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Enterprise Architecture to fight the 2nd law of Thermodynamics

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KEY WORDS

Entropy, Negentropy, Chaos, Complexity, Systemics, Cybernetics, Energy, Information, Enterprise Architecture, Intelligence, Ignorance, Convergence, Sustainable evolution, ISA88, ISA95, PRM, Zachmann

ABSTRACT

As any system the enterprise is subject to natural degeneration, aging. This may take different forms such as the tendency to privilege short-term benefits at the cost of the long term survival or the decrease of its differentiation and relevance in the marketplace. These are symptoms of degenerating intelligence and failing organization that scientists call Entropy. Ongoing ordering and learning is the cure to slow-down or counter the lethal destiny. As an open, complex system, an enterprise is capable of outpacing the pain and can actually improve: sustaining or increasing its relevance, hence its profits despite the low-income countries competition while assuming its social responsibility. Information is the key enabler in this process by raising the ordering of the system, actually decreasing its entropy. We call this phenomenon "intelligence" (economic, business, or manufacturing) to summarize ongoing development, adaptation, optimization of its main assets including human resources / organization, physical facilities,

product / process knowledge, market intuition, and business practices in line with an agile, actionable and sustainable strategy orientation.

This affects the tactical and operational implementation of the strategy thanks to the symbiosis of the information dimension within the system that it represents and reorganizes continuously. “Business / IT Convergence” and “Enterprise Architectures” are today’s buzzwords to designate this vision and the efforts to accomplish it.

Industrial enterprises must confront specific challenges regarding their manufacturing subsystem. The physical nature of their value creation processes does not naturally align with the virtual essence of information processing, while Information Technology (IT) investments hardly generate objective short-term income.

This paper discusses the enterprise and its information aspects through the lens of basic physical sciences to highlight the need for Enterprises to rethink their way of managing the life cycle of their manufacturing system and IT supporting artifacts in order to leverage, optimize and adapt their physical and knowledge assets to best and sustainably perform economically, socially and environmentally.

An integrated ISA88 and ISA95 framework is presented as a pragmatic modeling guide to implement an IT/manufacturing convergent subsystem within a global architecture enabling syntropic Enterprise intelligence and sustainable progress.

PAPER

1 Introduction

1.1 Information in Industrial Enterprise

Overwhelmed by information, we just seem to discover its primary importance. However, diverted – sometimes addicted - by the technology that supports it, we sometimes fail to figure out what information is really about.

Information tends to be centrally discussed around computer related topics, and the term “Information System” emerged to designate a dedicated entity that deals specifically with electronic information. This Information System, commonly perceived as a bunch of computers, data storage, networks, and software, is supposed to interact with and to support another system (an enterprise, a production facility) and its biological actors.

As a result, IT departments, though well aware of their dependencies with other Enterprise's entities, have positioned themselves as a secondary Enterprise gravity centre that aims at fulfilling a commodity purpose by building and managing the enterprise IT asset as a whole, namely the “Information System”.

This split between the Enterprise itself and its information dimension leads to undesirable effects such as the chronic inadequacy of IT resources and investments in industry either underestimating or exaggerating potential benefits[1]. Other examples are the additional burden and rigidities that sometimes come with over-ambitious IT projects, leading to major project failures.

1.2 Relative importance of IT in Enterprises

For some business sectors, IT is a production asset, a critical money making machine: Services, Banking, Insurance, Information providers, and Online Trade adopt an engineering approach to their IT assets to build and maintain an Information Production System. They expect, and obtain an objective and documented financial reward for their IT investment.

Industry generates money by manufacturing and selling physical goods. It invests in plants and machines that transform simpler, low-order materials into more sophisticated, high-order materials. IT is a commodity that is more considered an operating expense rather than an investment. It struggles to justify these expenses by subjective feelings, assumptions and hopes. This is particularly true for the “blue part” of the enterprise: the “white part” can more easily trigger appropriate IT investment for supporting money–close business processes (though...). Automation was acclaimed when it reduced the expensive and capricious biological workforce in the factories; however, the steps beyond are questioned.

1.3 Sustainable development and environment

Industry is a major component in the world eco-system. Their economic and physical roles determine a large part of the social and energy equilibriums. Since a decade or so, we observe a clear move of the enterprises to care about their “social responsibility”. Their may be motivated by their marketing image, compliance to regulation, long range vision and –why not? – humanitarian concern. This move drives the emerging need for enterprises to control and optimize their social, environmental and economical footprint.

1.4 Enterprise as a scientific subject

Enterprise is a scientific subject that is largely studied from various perspectives (technology, sociology, economics, physics...). Many studies do not pass the stage of valid philosophies to applied science, while many “intuitive”, common sense approaches are successful (Lean, 6 Sigma, TOC)

Most often, enterprises follow their way of survival through market law, short term shareholders’ and bankers' tyranny, social and environmental constraints thanks to genial managerial intuitions. That effectively works because of the Complex nature of the Enterprise system as we'll see it. However, competition and growing constraints are better addressed by smarter enterprises, those who understand themselves better and shape them to achieving a higher level of self organization and ability to adapt and progress. This “spiritual” behavior prevents them to shrink and die and makes them improving and performing on the long run by inverting their entropic fate while containing the resulting increase of the World entropy.

This paper presents some relevant physics principles that can help enterprises to satisfy short term reasonable and consistent performance objectives, while achieving a long term sustainable evolution and performance goal. These principles all converge to Information.

2 Physics for Enterprise

2.1 Chaos

The Chaos theory recognizes that some entities and situations can simply not be described by traditional spatiotemporal equations. If you want to measure the length of the French Brittany shores, the result will depend of the measurement increment you chose…. Looking at a map, with a scale where 1 cm represents 10Km you would find about 400 Km. Official “most accurate” estimates give 1772 to 2730 Km… This is an illustration of Mandelbrot’s fractals, the expression of “Chaos in Space” where a shape does not become simpler when you analyze it in smaller parts.

The second aspect of Chaos is illustrated by the Lorentz’s “Butterfly effect”, or sensitivity to initial conditions (a butterfly flapping its wings in Tahiti causes a tornado to occur in Miami). More realistically, a fancy trader hitting a key on his laptop can trigger billions of wealth or bankruptcies, illustrating the “Chaos in Time”…

As most complex, open systems, an enterprise is somewhat chaotic. All those who have some experience on finite capacity scheduling know very well what that means. Murphy's Law is a non-demonstrated avatar of Chaos.

2.2 Complexity

Complexity seems a fuzzy concept. My last physics teacher used to say “That’s easy… when you know!” Complexity seems a relative attribute: something is complex for ignorant, simple for scholar. Complexity in system theory is not taken in the sense of “complicated”, hard to understand, it is rather about “sophistication”.

“*A complex system is 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*” (en.Wikipedia)

Here we are. A human body is a complex system because some of its properties come from the collaboration of its components. Cut one leg, he will not walk anymore; the cut leg will not make it by its own. An enterprise is a complex system because its components collaborate and interact to generate an intended outcome. A single machine cannot do anything if it is not powered up, properly instructed and purposely activated. The organization of employee roles and their orchestration contribute to fulfill the enterprise goal. Complex system’s properties can be summarized as follow:

- It contains many components that interact nonlinearly. Having many components is not enough. A glass of water has many molecules, but it is not a complex.
- Complex systems have chaotic aspects: the same event in the same conditions does not necessarily lead to the same outcome. Beside Murphy’s Law, unpredictable events can be also seen as opportunities for the system to become smarter and more robust.
- Its components are nested to different scales, at every scale there is a structure. A factory can be layered into area, work centre, work unit, equipment modules, control modules, devices and parts.
- It is capable of emerging properties / behavior. Analyzing each component individually gives no clue about the actual capabilities of the whole system. A set of properly driven machines and associated knowledge can elaborate products that a single isolated machine could never achieve.
- Higher levels of complexity lead to self-organization that allows a system to change its configuration to address new situations. After the leg is cut, the human being recovers the walking function by adapting itself to its new structure, possibly acquiring a replacement wood leg. The enterprise is ever evolving to make new products and to adapt to internal or external changes. At the ultimate level, the system is self-reproducing. Not able to sustain itself for ever, it dies after starting a new life with fresh components, paving the way to Evolution.
- It involves cooperation and competition outside and within the system itself. Competition at the highest level of the structural hierarchy is supported by cooperation at the lower levels.

2.3 Entropy

Energy has many different forms: Chemical, Electrical, Radiant, Nuclear, Magnetic, Elastic, Acoustic, Gravitational… The 19th century scientists discovered the Thermodynamics “laws” relating to energy. The first law is easy to grasp: the total energy does not change with time. The second law is a little bit puzzling: if a system is isolated (no communication / interaction, so no energy exchange with the outside world), then its entropy keeps increasing. This means that one part of the energy becomes unusable, making the change irreversible - the perpetual movement is impossible. Time is often defined as the direction of entropy, one of the rare laws of physics that is sensible to “the arrow of Time”

The second law of thermodynamics pointed out a fundamental behavior of the nature. Another expression is: “A closed system evolves continuously toward a less ordered state”. A closed system is unable to order itself without an external help, it will always mess things up. Let your kid in a room with many toys, things and food, and observe how things go on... No kids? Don’t remember? Look at your office's desk. At the equilibrium, the entropy is maximal, it doesn’t increase anymore: the mess is absolute, you can guess nothing about the initial conditions, and how the situation showed up, where the things were before the mess occurred.

From deterministic simple situations that we can describe totally, to the total mess that let no clue for understanding, another word came to designate entropy, it is Ignorance. Measuring the mess, the entropy also expresses our inability to understand a situation, our ignorance, and lack of information… because we are part of the system.

Chaotic aspects of a system are the ones we can not extensively comprehend or measure. When we are trying to describe a system, we use approximation as we did for the French Brittany shores. The most we approximate, the most we create entropy: The actual, complex nature of the system is rounded in a way we can deal with it. This approximation simplifies the system representation: the difference between the real nature of the system and its representation is entropy… The more we know a system, the less its entropy.

Entropy hit also open systems. However, these systems can invoke external help to sort their disorder. Let the mother intervene in the kid's room entropic fate, the order will resume. One musician pretends that his music decreases the body’s entropy (makes you aging slower!) because the music ordering information tidies up molecules in cells…

2.4 Information physics

Information is intimately intricate within physics. First of all, Information is the ultimate science that we use to discuss and think. Physics and all other sciences derive from information. In Whitescarver’s Science 2.0 Principles, “*Nature is a Machine that can be understood as an information system: … An information system is a machine which has no dimensional or other constraints. Any machine can be modeled as an information system. The universe is in the countable set of information systems so far as it can be understood. An information system from which experience projected represents the machinery of the universe from one or more perspectives. The information system is the analog of the machine which may or may not represent the actual machinery of the universe*” [2]

At the very bottom of the microcosm, information plays such a leading role that some scientists dare to think that information could be the primary material of the universe (so we would be ghosts in a virtual – information made – universe). This assumption also led to an interesting interpretation of the notion of time. Beyond the Newtonian fundamental quantity that Time represents, it seems nowadays more exactly a fundamental intellectual structure necessary for human brains (and computers), not a part of the “real” world itself. Alexei Grinbaum puts Time = Ignorance, which makes sense when we consider that fast, “intelligent” computers need less time than slow, “dumb” computers and that God knows everything but time. So we have

- Time = Ignorance,
- Entropy = Ignorance,

⇨ Entropy = Time (it is the Arrow of Time, isn’t it?)

As seen before, Time and Entropy are both subjective thinking constructs to make up our understanding. Well, too much science makes crazy...

Information physics was of course concerned by entropy. Claude Shannon showed how arbitrary continuous information signals can be measured exactly as discrete bits. He found a form of entropy which expresses the minimum possible length of a message necessary to convey information: increasing information entropy corresponds to the declining part of useful information during a transmission because of suboptimal coding, noise and redundancy.

2.5 Energy and Information

Energy is necessary to create / store / process / transport information. A 2005 study by J.G. Koomey from Berkeley & Stanford found that Internet server farms in the world consume the electricity produced by the equivalent of 14 power generators of 1000 MW each.[3]

- Processing information does not produce mechanical energy. All the energy powering the computer converts to heat: a computer is an ultimate entropic machine.
- Opposed to Shannon information entropy, negentropy is a term that expresses the “negative entropy” that results of ordering things, putting more meaning, revealing more information, reducing ignorance in the system: information is the effective entropy antidote.
- The “information flow” that the computer pours in the system decreases its entropy: it will convert energy (and material) more efficiently, reducing losses.

If generalized to all information processing aspects, the Shannon information entropy expresses the difference between the entropy increase resulting of the information processing and the entropy decrease resulting of the efficient usage of this information. It is the reverse of the negentropic efficiency of an IT artifact. There should be a magnitude order between the energy consumed for computing and the effected energy, making adequate IT a giant lever to improve the energy transformation efficiency.

Information is intrinsically the ordering agent, influencing positively the systems it is part of. Information technologies can nevertheless have a negative impact. Their artificial, exogenetic nature makes them not fitting exactly the system they support, by possibly raising its entropy (preventing the proper understanding of the system through oversimplified or misleading representation) and reducing its complexity (behaving like a competing autonomous system toward the system it is supposed to support, reducing its inherent adaptability). Misinformation of course generates negative negentropy – increases entropy. Disinformation is an entropic weapon to beat competitors. It is also the machiavellian means to handle citizen consent in business enslaved, highly entropic perishing states.

2.6 Systemic / Cybernetics

“*Systemics is the emerging branch of science that studies holistic systems. It tries to develop logical, mathematical, engineering and philosophical paradigms and frameworks in which physical, technological, biological, social, cognitive and metaphysical systems can be studied and developed…. It has been developed by reaction of a tendency in modern science, towards reductionist, immanentist view, according to which knowledge concerning all the parts of a whole would additively entail a* *complete knowledge of also that whole. Systemics draws methodic attention upon contextuality: making clear the necessity to consider the functionings of the interacting elements from within that system, and furthermore the relation with the systems inhabiting the environment of that system. Systemics tends to generalize results obtained in cybernetics, classical engineering, systems theory and other sciences to derive principles common to many fields, based on scientific paradigms. …*" (Wikipedia).

We already talked about systems: systems don't need Systemics to exist and to be studied. Of course, only open, complex systems are of interest for us. J. De Rosnay gives this simple definition to open systems: "Set of elements in dynamic interrelation that are organized for a given purpose". Systemics provides a consistent framework to study – and improve – complex systems. The ISO/IEC622264 (international version of the US ,ISA95 standard) part 1 includes an annex about the System Theory to clarify the objects of the standard (specifically resource capacity/capability) in the context of the system they "talk about". But much more can be leveraged with this science beyond sociology, biology, and environment.

WBF public is generally well off with cybernetics, which is essentially about process control and PID loops. We learned how to model a system and to develop control strategies that make it doing what we expect from its usage. Beyond our apparently basic mechanical regulatory concerns, this is a largely spread mechanism in nature. Everything in a complex system and external interactions is under control through negative and positive feedback loops.

3 The Industrial Enterprise system

3.1 Purpose

The enterprise fight for short and long term survival implies to increase its self-knowledge and its intelligence, involving the totality of its constituents. The systemics holistic approach summarizes the physics that is involved in systems dynamics and can be purposely applies to the enterprise.

3.2 Industry eco-system

From the systemic perspective, Industry involves physical interactions (Earth, other Enterprises, internal Resources), noospherical interactions (World, Humanity, Owners, Humans, other enterprises goals), and social interactions (Nations, NGOs, Trade unions, Families…). Let first depict the purpose of industry in the global earth system. From the energy perspective, the industry fulfills the role of achieving the needed transformations to sustain life (Figure 1). The Sun, the only renewable energy source, provides low-ordered energy that can be use as-is (solar cells) or processed by natural metabolisms to generate more ordered, usable energy as plants, oil, wind, waterfalls. Some of these metabolisms are very slow (several 100K years to transform organic matter into petroleum). Nuclear fuel is a non-renewable energy that has been given to us only once. Industry appears to be the link that processes energy and food and produces goods by associating the biological (natural) and mechanical (artificial) workforce.

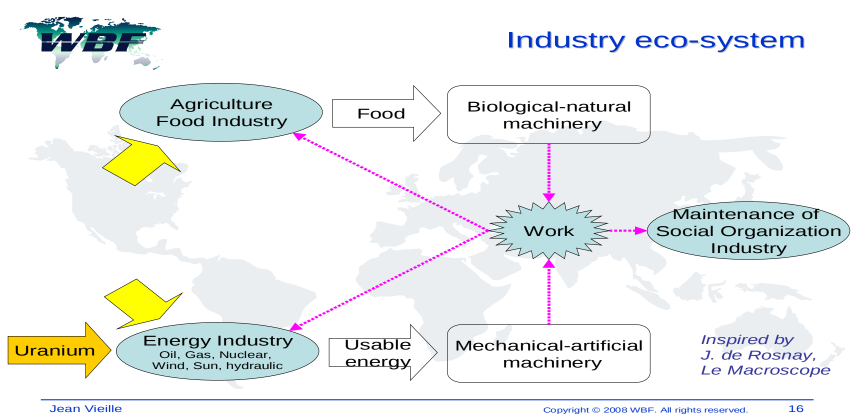


Figure 1

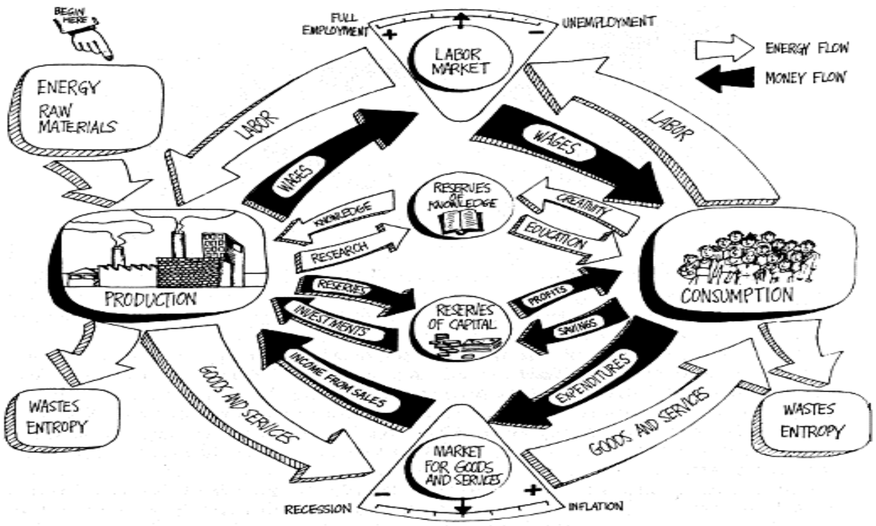


Figure 2 (*From J. de Rosnay, Le Macroscope* [6])

3.3 Industry economics

Figure 2 shows the basic sustainability mechanisms of the industry economics. Labor, Energy, Knowledge, Money flows and storages interact through Production and Consumption under the control of 2 main regulatory loops: the service and goods market adjusts the production to consumption; the labor market adjusts the employment rate. These are the energetic and sociologic industry duties:

- Addressing the energy related needs of the Society (energy, food, goods)
- Providing jobs by consuming biological resource (hiring human workforce)

3.4 Enterprise black box

Industry is a network of individual enterprises aiming to the biological consumer. Figure 3 shows the chain of energy interactions.

- **Energy**: Used & produced recoverable energy, raw & finished material, labor

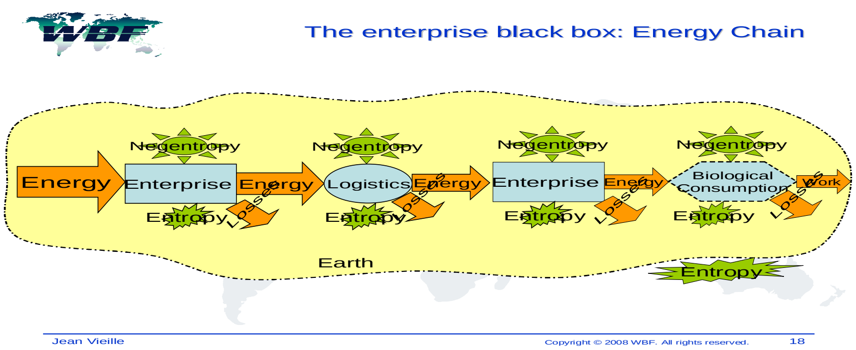


Figure 3

- **Losses**: Unrecoverable material & energy, spying
- **Entropy**: Disorganization, ignorance, lack of differentiation, depreciation, tiredness, discomfort…
- **Negentropy**: Organization, efficiency, differentiation, relevancy, knowledge

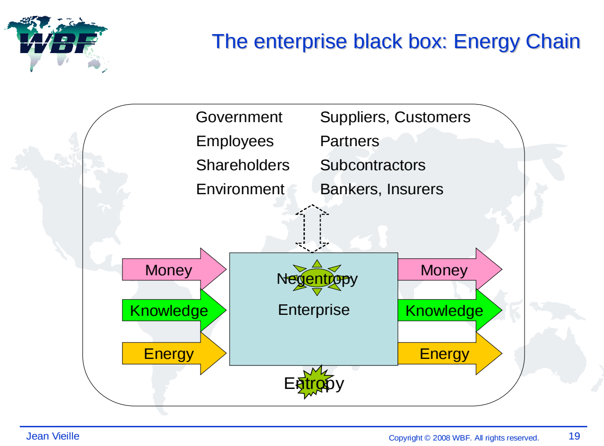


Figure 4

The Enterprise system interactions and I/Os are presented in Figure 4. The main flows are Energy, Money, and Knowledge. They involve external systems that interact more or less intimately. For example, employees are both external, autonomous biological systems, and dedicated off and on, "part" of the enterprise system. Information is of course not included here, it is part of the previous flows. Negentropy results of internal behavior; entropy is the externally measured contribution to Earth's entropy.

3.5 Opening the back box

Looking inside the enterprise system, we can identify its components and explore its interactions. An enterprise is a multi-dimensional layered system. Moreover, if some of its components are clearly defined with precise boundaries, others are not so apparent and must be guessed and approximated.

Static structure

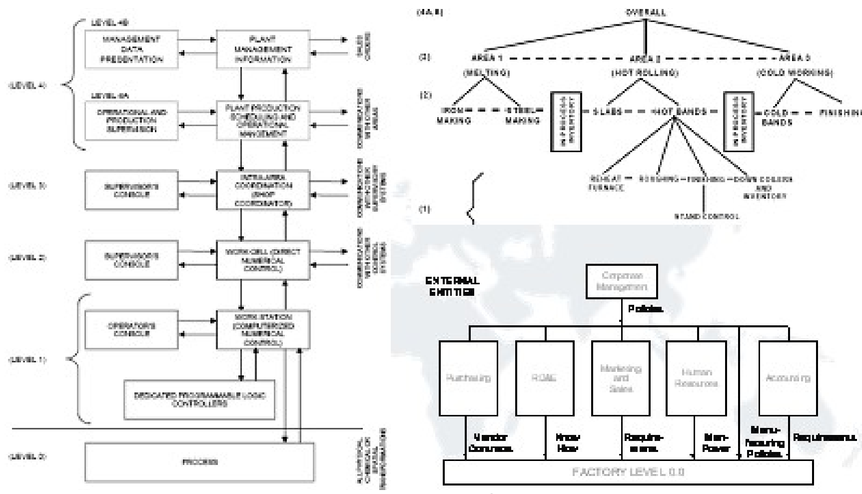


Figure 5 *(examples from PRM)*

When describing the structure of the system, we express the knowledge we have about its spatial properties. The structures can vary greatly from one enterprise to another. However, some common patterns can be identified and abstract meta-models have been published to help the reification of actual structures. The ISA88 and ISA95 standards as well as the Purdue Reference Model presented in ISA95 part 1 annex D provides some examples of possible structural arrangements. OPM offers human resource models. Examples of structural domains: (Figure 5)

- Physical asset (PRM D5->9, Physical ISA88/95 based representation)
- Product asset (ISA88 part 3 representation)
- Human asset (OPM standards)
- IT asset (PRM D1->3)
- Organizational aspects: Departments, divisions (PRM D12->14)

Interactions

The second aspect of the enterprise system concerns its temporal behavior: the dynamic interactions (common names are processes, activities, functions) that occur in the different situations that it encounters. These situations can be triggered by internal or external events. They involve the structural elements that must react and interact with other components or external systems' components. This is a more difficult exercise because of the complex and sometime chaotic nature of the enterprise and its environment. We can guess many situations, but never all situations in all the specific contexts they arise. This is where systemics helps: you can never know completely a system and drive it deterministically; its components' autonomy will make it in the unforeseen situations. As an example, scheduling is the art of establishing plans which are never respected: a strictly obedient workshop will never work. PRM, ISA88 and ISA95 function /activity models describe some common interactions that are involved in manufacturing operations.

A high level interaction view of an enterprise is useful to clarify the manufacturing domain we are specifically interested in. In Figure 6 we consider 3 main flows that pass through the enterprise: Energy (including material: $E=MC^2$), Money and Knowledge. They intervene in the corresponding interaction games that we have named respectively Energy Chain, Money Chain and Design Chain.

- The Energy Chain creates objective energetic value by combining simple elements into more complex elements of higher potential energy, making the requested products.

- The Money Chain creates economic value by connecting the energy chain to the market, creating economic value that is perceived by the customers

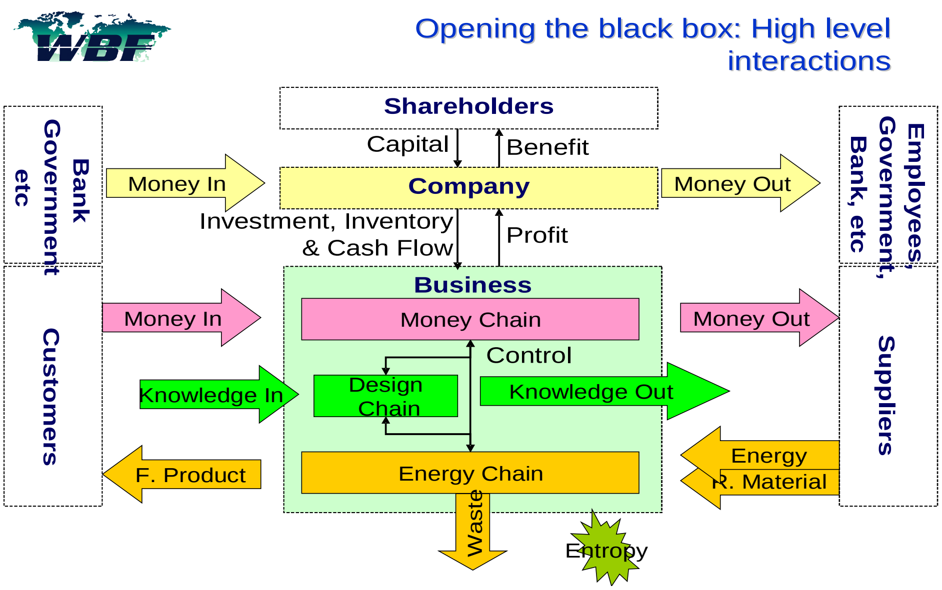


Figure 6

- The Design Chain exploits available knowledge and capabilities to transform money chain market requirements and constraints into feasible physical processes to be executed by the energy chain

We consider a basic structural breakdown in 3 components: The **shareholder's** pool that owns the enterprise, the **Company** that invests the capital in resources consigned to the **Business** which is the acting part of the Enterprise[4].

The manufacturing domain is part of the Business main structural element and concerns both the Design and Energy Chain.

3.6 Enterprise entropy

Enterprise, as any system is subject to constant entropy increase tendency that appears under different forms:

- Human resource: inefficiency, errors, tiredness, aging, illness, discontent...
- Equipment resource: wear & tear, inefficiency, breakdown...
- Material & energy resource: waste, energetic balance, uselessness (decreasing relevancy)…

High entropy increase rate does not necessarily make speculative owners unhappy. Actually, many enterprises run at a high entropy rate while achieving satisfactory short term financial performance by cutting costs and implementing money efficient processes at any "entropy expense".

Because the Enterprise is an open system that interacts with its environment, its entropy adds up to the surrounding system it is part of: the Earth and its unique energy source, the Sun. (The later has still billions years of fuel reserve, and higher space dimensions do not count at the humanity scale). Cybernetics will make sure that an enterprise which negatively impacts its environment to a point it cannot sustain (compensate its entropy) itself, will be hit back by retroaction, because the environment (the Earth super-system) actually controls it. The time constants are much longer however, and this is perceivable only by long sight managers and concerned employees. We all know both kinds of companies, those who seek short term revenues with short life expectation compared to those who are less flashy, but seemingly timeless.

3.7 Information, IT and Enterprise

As seen previously, Information is an integral part of any system. It cannot be discussed independently of this system. Each enterprise structural component and interaction occurrence is represented, generates or is driven by information as an intricate dimension of the reality. There is no such a thing called an "information system" that can be identified, build, or acquired as a separate entity. Information is not an attribute of a particular enterprise component, it is the enterprise itself. (outside industry sector, Google or banks have such production machinery that can be called an Information Processing System that consumes and produces the informational goods and services they sell). There are IT components in the enterprise, but they must not constitute a subsystem that would interact globally with the Enterprise system.

Information technology contributes to the Enterprise system assembly (spatially) and operation (temporally). What were once stored in people's memory and paper files, transported by couriers, telephone wires and pneumatic tubes, processed by human brain, analog computers or mechanical marvels is now additionally propelled by data storage devices, copper/fiber/wireless networks, and silicon based computers.

IT makes possible more interactions, more complexity and knowledge, less entropy… IT efficiency can be then directly measured in terms of its contribution to lower the enterprise entropy: decreasing its self-ignorance, increasing its knowledge, smartness and intelligence, reducing waste and environment negative impact, contributing to positive society development.

4 Enterprise Architecture

4.1 Enterprise system control

Human designed enterprises are complex systems that have not the self-reproduction and long term multi-generation evolution capabilities of natural biologic and sociologic systems. However, they have enormous adaptive and self-organization capabilities. Their components actively interact with each other and they have numerous cybernetic feedback loops. These interactions can be explicitly, willingly designed and implemented (our process control loops for example), but many are unintentional, emerging from complexity that results of the game of interactions, competition, and cooperation.

In cybernetics, we often represent a system as made of 2 subsystems: the operated system (tank, pipes, and pump) and the operating system (level sensor, controller, and valve). This arbitrary separation serves experimentation and engineering purpose. The quantum mechanics told as that we cannot separate the subject and the observer. The nature simply isn't like that. What if we include the level sensor and the valve in the operated part? What if I include the controller in the valve? (Haven't heard about Fieldbus distributed function blocks?) The control system is definitely part of the system. Controlling an enterprise and its different parts is not about installing a big computer that crunches the mass of data coming from all enterprise components and processes to direct the behavior of all actionable drivers. "Control" is an integrated part of the (enterprise, manufacturing) system and all its components. Control is implemented by implicit balanced interactions, information processing IT artifacts, human decision. The ISA88 Equipment Entity concept corresponds to this view.

4.2 Why an Enterprise Architecture?

Entropy is impacted by knowledge, organization, and information. The first prerequisite in order to win against entropy is to ensure a sufficient understanding of its spatial and temporal dimensions. Based on this understanding, we can improve the organization and increase the intelligence. This is the purpose of Enterprise Architecture that captures the enterprise structure and interactions, defines target improvements, scopes projects (including IT) and monitors achieved improvements.

4.3 What is Enterprise Architecture?

"*Enterprise architecture is a term used to describe the practice of documenting the elements of business strategy, business case, business model and supporting technologies, policies and infrastructures that make up an enterprise. There are multiple architecture frameworks that describe Enterprise Architecture. Enterprise Architecture can be described as 1: documentation describing the structure and behavior of an enterprise and its information systems, usually in a number of architecture domains. Or 2: a process for describing an enterprise and its information systems and planning changes to improve the integrity and flexibility of the enterprise*." (Wikipedia)

Simply termed, EA is for industrial enterprises what Architecture it is for the construction business. However, many EA efforts turn to become IT focused – with a strong emphasis on "T" as in the Wikipedia definition. EA did not appear with its naming, it has always existed implicitly or explicitly. The EA developments essentially boiled within the IT world, led by information gurus and software providers. This may hide the fact that EA is a full enterprise control tool for operational managers and executives to shape the enterprise better, not an IT primary subject, with IT being merely one of the many topics to implement the changes.

An enterprise is a "virtual entity" that assembles many different collaborative components of various natures. It is actually an Information entity that starts with ideas, exists by administrative recognition, builds its internal organization, connects with customers and suppliers, gathers or acquires resources, involves people… It is indeed much more than its buildings and facilities: most of its components are virtual – informational – by essence.

Today's buildings are designed to last a couple of decades matching the tax admitted depreciation rate (15 towers in Paris La Défense will be destroyed within the next 10 years). Architects only intervene at the construction time, and then a minimum maintenance keeps the global shape, elegance and security level until the building becomes too expensive to maintain and no longer attractive for the current epoch (defeated by entropy).

An enterprise is a much more dynamic architecture subject: it is never finished; it is modified continuously because the needs justifying its existence are ever changing. The architect is a full time agent who directs its ongoing re-construction.

The spatiotemporal description of enterprise architecture is then completed by the managerial processes to direct and implement its evolution, from strategic planning to project implementation and monitoring.

Systemics help to understand a common EA mistake: trying to control the enterprise re-engineering in a deterministic, rigid, top-down way is a recipe for failure. EA must aim at increasing knowledge (by collecting and sharing), not necessarily leveling it. Complex systems simply reject any attempt to reduce the autonomy of their components, their intelligence and their ability to adapt themselves – their complexity. When ordering and control succeed in killing the complexity, the system dies as the soviet planned economy.

4.4 Enterprise Architecture Modeling Frameworks

Models are spatiotemporal architecture blueprints that identify the enterprise and interactions (or processes). They are supposed to represent the enterprise system – actual or future. Modeling contributes to increase entropy because it simplifies the reality (mutilates the system…). Our limited brains and computing tools need this simplification to figure out how to drive the inherent complexity. A single box model means minimal understanding, maximal entropy: the system is driven “au pif” (at random). At the opposite, a full knowledge of the system without the computing power to process it won’t help much: the ignorance of the system move to the inability to understand and make use of its representation.

Many modeling framework are available from academics, standardization bodies, consulting groups, government administrations or proprietary industry initiatives, for example:

- PERA: the Purdue Enterprise Reference Model
- CIMOSA: Computer Integrated Manufacturing Open System Architecture
- Zachman Framework
- TOGAF: The Open Group Architecture Framework
- FEAF: US Federal Enterprise Architecture Framework
- IAF: Cap Gemini Integrated Architecture Framework

Take the Zachman Framework as an example (Figure 7). It forms a matrix that defines subjects as the intersection between 2 classification paradigms:

- Primitives interrogatives: What, How, When, Who, Where, and Why. The composite response to these questions is supposed to enable a comprehensive description of a complex idea
- Reification: the progression from abstraction to reality, successively Identification, Definition, Representation, Specification, Configuration, and Instantiation.

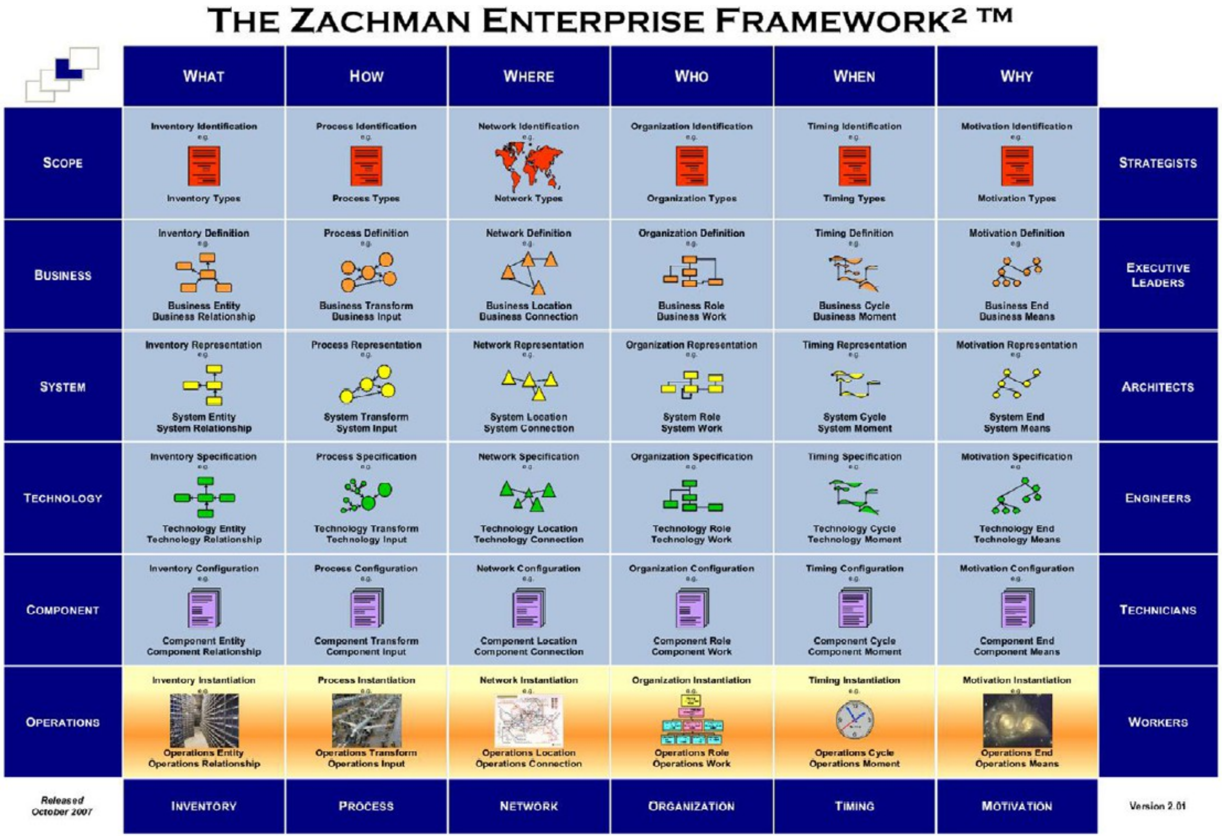


Figure 7

It does not impose any modelling structure and semantics, it is a meta-model for describing the structure of the enterprise (and its IT stuff), so it can be complemented by structural models like ISA88 and ISA95 [5]).

As many other frameworks, the Zachman framework focuses essentially on IT: exactly half of the framework cells are IT relevant (John Zachman was with IBM for 26 years). [6]

5 ISA88/95 manufacturing modeling framework[7]

EA frameworks aim at addressing the enterprise architecture in its globality. They allow modeling the “virtual” parts of the enterprise: its organization, its business processes. The matching between the actual components and interactions is almost perfect: organization, processes, workflows can be defined, documented and implemented in a straightforward way: the models and their subjects are both virtual – purely informational, evolving in the same spatiotemporal dimension.

When it comes to the manufacturing part of the enterprise, the complexity reaches higher levels, and the models no longer connect directly to the real world. Machinery and physical happenings is the reality that purely informational models shall represent. ISA88 and ISA95 standards help to close the gap between the manufacturing reality and its representation. They are prescriptive models that could conflict with similar approaches (they actually conflict with each other!). For this reason, they perfectly fit in the meta-nature of the published architecture frameworks (see above discussion on Zachman framework). The Figure 8 presents the manufacturing architecture dimensions for describing the manufacturing system structure, interactions and intelligent artifacts and its relationship with the ISA88 and ISA95 standards. This model has 2 main parts:

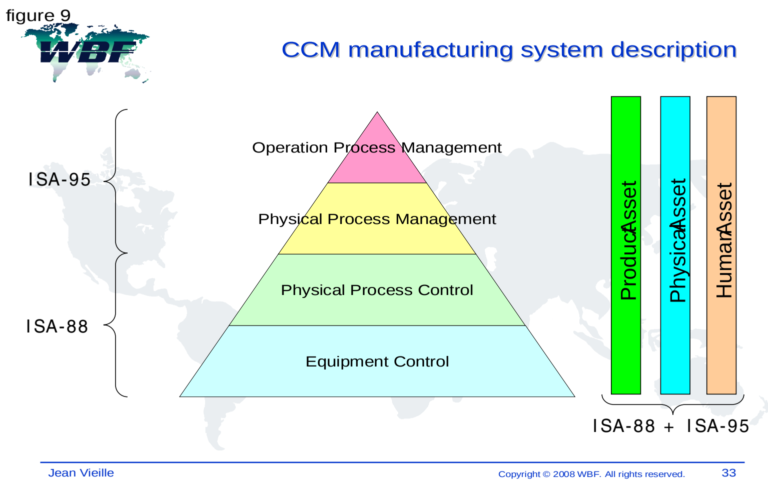


Figure 8

- The 3 vertical bars correspond to the spatial manufacturing structure, made of Equipment, Product and Human asset
- The 4 layers pyramid corresponds to the temporal manufacturing interactions / dynamics
  - ♦ Equipment control is the automation domain and corresponds to ISA88 equipment related knowledge (procedural, basic and coordination control)
  - ♦ Physical Process Control is the ISA88 Recipe domain and corresponds to the energy transformation knowledge.
  - ♦ Physical Process Management corresponds to ISA95 part 1 Process Segments. It provides the management grip to drive operation efficiency and to link energy and money chains.
  - ♦ Operation Process Management corresponds to ISA95 part 3 activity models. It covers the managerial aspects of the manufacturing operations in opposition to Equipment and Physical process control which concentrates on its physical aspects.

The Figure 9 presents the ongoing manufacturing architecture process based on this top level structure. It begins by the structural domain description, which forms actually the backbone of the manufacturing system, describing its components and dependencies (1a, b, c).

Then, the physical entities interactions provide a complete picture of the energy transformation part of the system (2, 3).

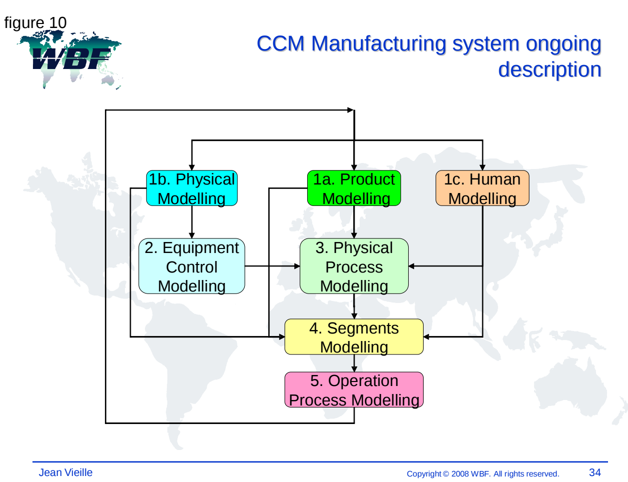


Figure 9

The next step identifies the relevant transformation entities for the operation management purpose, the ISA95 “Segments”. This could be considered as a structural element, but its does not pretend to be an accurate, fair detailed representation of the physical happenings, but a smoothed description to enable management interactions (4).

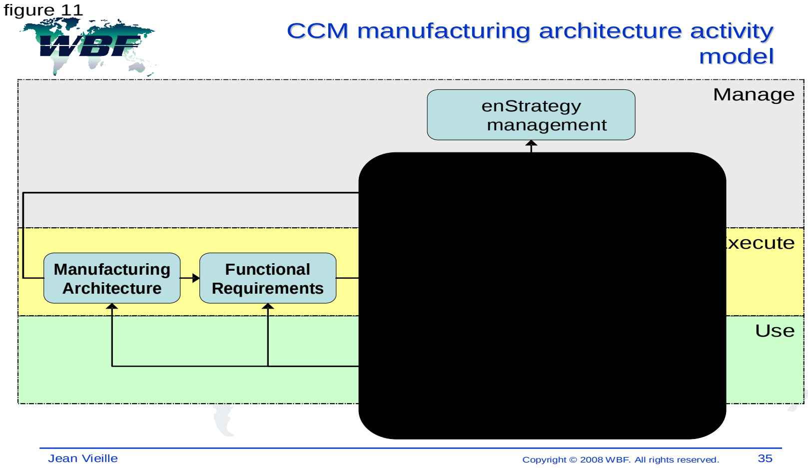
Finally, the description of top level interactions attempts to identify the most common situations that will occur during the facility life. This includes workflows and decision criteria to conduct the facility.

This model and process is a basis for a manufacturing architecture that can achieve a true IT-manufacturing convergence to support the global ongoing development, self-evolution of the enterprise.

The Business/IT Convergence process model (Figure 10) identifies 3 main interaction domains:

- The "Manage" domain
  - ♦ The enterprise strategy management process provides scope and time guidance to determine the area and roadmap for improvement.
  - ♦ The IT Master Planning process implements the strategy by directing the IT developments efforts.
- The "Execute" domain
  - ♦ The manufacturing architecture process is an ongoing activity that maintains the construction framework that is referred to by the IT Master Planning and realization processes.
  - ♦ The functional requirement gathering is called by IT construction projects or proactively fed by feedback from realization or operations.
  - ♦ The IT component development process designs the application components and software / hardware infrastructure elements.
  - ♦ The IT deployment process implements IT resources to fulfil functional requirements for a given architecture scope.
- The "Use" process domain
  - ♦ The Operate process corresponds to the run time usage of the IT applications and initiate requirements
  - ♦ The Support and Maintain process links the IT application usage to its design, adjusts the functional requirement and contributes to maintain the Manufacturing architecture.

figure 11



6 Conclusion

The second law of Thermodynamics revealed a basic behavior of Nature, the Entropy which prevents the reversibility of energy transformations. Later physics research expanded the notion to the many forms and consequences entropy takes today that can be summarized by disorder and ignorance. Information is both a negentropic factor – increase knowledge and order – and a target for entropy when it simplifies exceedingly or distorts the reality.

Enterprise obeys to physical laws. As an open, complex system, an enterprise can reverse this lethal entropy phenomenon by becoming smarter: knowing, adapting and organizing itself better. Information is part of the enterprise, not a separate matter.

An Enterprise results of an architectural effort. Compared to a standing building, an enterprise is rather a living organism: its ongoing re-engineering is an endless intuitive and strategic process guided by objectives, opportunities and constraints.

This process is supported by Enterprise Architecture to facilitate and speed up transformations. EA enables "Business and manufacturing / IT convergence" to leverage the information negentropic weapon for achieving a long term performing and sustainable evolution when it enables faster, smarter enterprise adaptation, and strategy implementation.

Convergence means that Information is not the subject of a particular system in an industrial enterprise. Information is all together the architecture design sketch, the shaping of building blocs and the cement of an ever building enterprise.

Manufacturing Architecture is a sub part of the Industrial Enterprise architecture. It is even more critical because of the high complexity and criticality of the “Energy Chain” in charge of physical transformations. ISA88 and ISA95 provide useful models to form a global manufacturing architecture framework for a manufacturing IT construction process that maintains the smallest gap between the requested and available intelligence to fit the enterprise evolution roadmap in the search of a long, harmonious life.

Entropy, the objective reverse indicator of smartness should be considered as an important parameter to drive IT development and monitoring. Further research will propose practical methods to measure it.

The tagline of the WBF 2008 EU conference suggests that a gap exists between manufacturing and IT, a sort of euphemism to express this concern as we have tried to expose it. This paper is purposely an attempt to shape a symbiotic approach to IT in industrial facilities where the dichotomy between IT and (physical) operations is the most challenging.

7 Annex: The "Ten Commandments" of the Complex System Management

I found useful in the context of this article to reproduce this early contribution of a great contemporary scientist that any manager should meditate, replacing the word “system” by the one he manages (i.e. an Enterprise).

Excerpt from The Macroscope [8]

The systemic approach has little value if it does not lead to practical applications such as facilitating the acquisition of knowledge and improving the effectiveness of our actions. It should enable us to extract from the properties and the behavior of complex systems some general rules for understanding systems better and acting on them.

Unlike the juridical, moral, or even physiological laws which one might still cheat, a misappreciation of some of the basic systemic laws could result in serious error and perhaps lead to the destruction of the system within which one is trying to act. Of course many people will have an intuitive knowledge of these laws, which are very much the result of experience or simple common sense. The following are the "ten commandments" of the systemic approach.

1. Preserve variety.

To preserve stability one must preserve variety. Any simplification is dangerous because it introduces imbalance. Examples abound in ecology. The disappearance of some species as a consequence of the encroaching progress of "civilization" brings the degradation of the entire ecosystem. In some areas intensive agriculture destroys the equilibrium of the ecological pyramid and replaces it with an unstable equilibrium of only three stages (grain, cattle, and man) controlled by a single dominant species. This unbalanced ecosystem tries spontaneously to return to a state of higher complexity through the proliferation of insects and weeds-which farmers prevent by the widespread use of pesticides and herbicides.

In economy and in management, excessive centralization produces a simplification of communication networks and the impoverishment of the interactions between individuals. There follow disorder, imbalance, and a failure to adapt to rapidly changing situations.

2. Do not "open" regulatory loops.

The isolation of one factor leads to prompt actions, the effects of which often disrupt the entire system. To obtain a short-term action, a stabilizing loop or an overlapping series of feedback loops is often "cut open"-in the belief that one is acting directly on the causes in order to control the effects. This is the cause of sometimes dramatic errors in medicine, economy, and ecology.

Consider some examples of what happens in the rupture of natural cycles. The massive use of fossil fuels, chemical fertilizers, or nonrecyclable pesticides allows the agricultural yield to grow in the short term; in the long term this action may bring on irreversible disturbances. The fight against insects leads as well to the disappearance of the birds that feed on the insects; the result in the long term is that the insects return in full force-but there are no birds. The states of waking, sleeping, and dreaming are probably regulated by the delicate balance between chemical substances that exist in the brain; by regularly introducing, for short-term effect, an outside foreign molecule such as a sleeping pill, the natural long-term mechanisms are inhibited-worse, there is the danger of upsetting them almost irrevocably: persons accustomed to using barbiturates must undergo a veritable detoxification in order to return to a normal sleep pattern.

3. Look for the points of amplification.

Systems analysis and simulation bring out the sensitive points of a complex system. By acting at this level, one releases either amplifications or controlled inhibitions.

A homeostatic system resists every measure, immediate or sequential (that is, waiting for the results of preceding measures in order to take on new ones). One of the methods that influence the system and cause it to evolve in a chosen direction is the use of a policy mix. These measures must be carefully proportioned in their relationships and applied simultaneously at different points of influence.

One example is the problem of solid wastes. There are only three ways to reduce the flow of the generation of solid wastes by acting on the valve (the flow variable): reducing the number of products used (which would mean a drop in the standard of living), reducing the quantity of solid wastes in each product, or increasing the life expectancy of the products by making them more durable and easier to repair. The simulations performed by Jorgan Randers of MIT show that no one measure *alone is enough (see notes). The best results came from a policy mix, a combination of measures used at the same time: a tax of 25 percent on the extraction of nonrenewable resources, a subsidy of 25 percent for recycling, a 50 percent increase in the life of the products, a doubling of the recyclable portion per product, and a reduction in primary raw material per product (Fig. 67).*

4. Reestablish equilibriums through decentralization.

The rapid reestablishment of equilibriums requires the detection of variances where they occur and corrective action that is carried out in a decentralized manner.

The correction of the body's equilibrium when we stand is accomplished by the contraction of certain muscles without our having to think about it even when the brain intervenes. Enzymatic regulation networks show that the entire hierarchy of levels of complexity intervene in the reestablishment of balance (recall the example of the service station on page 51). Often corrective action has been taken even before one has been made conscious of taking it. The decentralization of the reestablishment of equilibriums is one application of the law of requisite variety. It is customary in the body, the cell, the ecosystem. But so far it appears that we have not succeeded in applying this law to the organizations that we have been assigned to manage.

5. Know how to maintain constraints.

A complex open system can function according to different modes of behavior. Some of them are desirable; others lead to the disorganization of the system. If we want to maintain a given behavior that we consider preferable to another, we must accept and maintain certain kinds of constraints in order to keep the system from turning toward a less desirable or a dangerous mode of behavior.

In the management of the family budget one can choose a high style of living (living beyond one's means), with the constraints that it implies with respect to banks and creditors. Or one can choose to limit expenditures and do without goods one would like to possess-a different set of constraints.

In the case of a nation's economy, those responsible for the economic policy choose and maintain the constraints that result from inflation with all their injustices and social inequalities-for they are judged a lesser evil than those brought about by unemployment.

At the level of the world economy the growth race entails social inequalities, depletion of resources, and pollution. Theoretically, however, it allows a more rapid increase in the standard of living. The transition to a "stationary" economy would imply the choice of new constraints, founded on privation and a reduction in the standard of living and the imposition of more complex, more delicate, and more decentralized forms of control and regulation than in a growth economy. These means would call for increased responsibility on the part of each citizen.

Liberty and autonomy are achieved only through the choice and application of constraints; to want to eliminate constraints at any price is to risk moving from an accepted and controlled state of constraint to an uncontrollable state that will lead rapidly to the destruction of the system.

6. Differentiate to integrate better.

Every real integration is founded on a previous differentiation. The individuality, the unique character of each element is revealed in the organized totality. This is the meaning of Teilhard de Chardin's famous phrase, "union differentiates." This law of the "personalizing" union is illustrated by the specialization of cells in the tissues or the organs of the body.

There is no true union without antagonism, balance of power, conflict. Homogeneity, mixture, and syncretism are forms of entropy. Only union through diversity is creative; it increases complexity and leads to higher levels of organization. This systemic law and its allied constraints are well known by those whose purpose is to unite, to assemble, to federate. Antagonism and conflict are always born of the transition to a unified entity. Before regrouping diversities, we must decide to what limits we should push the process of personalization. Pushed too soon, it leads to an homogenizing and paralyzing mixture; pushed too late, it leads to the confrontation of individualism and personality-and perhaps a disassociation still greater than what had formerly existed.

7. To evolve, allow aggression.

A homeostatic (ultrastable) system can evolve only if it is assaulted by events from the world outside. An organization must then be in a position to capture the germs of change and use them in its evolution-which obliges it to adopt a mode of *functioning characterized by the renewal of structures and the mobility of men and ideas. In effect all rigidity, sclerosis, and perpetuity of structures or hierarchy is clearly opposed to a system that allows evolution.*

An organization can maintain itself in the manner of a crystal or that of a living cell. The crystal preserves its structure by means of the balance of forces that cancel out each other in every node of the crystalline network-and by redundancy, or repetition of patterns. This static state, closed to the environment, allows no resistance to change within its milieu: if the temperature rises, the crystal becomes disorganized and melts. The cell, however, is in dynamic equilibrium with its environment. Its organization is founded not on repetition but on the variety of its elements. An open system, it maintains a constant turnover of its elements. Variety and mobility enable it to adapt to change.

The crystal-like organization evolves slowly in the give and take of radical and traumatic reforms. The cell-like organization tries to make the most of events, variety, and the openings into the outside world. It is not afraid of a passing disorganization-the most efficient condition for readaptation. To accept this transitory risk is to accept and to want change. For there is no real change without risk.

8. Prefer objectives to detailed programming.

The setting of objectives and rigorous control-as opposed to detailed programming at every step-is what differentiates a servomechanism from a rigidly programmed automatic machine. The programming of the machine must foresee all disturbances likely to occur in the course of operation. The servomechanism, however, adapts to complexity; it needs only to have its goal set without ambiguity and to establish the means of control that will enable it to take corrective measures in the course of action.

These basic principles of cybernetics apply to every human organization. The definition of objectives, the means of attaining them, and the determination of deadlines are more important than the detailed programming of daily activities. Minutely detailed programming runs the risk of being paralyzing; authoritarian programming leaves little room for imagination and involvement. Whatever roads are taken, the important thing is to arrive at the goal-provided that the well-defined limits (necessary resources and total time allotted to operations) are not exceeded.

9. Know how to use operating energy.

Data sent out by a command center can be amplified in significant proportions, especially when the data are relayed by the hierarchical structures of organizations or by diffusion networks.

At the energy level the metabolism of the operator of a machine is negligible compared to the power that he can release and control. The same applies to a manager or to anyone in charge of a large organization. We must distinguish, then, between power energy and operating energy. Power energy is represented by the electric line or the current that heats a resistance; or it may be the water pipe that carries water pressure to a given point. Operating energy renders itself in the action of the thermostat or the water tap: it represents information.

A servomechanism distributes its own operating energy through the distribution of information that commands its operational parts. In the same way the leader of an organization must help his own system to distribute its operating energy. To accomplish this he establishes feedback loops to the decision centers. In the management of an industry or in the structure of a government, these regulatory loops are called self-management (autogestion), participation, or social feedback.[14]

10. Respect response times.

Complex systems integrate time into their organization. Each system has a response time characteristic of that system, by reason of the combined effects of feedback loops, delays at reservoirs, and the sluggishness of flows. In many cases, especially in industry, it is useless to look for speed of execution at any price, to exert pressure in order to obtain responses or results. It is better to try to understand the internal dynamics of the system and to anticipate delays in response. This type of training is often acquired in the actual running of large organizations. It gives rise to a sense of timing, the knowing when to begin an action, neither too soon nor too late, but at the precise moment the system is ready to move in one direction or the other. Sense of timing allows the best possible use of the internal energy of a complex system-rather than to have to impose instructions from outside against which the system will react.

8 Acronymes

EA: Enterprise Architecture

IS: Information System

ISA: The Instrumentations, Systems, and Automation Society

IT: Information Technology

MA: Manufacturing Architecture

OPM: US Office of Personnel Management

PID: Proportional, Integral, and Derivative (controller)

PRM: Purdue Reference Model

TOC: Theory of Constraints

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