

From General Systems Theory to Cyber-Physical System

The theory that is shaping our world ...

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Topic

1. Relevance & Motivation
2. The Origins of the idea
3. Real-Time Systems (Quest for Stability or Optimum State)

Motivation

Systems need to respond to externally generated stimuli within a finite-specified period (i.e. Real-Time)

1. Better Situation Awareness for Quick Response

- ▶ Producing time-critical accurate knowledge about the state of the system still remains a major challenge

2. Innovation in the Industry

- ▶ The knowledge is critical to the safety and the integrity of the operators and equipment

3. Economical Gain

- ▶ Industrial systems' capability to capture data (SCADA) and flexibility to adjust to changing system requirements

4. Existing Technological Capabilities

Origins of Systems Modelling

- Second Maxim of Descartes “*Discourse de la Methode*”
- To understand the *Whole* we must know both parts of the relations
- We are now used to breaking down problems – isolating them
- People have challenged the principles of isolating the components (especially starting in the 1940s)
- The “*How*” to integrate isolated systems is a major challenge for engineers!
- Simultaneous differential equations
- Continuous vs Discrete

Purpose

- To understand (i.e. be able to explain)
- To relate excitation with behaviour
- To predict (what happens?)
- To stabilise (Control)
- To optimise (Operational Research)

Why do you want to know about a system?

Attributes of Real-Time Data

- Created, Consumed, Collected by embedded systems
- Devices, Plants normally have embedded and SCADA systems
- Challenge is to make sense of it soon and take corrective action

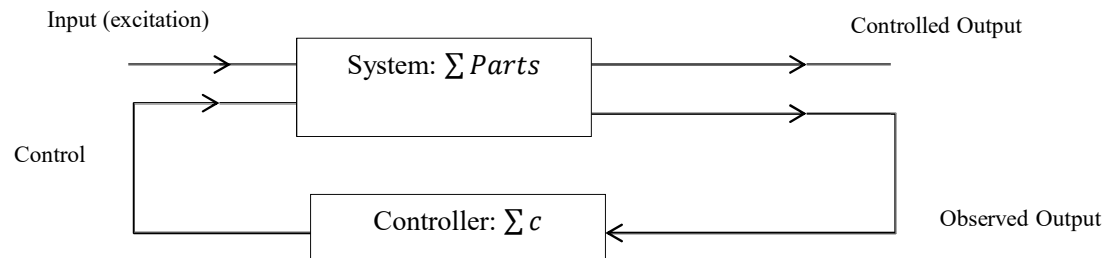
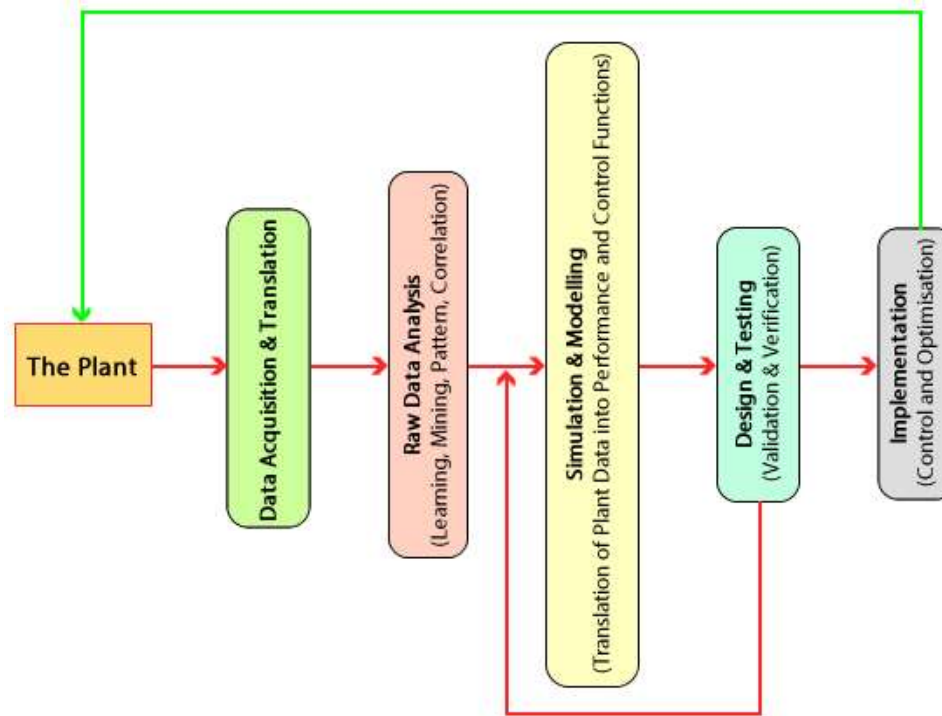


Fig 1

Engineering Project



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Fig 2

Engineering Project

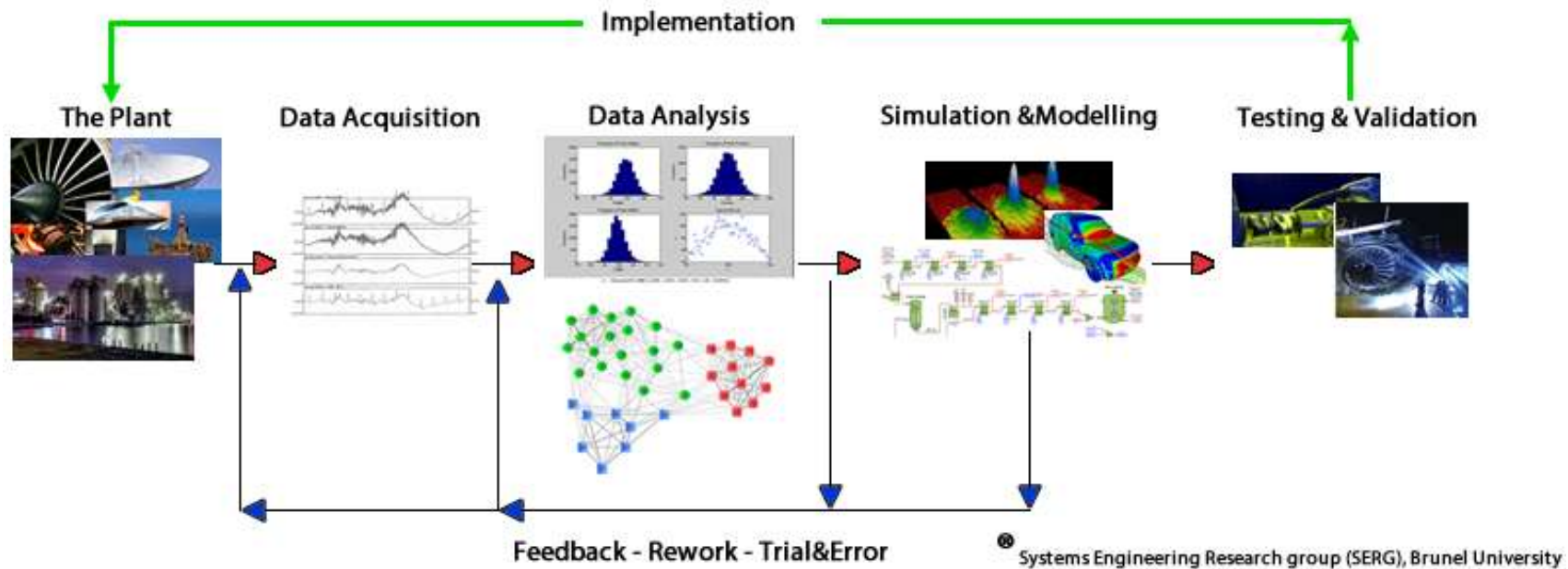


Fig 3

Integrating Engineering with Management

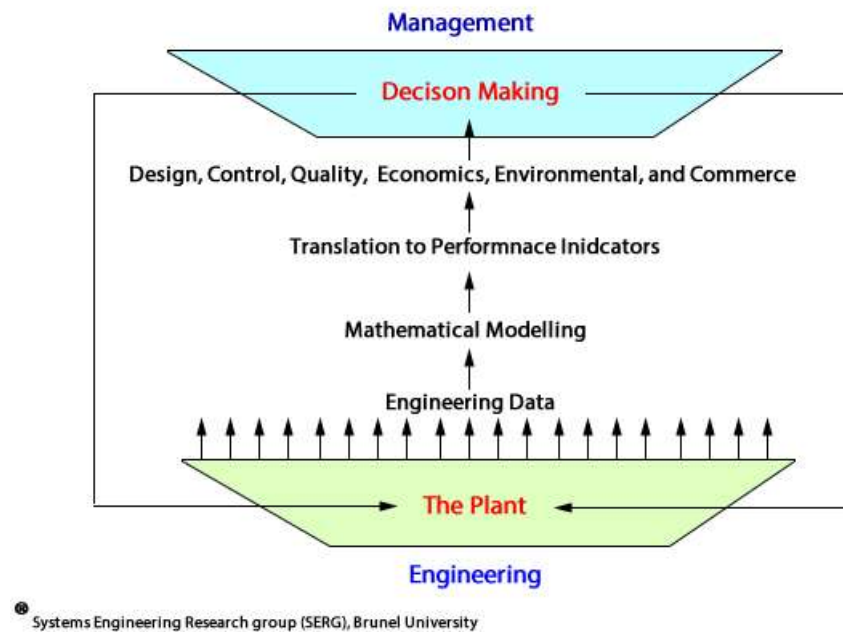


Fig 4

Key Questions

- Is the information we collect the best information for translating engineering data into performance indicators?
- Can we improve the quality/quantity of data efficiently and effectively?
- Can we reduce the cost of mistakes?
- Can we provide important information as soon as possible?
- Can we reduce the cost and time in translating data into control and optimisation rules?
- Can we reduce the reliance on Experts continuous interference?
- Can we improve the quality of predictive models?

Event Modeller in Cement Production

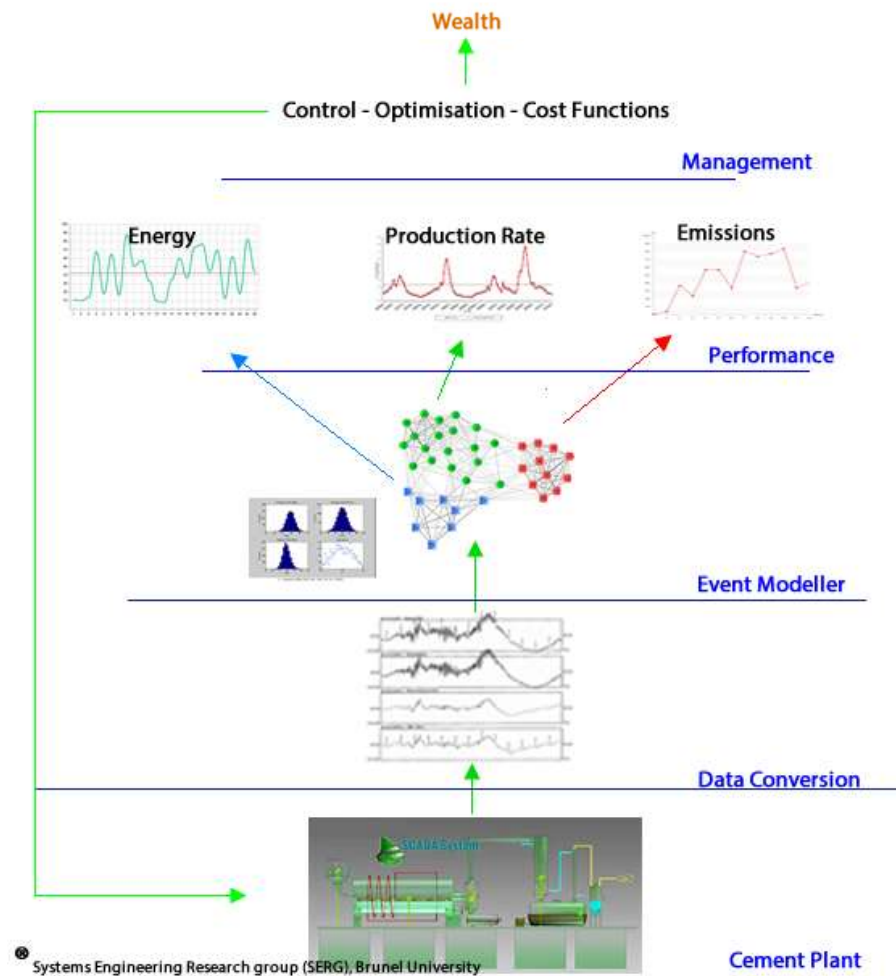


Fig 5

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Event Modeller in Manufacturing & Process

Management and Performance

Product Quality

Process Efficiency

Inventory/WIP

Environmental Impact

Data Engineering & Management

Event Modeller

Engineering

Data Acquisition, Controllers, Networks and IT Architecture



Example in High Performance Cars

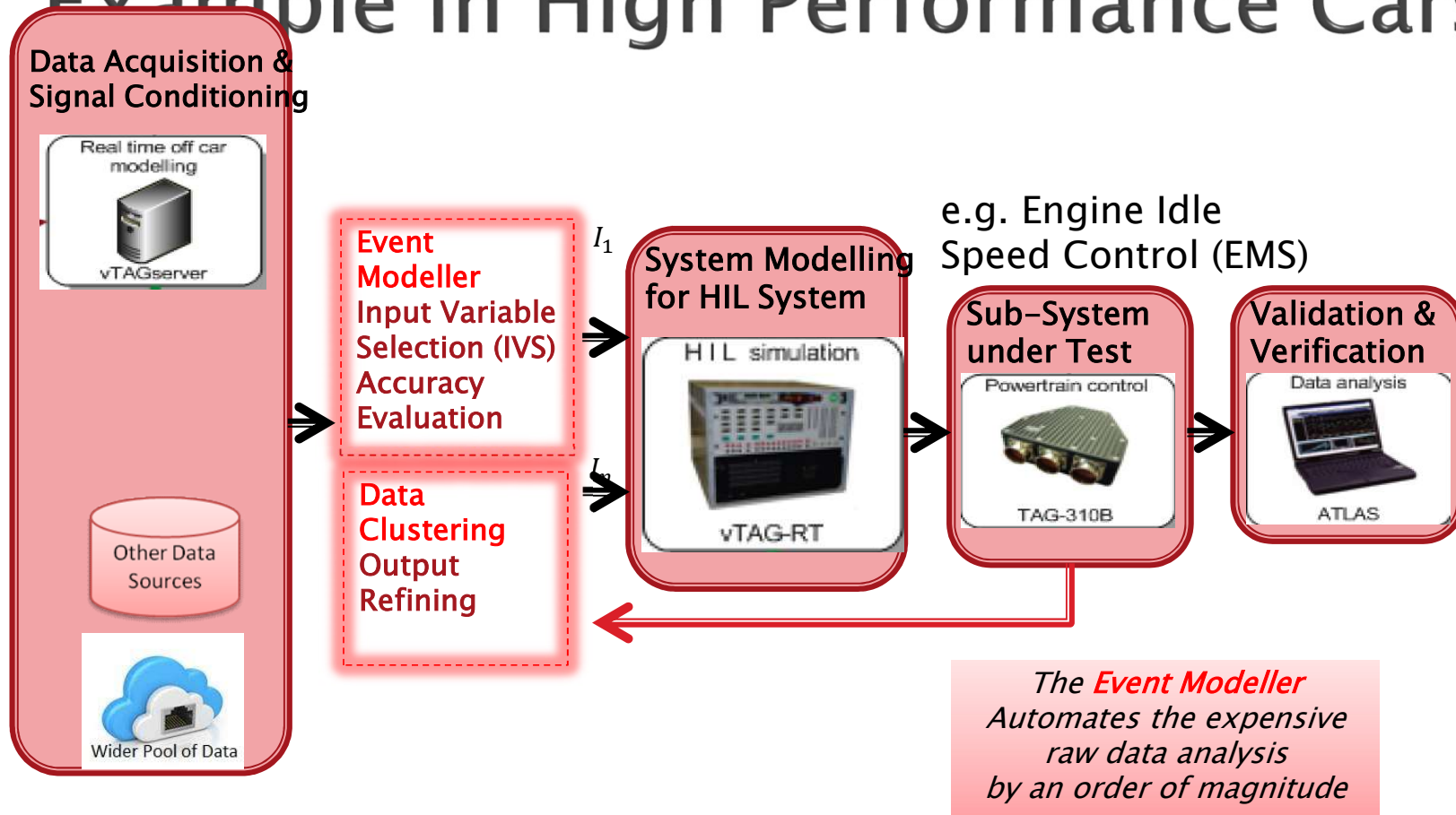


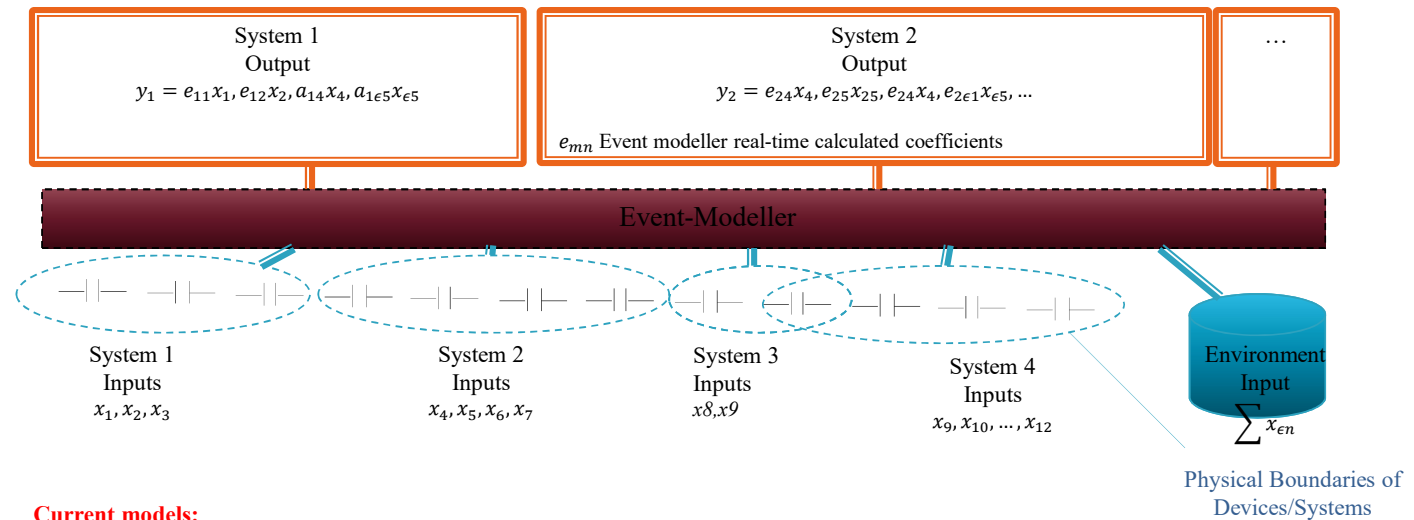
Fig 6

Event-Modelling (Mousavi et al 2013-14)

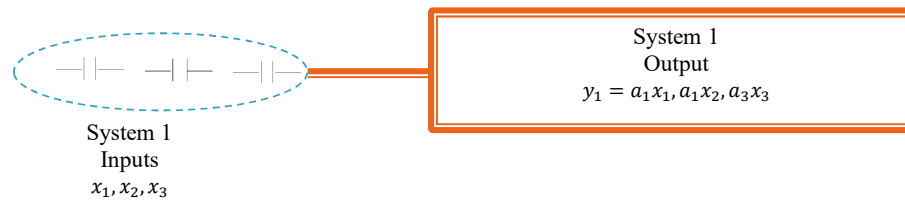
- The underpinning philosophy of the proposed technology is based on Decartes' philosophy of "*Discours de la Methode*",
- "*breakdown every problem into as many separate elements as possible*", and then reassemble it in the form of **eco-system of causality** of the smallest units.
- We also Borrow the concept of "*coincidentia oppositorum*" or the "*fight among parts*" from Cusa (1600 AD), and interpret the concept as the **causal interrelationships** of parts in the whole.
- In the language of engineering, how the excitation of the system driven by events and demonstrated by measurable inputs contribute/affect the behaviour, stability and safety of a system.
- Also Lorenzo's butterfly effect

Event-Modeller (tracker+cluster)

The Event-Modeller



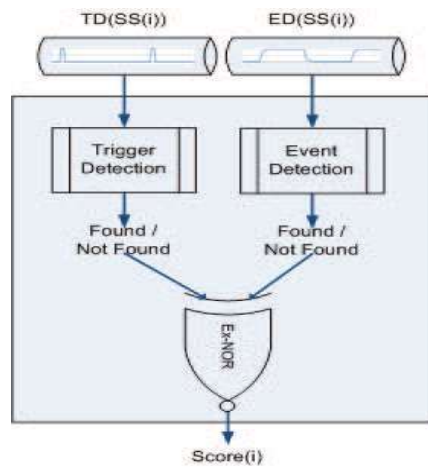
Current models:



a_n known or historically calculated coefficients

The algorithm

1: Stepwise Scan & TT detection



2: Two-way Matching

Input 1	Input 2	Output
0	0	+1
0	1	-1
1	0	-1
1	1	+1

3: Summation of two-way matching (Sensitivity Index at time t)

$$SI_{(t)} = \sum_{1}^{n} \text{Search Slot Scores}$$

Where n is number of Search Slot in an Analysis Span

Algorithm continued

4. Normalisation:

$$\tilde{S} = \frac{SI - l}{u - l}$$

Upper Bound

Lower Bound

Sensitivity index

The diagram shows the formula $\tilde{S} = \frac{SI - l}{u - l}$ with three labels and arrows pointing to the corresponding parts of the formula: 'Upper Bound' points to the denominator $u - l$, 'Lower Bound' points to the lower bound l in the numerator, and 'Sensitivity index' points to the numerator $SI - l$.

An example for 10 search slot, 1 event and 3 sensors

1. Detected Events

2. Two-Way Matching Scores

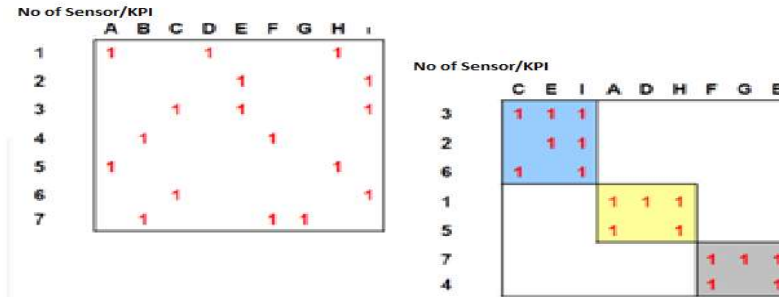
Search Slot	0	1	2	3	4	5	6	7	8	9	10
ED	*	*		*		*	*	*		*	*
TD1			*			*			*	*	*
S1	-1	-1	-1	-1	1	1	-1	-1	-1	1	1
SI1	-1	-2	-3	-4	-3	-2	-3	-4	-5	-4	-3
SIn1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TD2	*				*	*	*	*		*	
S2	1	-1	1	-1	-1	1	1	1	1	1	-1
SI2	1	0	1	0	-1	0	1	2	3	4	3
SIn2	1.00	1.00	1.00	0.67	0.33	0.33	0.67	0.75	0.80	0.80	0.75
TD3		*		*		*		*		*	
S3	-1	1	1	1	1	1	-1	1	1	1	-1
SI3	-1	0	1	2	3	4	3	4	5	6	5
SIn3	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

ED is most sensitive to TD3 and shows no sensitivity to TD1

3. Summation of two-way matches

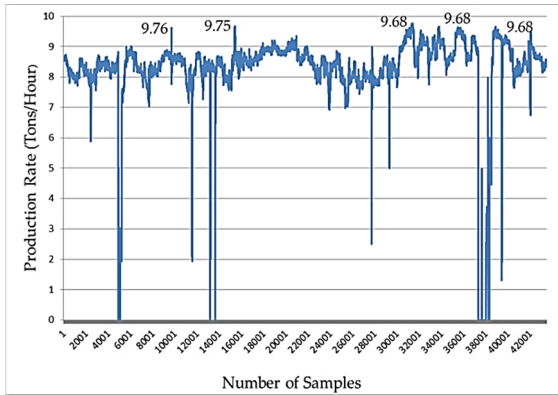
4. Normalised sensitivity index

Event Cluster



- Group and linking a set of inputs to any given output
- Tests with 200 sensors and 2 Key performance indicators in Cement
(energy & production output)
- 43000 real-time samples over 30 days
- Grouped all the relevant inputs to the 2 outputs.

EventiC sample results on Factory Data



Input Name	Sensitivity Level of Plant Production Rate	Subjective Importance Level
Kiln temperature	92%	High
CO output	93%	High
I/h return in Kiln	57%	Moderate
Kiln fan	98%	High
CO ₂ output	97%	High
Motors pulls material from kiln	92%	High
Injected O ₂ to Kiln	37%	Low
Injected NO _x to Kiln	54%	Moderate
Injected SO ₂ to kiln	36%	Low

	Kiln Production Rate (Tons /Hour)	Kiln Temperature (degree Celsius)	CO output (mg /m ³)	Kiln fan (on/off)	CO ₂ output (%)	Motors pulls material from Kiln(on/off)
Solution 1: Minimum Kiln Temperature	9.76	1274	374.05	1	15.47	1
	9.75	1355	370.86	1	15.50	1
Solution 2: Minimum CO ₂ emission	9.68	1368.37	365.34	1	14.52	1
	9.68	1369.65	371.15	1	15.55	1
	9.68	1371.7	369.05	1	15.47	1

	Kiln Production Rate (Tons /Hour)	Kiln Temperature (degree Celsius)	CO output (mg /m ³)	Kiln fan (on/off)	CO ₂ output (%)	Motors pulls material from Kiln(on/off)
Solution 1: Minimum Kiln temperature	8.10	1283.3	383.28	1	0.037	1
	8.57	1371.37	389.68	1	0.037	1
	8.09	1283.7	383.4	1	0.037	1
Solution 2: Max Kiln Production rate	9.34	1395.7	379	1	0.037	1
	9.27	1315	357.5	1	0.055	1

Potentials

- Use the technique to improve control transfer models and character equations
- Use the technique to deal with *Known-Unknowns* and potentially the *Unknown-Unknowns!*
- Technically and in real-time (**Engineering and Not Mathematically**) use the I/O relations to stabilise the system
- Optimise process by identifying the best process points and then adjusting the inputs to reach the desired output.
- Intelligent-Autonomous Control for Complex Systems

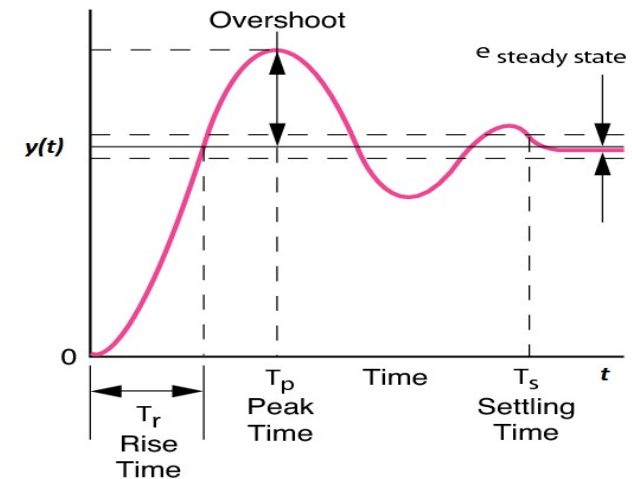
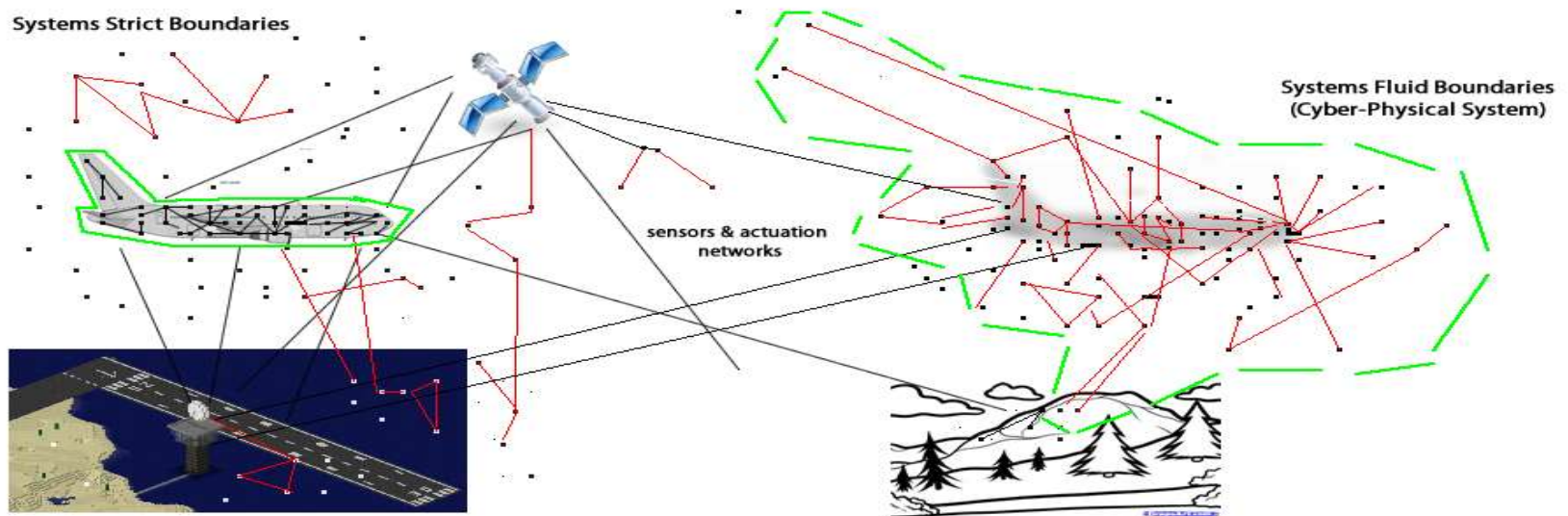


Fig 7

Applications

- ▶ Aerospace Industry
- ▶ Automotive
- ▶ Smart Control (Buildings/Facilities)
- ▶ Process Control (Manufacturing)*
- ▶ Deep Drilling Industry*

Imagine



- In this **new concept** systems will lose their *known boundaries*,
- Their boundaries becomes *fluid* depending on their state space and their physical position.

EventTracker and EventiC in Aerospace and Aviation

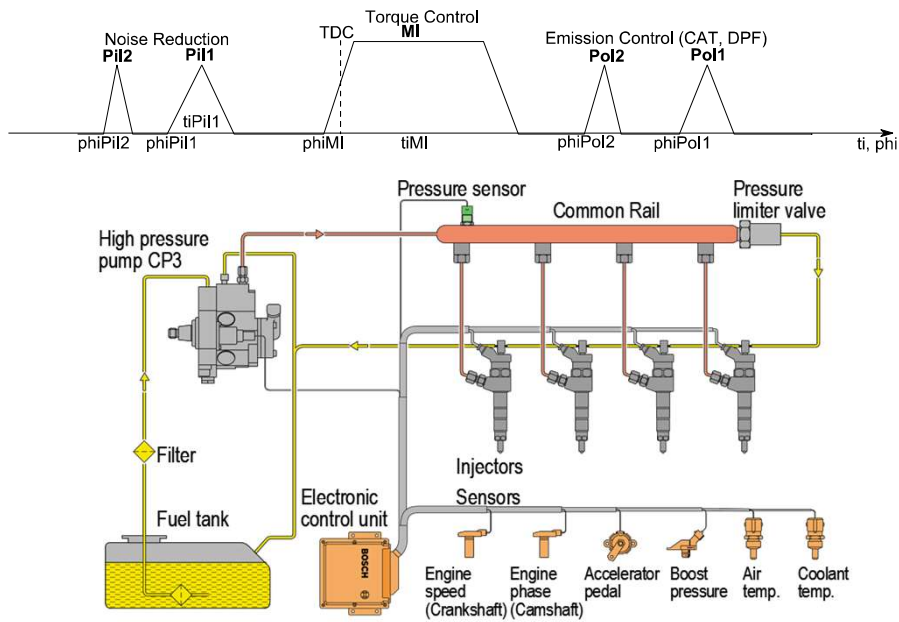


- Flight Tracking
- Digital Avionics
- Increased data acquisition parameters and sampling rates
- Additional sensors, switches, digital data
- Airborne event detection and reporting (ACARS/Datalink)
- Transcription of raw flight data into engineering values
- Comparison between recorded flight data and flight profile
- **Accurate Prognostics and Preventive Management**

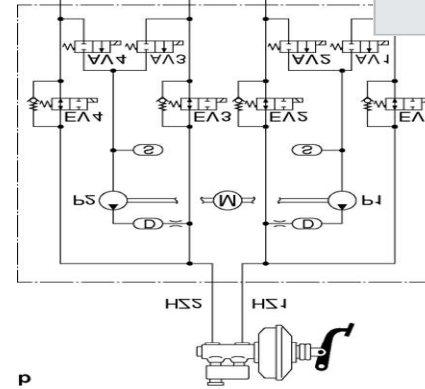
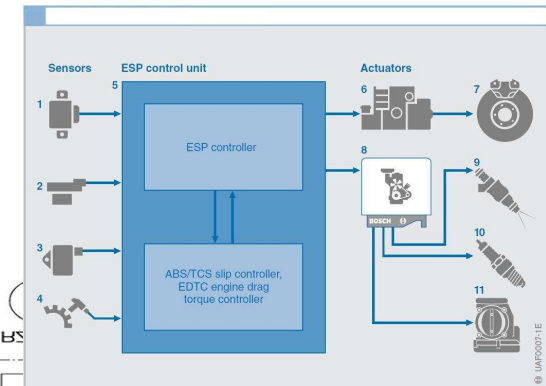
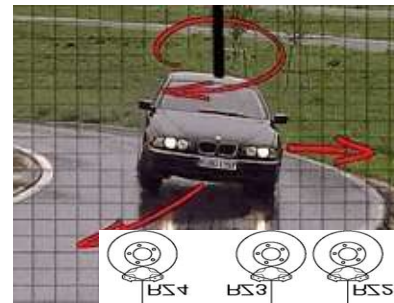
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Event Modeller in Automotive

Engine Management

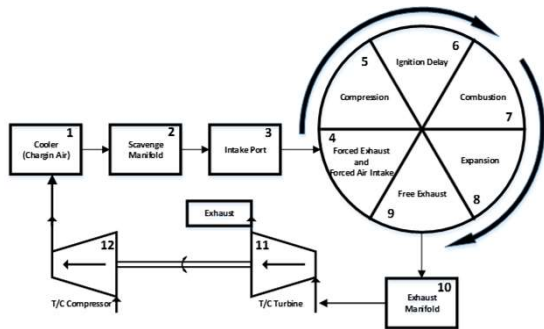


Electronic Stability Program

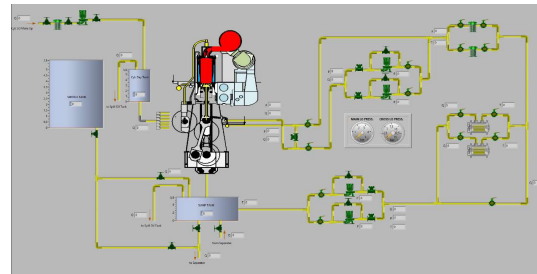


Event Modelling in Marine Industry:

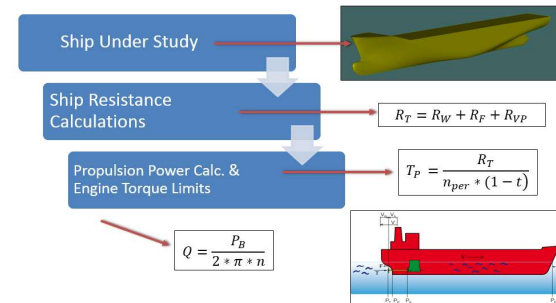
Event Based Analysis and Prognostic Algorithms for Use in the Autonomous Control of Unattended Engine Rooms



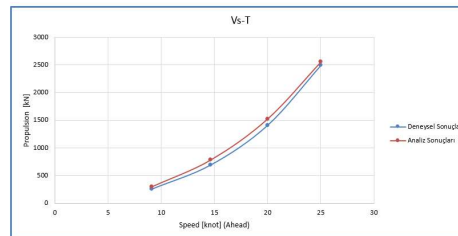
Ship Engine



Oil Distribution System Simulator



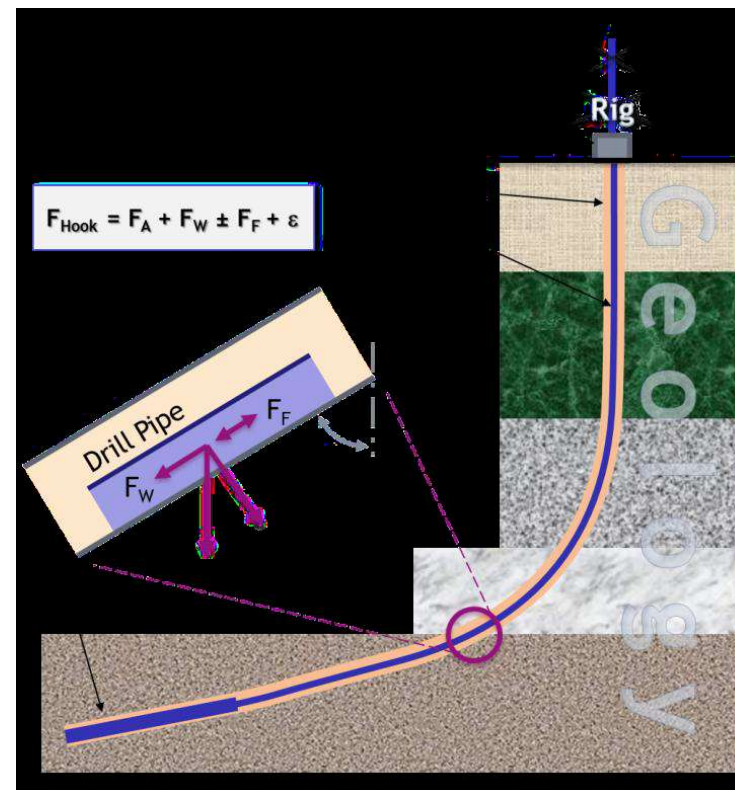
Modeling the Propeller for the Simulator



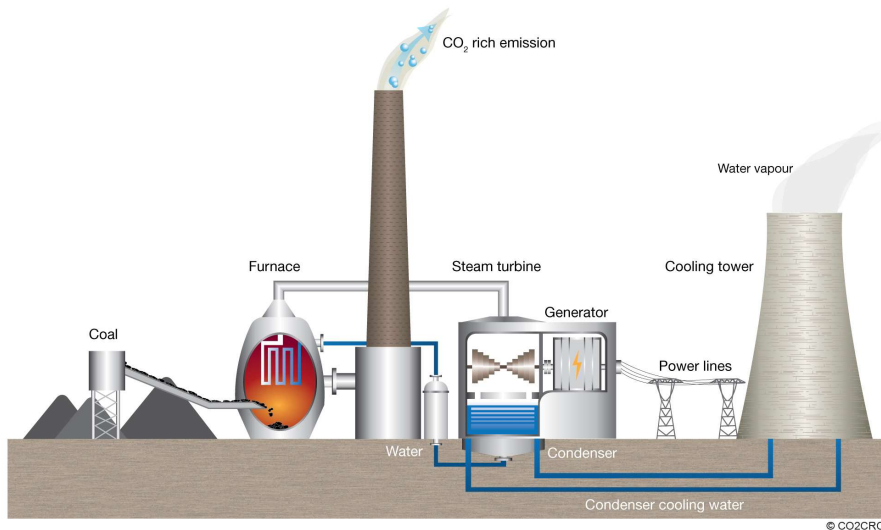
Ship Engine

Event Tracker in Deep Drilling

- 100 Variables input time series
- 10 Sensors
- 6 Systems States
- 100 *msec* Triggers



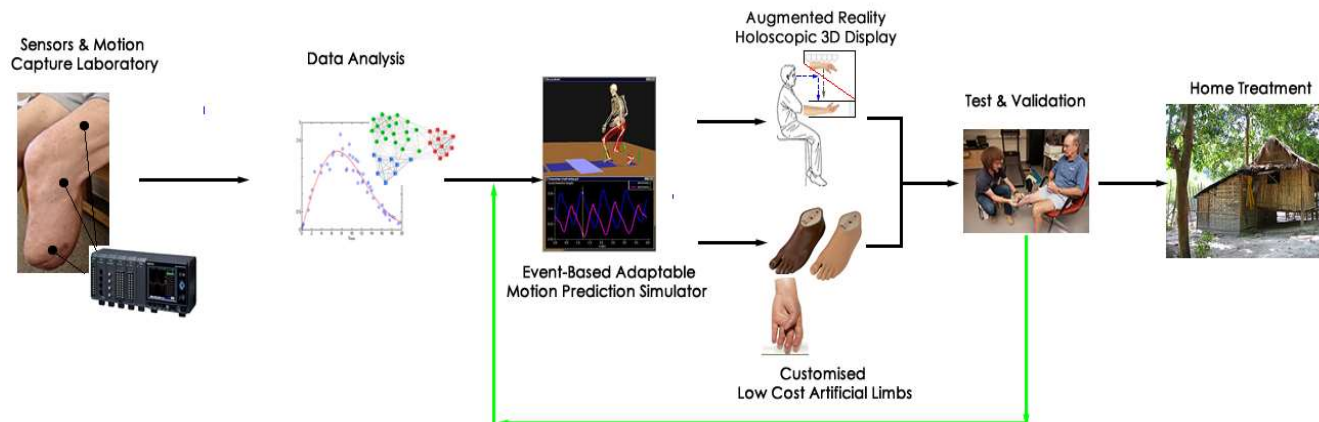
Event Modeller in Electric Power Generation & Distribution



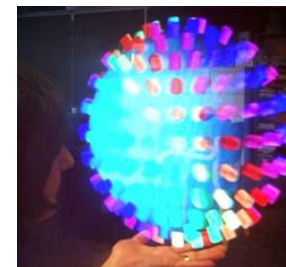
- Power Plant in Malaysia
- Issues with Harmonic Filter Burns
- Overall improvement in Power Generation
- Power Distribution
- Reduction in Environmental Impact

Phantom Limb Pain

A Highly Customisable Home-Based and Affordable Technology for Phantom Limb Pain
[Project Life Cycle]



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Our Group

- Over 30 years of Applied Control and Systems Modelling & Simulation
- 20 years of research in Manufacturing Industry
- 12 years Automotive Industry
- 10 Years experience in ECU development with specialty in Engine, ESP, and ABS with ECU's.
- Event Modeller's key contribution is that it increases accuracy and reduces analytical & computational overheads