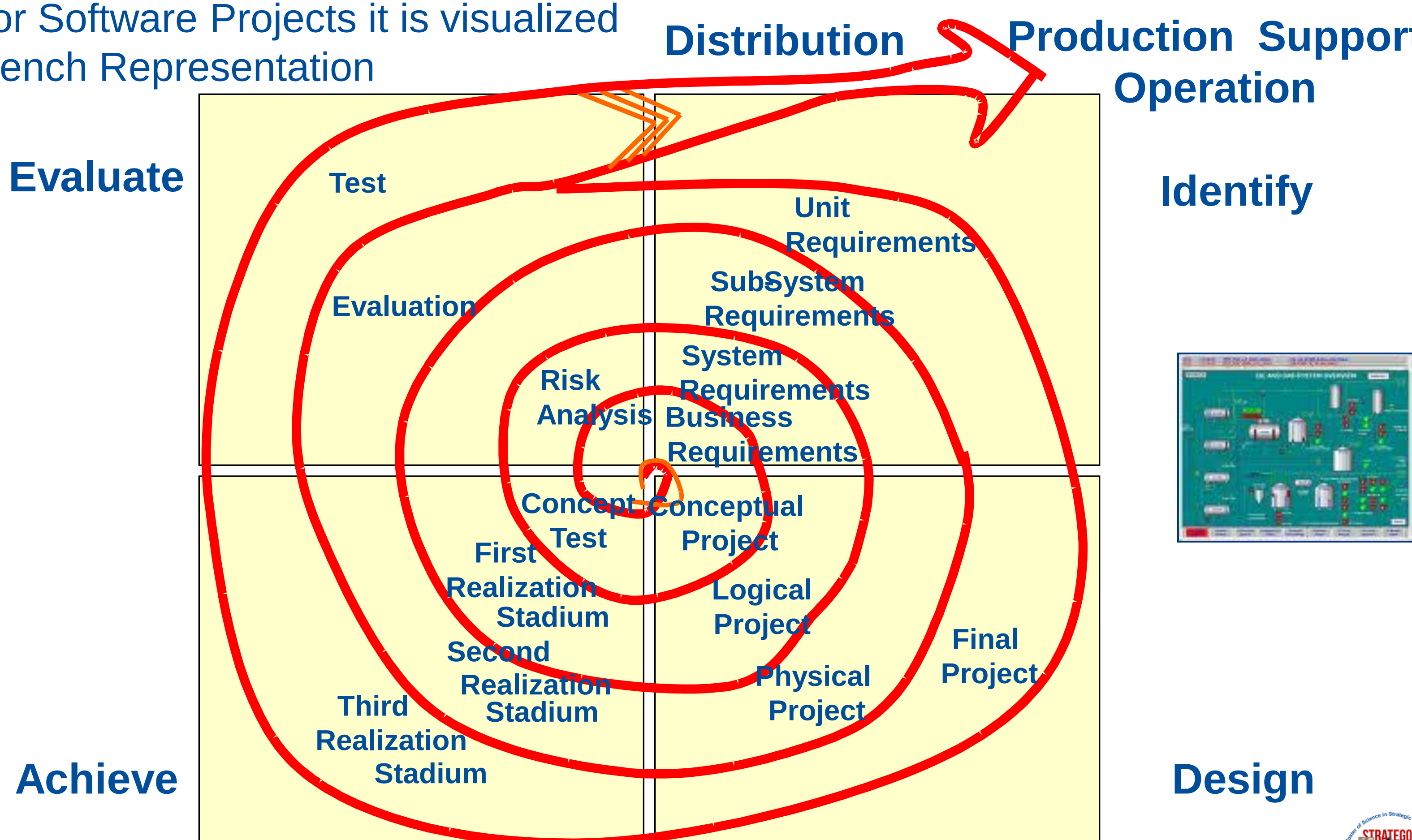


IND = Investigation New Drug Application
NDA= New Drug Application

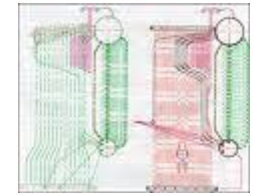
Approval

Muench & Co. Representation

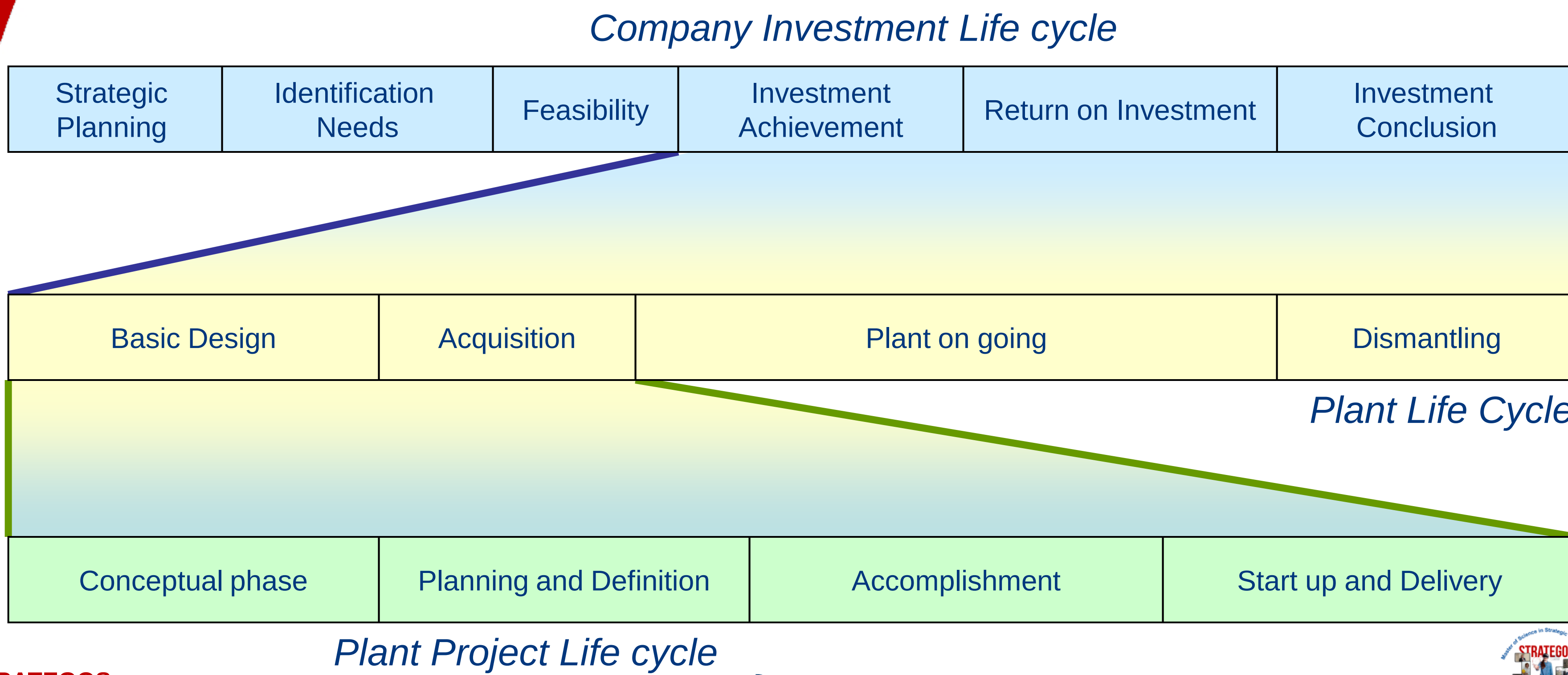
For Software Projects it is visualized Muench Representation



Nested Life Cycles for Project Management



Plants have several feasible life cycle linked among that are nested each other



Tools and Techniques for the Preparation Analysis

Project Selection Criteria

It is possible to identify two wide categories of selective methods:

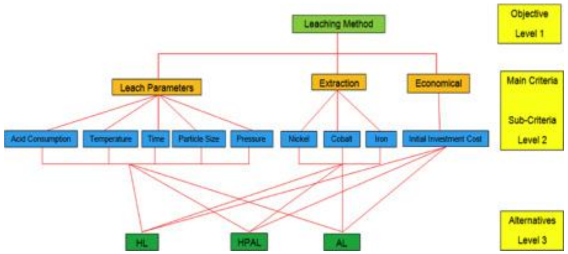
- Based on the Earnings assessment: comparative approaches, economic models, performance evaluation
- Based on the constraints optimization: mathematical models, Linear optimization, multi-objective analysis etc..

These methods allow to develop DSS (Decision Support System) that are based both on traditional techniques (decision trees, forced choice) than on specific ones (Analytic Hierarchical Process, logic Analysis, Simulation, etc.)

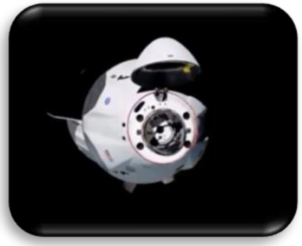
Experts Opinion

The Experts Opinion is often required to achieve the final decisions and it is expected to use:

- Specific Division of the company structure
- Consultant
- Technical Professional Associations
- Industrial Groups



SOW



A key point is to correctly define the job description to be done, at this phase it is important both technical and contractual clear understanding.

The SOW (Statement of Work) is defined as the narrative description of the work required for a project. This could be defined by Customers or developed by the PM Team and proposed to the customer for approval.

In this second case there are two types of SOW: SOW used in the proposal CSOW (Contract Statement of Work), as well as a WBS (Work Breakdown Structure) and a CWBS (Contract Work Breakdown Structure).

Obviously it is necessary to take care of the contract terms in order to avoid discrepancies between SOW / WBS and CSOW / CWBS.

Mistakes in this phase are very difficult to be solved and often they are fatal to the project good success.

Introduction
General Conditions

Purpose
Why we do it?

Objectives
What we have to do?

Where
Were to do it

Tasks
What Activities to be done

Milestones
What are Critical Dates & related achievements

Deliverables
What, When and How we will deliver

Schedule
Project Activity Scheduling

Standards & Tests
What standards & tests we will use in the Project

Success
What is the finale measure of success

Requirements
Description of Requirements

Payment
How much, how and when we get paid

Other
Various elements and Details

Closure
Mode to deliver and close the proejct

SOW: Problems Causes

The main problems causes are due to:

- Mixing tasks, objectives, approvals and special instructions
- Using imprecise words (optimum, approximately, at)
- Lack of structural order or chronological
- Wide variability of the required activity
- Wide variations in the job details description
- Lack of review by a third party

Examples from real cases:

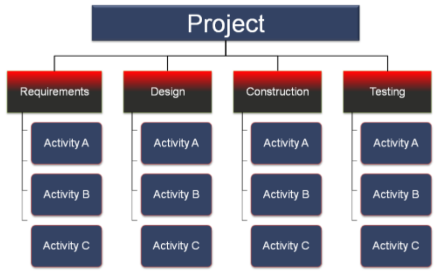
SOW for a new type of sports car airbag requires a minimum of 10 tests, the budget is set to 15 for security, at the end of the tests, the customer declares them not significant and requires 10 more for an extra cost of 500 million.

In a power plant design in the middle of the desert it is remarked that the request "civil support" includes a 40 km road to connect the town with an extra cost of 60 billion.

The Navy in the SOW requires water testing for a torpedo; the prototype is tested in hydraulic tanks, however, the Navy defines water as the actual conditions of the Atlantic Ocean, so it is required to repeat all the tests in the sea with an additional cost of several billion

The CSOW requires to transport materials in ventilated containers; the load is located in open-top containers; during the travel a series of torrential rainstorms damaged goods, the customer declares that he intended containers aerated from below: the question is in the hands of a judicial court to decide the correct meaning of the term.

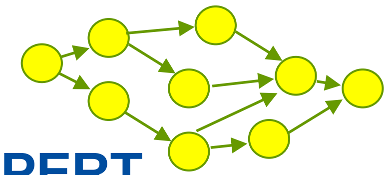
WBS: General Concepts



- The first three levels of the WBS represent an integration effort and should not be linked to specific business units, whose efforts should instead be included in levels 4 and 5.
- The sum of all the elements belonging to a layer must represent the overall work.
- Each working activity must be assigned to one and only one level.
- The project management level is sometimes called the Work Package level and may correspond to any level between 2 and 6
- The WBS must include a description of the objectives and required efforts : it aims to reproduce the customer requests within the WBS.
- Usually the best policy for PM is to leave the Line Manager responsible for identifying the risks in the SOW
- Some companies try to define the levels 1-3 uniquely for all projects by changing only levels 4-6: that works for companies carrying out many projects quite similar.

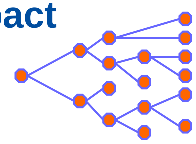
WBS: Structure for Control & Evaluation

Time check and Scheduling



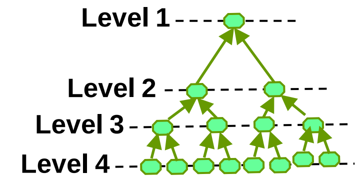
PERT

Risks check & Decisions Impact



Decision Tree

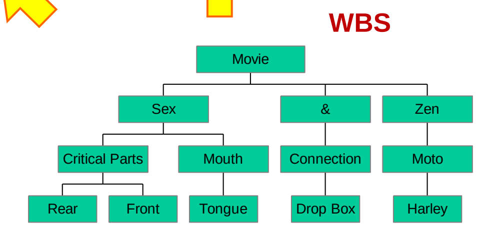
Total Cost Verification



Cost Flow Objective Network

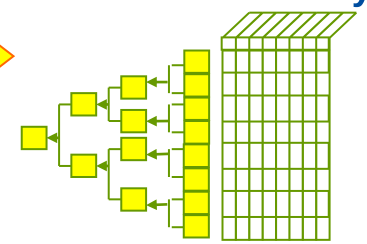
Management Coordinates Check

Feeder Objectives



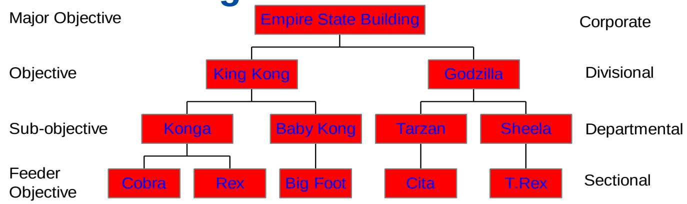
Work Packages

Working Methods Check and Accountability



Work Packages Matrix

Organization Check



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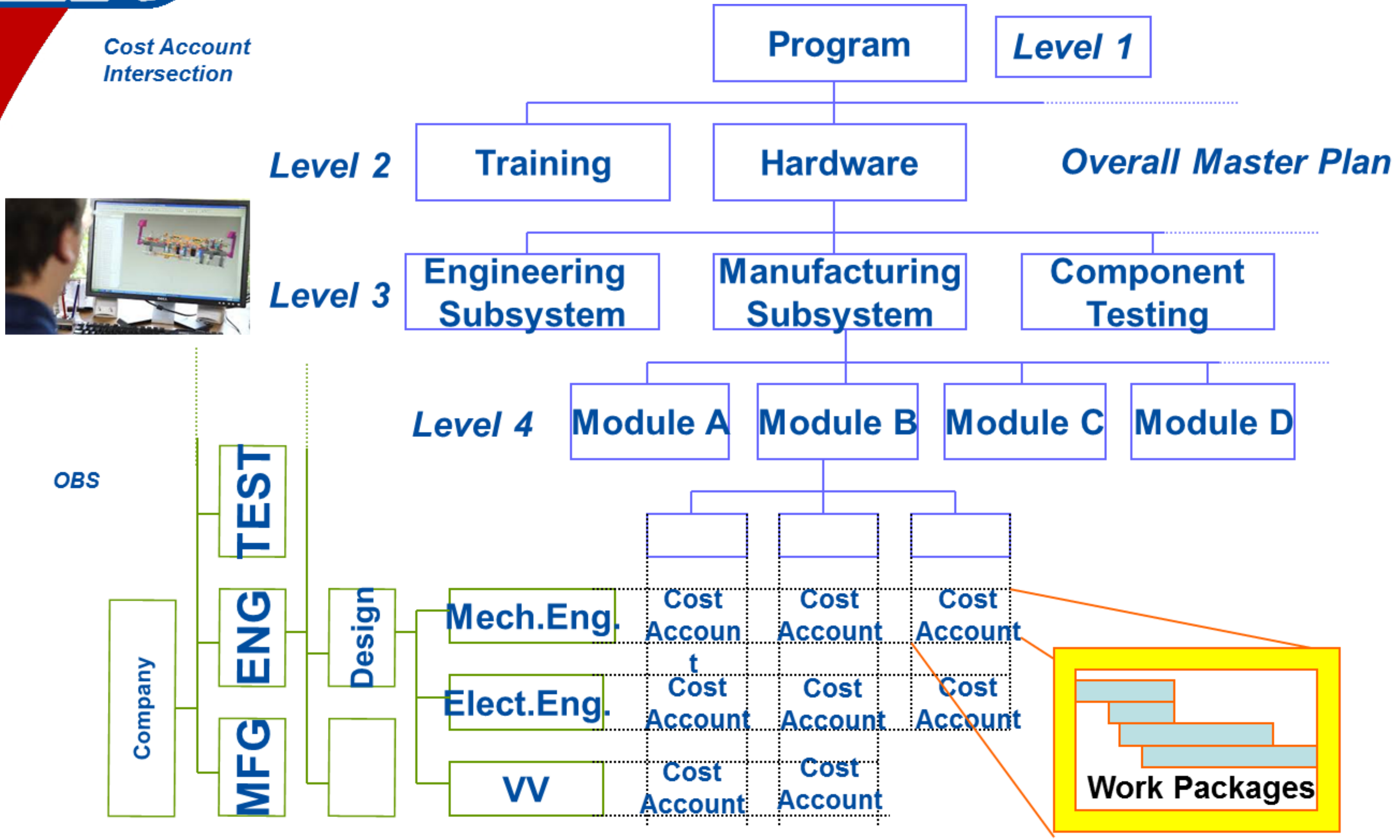
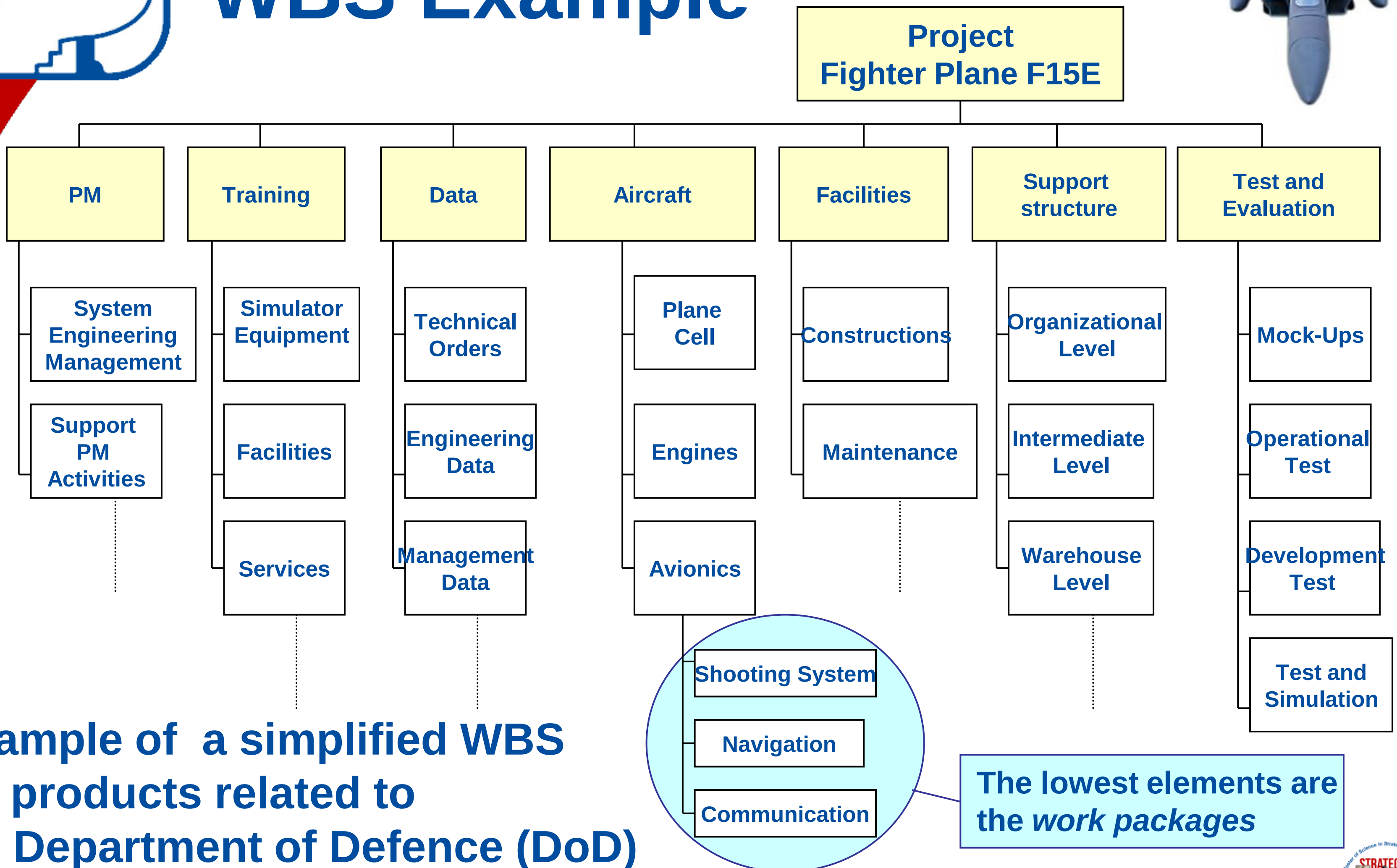
The Critical level of Work Packages Management



WBS Example



Example of a simplified WBS for products related to US Department of Defence (DoD)

Tools for Activities Sequencing

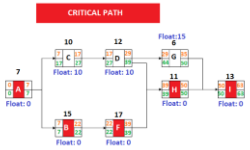
Precedence Diagramming Method PDM

It allows to formally present a project through a network where nodes represent activities and the connections represent dependencies and relationships, this technique is also indicated as an AON (Activity On Node).

Arrow Diagramming Method ADM

This method is devoted to the diagram construction through connections of nodes with arrows; if the connections are activities while the nodes represent the dependencies they are called AOA (Activity On Arrow), a typical example is the AOA PERT diagram; a typical case of ADM, where the nodes represent activities is the CPM (Critical Path Method) AON.

Conditional Diagramming Methods

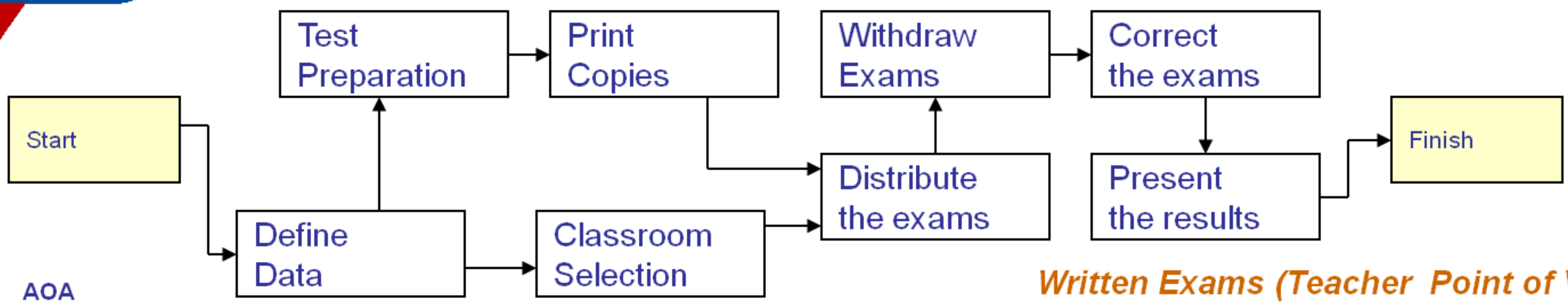


Include dynamic models, GERT (Graphical Evaluation and Review Technique) graphs allowing to reproduce non- sequential activities (i.e. cycles: a test that must be repeated several times) or conditional activities (i.e. an engineering change taking place only after inspection and defects identification); ADM and PDM don't allow to represent these types of phenomena.

Network Templates

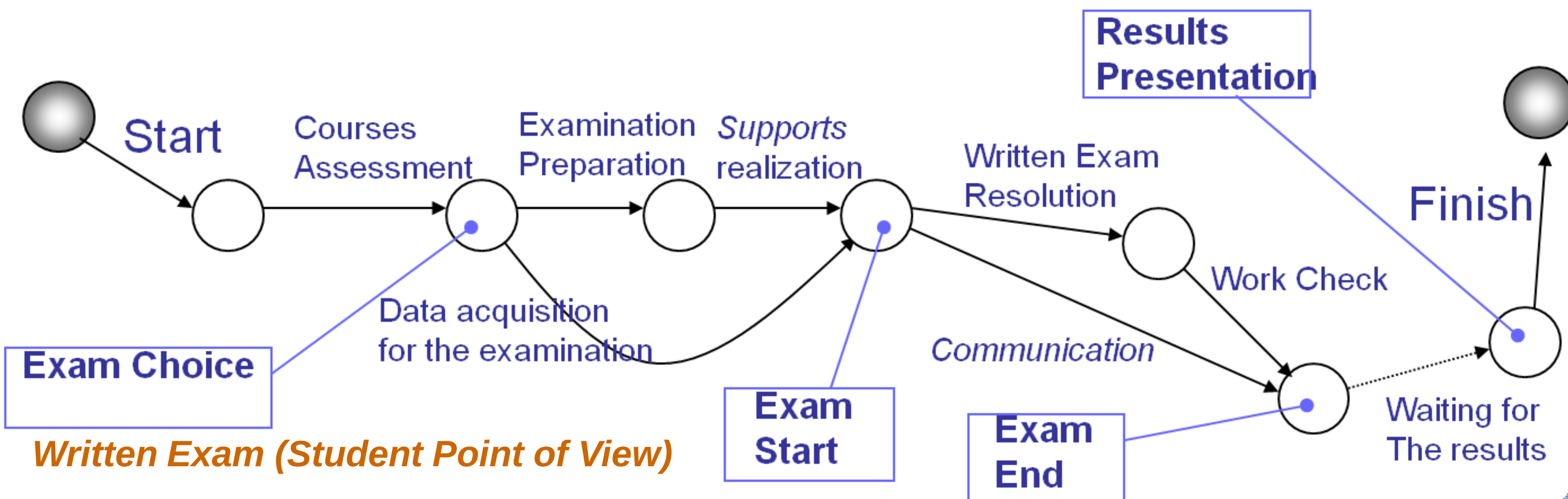
References related to standard planning complete or hierarchically subdivided in sublevels (*subnets* or *fragnets*)

Activity on Arrow & Activity on Node



Written Exams (Teacher Point of View)

AON



Written Exam (Student Point of View)

Simulation Team

PERT: Origins

Project Review Evaluation and Technique

It was developed in 1958-1959 to satisfy needs of complex new projects as evolution of Gantt. It was created by Special Projects Office of US Navy to apply Project Management to a new Weapon System:

Polaris Project (SLBM) 1958; success. Booz, Allen & Hamilton further developed the PERT.

Since 1960 US Navy directive requires PERT:

- **All individual tasks must be clearly displayed in a network that highlights events and activities, i.e. following the WBS**
- **Events and activities must be placed in logical sequence to identify the critical path; The network could exceed hundreds activities, but it is recommended it includes at least ten or twenty**
- **he estimated time must be based on three criteria: Optimistics, Pessimistic and Most likely Estimation by the Subject Matter Experts (SME)**
- **PERT allows to identify critical path and quantify duration, risk and slack times**

CPM: Industrial Solution

Critical Path Method

PERT when improperly introduced generates extra costs for its preparation: initially main contractors were using PERT for US Navy while their planning was based on their own internal methods duplicating activities and creating inefficiencies

PERT was generated to overpass limitation of Gantt and Milestone charts, unable to show connections among activities and events. As simplified approach it was proposed the CPM in same years*:*

CPM Critical Path Method

- In Late ’50, DuPont company developed CPM to be used in Process Industry, Constructions and EPC

CPM faces same issues than PERT, but estimates the duration by a single deterministic value

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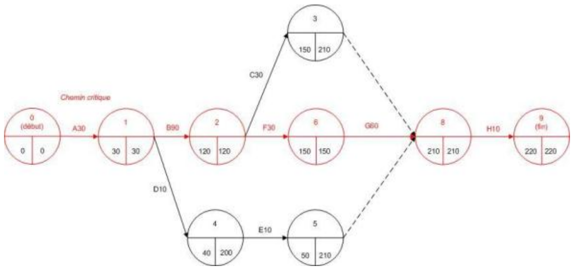
PERT Duration & Risks



PERT Activities use Beta Distribution to estimate time

a	Optimistic Estimation of the Duration of the Activity
b	Pessimistic Estimation of the Duration of the Activity
pp	Most Probable Estimation of the Duration of the Activity

PERT allows to compute the reference duration and standard deviation as

$te = \mu = (a + b + 4 m) / 6$

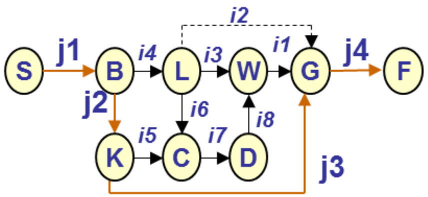
te	Equivalent Duration usually corresponding to μ used in CPM

$\sigma = (b - a) / 6$

σ	Standard Deviation of the Activity Duration
σ^2	Variance of the Activity Duration

Standard Deviation could be useful to compare different activities.
The Percentile used corresponds to different probabilities (+/- 1 sigma 68%, +/- 2 sigma 95%, +/- 3 sigma 99%). The Total Standard deviation of the project is evaluated based as square root of the sum of variances of activities located over the critical path :

$$\sigma_{tot} = \sqrt{\sigma^2_{j1} + \sigma^2_{j2} + \sigma^2_{j3} + \sigma^2_{j4}}$$



PERT Preparation

The preparation of a PERT is developed as follows

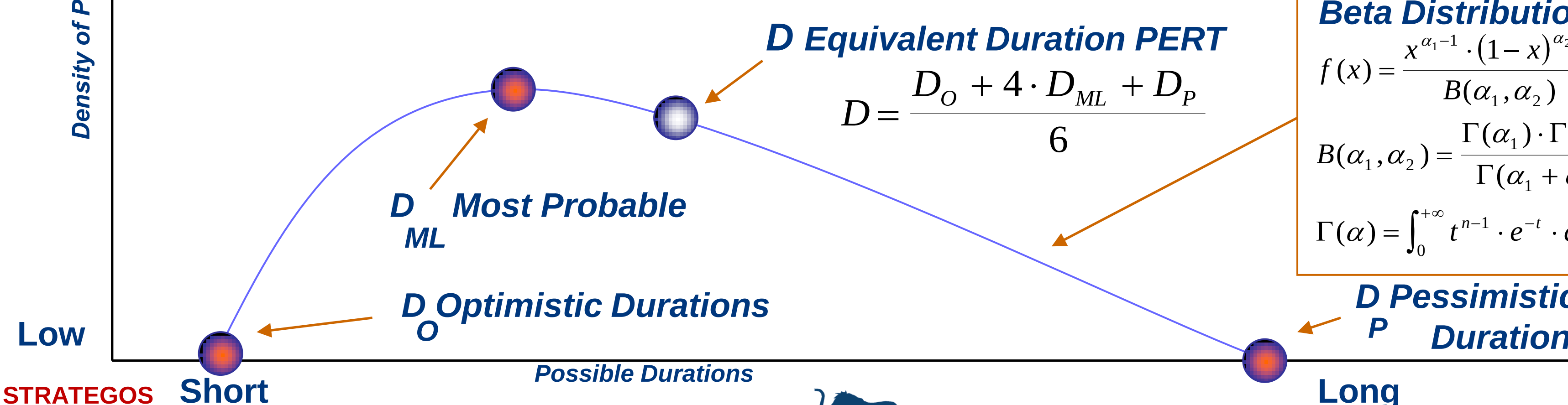
1. The PM (Project Manager) writes the list of activities
2. The PM has activities' second priority criteria (Drafts, Arrow Diagram Methods ADM, Precedence Diagram Methods PDM, networks etc.)
3. The PM reviews the diagram with line managers (experts) and verifies that it is properly estimated, complete and correct
4. Functional managers create PERT by inserting durations (Estimated on the basis of infinite resources as the timetable is not yet known)
5. The PM looks PERT and verify if it meets the key dates and the project schedule, and if not proceeds to retrofit (i.e. crashing activities) and asking manager to remove the fat from their planning
6. The PM sets the reference dates on the calendar and starts reorganize the PERT based on limited resources.

Comparison among Time Management Techniques

Critical Path Method (CPM) deterministically computes the parameters Early and Late Start and Ending time, to identify the activities 'that have less flexibility' (path Critical) based on the most 'common durations

Graphical Evaluation and Review Technique (GERT) allows probabilistic and conditional alternatives in the flow diagram it is in the logic that in the lives. It highlights the influence of activities 'that could happen just under specific stochastic conditions

Program Evaluation and Review Technique (PERT) uses a feed-forward network and beta distributions to calculate the durations of the activities and of the project; today often these assessment methodologies the durations are also used in the CPM method



$$D = \frac{D_O + 4 \cdot D_{ML} + D_P}{6}$$

Beta Distribution

$$f(x) = \frac{x^{\alpha_1 - 1} \cdot (1-x)^{\alpha_2 - 1}}{B(\alpha_1, \alpha_2)}$$

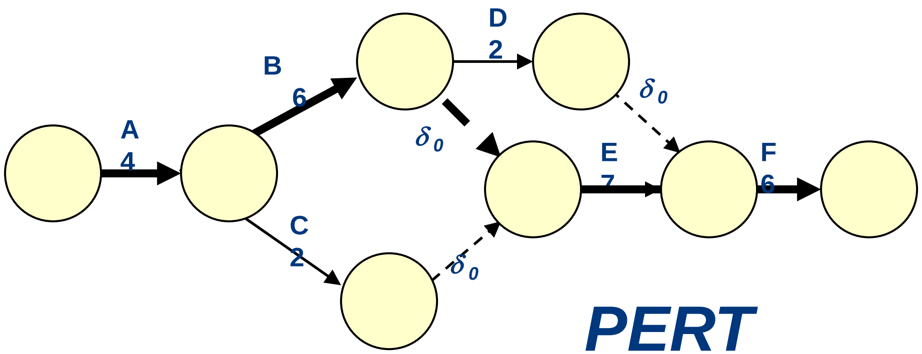
$$B(\alpha_1, \alpha_2) = \frac{\Gamma(\alpha_1) \cdot \Gamma(\alpha_2)}{\Gamma(\alpha_1 + \alpha_2)}$$

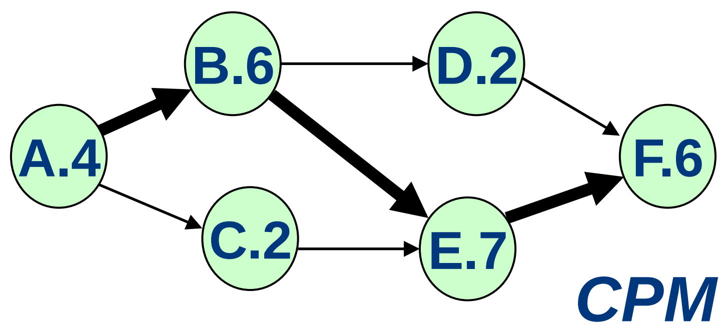
$$\Gamma(\alpha) = \int_0^{+\infty} t^{n-1} \cdot e^{-t} \cdot dt$$

PERT vs. CPM

Main Difference is CPM don't allow to quantify risks

PERT	vs.	CPM
Usually Event Oriented		Usually Activity Oriented
Main Focus on Event (**)		Main Focus on Activities (**)
Time Oriented (*) (**)		Costs Oriented (**)





(*) In reality both PERT and CPM are able to estimate costs in addition to times
Therefore PERT is usually used when the (delays) risk is high and CPM in regular project (budget)
(**) PERT and CPM could be both presented as AOA (Activity on Arrow) and AON (Activity on Node)

X.N
X = ID Activity
N = Acitivty Duration

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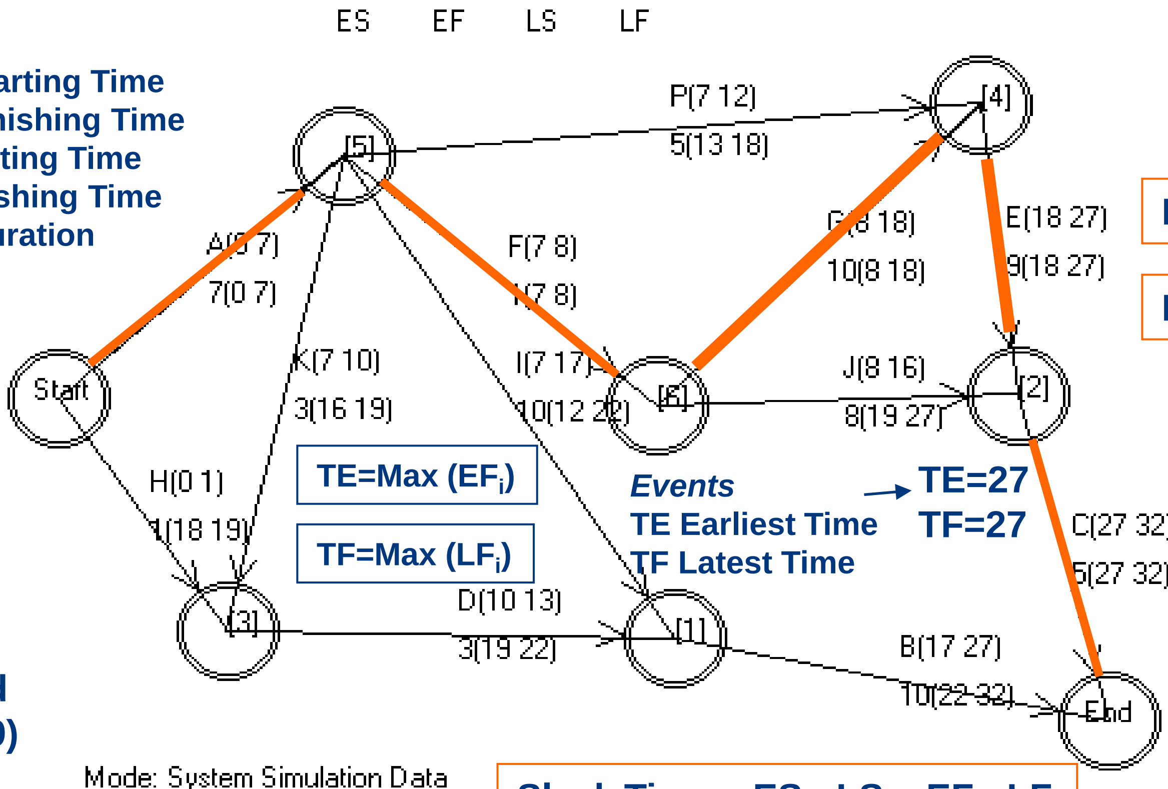
Example of PERT

Activities
ES Earliest Starting Time
EF Earliest Finishing Time
LS Latest Starting Time
LF Latest Finishing Time
d Activity Duration



TE=Max (EF$_i$)

TF=Max (LF$_i$)

Events
TE Earliest Time
TF Latest Time

TE=27
TF=27

PERT

EF-ES=d

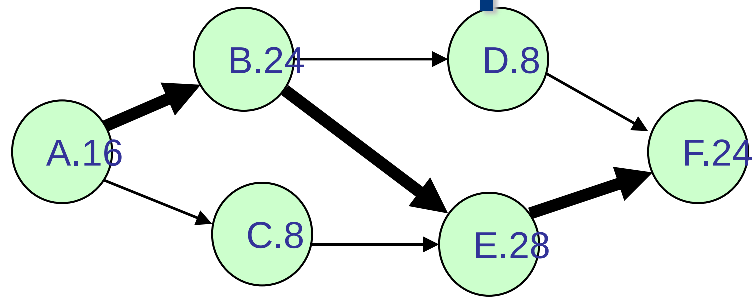
LF-LS=d

PERT increases success rate by 30% when adopted (Marquis 1969)

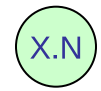
Slack Time = ES - LS = EF - LF

Critical Activities ⇔ Slack Time = Zero

Crashing Time to Respect Times



The time Crashing allows
To compress the project duration
and it concerns with the activities
shortening against the costs
increasing



X = ID Activity
N = Activity Duration

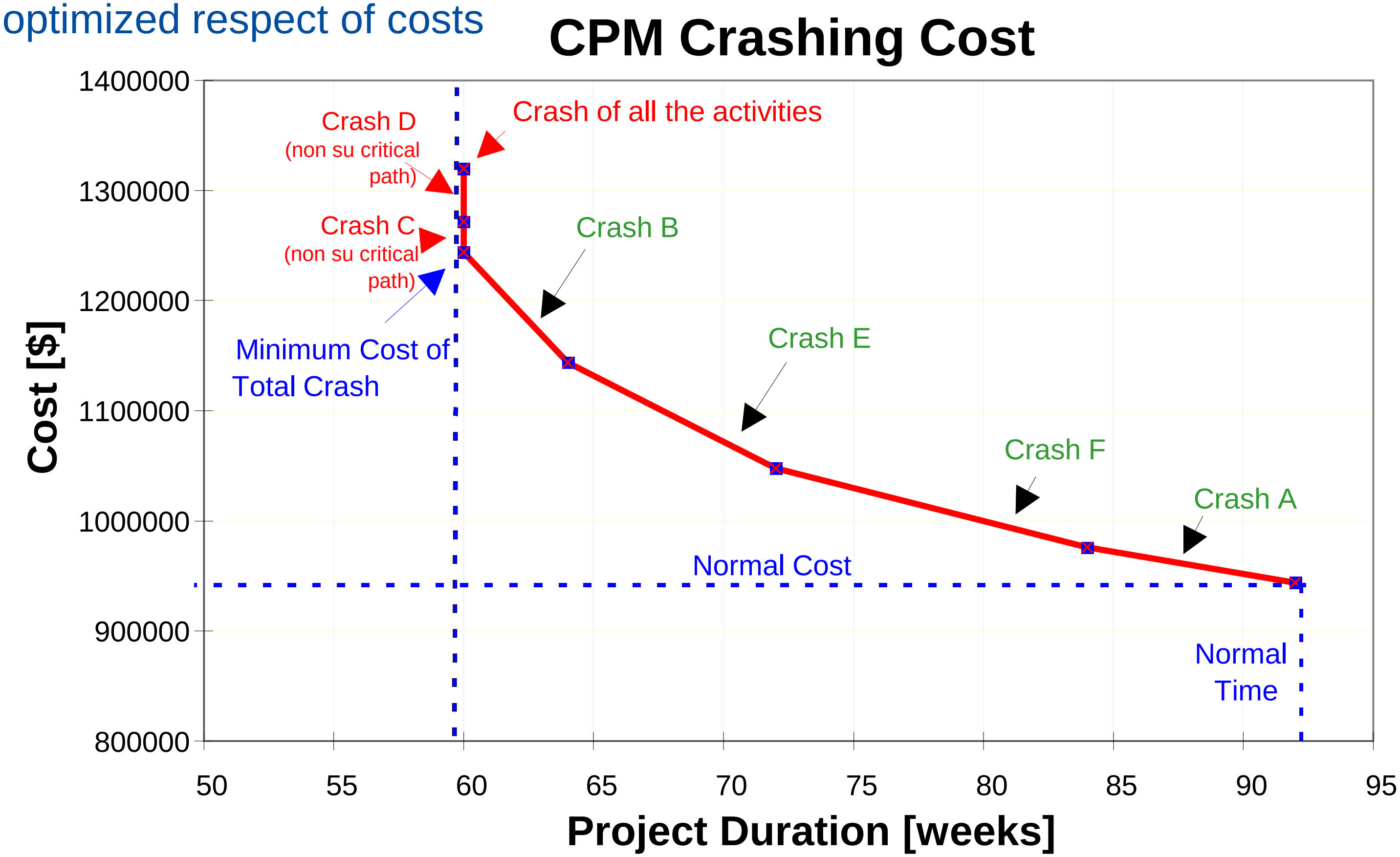
Consider the activities on the critical path with lower crash cost per time unit and compress them by taking into account that at each step the critical path may change.

Example: first A (4000 $/w) then F (6000$/w), then E (12000$/w) because both D and C are not on the critical path and finally B (25000$/w) = costs increasing from 944000$ to 1.244 m$ (+32%), with a time reduction equal to 32 weeks (-35%)

	Required Time [weeks]		Cost [$]		
Activity	Normal	Crash	Normal	Crash	Crashing Cost [$/week]
A	16	8	80000	112000	4000
B	24	20	240000	340000	25000
C	8	4	48000	76000	7000
D	8	4	96000	144000	12000
E	28	20	320000	416000	12000
F	24	12	160000	232000	6000

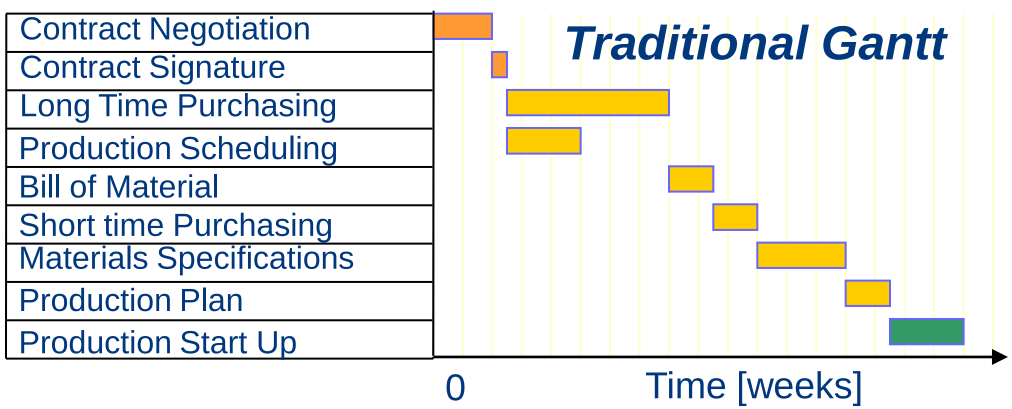
Ratio Cost/Efficiency in the Crashing

To apply the Crash technique of the CPM leads to a contraction of the times that are optimized respect of costs



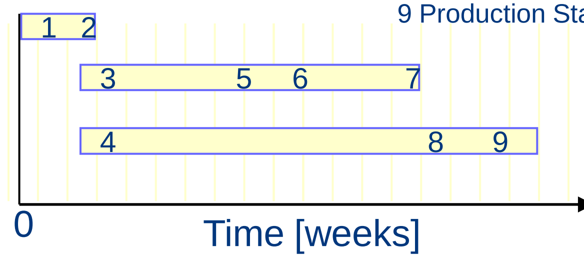
Gantt Diagrams

The Horizontal histograms are used to show the planned activities over time; they were introduced by Henry Gantt at the beginning of 1900; they represent a temporal scheduling and not a logic correlations network; they are the most used system for Project Schedule presentation. There are may representations



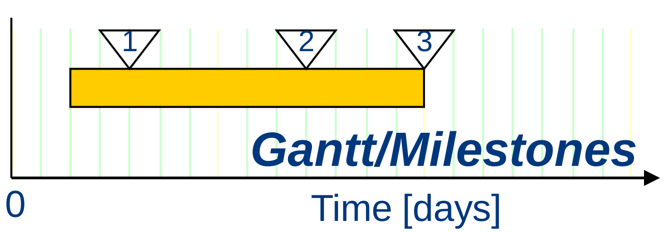
Gantt based on Combined Activities

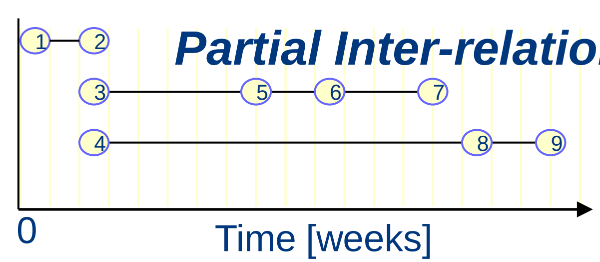
1 Contract Negotiation
2 Contract Signature
3 Long Time Purch.
4 Production Scheduling
5 Bill of Material
6 Short time purchasing
7 Material Specifications
8 Production Plan
9 Production Start up



Short Time Purchasing

Milestones
1 Order Emission
2 Invoice Rec.
3 Material Rec.



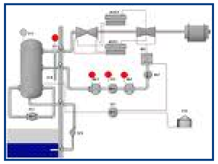


Project Budget during early Phases

Budget Plan Development is based on historical data and on general "parameterizations" according to a cost index (ie USD / kW per power plants). The cost assessment often takes into account a "scale factor"

$$C = C_0 \left(\frac{P}{P_0} \right)^M$$

C, P	Cost and Capability of the plant in exam
Co, Po	Cost and Capability of the reference Plant
M	Scale Factor (typically between 0.6 e 0.9)

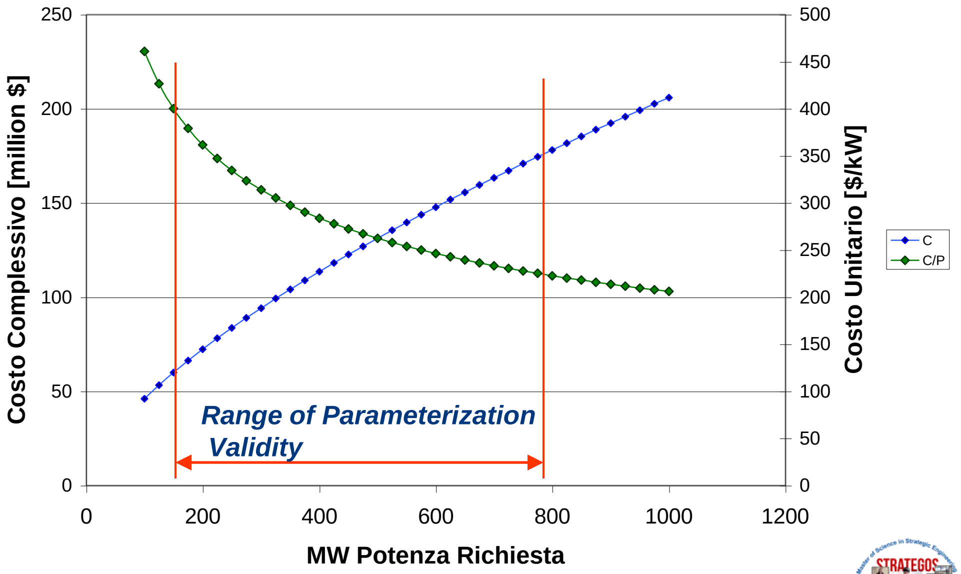


$$\frac{C}{P} = C_0 \frac{P^{M-1}}{P_0^{\,M}}$$

$$\log \frac{C}{P} = \log C_0 - M \cdot \log P_0 + (M+1) \cdot \log P$$

$$M < 1$$

C / P = Unit Cost



This allows to evaluate the Unit Cost based on a historical data linear regression by applying logarithms (parametric-statistic approach)

Plant Cost Estimation

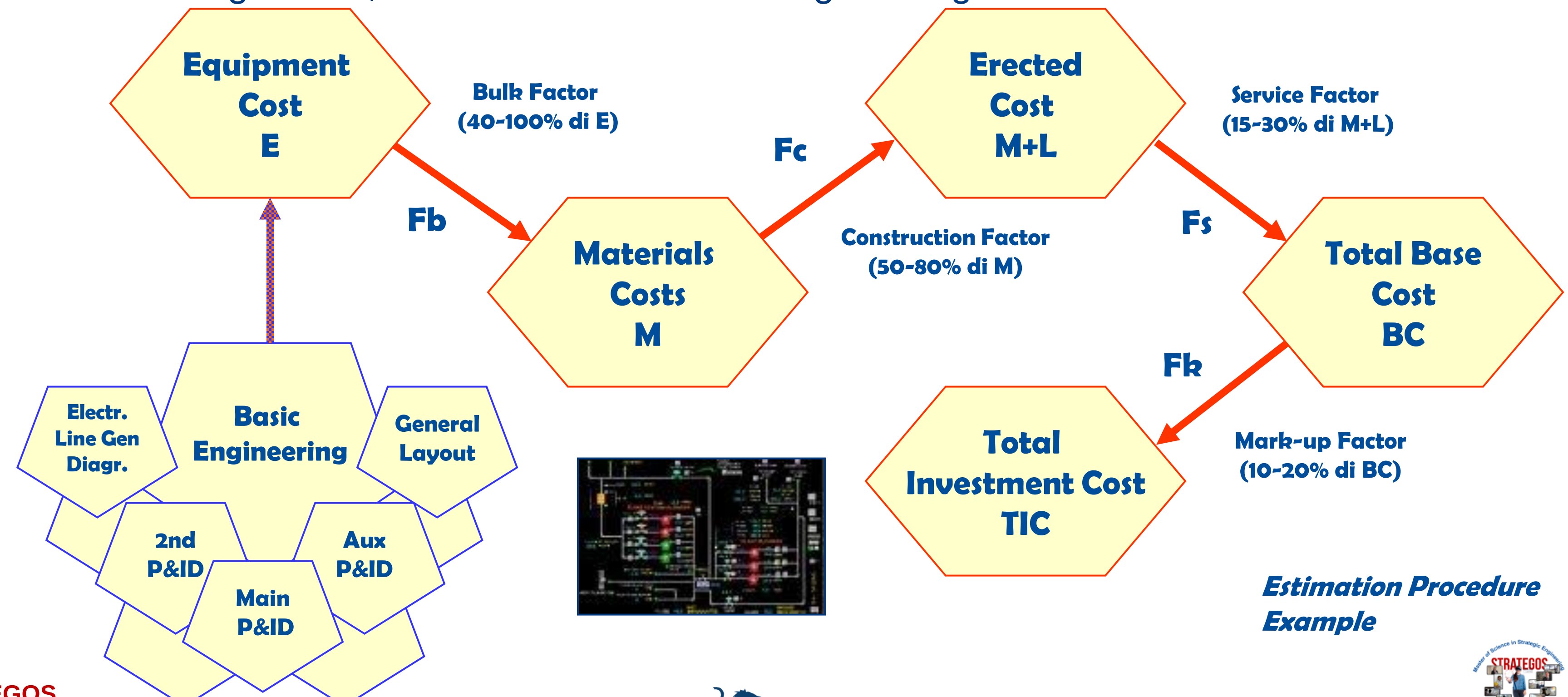
It is based on plant type and size and takes into consideration as reference similar plants already developed by using the “scale factor” and by applying some corrective parameters:

Location Factor (position influence)
Escalation Factor (increases due to time dilation)
Contingency Factor (Unexpected events influence)
etc.

It is possible to estimate with a level of subdivision for the next refinement stage: Mechanical Plants (cost per ton), Power (kW) and Instrumentation (Control Loops), by considering then the different realization costs (services, transport, civil works etc. .) as percentages on the materials.

Semi-Analytical Evaluation

It is used for the feasibility study and is based on an branched analysis of the costs that studies the major plant components (items) costs in an analytical way and the remaining entries (ie, bulk materials, services) in a parametric-statistical one; it is based on a default configuration, and then on the basic engineering work.



Estimation Procedure Example

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Analytical Estimation

It is necessary for preparing the commercial proposal and requires a complete and correct definition of the basic engineering; so for power plants it is possible to refer to Main, Secondary, Auxiliary P&IDs (Process & Instrument Diagrams), General Layout and the Electric One Line General Diagram, as well as to the major components (generator, turbine, boiler, DCS) sizing.

Examples of Costs are:
- *Engineering*
- *Materials (bulk materials)*
- *Plant Components (items)*
- *Transportation*
- *Civil Constructions*
- *Electro-Mechanical erections*
- *Erection Supervision*
- *Sites Different Costs*
- *Sub-contracts*
- *Technological Licenses*
- *Maintenance Equipment*
- *Start up Costs*
- *Spare Parts*

Transportation	Personnel	Equipment	Materials
Weights and volumes estimation of the material to be transferred	Estimation of the activities to be carried out as standard hours and as Expected Man Hours with yield coefficients.	An evaluation of the amortization costs is estimated from purchase cost and useful life	Possibilities a) Parametric b) Based on quantities provide by th engineering team (“material take-off”)

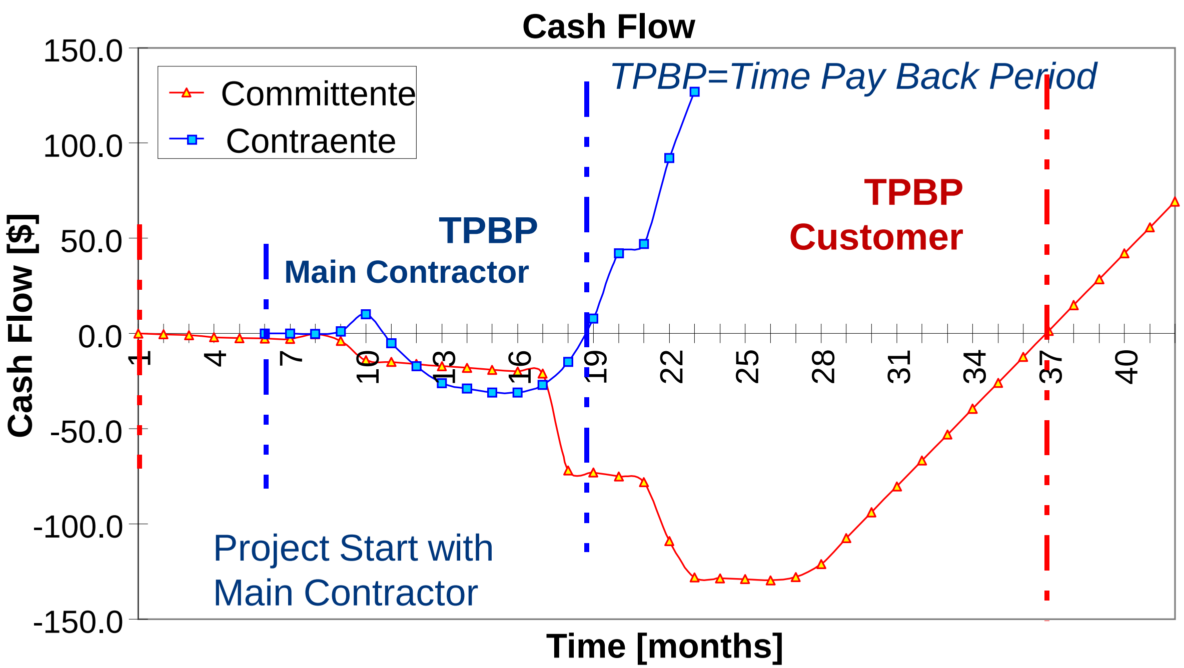
COST

Escalation
Contingencies
General Costs
Financial Costs
Sureties
Taxes
Foreign Exchange
Revenue
etc.

PRICE

Project Cash Flow

The contract provides the payment structure, corresponding to the cash-flow (both of the customer both of the supplier); obviously it is regulated by strong financial leverages for big projects due to the time size, to the currency exchanges, materials costs and inflation phenomena. For projects where the user is a private provider of services / goods produced by the plant, the cash flow is strongly influenced by time (i.e. build a fast ferry for a private company or a power plant for a private supplier vs. build a ship for the Navy or a Power Plant for ENEL)



Financial Leverages are used to guarantee less financial expenses.
For a project of 150 MUSD three year duration the financial expenses trend is generally about 3-4% (maybe with a margin of 2-5%)

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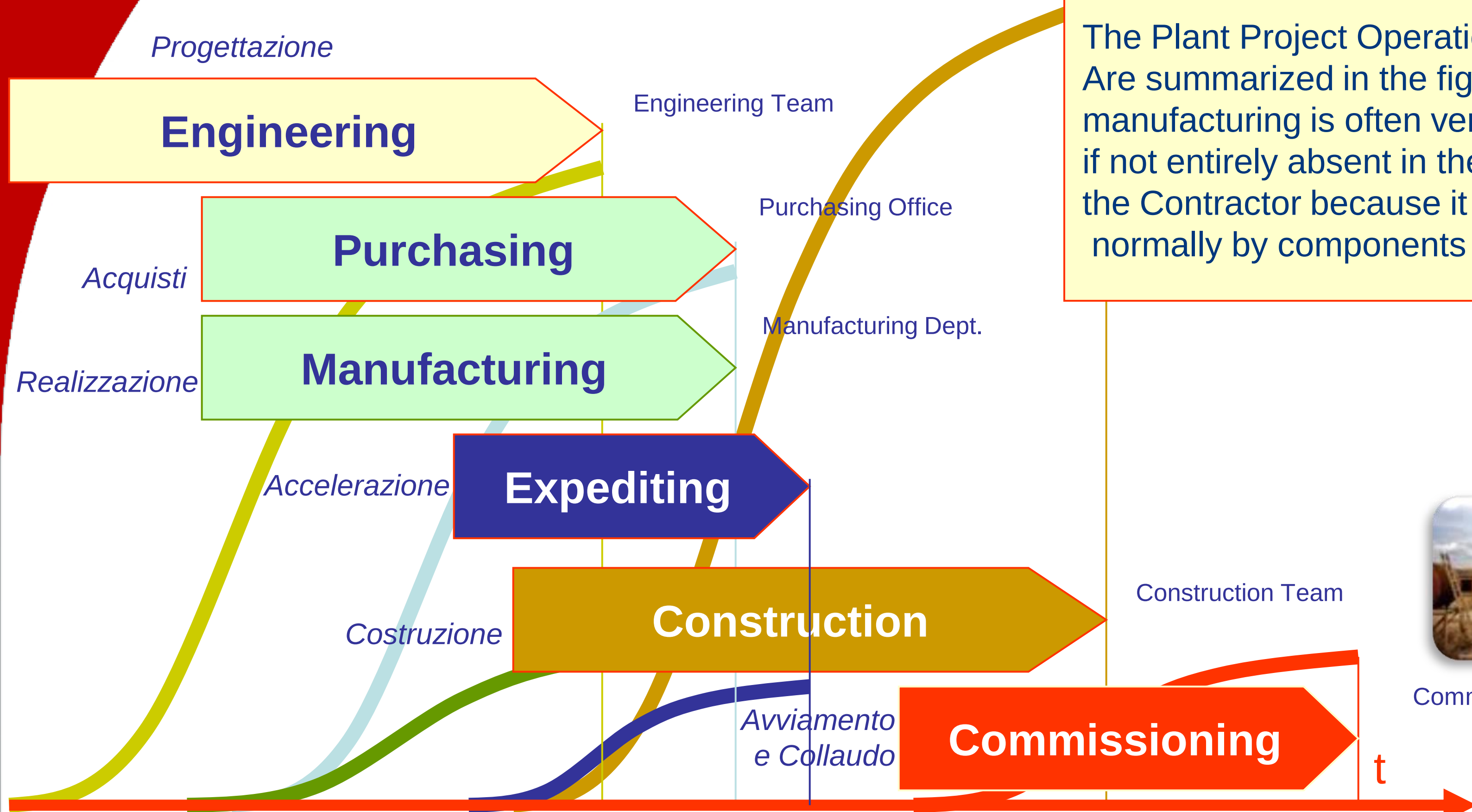
Plant Project Processes and their Phases

The Plant Project Operational Phases Are summarized in the figure; the manufacturing is often very limited if not entirely absent in the vision of the Contractor because it is managed normally by components providers.



Obviously uncertainty on Costs and Times decreases as Project Advances

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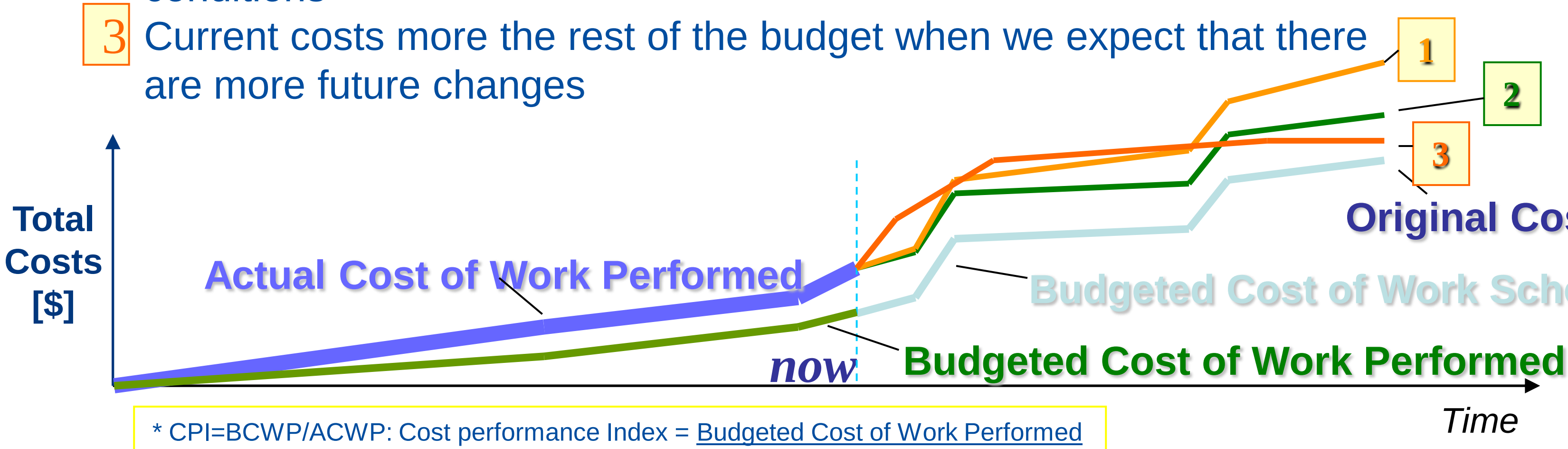
EAC: Projection to the Project Costs

The Costs Projections at completion (EAC=Estimate at Completion) are based on various hypothesis; among the most common it is possible to underline:

1 Current costs more remaining budget modified by a performance factor (i.e. CPI *) used when it is expected that the current changes are similar to the future

2 Current costs more a new estimate of all the remaining work used when it is noted that initial estimates were wrong, or are no longer valid for changes in boundary conditions

3 Current costs more the rest of the budget when we expect that there are more future changes



* CPI=BCWP/ACWP: Cost performance Index = Budgeted Cost of Work Performed / Actual Cost of Work Performed

EVA: Earned Value Analysis

The EVA is a very popular technique based on the computation of three key values for each activity:

BCWS	***Budget***	Budgeted Cost of Work Scheduling
ACWP	***Costo Attuale***	Actual Cost of Work Performed
BCWP	***Earned Value***	Budgeted Cost of Work performed

It is also possible to work on discrete values of the completion to evaluate the Earned Value (i.e. 10 % - 20% …, or only 0% or 100%)

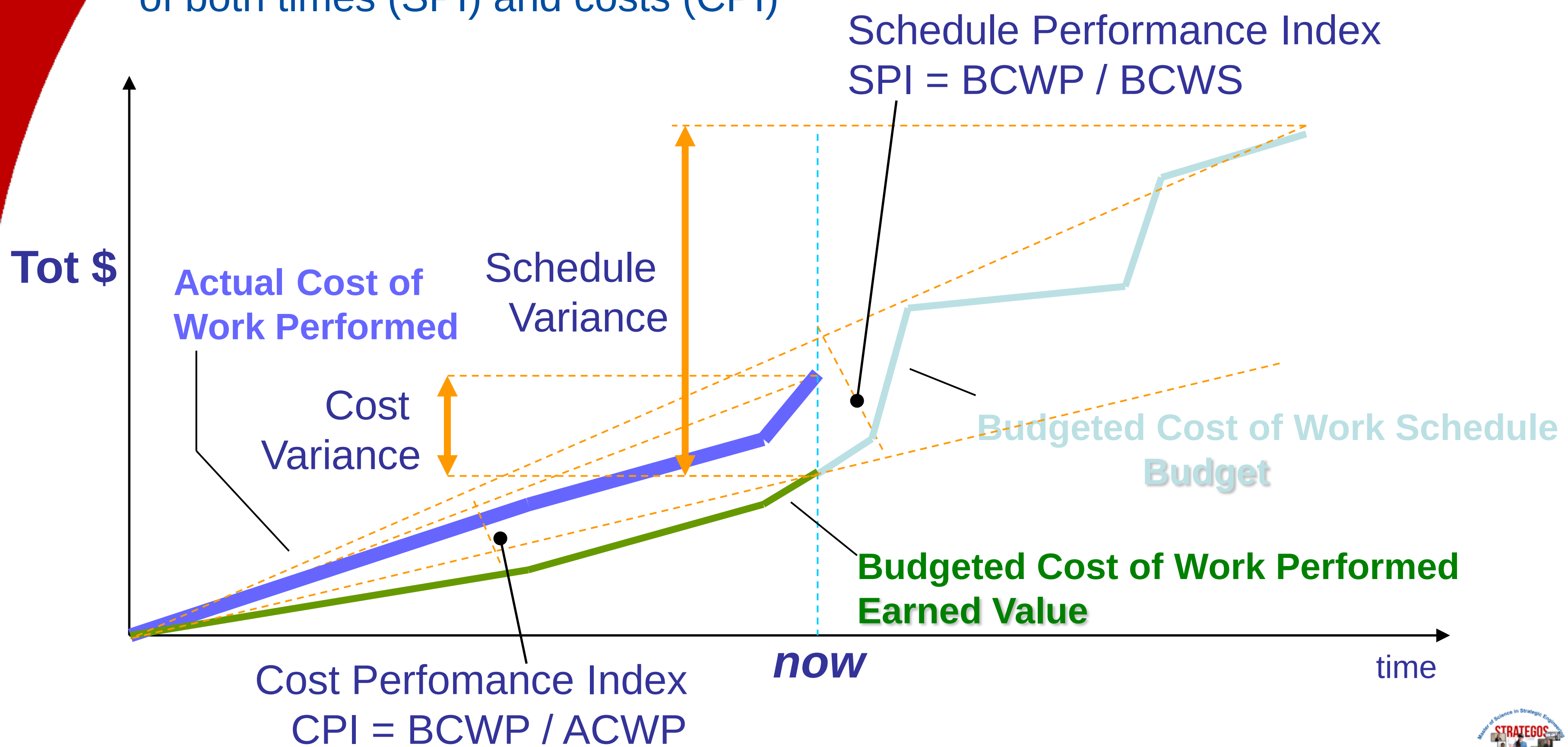
The combined use of these terms provide the assessment parameters:

CV = BCWP - ACWP	***Cost Variance***
SV = BCWP - BCWS	***Schedule Variance***
CPI= BCWP/ACWP	***Cost Performance Index***

Often it is used the total **CPI** to make previsions on Project Costs at the completion; while often it is used the **SPI** = BCWP/BCWS (***Schedule Performance Index***) to estimate the completion date.

EVA : Interpretation of Different Terms

EVA parameters are often the reference for estimations and future previsions of both times (SPI) and costs (CPI)



EVA: Cumulative & Hierarchical Approaches

EVA is a set of parameters that can be detailed for each activity WBS and/or cumulated to make estimates on the whole project.

WBS Elements		Budget	Earned Value	Actual Cost	Costs Variance		Variance on Project Schedule	
		BCWS	**BCWP**	**ACWP**	**BCWP-ACWP**	**BCWP/ACWP**	**BCWP-BCWS**	**BCWP/BCWS**
		[USD]	[USD]	[USD]	[USD]	[%]	[USD]	[%]
1	Pilot Planning	56000	52000	55000	-3000	-5.5%	-4000	-7.1%
2	Checklists Draft	48000	46000	42000	4000	9.5%	-2000	-4.2%
3	Life Cycle Project	39000	35000	40000	-5000	-12.5%	-4000	-10.3%
4	Medium Term Evaluation	84000	84000	86000	-2000	-2.3%	0	0.0%
5	Supports Implementation	11000	7000	6000	1000	16.7%	-4000	-36.4%
6	User Manual	6000	5000	4800	200	4.2%	-1000	-16.7%
7	Development Plan	32000	18000	23000	-5000	-21.7%	-14000	-43.8%
Total		**276000**	**247000**	**256800**	**-9800**	**96.2%**	**-29000**	**89.5%**

By using a such kind of estimation it is easy to reprogram the timing and project costs having at each moment the control of detailed complete and checked internal parameters.

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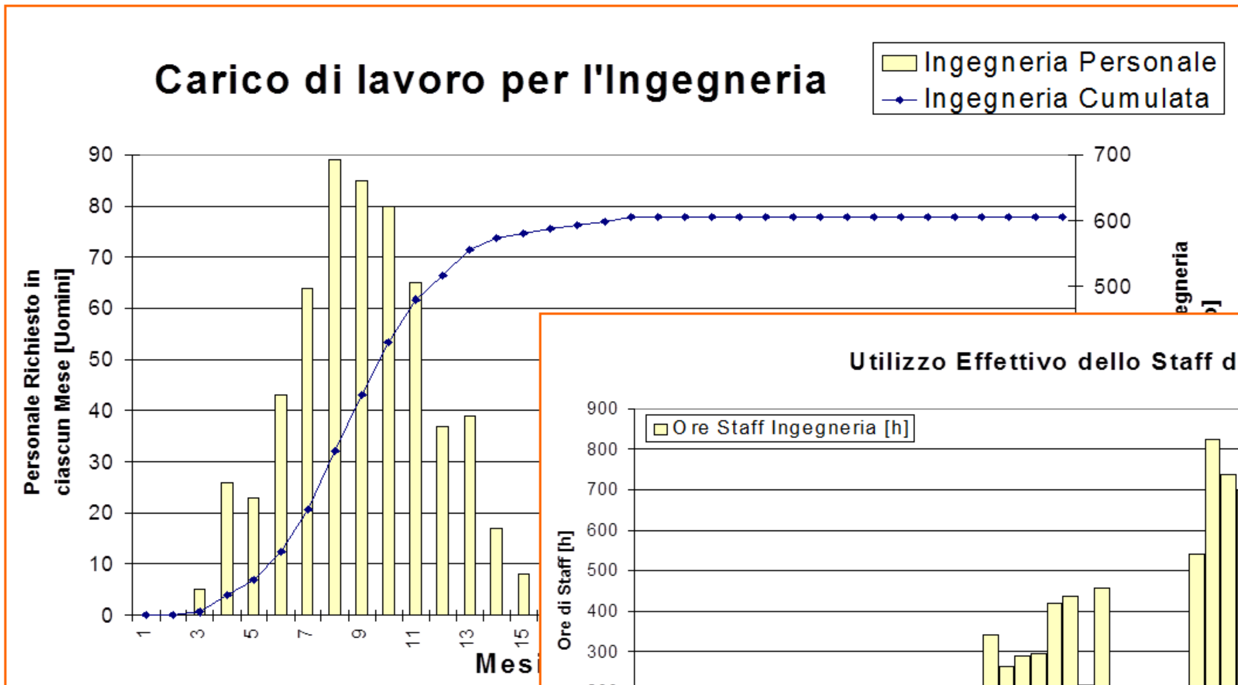
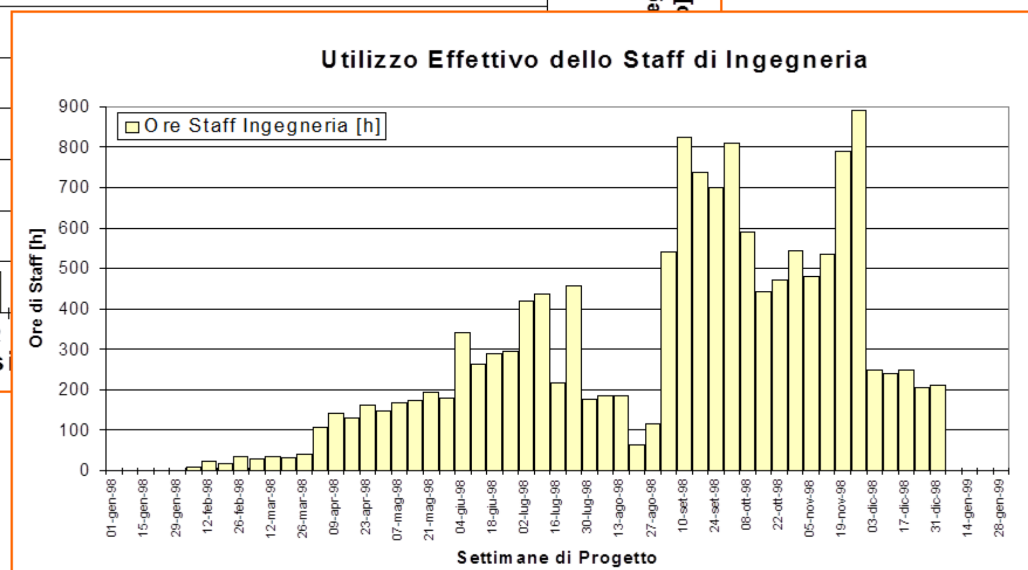
Planning and Consumptive Histograms

Replanning





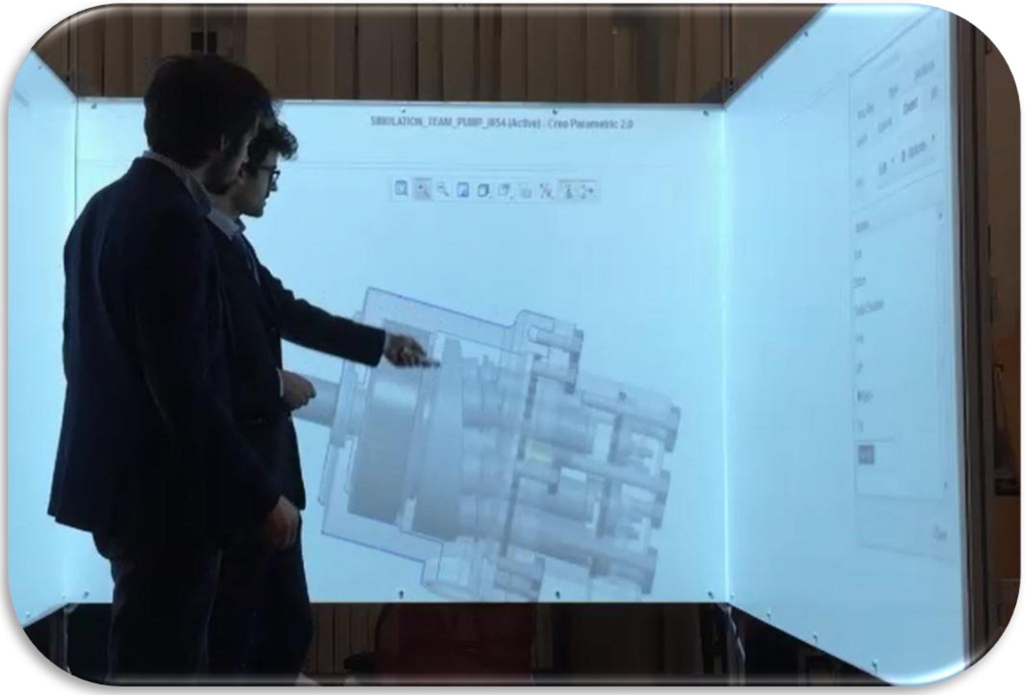
Reports

Project Objectives and PMB vs. Product Configuration

- **It is fundamental that Project Objectives and Project Statement of Work (SOW) is kept aligned with Product Configuration to avoid problems.**
- **Consequently PMB need to be updated in correspondence of each change during Project Review Meetings**

Aligning Multi Activities among Different Entities

- *Fluid Real Time Exchange of Data*
- *Collaborative tools for integration of data from different contexts*
- *Interoperable tools to fuse data from different contex*



Source Web

Joint Ventures and Cooperative Frameworks

In Projects Management there are different participation formulas devoted to the risk subdivision, to the competition reduction, to the integration of different technologies and skills and / or to enter specific markets.

These collaborations exist in many forms:

Virtual Company

Legal Company created ad hoc for the Project

Consortium

Entity pooling Institutions and Companies

Joint Venture

Cooperation Agreements for specific Projects

Sub-Contracting

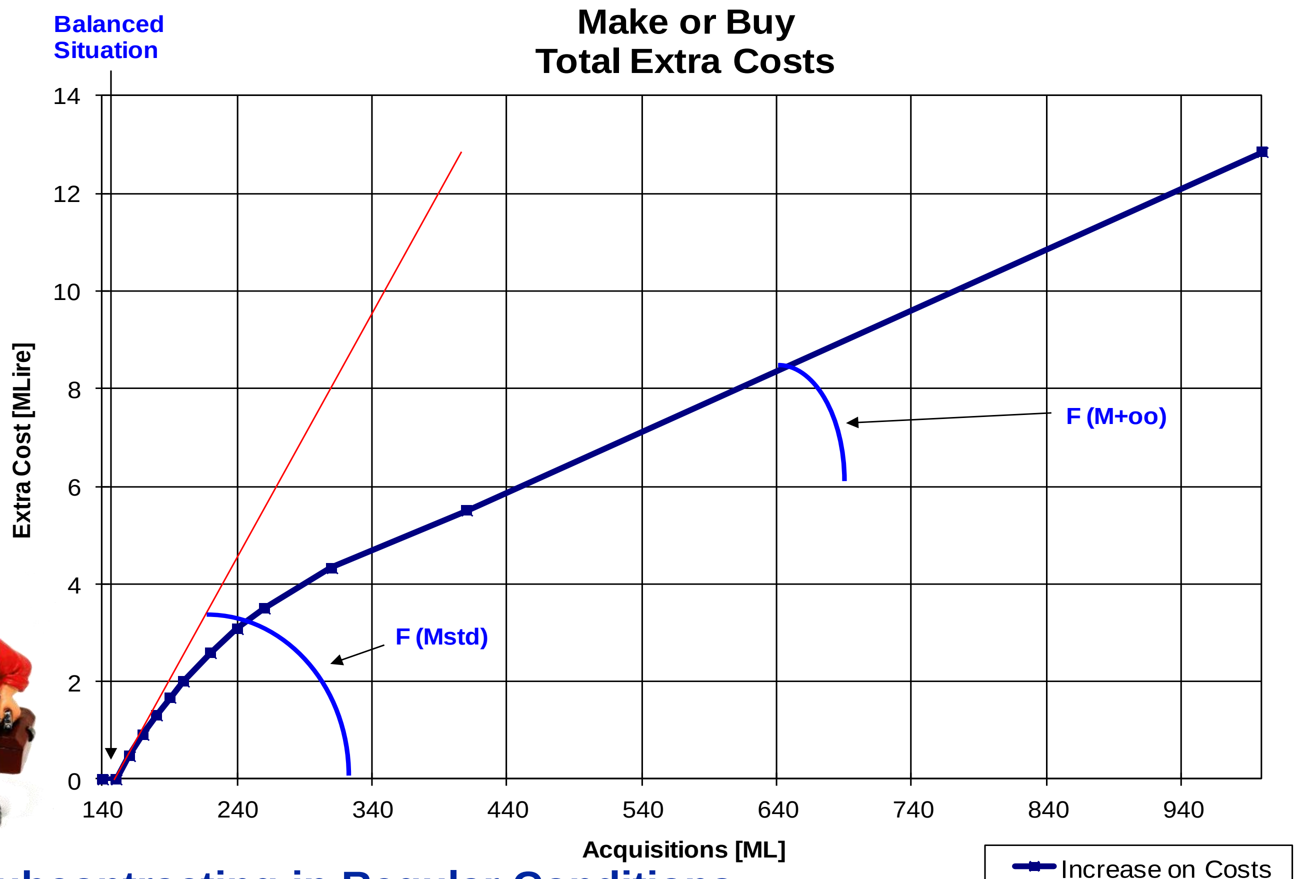
Commitments Signature from suppliers directly with the Customer

Supplying

Traditional Supply to the Contractor

Margins on Subcontracts

It is evident that by operating on different markets, the preventive coefficients Mstd and M* are different and it is required eventually and additional computation



Mstd **Margins on Subcontracting in Regular Conditions.**
M* **Limit Margin for Sub-Contracts in case of total Outsource**

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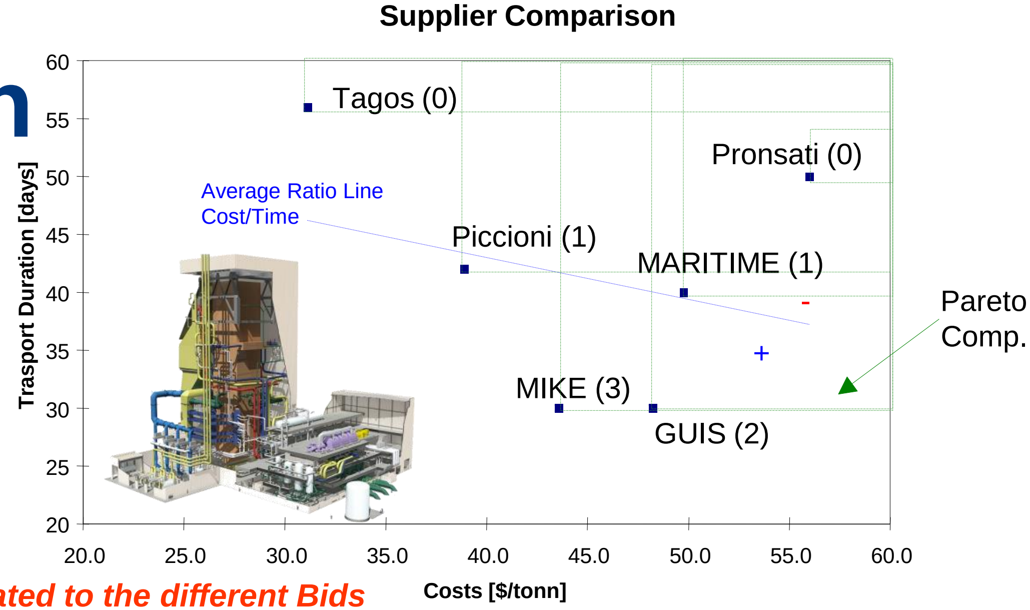
Selection Example

In this case it is proposed an example of analysis of sub contractors for transportation service of a boiler from Civitavecchia to Yalta, as shown by the method without weights the winner result to be a Company that would be eliminated if screening had initial required previous experiences.



Initial Data related to the different Bids

	Costo [$/ton]	Durata Op. [days]	Mezzi Propri	Fatturato [m$]	Esperienze Precedenti
Piccioni	38.9	42	No	150	Si
Pronsati	56.0	50	No	non noto	Si
MIKE	48.2	30	No	70	No
Targos	31.1	56	Si	65	No
MARITIME	49.8	40	Si	~400	Si
GUIS	43.6	30	Si	>200	No

	Solo Costo	Solo Tempi	Linea Media	Costi x Tempi	Lavori Precenti	Navi Proprie	Pareto Comp.	Fatturato	**TOTALE**
Weight	16%	16%	32%	8%	8%	4%	12%	4%	100%
Piccioni	0.32	0.64	0.32	0.32	0.08	0.16	0.36	0.12	2.32
Pronsati	0.96	0.8	1.28	0.48	0.08	0.16	0.6	0.24	4.6
MIKE	0.48	0.16	0.32	0.24	0.32	0.16	0.12	0.16	1.96
Targos	0.16	0.96	1.28	0.16	0.32	0.04	0.6	0.2	3.72
MARITIME	0.8	0.48	1.28	0.4	0.08	0.04	0.36	0.04	3.48
GUIS	0.64	0.16	0.32	0.08	0.32	0.04	0.24	0.04	1.84

1st

Ranking list for Suppliers based on different Criteria

Project Risk Management

The Projects are stochastic activities so they are connected to direct and indirect risks, but also opportunities.
So it is necessary to manage them as following:

- **Risks Identification**
  Identify risks that could affect the project and document it
- **Risks Quantification**
  Evaluate risks and their interactions to estimate the influence on the project
- **Development of Plans for Risks Management**
  Define steps and procedures to react effectively to the different conditions
- **Applied Countermeasures Control**
  Reply to the risks evolution during the project life

In Project Management related to industrial Plants there are some common risks including environmental conditions (e.g. weather working days), accidents in addition to traditional economic and financial risks.

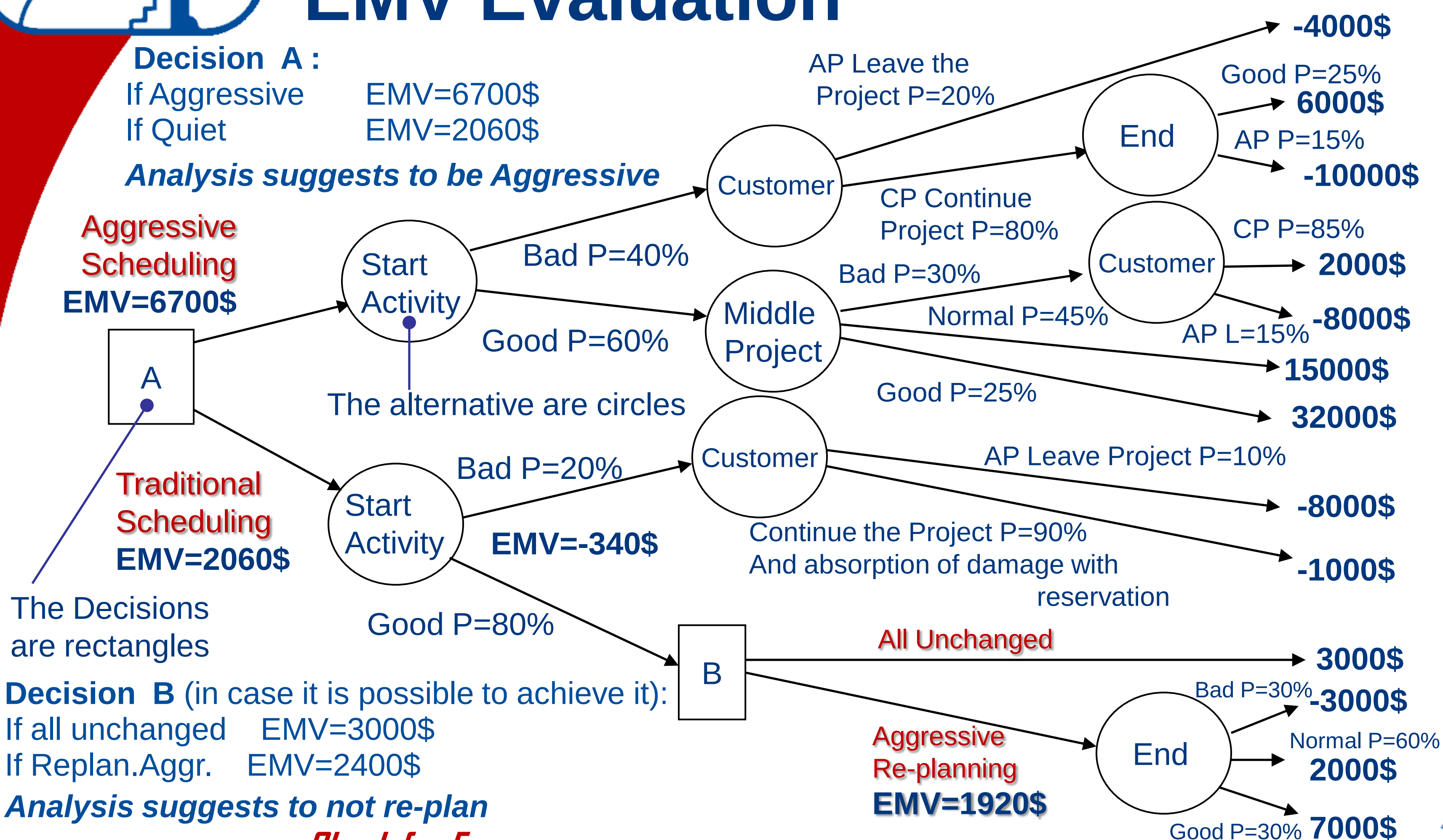
Decisional Tree for EMV Evaluation

Expected Monetary Value

EMV = $ x %

Decision A :
If Aggressive EMV=6700$
If Quiet EMV=2060$

Analysis suggests to be Aggressive



Decision B (in case it is possible to achieve it):
If all unchanged EMV=3000$
If Replan.Aggr. EMV=2400$

Analysis suggests to not re-plan

Tangible and Intangible Risks

In the risk assessing there are two types of factors: tangible and intangible; the first type is quantifiable, while the second not (i.e. effects on future activities external to the project, favorable or detrimental conditions to future developments, factors of image etc..).

It is necessary however to consider in the risk assessment also intangible factors; to neglect intangible risks (not normally detectable by quantitative analysis) leads to dangerous distortions of the evaluation, moreover aggravated by the stakeholders trust on quantitative estimates generating high risk of wrong decisions and underestimation of losses in adverse circumstances and overestimation of earnings in case of opportunity.

I.e.: two engineering solutions have the same EMV, but the second involves the risk of making a terrible image with the customer; that could affect future relationships => so they are not equivalent

Statistical Sum: Combinations in Sequence

Progetto di:	Acquisto tre nuovi Computers					
Attivita`	Durate Stimate (giorni)			Valori Calcolati		
	Ottimistica a	Piu` Probabile m	Pessimistica b	Media μ	Scarto σ	Varianza exp(2 ln(σ))
Preliminari						
Acquisizione Offerte	2	7	15	7.50	2.17	4.69
Confronto Preliminare	1	3	6	3.17	0.83	0.69
Selezione Iniziale	1	2	3	2.00	0.33	0.11
Effettive						
Negoziazioni	1	3	10	3.83	1.50	2.25
Offerte Definitive	4	7	21	8.83	2.83	8.03
Valutazione Offerte	2	3	5	3.17	0.50	0.25
Selezione Definitiva	4	5	10	5.67	1.00	1.00
Ipotesi di distribuzione Beta di Probabilita` per le durate						
Totale Durata del Progetto		30		34	4.13	17.03

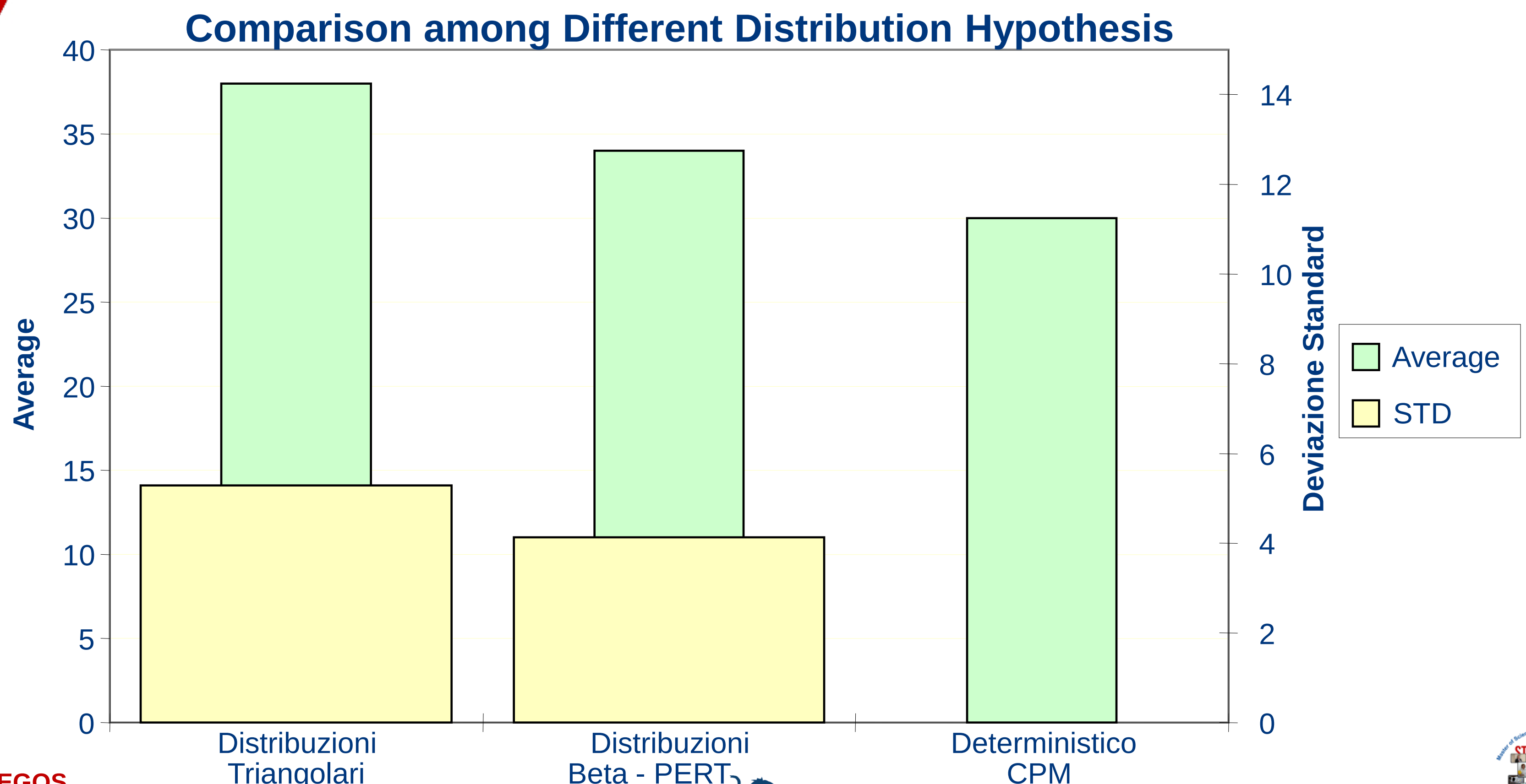
If you make different hypothesis about the distributions, different values are obtained (they can be combined as desired).

Progetto di:	Acquisto tre nuovi Computers					
Attivita`	Durate Stimate (giorni)			Valori Calcolati		
	Ottimistica a	Piu` Probabile m	Pessimistica b	Media μ	Scarto σ	Varianza exp(2 ln(σ))
Preliminari						
Acquisizione Offerte	2	7	15	8.00	2.68	7.17
Confronto Preliminare	1	3	6	3.33	1.03	1.06
Selezione Iniziale	1	2	3	2.00	0.41	0.17
Effettive						
Negoziazioni	1	3	10	4.67	1.93	3.72
Offerte Definitive	4	7	21	10.67	3.70	13.72
Valutazione Offerte	2	3	5	3.33	0.62	0.39
Selezione Definitiva	4	5	10	6.33	1.31	1.72
Ipotesi di distribuzione Triangolare di Probabilita` per le durate						
Totale Durata del Progetto		30		38	5.29	27.94

It is always valid for activities in sequence:
The total average duration is equal to the sum of mean values
The ***total variance*** is equal to the variances sum
The ***standard deviation*** is the square root of the total variance

Combining different Statistical Distributions based on *a, m & b*

By using the distributions with three references (beta, triangular); if m values approach the left worse estimations are achieved respect of the CPM value



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Montecarlo Simulation and Risk Analysis

The Monte Carlo method is a basic and traditionally stochastic simulation very common in the PM. First step is to define for each variable (I.e. length or cost) the of most correct statistical distributions (e.g. continuous, discrete beta, normal, exponential negative, etc.) to be used. The computer compute the final values of the project by replicated runs obtained by extracting every time new values from the corresponding distributions; at the end of n replicated run it is possible to compute the overall performance (e.g. average duration, max, min, risks etc.) of the whole project

Replicazioni	*Attivita` 1 Uniforme 3 - 8 Continua*	*Attivita` 2 Exp.Neg 3 Continua*	*Attivita` 3 Gaussiana 6, 1 Continua*	*Attivita` 4 Uniforme 5,11,14,17 Discreta*	*Attivita` 2 Deterministica 5 Continua*	Singolo Run **Durata Totale**
1	5.5	2.9	4.8	5.0	5.0	23.24
2	3.6	1.9	6.1	11.0	5.0	27.59
3	3.4	0.6	7.2	14.0	5.0	30.22
4	5.2	5.4	7.0	17.0	5.0	39.57
5	7.3	2.7	6.3	11.0	5.0	32.34
6	3.4	2.1	7.3	17.0	5.0	34.78
7	7.6	7.0	5.9	14.0	5.0	39.42
8	7.7	12.5	6.3	14.0	5.0	45.59
9	5.6	7.9	4.9	5.0	5.0	28.39
10	4.2	0.2	6.1	17.0	5.0	32.45
11	3.8	2.3	7.1	17.0	5.0	35.14
12	6.4	0.3	5.4	11.0	5.0	27.96
13	7.8	0.1	4.9	5.0	5.0	22.77
14	5.7	3.5	5.8	5.0	5.0	25.03
15	3.2	0.2	6.1	17.0	5.0	31.50
16	5.4	0.3	4.2	5.0	5.0	19.85
17	6.6	2.1	4.0	17.0	5.0	34.63
18	4.2	0.8	8.0	14.0	5.0	32.06
19	6.3	6.2	6.4	14.0	5.0	37.85
20	6.4	0.3	7.2	14.0	5.0	32.92
21	6.6	0.2	7.4	5.0	5.0	24.13
22	7.0	0.9	6.0	17.0	5.0	35.86
23	4.2	4.6	5.1	5.0	5.0	23.88
24	3.1	5.5	6.4	17.0	5.0	37.09
25	6.8	0.2	9.1	17.0	5.0	38.07
26	4.1	1.3	5.8	11.0	5.0	27.20
27	5.1	10.6	6.3	11.0	5.0	37.98
28	3.0	2.5	6.3	17.0	5.0	33.91
29	3.9	3.3	6.6	5.0	5.0	23.77
30	5.1	13.0	6.3	14.0	5.0	43.44
31	5.7	5.3	6.6	11.0	5.0	33.65
32	4.4	0.1	4.6	5.0	5.0	19.04
33	6.4	1.7	6.0	11.0	5.0	30.06
34	5.1	5.5	5.6	5.0	5.0	26.23
35	5.3	2.1	6.4	11.0	5.0	29.81
36	6.9	0.8	5.6	14.0	5.0	32.22
37	5.2	0.2	5.7	11.0	5.0	27.11
38	4.2	2.4	6.6	5.0	5.0	23.13
39	4.9	2.0	5.0	14.0	5.0	30.85
40	4.5	0.5	6.5	11.0	5.0	27.47
41	4.2	4.4	7.4	14.0	5.0	34.96
42	4.3	0.1	5.5	14.0	5.0	28.89

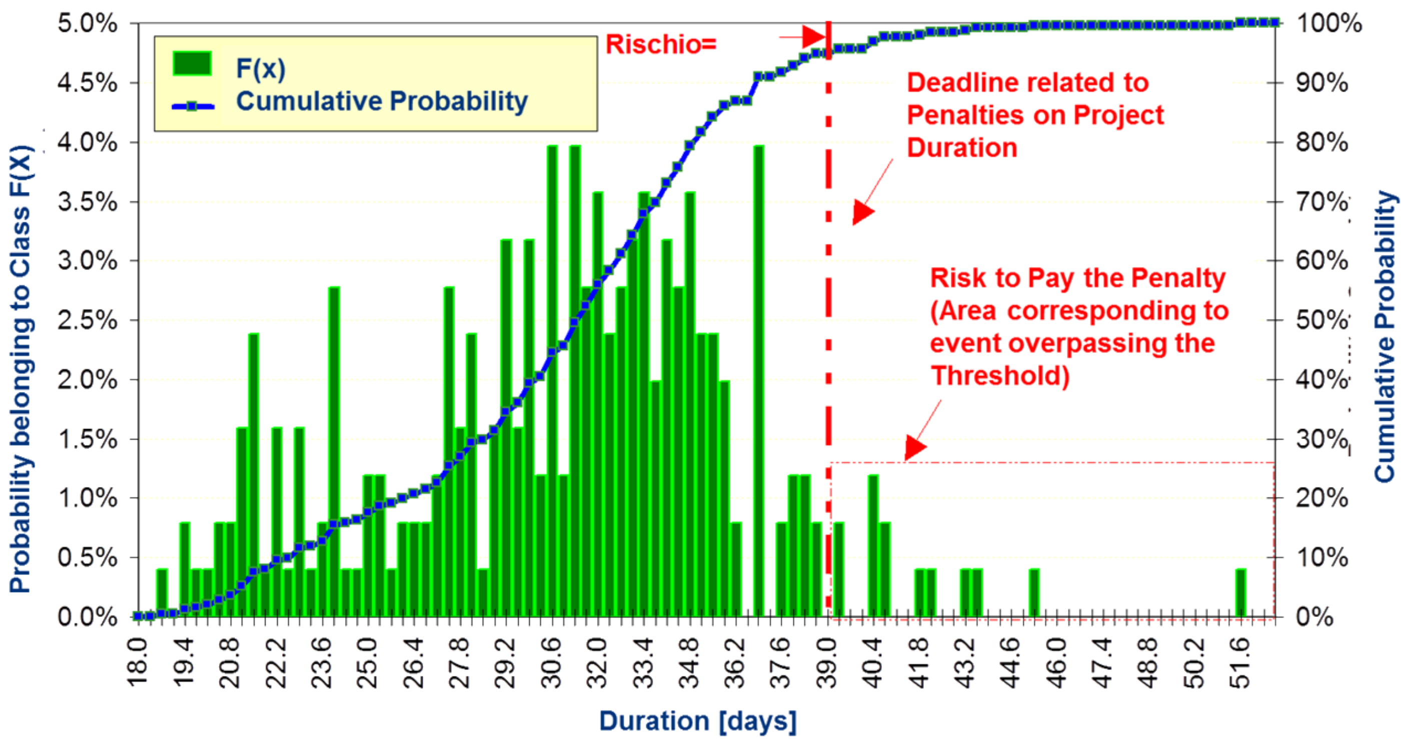
CONSUNTIVO PROGETTO	**Media**	**31.0**
42 Replicazioni	**Scarto**	**6.1**

Simulation Team

Overall Risk based on Monte Carlo Simulation

By using the simulation it is possible to evaluate the overall risk (i.e. a total duration of the project). As result it is obtained the estimation of risks for overall project

Overall Distribution of Probability related to Overall Project Duration Obtained by Simulation



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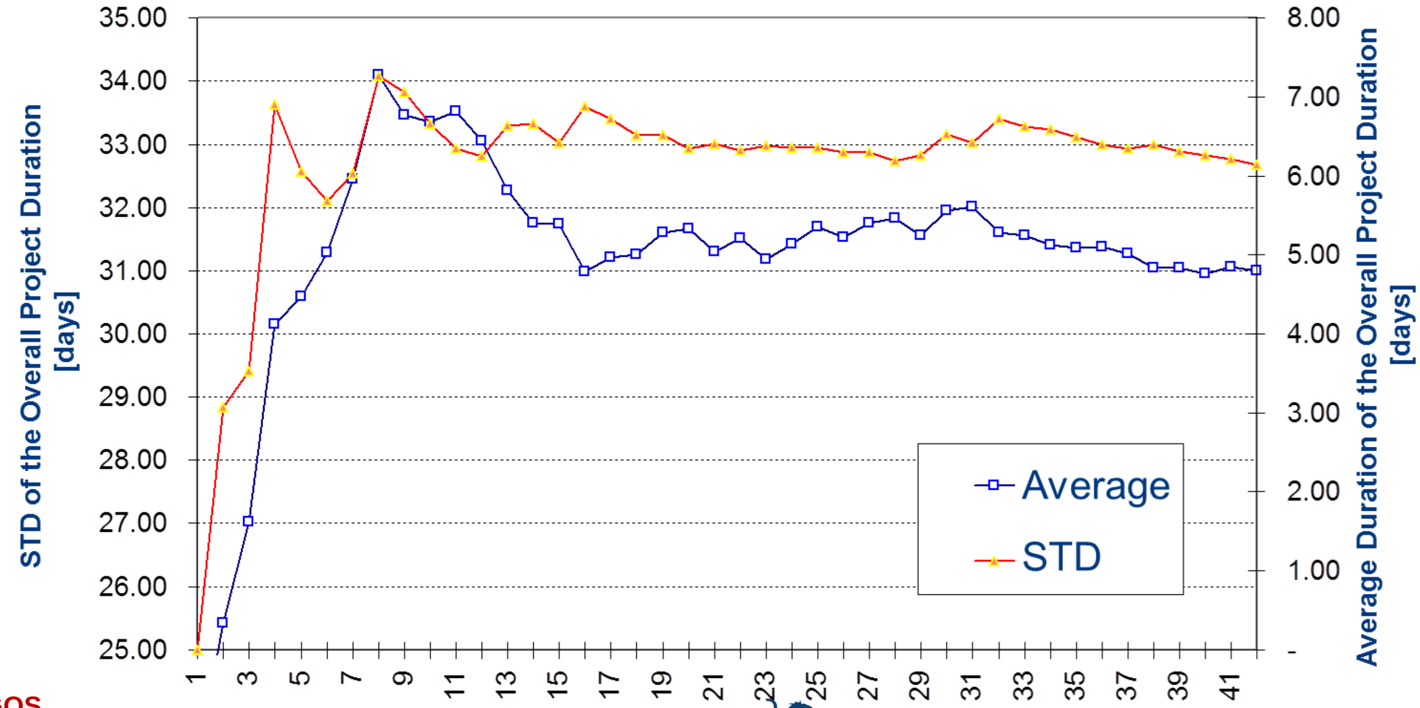
Validating & Verifying Monte Carlo Simulation

Monte Carlo method requires Validation and Verification of the number of replications based on Experimental Error Analysis

Influence of Replication Number of the Analysis carried out by Montecarlo Technique



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Strategies & Security for Complex Systems

Use of new Solutions

Major Goals include:

- To improve Safety and Security in by use of Innovative Solutions such as AI, XR (eXtended Reality) & Simulation
- To empower Effective and Efficient Trans-Disciplinary Teams involving Subject Matter Experts, Industrial Users, Engineers and Scientists by new Solutions
- To experiment the potential of new Paradigms (e.g. Industry 4.0) in addressing Operational, Safety, Security and Environmental issues in Industrial Plants
- To investigate Challenges and Opportunities in Industrial plants by using Modeling, Simulation, AI & XR
- To outline the crucial advantage of using Strategic Engineering approach based on combined use of Modeling, Simulation, AI, Data Analytics Methodologies
- To analyze as examples cases related to Port and to Projects for improving Safety and Security
- To Estimate potential Outcomes and Goals

XR: VR, AR, MR Concepts & Technologies

VR: Virtual Reality

AR: Augmented Reality

MR: Mixed Reality

XR: eXtended Reality

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Challenges & Opportunities

Human Perceptions, Immersivity & Engagement

Persistency vs. Invasive Device & Intuitive Sense

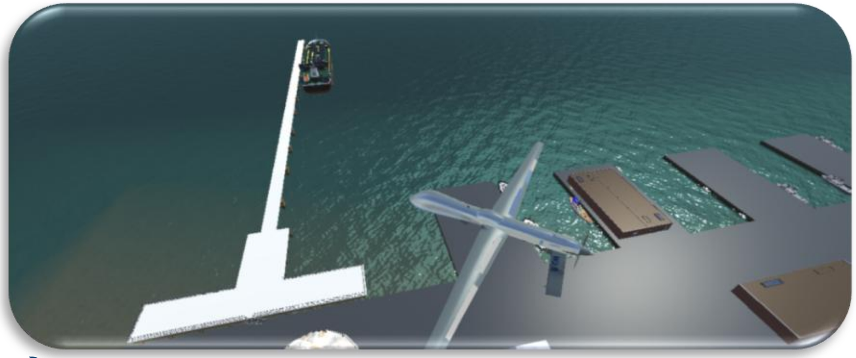
Synchronization & Interaction with Real World

Interoperabilities & Collective Use

Email {agostino, kirill}@simulationteam.com
URL www.itim.unige.it/strategos

Port Plants as an Examples

Safety and Security are two major aspects to guarantee functionality and sustainability of Plants and Critical Infrastructures. We propose hereafter applications mostly in Port Plants, therefore the use of XR techniques such as VR, AR, MR could be in very similar way applied in any kind of Industrial Plant. It is evident that to protect and guarantee safe and efficient operations in Industrial Plant the possibility to use Immersive Interactive Synthetic Environments based on Virtual Reality allows to support training, education and design of safety and security technological & procedural solutions



Port Traffic…

Top 10 ports of the World, 2018 - 2015

			2018	2017	2016	2015
1	Ningbo & Zhoushan	China	1080.0	1010.0	920	889.0
2	Shanghai	China	730.5	750.5	701.8	717.4
3	Tangshan	China	637.0	570.0	520.0	490.0
4	Singapore	Singapore	630.1	627.7	593.3	575.8
5	Guangzhou	China	613.0	590.0	543.6	519.9
6	Qingdao	China	540.0	510.0	510.0	500.0
7	Suzhou 1 (river port)	China	532.4	605.0	579.0	540.0
8	Port Hedland	Australia	519.4	500.9	460.4	452.9
9	Tianjin	China	508.0	501.0	551.0	541.0
10	Rotterdam	The Netherlands	469.0	467.4	461.2	466.4

Port Traffic… new Issues…

Top 1

					593.3	575.8
5					543.6	519.9
6					510.0	500.0
7					579.0	540.0
8	Po				460.4	452.9
9	Tianjin	China	508.0	501.0	551.0	541.0
10	Rotterdam	The Netherlands	469.0	467.4	461.2	466.4

10% more than first European Port

… and Safety and Security

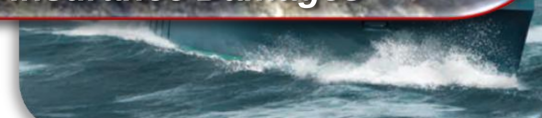
Top 1

Town, Port and Industry growth created a intensive dangerous Area

6	
7	
8	
9	Tianjin

Cleaning and Restoring operations Is even more expensive than crisis

Tianjin Explosion
August 12th, 2015
800 tons Ammonium Nitrate, 336 tons of TNT explosion equivalent
173 casualties, 2km range, 9bUSD Insurance Damages



Just a Huge Accident caused by the Dangerous Materials present in the Port & Errors

Accidents in Ports

Seaports are critical infrastructures and have significant impact on economy and people's life. Indeed, nowadays they manage huge flows of goods and passengers, create numerous work opportunity and are essential parts of economy of countries where they are located. Unfortunately, such environments are characterized also by high risk of accidents; for instance, handled materials could be dangerous (e.g. toxic products, explosives) while heavy, huge and cumbersome equipment and ships might collide each other or with goods and port structures.

In order to identify main safety issues in seaports, it is necessary to analyze existing situation as well as past events. Simulation, AI, XR and other new Technologies could be used in many ways to reduce the risks

Crane collapse at Jebel Ali Port, Dubai

Port Historical Examples

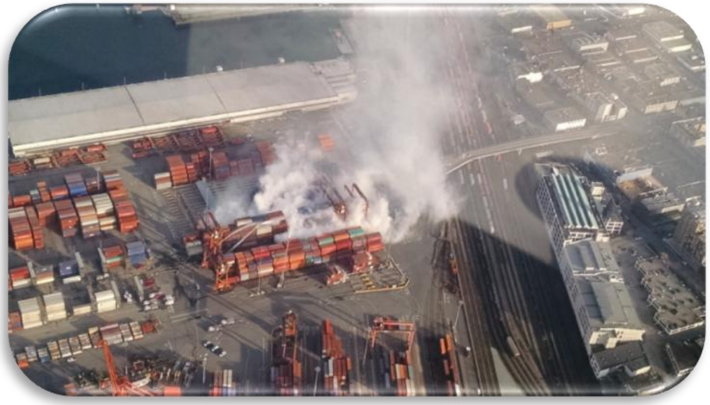
Collision of ships and consequent fire caused explosion in port of Halifax (1917)

Improper handling of ammuntion caused explosion in Chicago (1944)

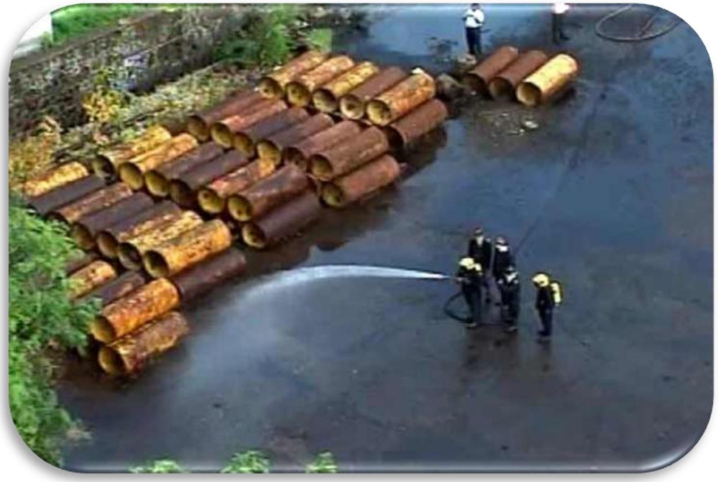
Ammonium nitrate detonation in Galveston Bay (1947)
One of largest non-nuclear explosions: 567 casualties

Recent Cases: Fire & Leakages in Ports

Ferry collided with port crane causing fire, Barcelona (October 2018)



Fire in containers with trichloroisocyanuric acid at Port Metro



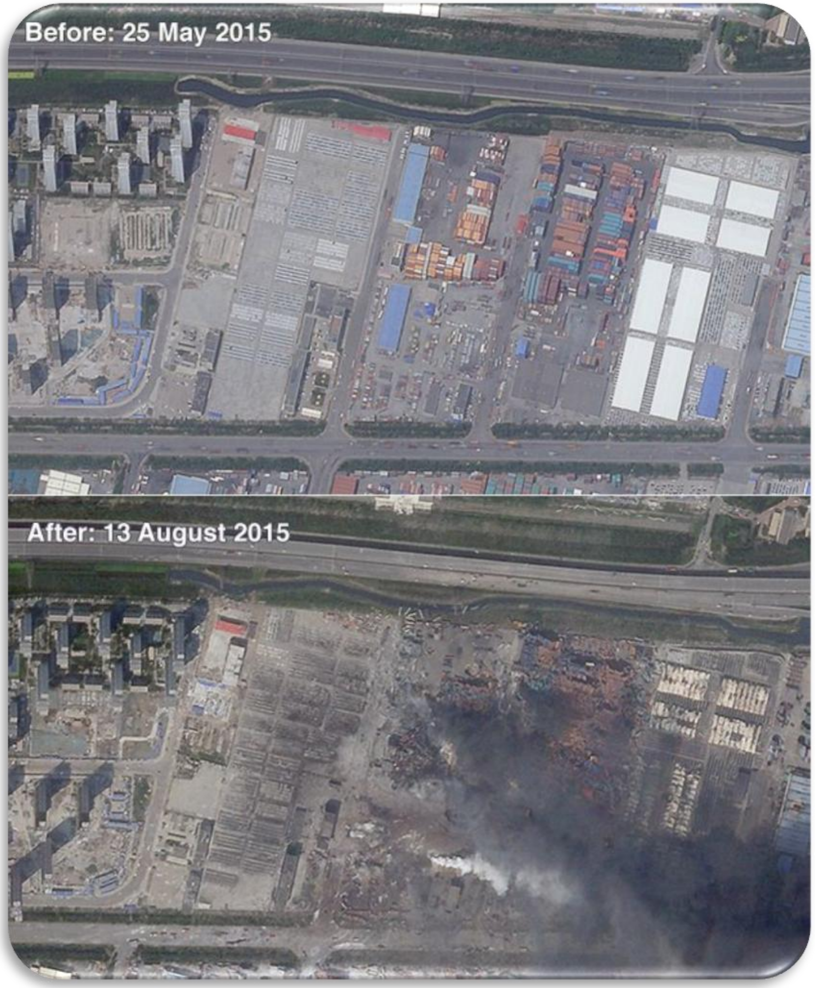
More than 120 persons hospitalized after chlorine leakage in Mumbai Port (July 2010)

Hundreds of cars burned in Savona port during storm (October 2018)

Recent Cases: Explosions

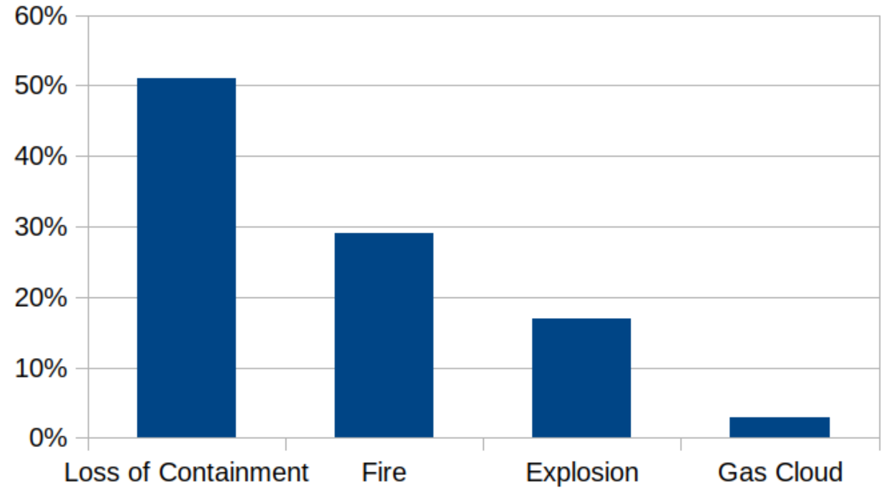
Even modern big ports face sometime issues with planning and communication, which impact safety of persons.

For instance, in case of Tianjin port explosion (China), firefighters were not informed about presence of calcium carbide and tried to extinguish fire by water, which is considered as one of main cause of the explosion. Furthermore, distance between the storage of hazardous materials and nearby houses was less than one km, which caused additional casualties

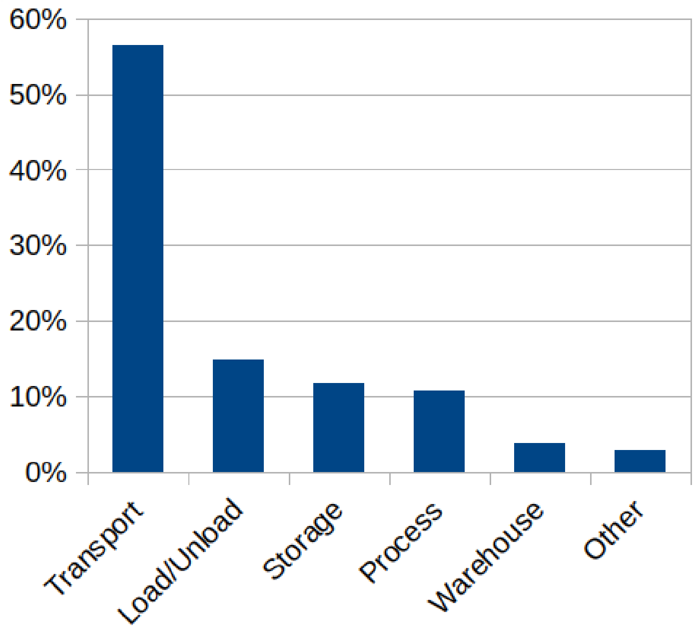


Tianjin port explosion (China) Source: bbc.com

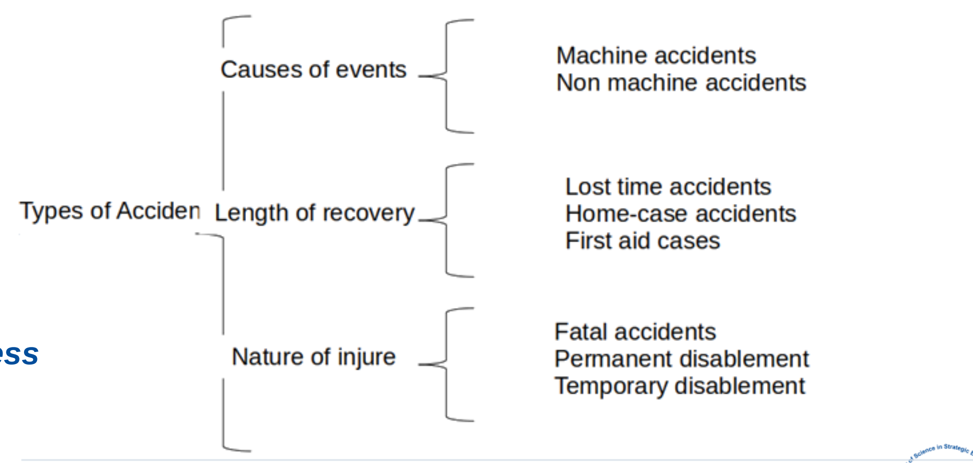
Analysis of Typical Port Problems



Occurrence rate of accidents by type



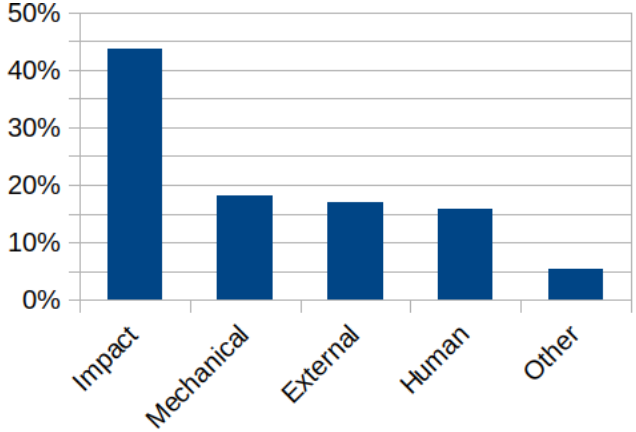
Place or activity in which the accident occurred: process plant, storage, transport, load/unload, waste, other



Classification of accidents

Causes and Effects

In general, analyzing the statistical data, it is possible to conclude that number of accidents in seaports is constantly growing despite continuous improvements in safety procedures, even due to a constant increase in flows and operations. This could be explained by the continuously increasing sea traffic. In addition, the frequency of domino effect accidents is decreasing, even if their occurrence is still quite high. Finally Urbanization and Industrial Activities growth increase impact of the accidents



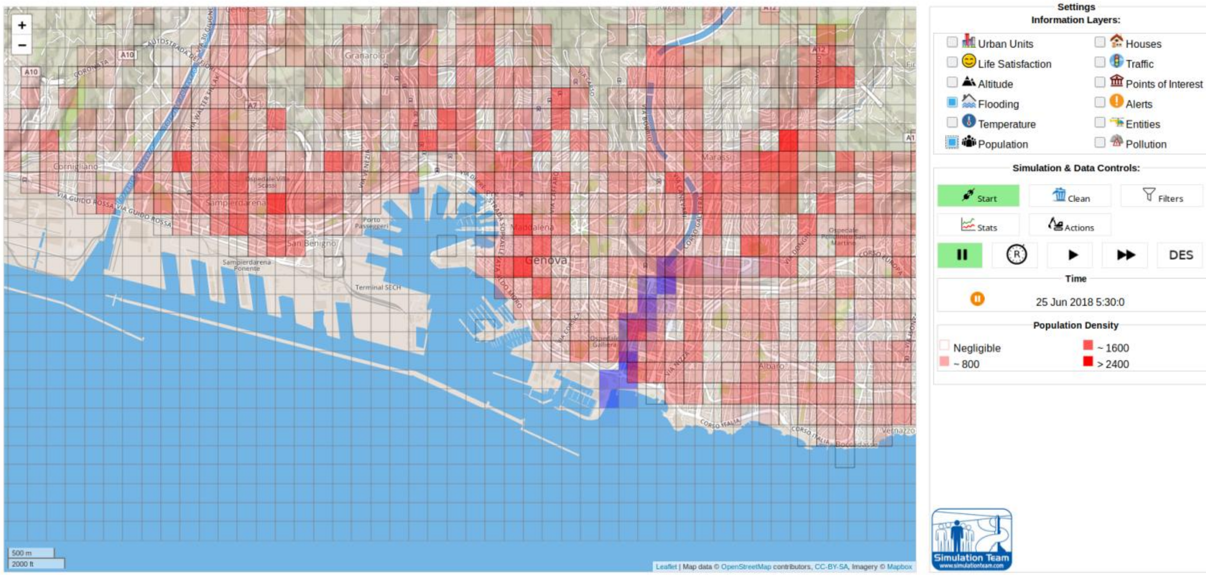
Causes of accidents

Fire and chemicals leak in Laem Chabang

Simulation for Emergency Management

Simulation is a strategic science, capable to analyze existing or future complex systems through experimentation over models, which makes it a perfect tool to be applied to the context of emergency management.

PONTUS is a city model, which simulates the entire population along with social activities and its behavior in case of critical events. It allows to calculate flooding zones caused by rain and analyze impact on population, with particular attention to the situation in the points of interest.

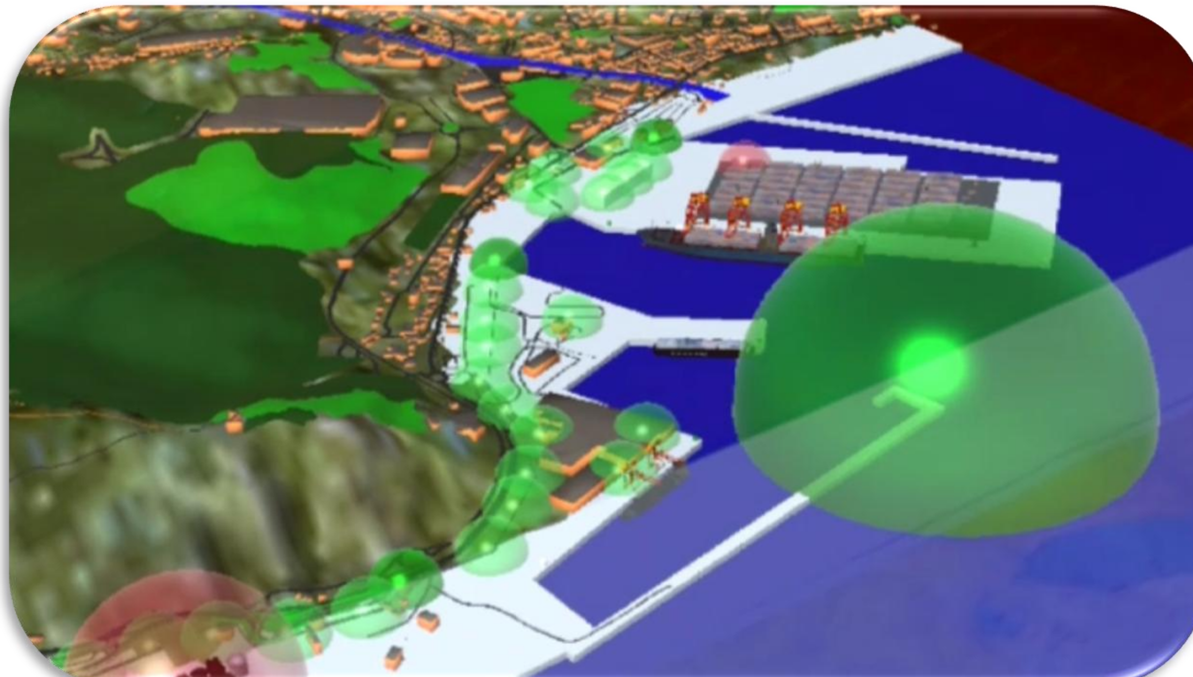


PONTUS: Model of Human Behaviour and Flooding Population Density in Areas at Risk

Virtual Lab for Ports

In virtual laboratory it is possible to test the effectiveness of new technological and infrastructural solutions to reduce vulnerability, mitigate damage and prevent emergencies. The simulation techniques adopt the new MS2G paradigm (Modeling, interoperable Simulation and Serious Games) to combine different

Libya Es Sider Port, Oil Tank Fire (2014)

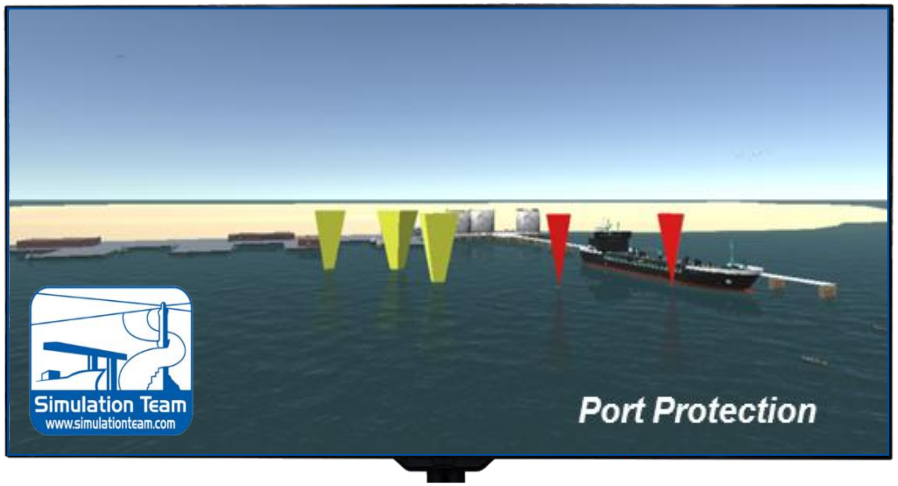


Virtual Port in Mixed Reality by Simulation Team with Risk Areas

AI & IA

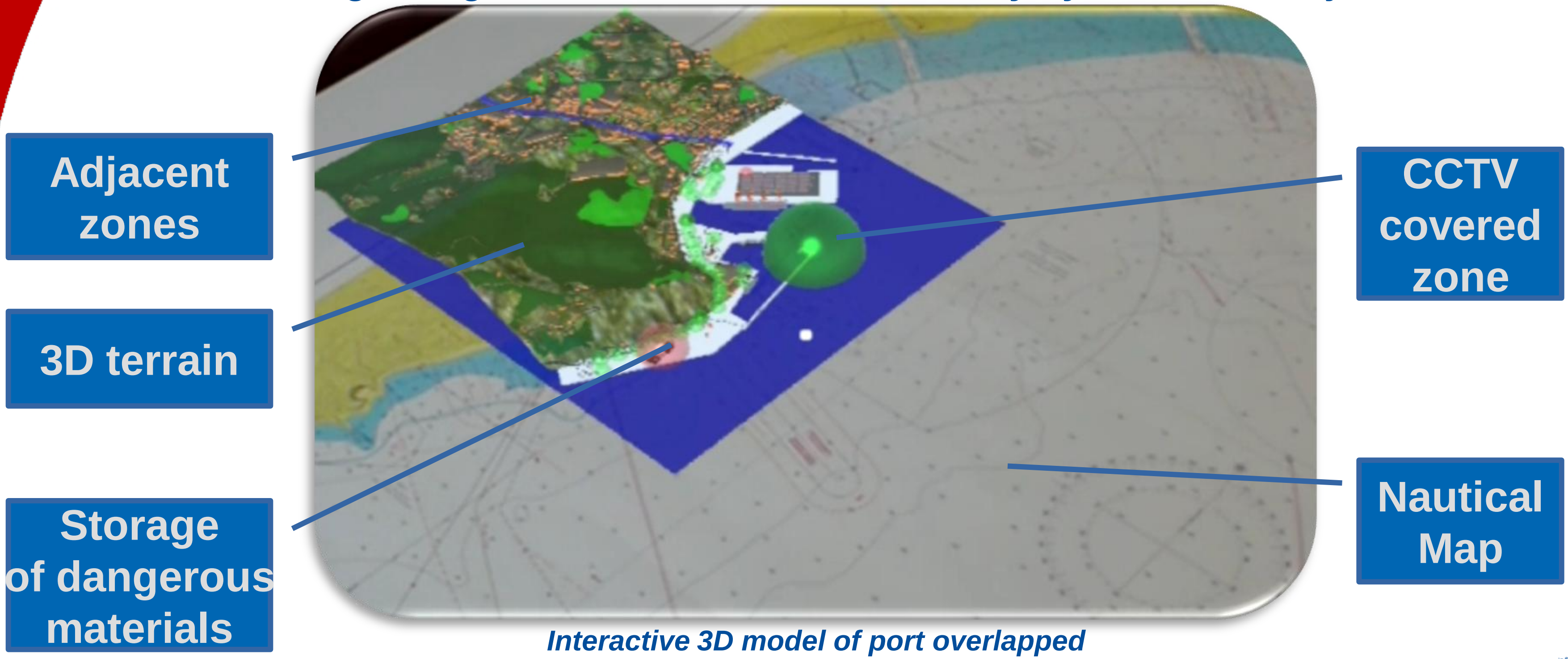
Artificial Intelligence (AI) is based on techniques designed to reproduce intelligent processes. The M&S and AI are strongly connected because simulation often has to incorporate intelligence to control assets, virtual human beings, virtual organizations, planning activities. Intelligent Agents (IA) represent a crucial element for coupling complex scenarios with many entities that interact in a complex way. AI generally represent people, groups or units and reproduce the corresponding desired behaviors.

IAs allow an object to react to situation changes based on his perception. The use of AI-driven simulations reproducing the behavior human (HBM) is fundamental to recreate complex and extended scenarios which include the reactions of people and the population.



AR & VR Solutions

Augmented Reality allows to overlap 3D terrain and Port Plants & Infrastructure over a real nautical map of the zone of interest; such technology allows to extend information provided by "hardcopy" map. In this example, it adds information regarding hazardous materials, security systems and adjacent zones



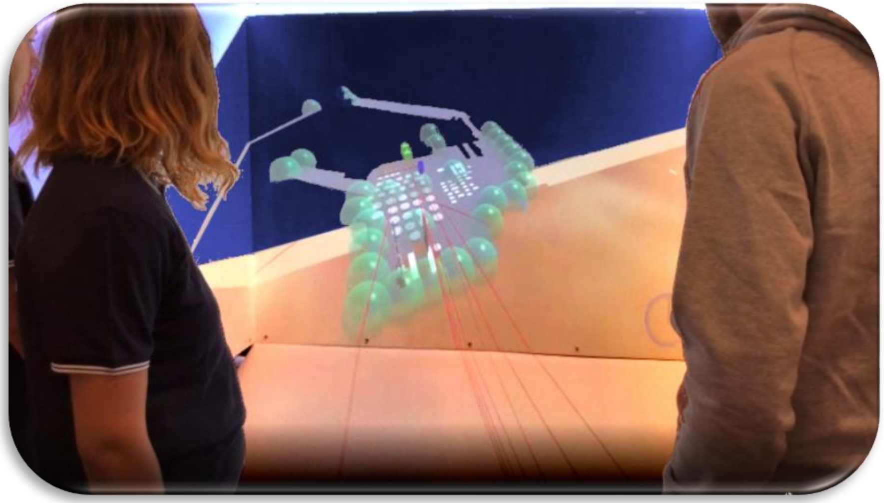
Interactive 3D model of port overlapped with nautical map, view from Hololens

AR & VR Live Demonstration

Thanks to Augmented & Virtual Reality it becomes possible to recreate the emergency scenario using immersive virtual reality technologies, allowing the operators to take actions and simulate their work in environment that reproduces the real emergency conditions and that guarantee to

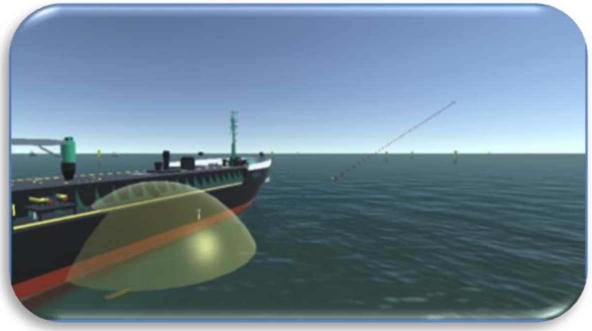
Cyber space simulation in SPIDER CAVE

Using Oculus Rift in maritime frmework



T-REX simulator in SPIDER CAVE

ALACRES2



the ALACRES2 laboratory investigates and analyzes the behavioral procedures & protocols for:

- Vertices of the chain of command and / or operating centers of management, or those who are deputies to manage an emergency condition lasting over time (widespread and prolonged fire, spill in uncontrolled water, evolving toxic cloud, etc.)
- Operational subjects in charge of the first intervention activities aimed at curbing the emergency and / or reducing the causes that generated the indicator (fire brigade, emergency workers, etc.)

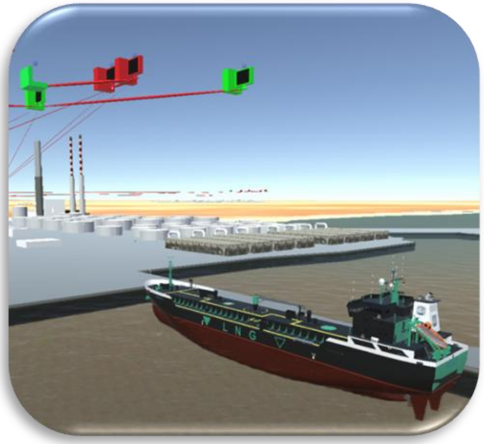
ALACRES2 is based on simulation techniques of operational and decisional behaviors aimed at training the different subjects to perform their respective tasks in conditions of mental and physical stress and work overload, in order to evaluate incorrect processes, incorrect methods of sending and / or information management, decisions that do not comply with external conditions, etc.

The simulation makes it possible to reproduce the evolution of the crisis and the impact on structures, systems, people and goods, considering the physical aspects and the domino effect in its dynamism.

ALACRES2 is able to evaluate new solutions to reduce vulnerability, mitigate damage and prevent emergencies. The MS2G paradigm will be adopted (Modeling, interoperable Simulation and Serious Games) to be able to combine different models and guarantee a high level of fidelity and at the same time the simplicity of use, the intuitiveness and the immersive capabilities

Case Studies & Expected Results

After problem identification, it is possible to perform preliminary risk assessment and identify potential scenarios of interest, to be used for developing a simulation-based solution. It should be considered the use of multiple types of accidents (e.g. fire with subsequent explosion) and causes. In the same time, the model should take into account the external conditions, such as presence of personnel, proximity of residential areas, meteorological conditions and configuration of the port. So, it is possible scenario could include leakage of toxic material from tanks in the port while ferries are docked in proximity. In such case, analysis of the possible outcomes should include such factors as weather conditions (e.g. wind, fog, temperature, even time of the day) passengers' behavior (e.g. organized evacuation, panic) logic and actions of personnel and first responders, impact on port structures and nearby urban zones (domino effect, evacuation of urban areas).



Screen shot T-REX Defending Port against Cyber Physical Threats

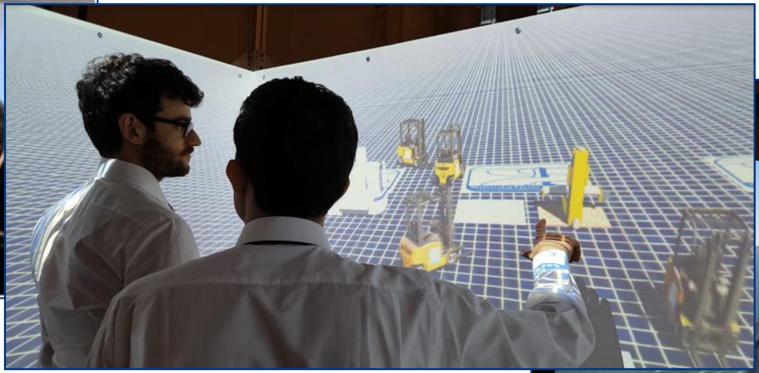
Simulation Team

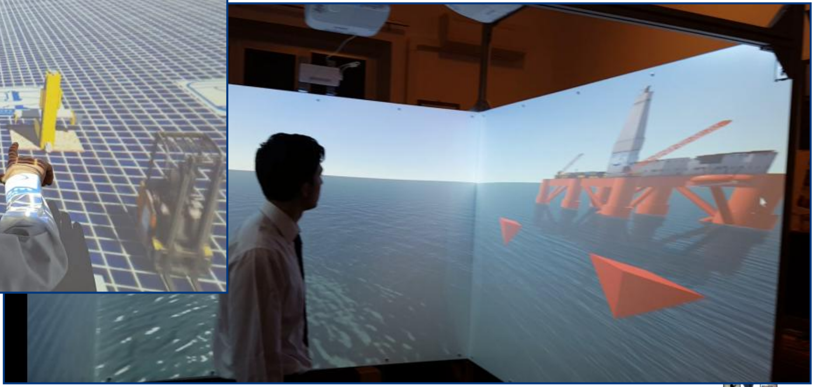
SPIDER

Simulation Practical Immersive Dynamic Environment for Reengineering

The SPIDER (Simulation Practical Immersive Dynamic Environment for Reengineering) is an innovative Interactive and Interoperable CAVE (Cave Automatic Virtual Environment) developed by Simulation Team. The basic configuration is compact (just 2m x 2m x 2.6m) and could be embedded within a standard Container and integrated in any interoperable simulator.

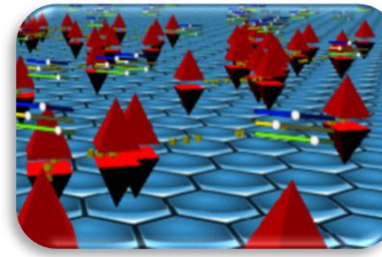
The SPIDER is interactive through touch screen technologies.



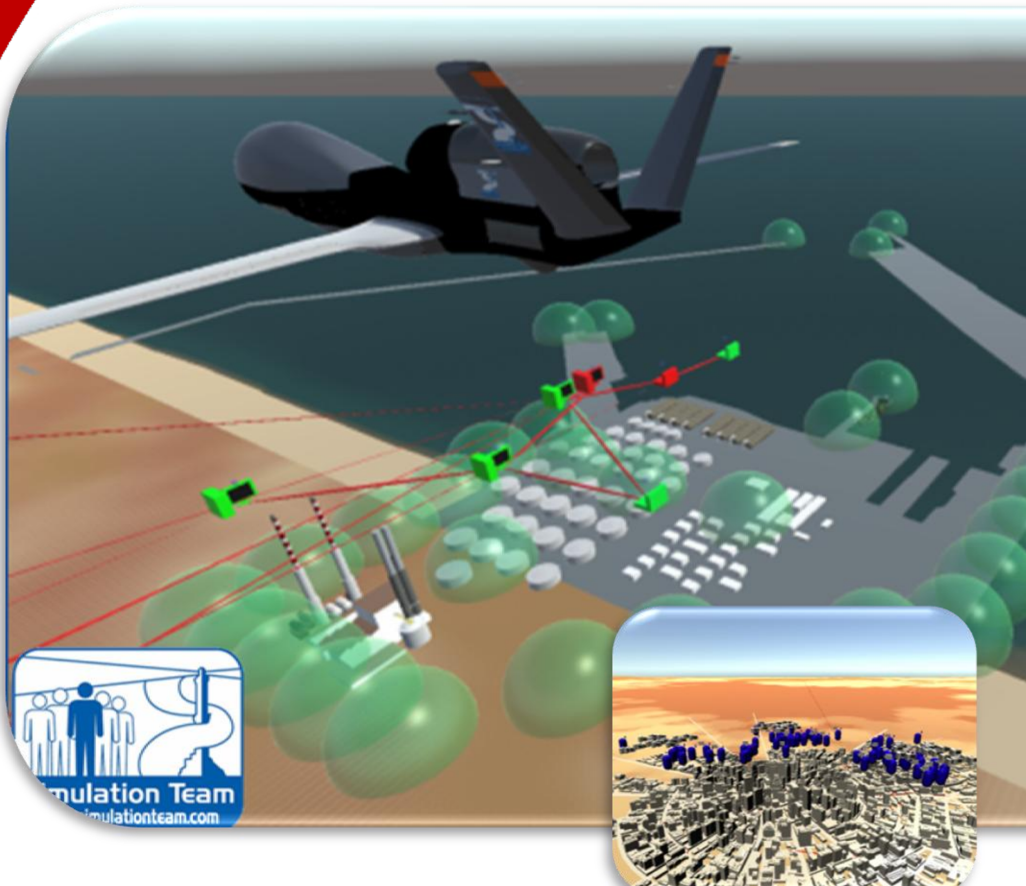


The SPIDER is fully Immersive including sound and motion.

Simulation Team



Hybrid Challenges & Autonomous Systems



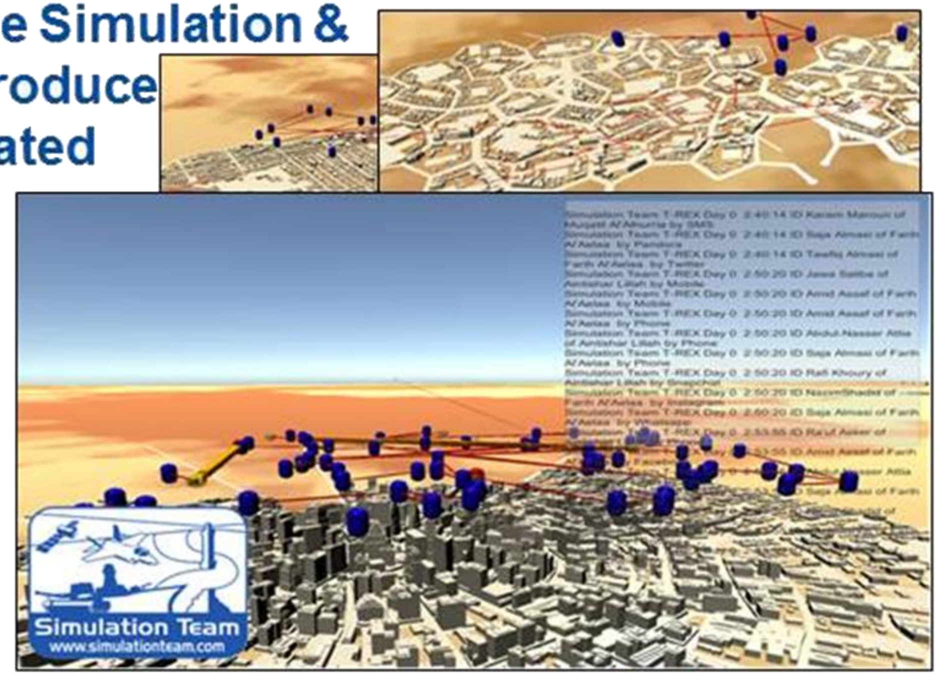
Autonomous Systems represent crucial elements for Hybrid Challenges both in terms of available Resources and Threats The T-REX simulates towns, infrastructures, people, UxV as well as Cyber & Real coordinated actions that affect whole System

Simulation Team

T-REX

Threat network simulation for REactive eXperience

T-Rex (*Threat network simulation for REactive eXperience*) is a MS2G (Modeling, interoperable Simulation & Serious Game) devoted to reproduce Hybrid Warfare and to be federated with other elements to evaluate the impact of these actions.



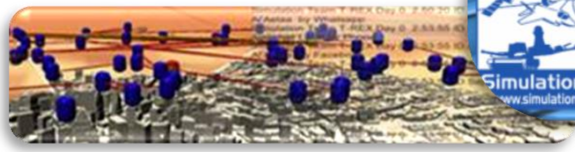
T-REX reproduces urban, as well as extra urban contexts over multiple domains including land, air, sea, space and cyberspace. The models allows to consider media communications and possibility to use different assets and to experiment virtually the different decisions in terms of COAs (Courses of Actions)

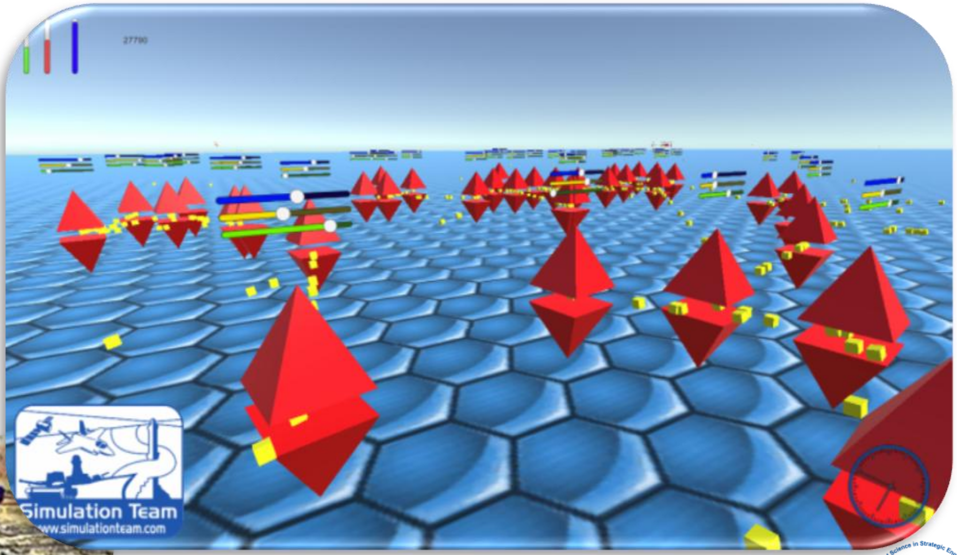
T-REX Cyber Layer

- **T-REX and IA-CGF (Intelligent Agents Computer Generated Forces) drive actions on the Cyber Layer where it is mapped the ICT domain and related levels of Confidentiality, Accessibility and Integrity for *each node and link***

Cyber Attack:
- Resources
- Responsiveness
- Efficiency
- Effectiveness
- Virus Dynamism
- Virus Initial Injection
- Virus Infectivity
- Virus Resilience
- Virus Level

Cyber Defense:
- Resources
- Responsiveness
- Efficiency
- Effectiveness
- Anti Virus Diffusion
- Anti Virus Resilience
- Anti Virus Level





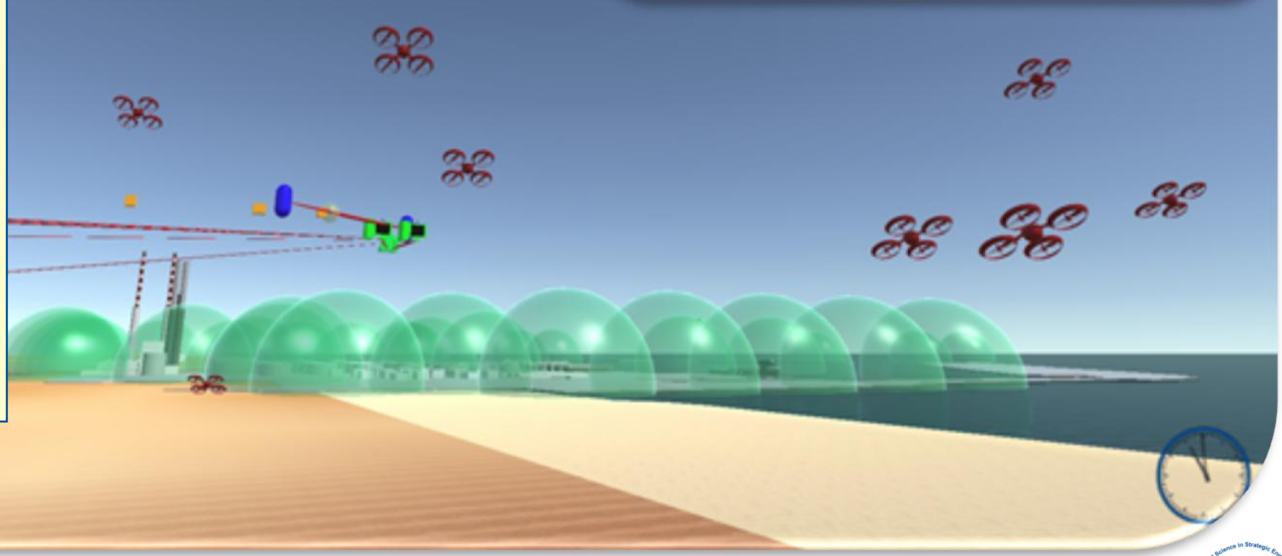
T-REX: Socials & Population

The Simulator reproduces the Social Network, Cyber Space and Population and how they react to their perception of the Scenario Evolution.

T-REX: Autonomous Systems

Autonomous Systems, on both sides, are driven by Intelligent Agents and interact with traditional Assets. Coalition UxV (Umanned multidomain Vehicles) support JISR (Joint Intelligence, Surveillance and Reconnaissance), while hostile UAV (Unmanned Aerial Vehicles) are conducting coordinated attacks

Simulation Team demonstrated this attack in 2015… on September 14, 2019 an equivalent attack was successfully carried out by drones on Saudi Aramco's Abqaiq, the World Largest Oil Refinery



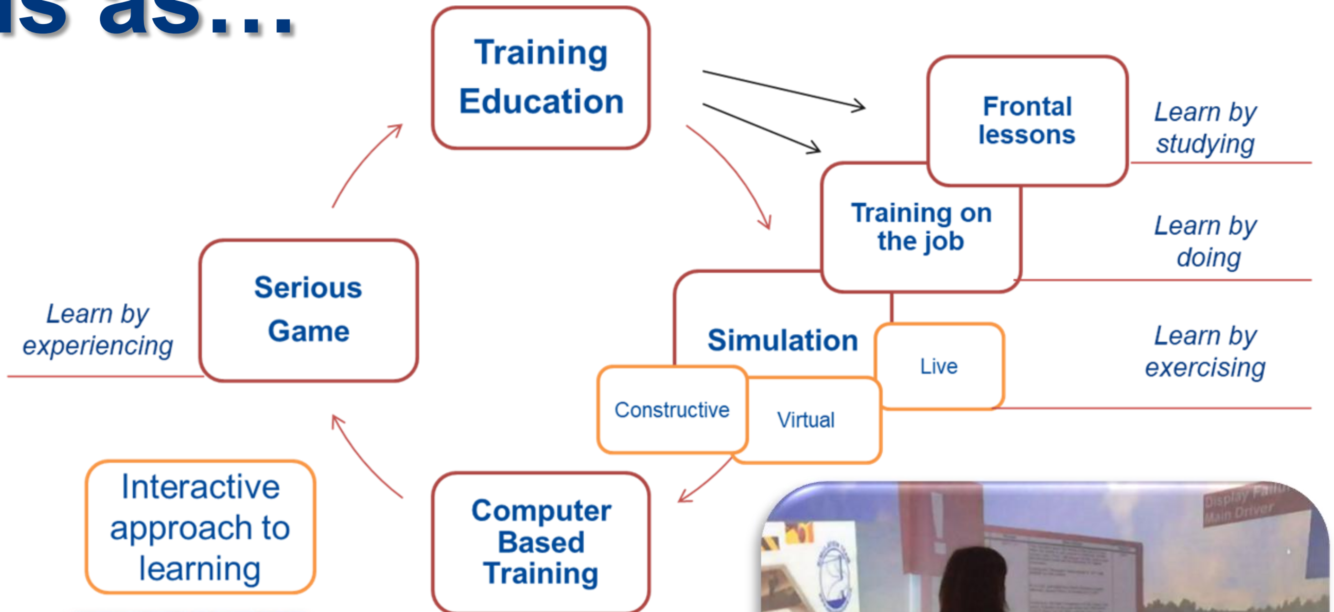
One Reason to adopt Models, Simulation & Serious Games?

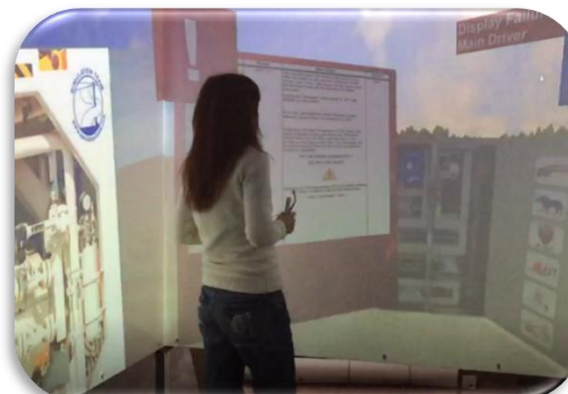
- ***Determining if Training is Needed***
- ***Identifying Training Needs***
- ***Identifying Goals and Objectives***
- ***Developing learning activities***
- ***Conducting the training***
- ***Evaluating program effectivenes***
- ***Improving the program***
- ***Training must align with job tasks.***

Training Guidelines for Safety, OSHA

OSHA Occupational Safety and Health Administration, USA

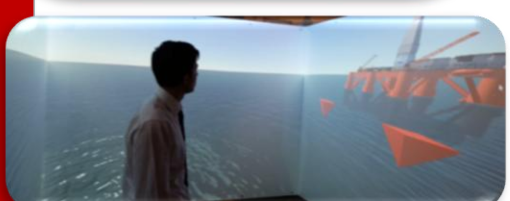
Cyber Security & Training Aids as…





"Tell me and I will forget. Teach me and I will remember. Involve me and I will learn", **Confucius**

… Serious Games Evolve into Simulation Team Roadmap



Training on the Job

Simulation for Training

Experimenting on the Simulator

Serious Games for Training

Playing while Learning

Experimenting on Games

Many Installations
Many More Users

New Education Modes
New Utilization Modes

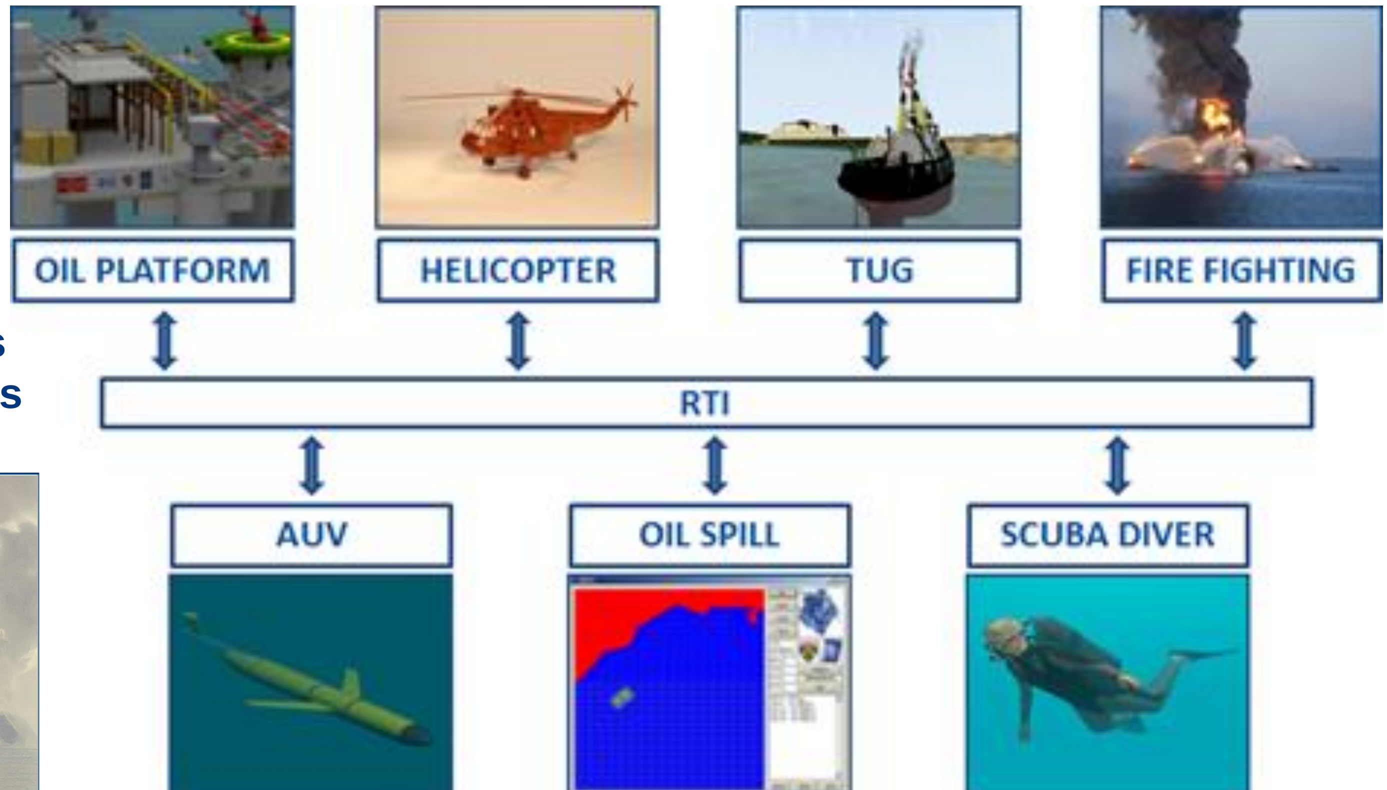
[Nuclear War]
..a strange game the only winning move is not to play
Joshua in War Games Movie

MMO Massively Multiplayer Online Game
MMORPG massively Multiplayer Online Role-play Game

Simulation Team

Interoperable Simulation to Address Real Challenges

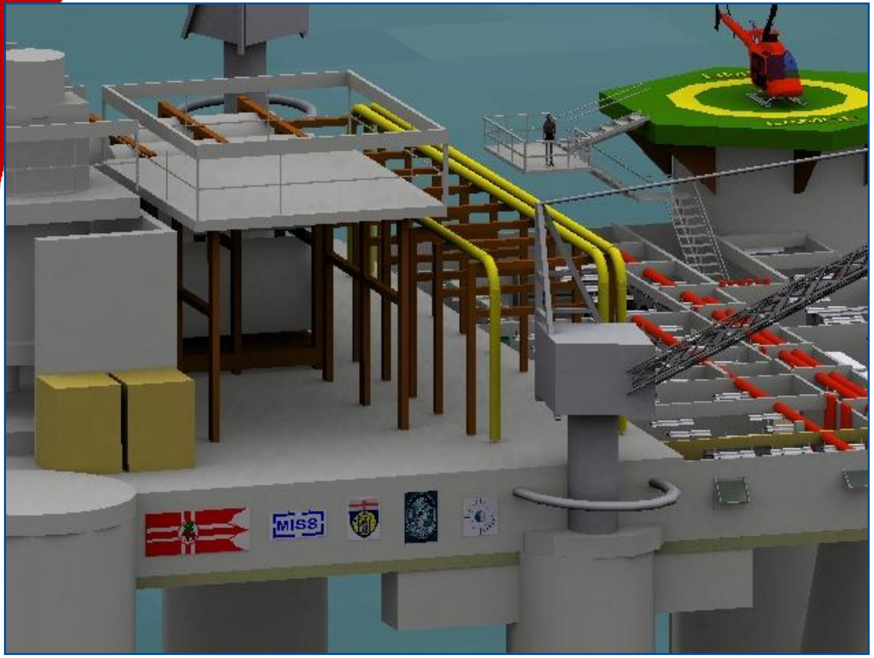
All these Models were available, therefore no joint simulation was existing to address Deep Horizon Crisis in Mexican Gulf



The Criticalities in Safety and Security is related to the Interoperation among Systems!

Operational Drivers….

From Modeling Oil Platforms for Helicopter Landing, Operator Training, Crew Coordination



Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September

forward to <u>Eco-Mega-Crisis Management</u>
(Economic/Ecological)

… Technology Enablers

Traditional progressive improvements on systems is sometime tackled into cul-de-sac

Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September

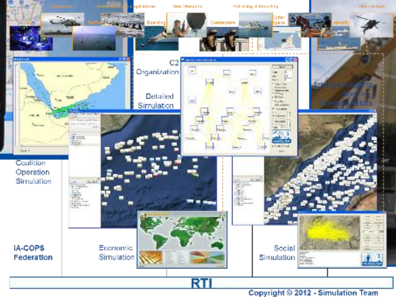
… but new approaches arise from new technologies

New Opportunities by Technologies

Major technologies and methodologies arising for M&S within Marine Domain could be identified:

- AI and Data Fusion
- IoT and Big Data
- Persistent Surveillance
- Human Behavior Modeling
- Intelligent Agents and CGF
- Virtual Worlds & Augmented Reality
- Cloud Sourcing & Computing

Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September



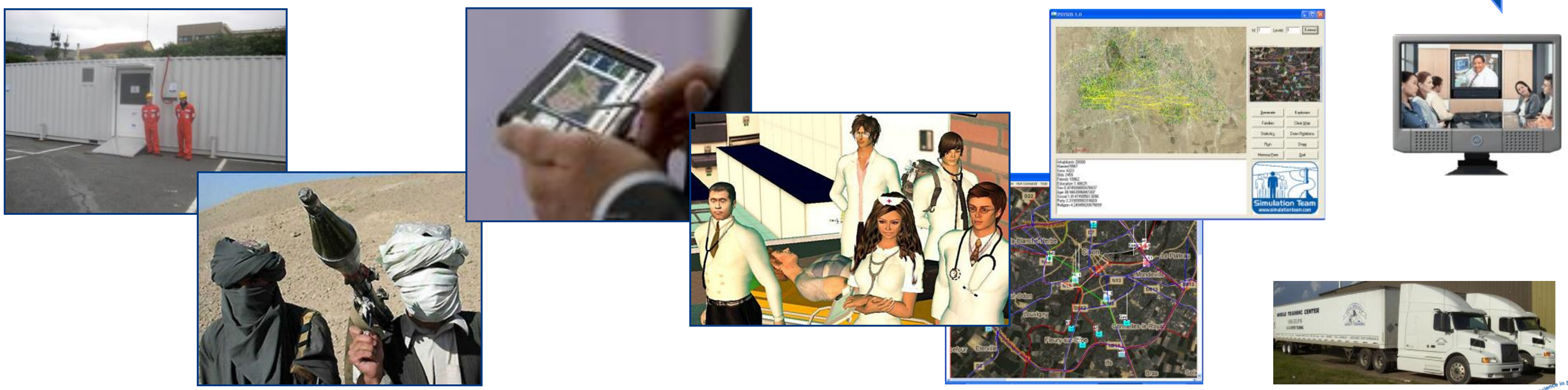
Examples of Simulators from Simulation Team

Advances and Enablers vs. Requirement Evolution

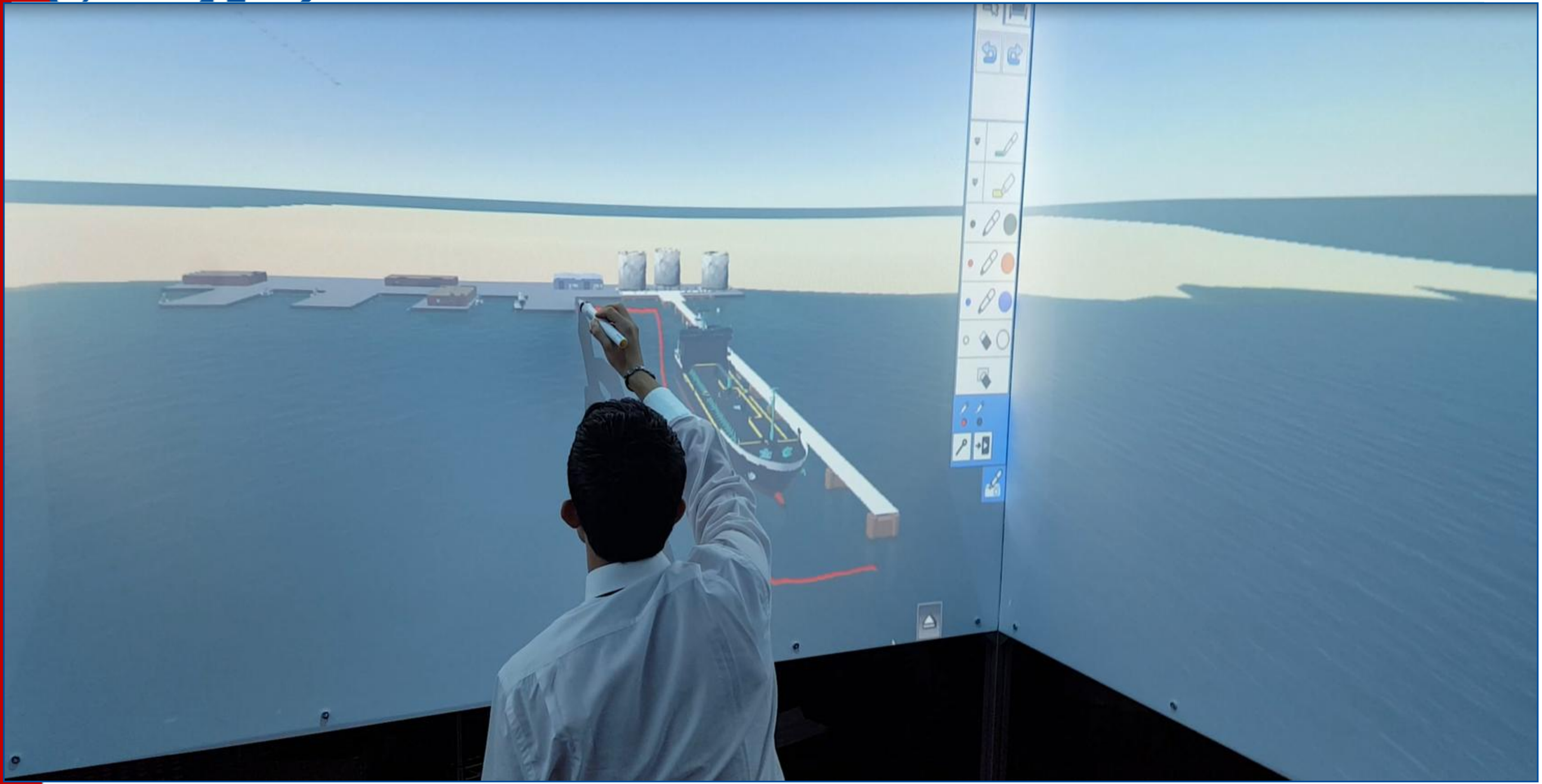
Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September

Operational World is evolving so new Requirements are emerging for Training

New Technologies are appearing becoming enablers for new Training approaches



Marine Domain and Complexity

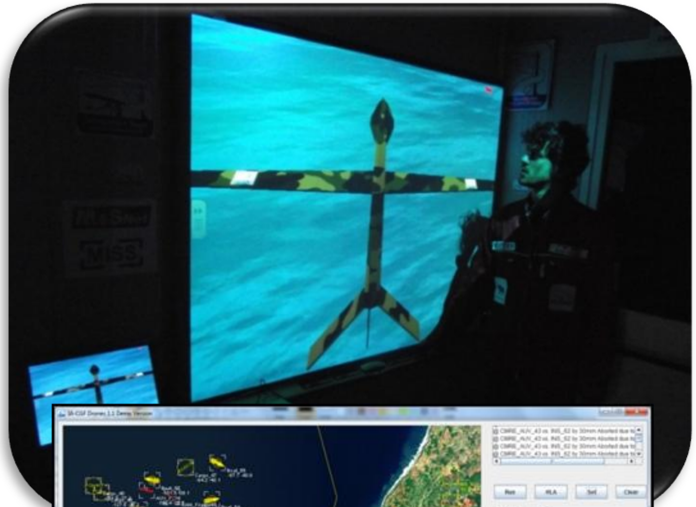


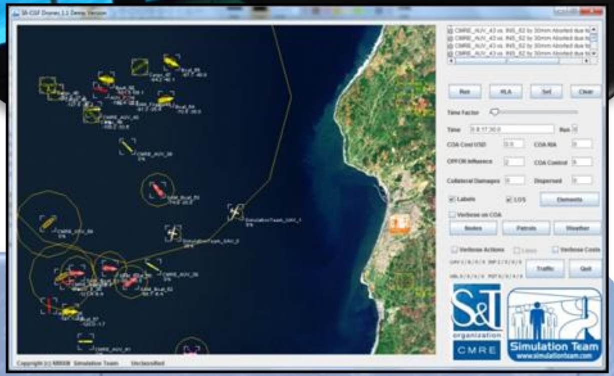
Simulation Team

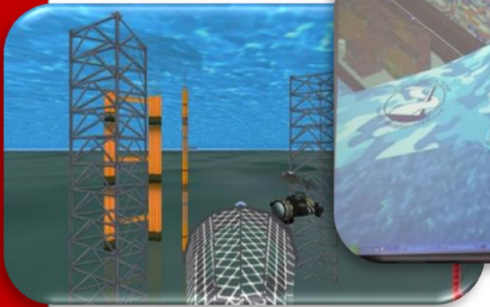
M&S and Experimentation

Simulation allows testing new standardized **components** without committing resources for their acquisition.

M&S explores and compares many options related to different **operating procedures** reducing risk and saving time and costs with respect to experimentation the real world context. Combining heterogeneous systems and remote human controllers is another important issue due to the implications on aspects such as engineering, use modes and training.

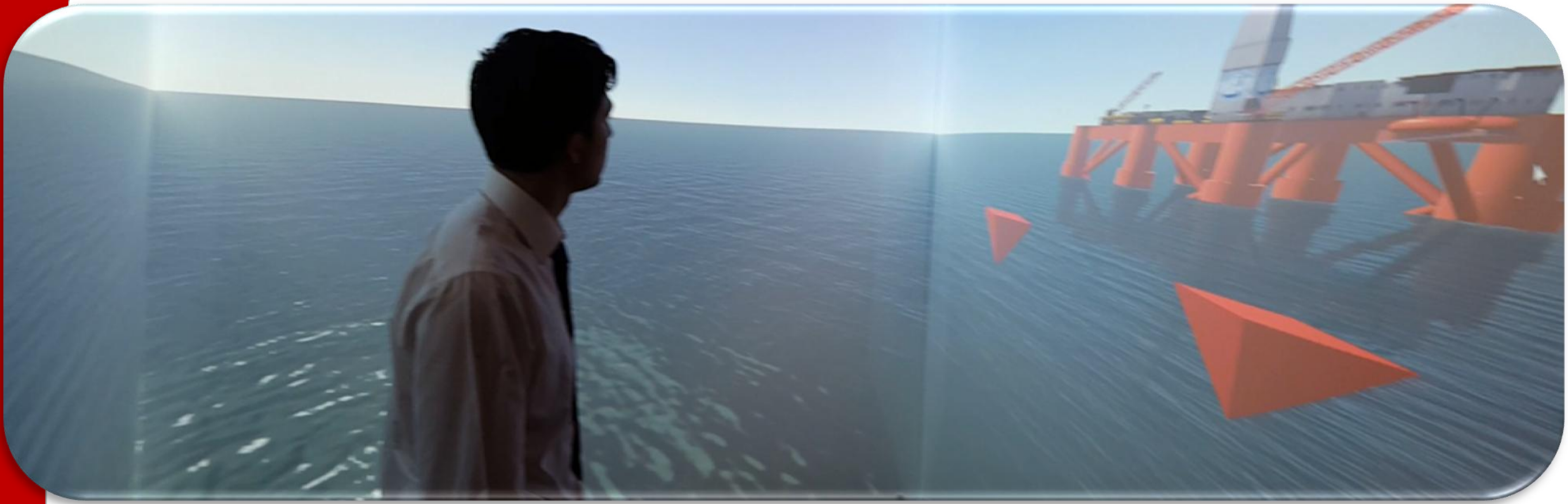




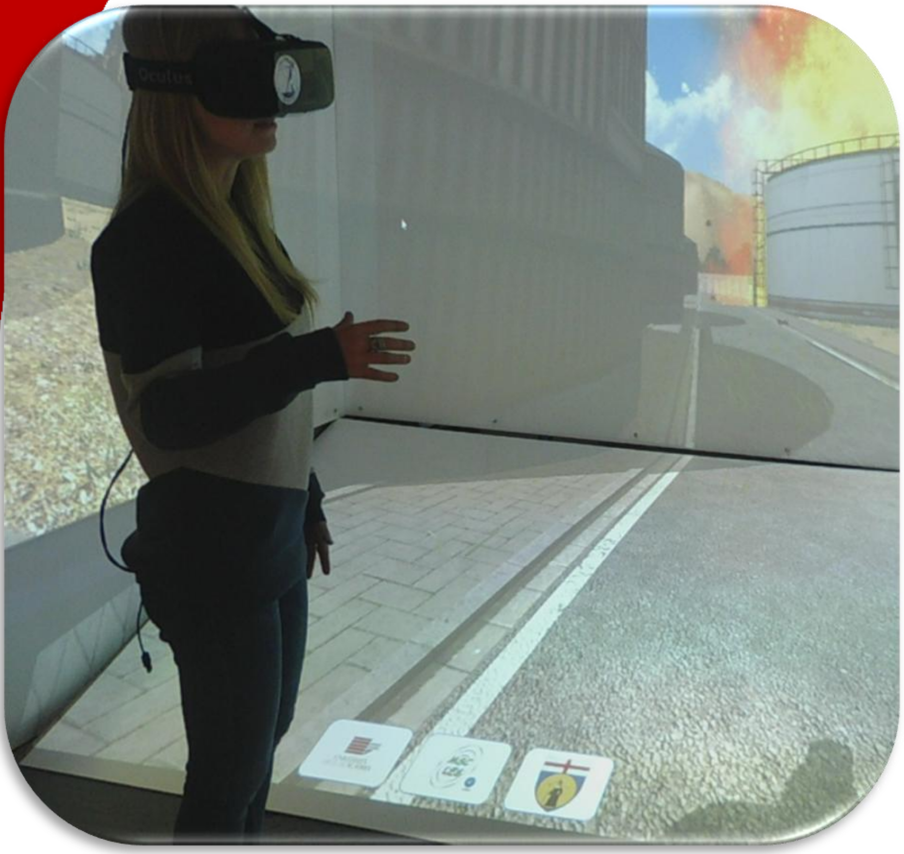


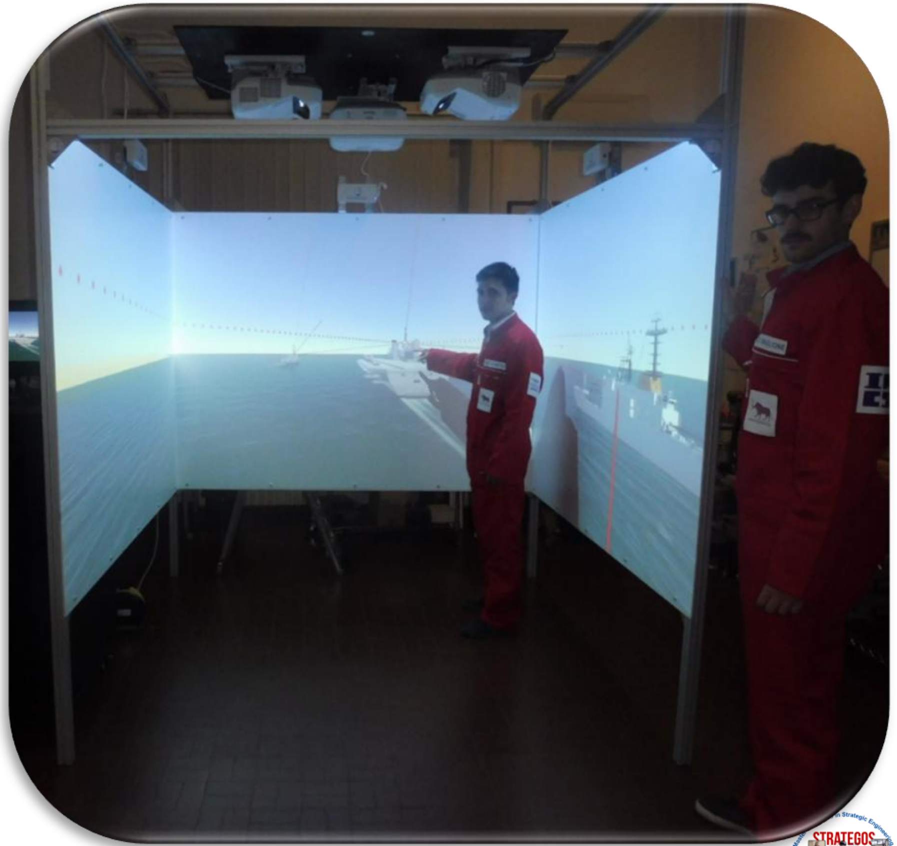
Investigation & Solutions by AI & Autonomous Systems

New generation of AI & Autonomous Systems are expected to bring strong benefits from their operational interoperability with other systems including legacy assets. The interoperability and standardization procedures need to be defined through experimentation in virtual environment. M&S addresses specific issues related to training in future scenarios, as well as on capability assessments.



Experiencing the Virtual World within an Immersive Collaborative Environment

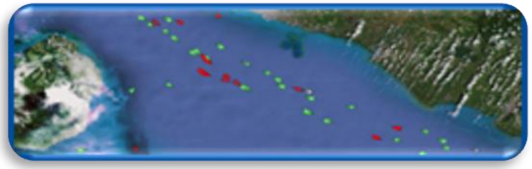




Human Modeling Challenges


- RATIONAL DECISION MAKING
  - Intelligent Individual Behavior
  - Organization & Hierarchies
- EMOTIONS & ATTRIBUTES
  - Psychology, Culture, Social
  - Crowd Behavior
  - Social Networks





Safety Assessment & Training as Needs and Opportunities

For Instance VISSAT (Virtual Security and Safety Assessment and Training) is an example of simulation federation that allows to Simulate Security and Safety Issues in Complex Framework such as that one related to Port Environments.

VISSAT combines Constructive Sim of organizations and layouts as well as Synthetic Environment for Virtual Sim supporting Distributed Cooperative Training among different Actors (i.e. Port Authority, Coast Guard, Custom Resources, Terminal Operators, Public Urban Authorities) within different Scenarios

Simulation Team

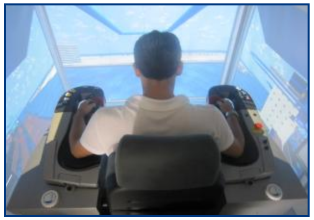
Modularity & Flexibility

Interoperable Virtual Simulators

The Simulators developed by Simulation Team are an important support in Training both Operative Resources and Decision Makers. The Interoperability of our simulators is based on state of art standards (i.e. HLA High Level Architecture) and emphasize in addition to traditional stand-alone training in Operating, even Concurrent Cooperative Training in Operations and Policies; Simulation Team collect long experience in Professional and Executive Training.

ST_VP: Virtual Port Simulation

The ST-VP is an example of fully integrated Simulation Framework and includes all the different crane types and New Solutions for Operator Training, Safety and Security, Procedure Definition, Equipment Design and Virtual Prototyping



ST-VP is fully containerized real-time distributed HLA Simulator reproducing Port Operations. ST-VP is integrated in a 40' High Cube Container ready to be used on site immediately after arrival.

ST-VP Simulator allows to operate all the different Port Cranes in a Virtual World by an immersive Cave (270 ° Horizontal and 150° Vertical), reproducing Sounds, Vibrations, Motion in all weather conditions

ST-VP includes a Full-Scope Simulation for Training Operations & Procedures, an Integrated Class Room, the Instructor Debriefing Room, and secondary Interoperable Simulators of all the Port Cranes and a Biomedical Module for Safety, Ergonomic and Posture Enhancement.

ST-VP World is customizable for each Port, Crane & Procedure and Equipment.

Simulation Team

CTSim

Serious Game for Ro-Ro Operations

CTSIM is a project developed by MSC-LES, Genoa Univ, CAL-TEK under the umbrella of Simulation Team. CTSIM can be used to train operators working in car terminals with particular attention to drivers, marshalls, quality checkers and tally men.

The architecture is based on interoperable simulation and makes use of dedicates external hardware (i.e. motion controllers, immersive headset, glove, wheel, pedals, etc) to provide users with the sensation in a real car terminals.

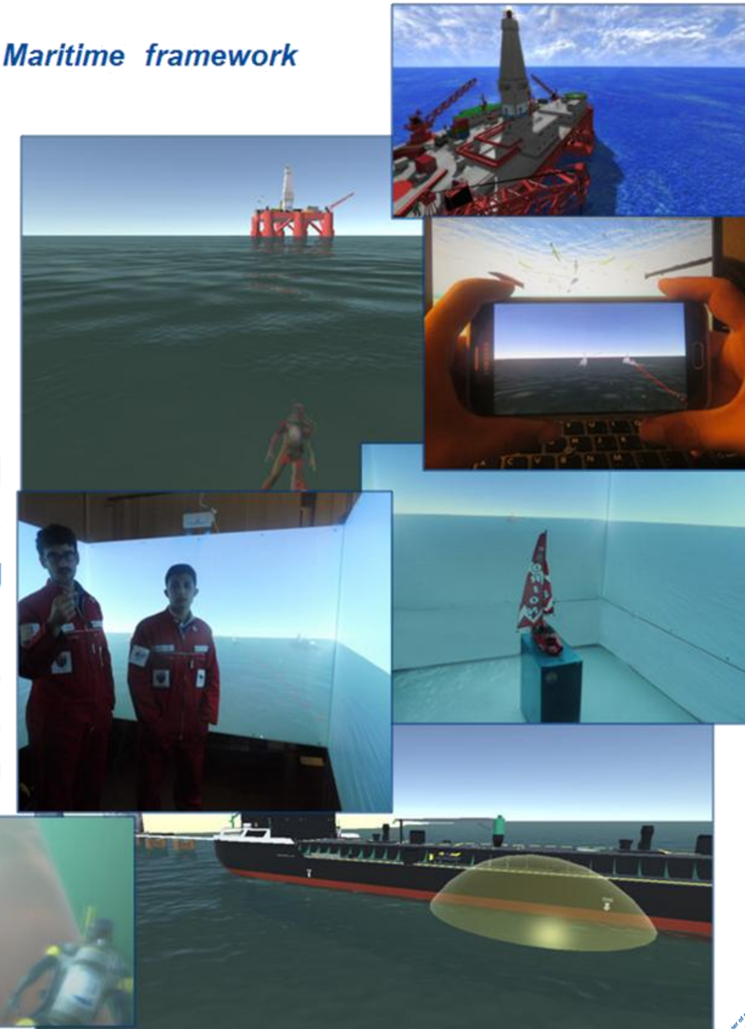
Multiple scenarios are available in terms of different terminal layouts (based on real existing terminals), multiple vehicles (i.e. cars, trucks, buses, etc.) and multiple types of available operators.

www.sim4future.com/cloud_1.html

Simulation Team

CRIPEM

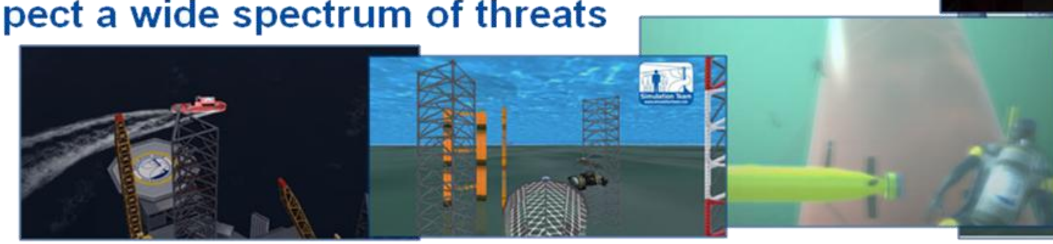
CRitical Infrastructure Protection in Extended Maritime framework



Oil Rig Protection (ORP) is a virtual MS2G (Model, interoperable simulator & Serious Game) reproducing operations devoted to protect critical infrastructure at sea from multi domain threats.

The simulator reproduces use of traditional assets as well as innovative autonomous systems in reference to different potential targets including ports, terminals and Oil Rigs.

The Simulator could be used for training, education as well as for capability assessment, vulnerability reduction and procedure definition respect a wide spectrum of threats

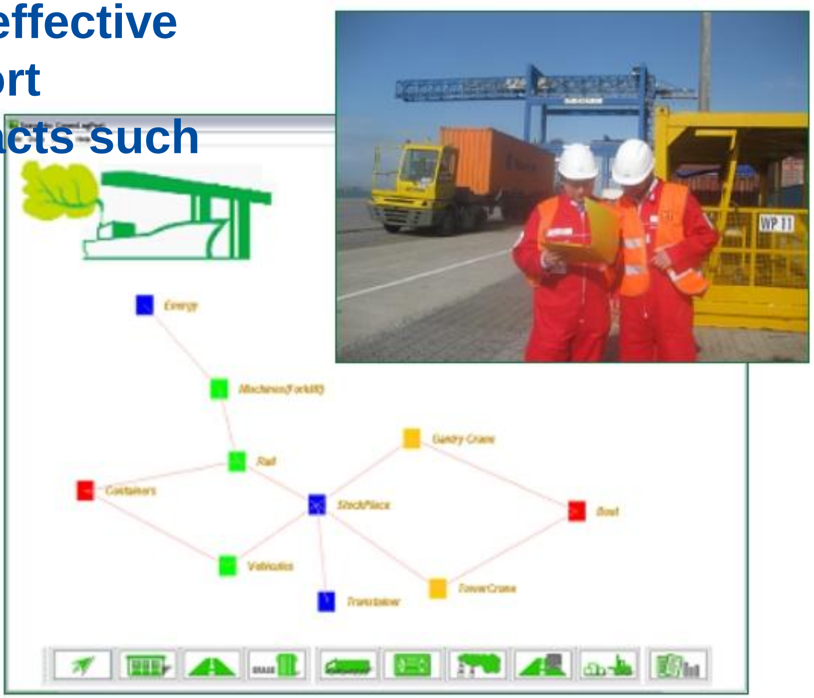


The Example of GREENLOG Port...

GreenLog Port Simulator

The analysis of Port Environment is strongly related to the possibility to develop effective Simulation Module devoted to support estimation of its Environmental Impacts such as

- Garbage & Port Waste
- Dredging
- Dust
- Noise
- Ship Air Emissions
- Air Quality
- Hazardous cargo
- Bunkering
- Port development
- Ship Discharge



Developed in Cooperation with Simulation Team & DIPTEM

MAST

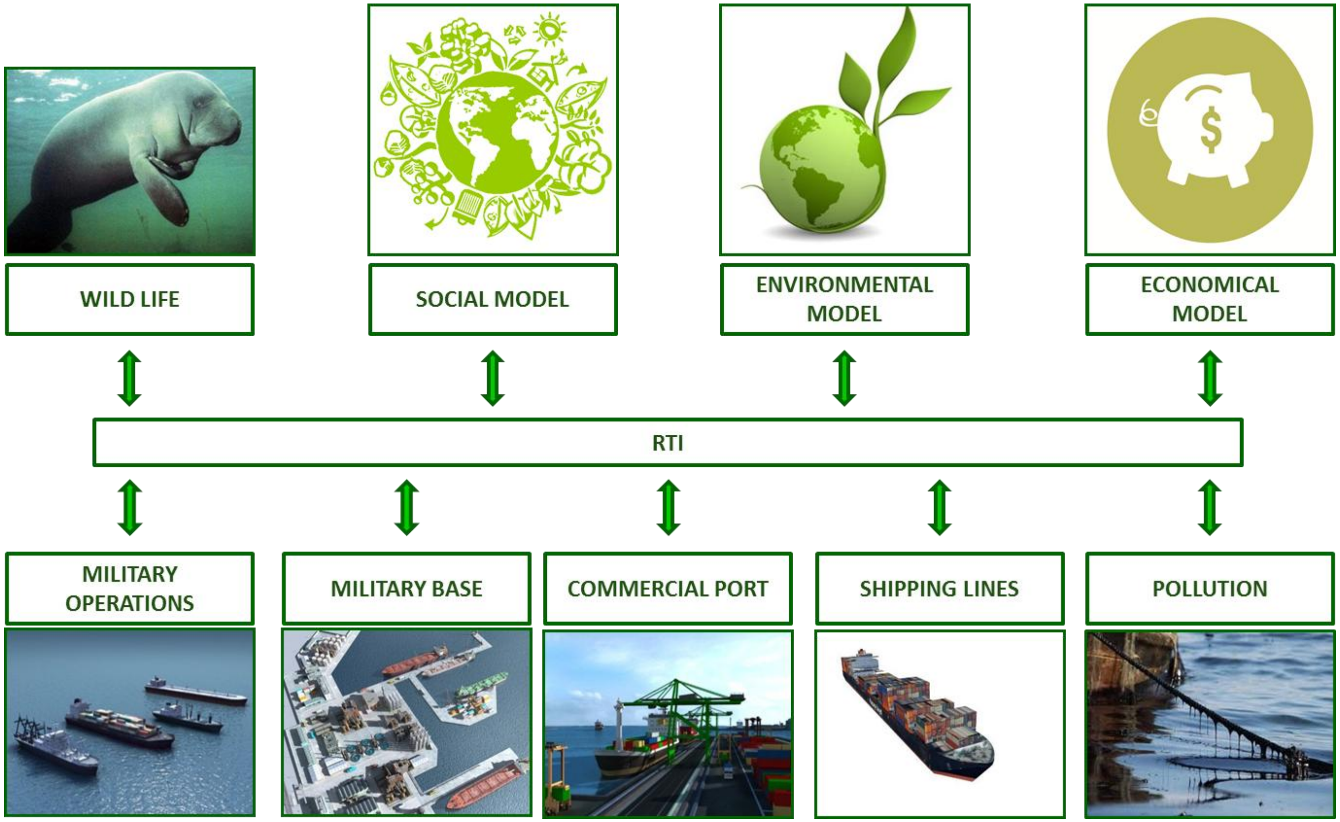
… and GREENLOG Ship

GreenLog Ship Simulator

GreenLog Ship is another example of specific Simulation Module devoted to analyze the Environmental Impact of the Ship for supporting monitoring, alternative evaluation, saving and benefits from different solution in use, handling, operating as well as in Ship Design GreenLog Ship Includes Air Emission, Consumption, Ship Paints, Garbage/Waste Disposal, Noise, Ship Discharges, Hazardous Cargo, Spills

Logistics, Economic, Social & Environmental Sustainability

Extract from Bruzzone A.G., Gough E. (2012) "M&S in Maritime Environment: Challenges and Opportunities", Invited Speech at I3M2012, Wien, September



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Summarizing

- The Ports and EMF (Extended Maritime Framework) are major Strategic Resources that require to develop solutions to reduce Vulnerabilities and improve Safety
- Direct Connection between Operators, Users, Players Scientists, Subject Matter Experts is a key enabler
- Marine Domain is fast evolving introducing new issues and new threats affecting more and more subjects that need Models to support decisions
- Simulation, AI and Cognitive Technologies are key issues for investigating Marine Domain respect new threats and supporting development of New Solutions
- It is fundamental to develop Trans-disciplinary Teams with strong common background on Marine Framework and to develop Networking with Excellence Centers
- The Comprehensive approach related to Marine it is a challenge that need deep scientific know-how in the different areas as well as interoperability capabilities and simulation experience

Proposed Solution

We propose the integration of new and legacy simulation as solutions for maritime security based on the innovative concept of MS2G (Modeling, interoperable simulation and Serious Games) and SaaS (Simulation as a Service). The examples carried out on Extended Maritime Framework confirmed the benefits of this approach. Currently several services and products have been completed and new ones are on going. Future developments involve the engagement of SME (Subject Matter Experts) in using our models for analyzing maritime security and port safety scenarios and identifying specific solution that should be adopted.

Strategic Engineering on these Subjects

The objective of these example is to demonstrate the potential for use of innovative Solutions able to identify, test and validate procedures for emergency management in the event of crises or significant accidents. The EMF cases were used as examples of available synergies between Safety and Security in hazardous material as well as in Sustainability within ports

It is evident that are many useful models to be used, paradigm to be adopted and general architectures: a Strategic Engineer should be able to choose best ones and to finalize the scenario modeling & critical issues to be solved

Fires in New York South Street Seaport

Explosion In Tianjin

Fire and Chemicals Leaks in Laem Chabang

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Summary & Questions

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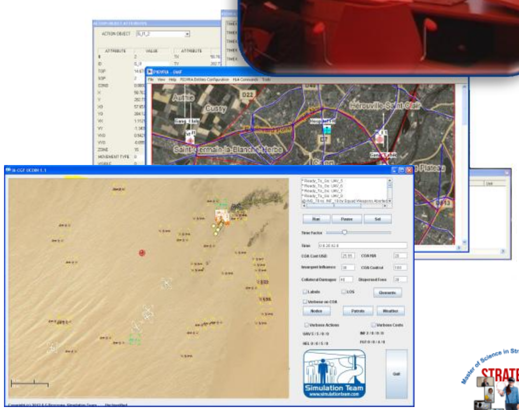

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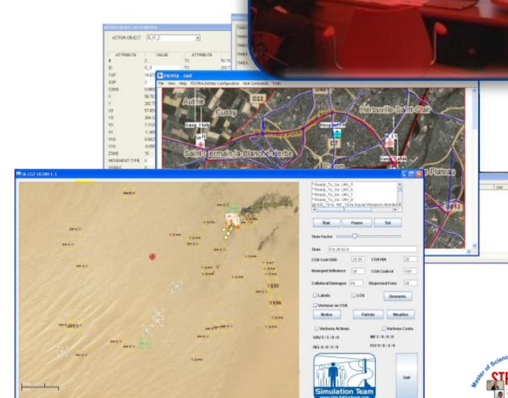

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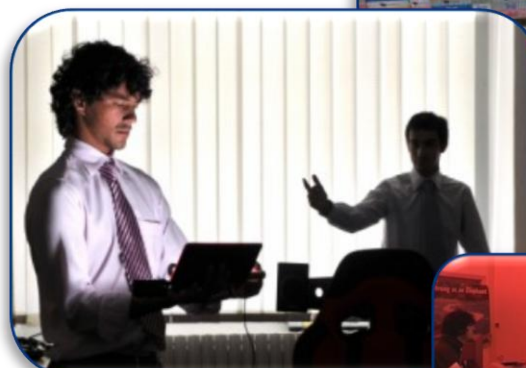

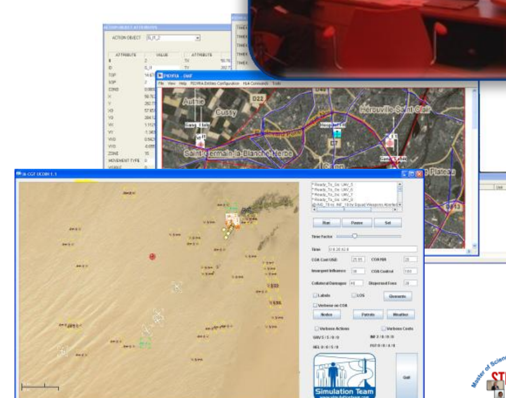


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References

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