National Academy of Technologies of France (NATF)

# Large Socio-Technical Systems

Translated from the original French version
« Les grands systèmes socio-techniques » (GSST)
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Report approved in Plenary Session
January 2013

Printed in France
ISBN : 978-2-7598-1015-4

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# OVERVIEW

Large Socio-Technical Systems (or LSTSs) that function over a network — such as the railroad systems, air traffic systems, the electric systems, telecommunications systems and their derivatives, the Internet — have all gradually and deeply modified our life-styles and, in more general terms, Society at large. As far as citizens are concerned, in their daily lives, the LSTSs are seen as combining sciences and technologies, offering services that have become essential and inevitable with a concomitant, significant fraction of family budgets today. Developing nations are trying to follow suit as best they can.

Beyond their specific missions, LSTSs have certain common characteristics: often the networks are continental in scale, or even global ; users expect from them a no-break service quality ; they are constituted by millions or even billions of elementary component parts ; the correct overall functioning of which depends on co-operation of a large number of human agents with very different skills. Finally they are considered — in terms of human life — as eternal entities.

Their importance — if only in terms of the employment positions they offer and sustain — justify an investigation. The National Academy of Technologies of France (NATF), is therefore directly concerned since its commitment and the one of its members is, as epitomized by its motto:

*Sharing Reasoned, Chosen, Progress*

that illustrates the relationship between technology and Society.

When dysfunction occurs — and Society accepts this less and less – the associate costs run into billions of euros and, what is more, can cost people their lives. The evidence is that beyond being extremely successful, LSTSs share an increasing factor of vulnerability: constant development of the systems themselves, incorporation of new technologies, inroads made by ICTs, liberal market approaches and consequences are both sources for regularly renewed services but also, given the 'complexification' and induced inter-dependence, for new degree of vulnerability to appear. Such trends, moreover, have led to a multiplication for each LSTS of a number of more or less autonomous entities agents, needed to operate them and which obey their own logics which in turn increases fragility and complicates system governance as a whole.

Moreover we can observe that LSTSs are becoming more and more international in scope. Over Europe, the railways systems, telephone systems, electric systems have moved on from being national or regional monopolies with vertical integration and low coupling to new models that are less integrated and are characterized by a new division of responsibility, as dictated by the European directives when transposed into national law and regulations. The experience gained over the past 15 years, confirmed in the hearings conducted by the NATF-WP, shows that there is a real difficulty when it comes to drafting new regulatory texts designed for sustainable development of the LSTSs. The latter must incorporate technical trends while trying to strike a balance between local aspirations and nation-wide issues. They must also enable industrialists not only to invest, but to be in a position to assure the services they offer at a reasonable cost to consumers/clients/subscribers, in full compliance with global challenges in their respective areas.

The importance of LSTSs, also called critical infrastructures by the European Commission and the thinking described above led the NATF-WP to issue three academic proposals, which we can summarize at this stage as follows:

- a serious 20 years return on experience (ROE) analysis should be conducted for each LSTS, without indulging in lip-service or any *a priori* considerations. The ROE would cover operations, costs, governance and regulation, crises situations/incidents and identify the degrees of dependence vis-à-vis the other LSTSs… ;
- prospective reflexions should be engaged to identify the possible trends for the coming two decades (in terms of services, quality, costs, jobs, risk control, governance) all in keeping with the logic of sustainable development,

using the ROE not only from 1° above but also by using a cartography of skills and know-how available in France, notably, to guarantee having a global vision which alone allows us to ensure system operational status and control in advance of changes ;

- the LSTSs should be 'taught' in our education system in order that the next generations know them and appreciate them better. In this way, the LSTSs, offering, as they do, new forms of employment, will also and furthermore enable a better comprehension and appreciation for the underlying sciences and technologies thereby serving to demonstrate that they results from ongoing innovations in real life.

Implementing these three academic proposals should contribute to better informed decision processes by our politicians and industrialists and would, consequently, enable our children to benefit fully from these magnificent fruits of recent human activities, *viz*., the LSTSs.

# INTRODUCTION

Large scale Socio-Technical Systems (LSTSs) operating over networks (such as the electricity system, the railways, the airspace system, Internet…) have radically changed our daily lives over the past few decades and also transformed the way our Societies work. They represent a phenomenon that is conducive to enthusiasm, which contributes to the democratization process of societies everywhere, offering new features and services over the coming years, consequences and sources of new techniques and technologies: in this light, LSTSs appeared as a natural field for investigation by our Academy.

They have undergone considerable development already (and continue to do so) not only in terms of technological progress in their on area (photovoltaic arrays to produce electricity commercially, high speed trains (TGVs in France) for rail transport, mobile phones for inter-personal communications…) but also thanks to new ICTs, themselves being sources of change in the way they work and the scope of services they offer.

Taken together they now account, directly or indirectly, for a non negligible fraction of household budgets. Hundreds of thousands of jobs in France depend on these LSTSs, and we can count in millions in Europe and the World. Development has an impact on land planning and the level of attractiveness of regions, areas, cities… These points in common are not, however, the only factors to be considered and for this reason the choice made, *viz.*, to study the LSTSs as a whole, beyond any specific differences, can prove interesting.

A further reason to study LSTSs lies in the fact that even if globally speaking their operation is deemed satisfactory and has adapted itself remarkably over the years — at least in Western countries — it nonetheless remains that dysfunctions can have serious consequences. This indeed is why these systems in Anglo-Saxon terminology are referred to as “critical infrastructures”. It is therefore useful to try to analyze the main factors of change, to try to deduce certain “laws” and to make some proposals to counter possible risks. This approach seemed all the more relevant that most members of the NATF-WP became convinced, as the studies progressed, that most of the large scale systems are becoming more and more fragile.

The NATF LSTS WP has noted that even the least developed countries are now endeavouring to develop similar systems, to the extent that they are now vital to their future. For countries like these, many additional questions arise, appertaining to technical, economic, social and political issues ; these questions call for more studies.

The core text sets out the main factors for change for LSTSs and the proposals drafted by the NATF’s WP that the Academy addresses to politicians, regulators, industrialists, in short, the actors of the systems, without any exclusion of the citizens/users/clients who have their role to play.

The notes, comments in the appendices (referenced in the text) are grouped together *in fine*.

Our document ends with a set of Internet sites that will enable readers who are interested to follow up their studies about LSTSs.

# THOUGHTS ABOUT THE EVOLUTION OF LSTs

Every time you plug a vacuum cleaner, a laptop (or a mobile phone to recharge it), into an electric outlet socket, you rarely see this gesture as being extraordinary, do you? And you assume that all the electric power needed will be available, don't you? Well, this tenet holds at least in a country like France. Without thinking about it, we are in fact mobilizing the whole electric system that runs from the plug outlet to the hydroelectric dams, or nuclear power stations or wind-turbines, for example. The power travels over the grids and networks and we can be assured of having the electricity we need in the right quantities and quality, all the time, except for perhaps some small breaks totalizing no more than a few dozen min per year. Nor do we think about the millions of technical component objects assemble to provide this service, nor about the tens of thousands of agents who work in and for the electric utility, round the clock, day in, day out. Nor do we often spare a thought for the billion and more people round the world that simply do not have access to a power socket, or a use for it.

In like manner, when we pick up the phone handset, we know we shall hear a dial tone and that after only a few seconds or tens of seconds at most we will be talking to someone else in the world, whether he or she is only a hundred yards away or at the far end of the world. In addition to this conventional service of enabling direct dialogue between two persons *via* fixed phones, we now have pervasive mobile phones and likewise Internet with their specific data exchange facilities and which continue to grow continuously. Where the telephone is concerned, and the same goes for Internet, each of us, whether we are a client or a user, mobilizes part of a huge technical system with thousands of kilometres of networks, thousands of server relay stations each with their own software and data where again, their operation is ensured in France and elsewhere in the World by tens of thousands of agents.

When we board an aircraft, we do not necessary lend thought to the civilian passenger airspace system which, over and above the aircraft on the ground and in the air, includes the airport terminals and facilities, air traffic control, aircraft maintenance … where, if we ignore incidents and accidents, we can literally go where we want in the world in a few hours.

**These three examples of Large-Scale Socio-Technical Systems that we designate by the acronym LSTS or simply Large Systems** (1)[1] in the remainder of this document are not the only ones that exist: railways and roads are two other LSTSs. The system whereby hydrocarbon fuels are delivered has some analogies with LSTSs. Urban water distribution is usually more ‘local’, *i.e.*, does not extend over hundreds of kilometres but nonetheless present analogous problem areas and themes. The major distribution networks and even the finance system, to some extent, present similar features.

**These LSSTs are in fact supports to our daily, personal life styles, and similarly to our interactions with others, in many ways of life.** Because of this relationship, we have clear demands on the systems, both in terms of costs and in regard to service quality assurance.

As far as costs are concerned (prices or tariffs), they have a “political connotation” and the utilisation of LSTSs by the least favoured citizens can lead to special measures being taken to provide them with certain essential services.

Where quality assurance is needed, in a country such as France, we are quite accustomed to seeing the LSTSs operating, like latter day cathedrals, 24/24, 7/7, indeed we accept less and less readily that they run irregularly or that they can fail. This level of demand is generally satisfied while at the same time, almost paradoxically, the vulnerability of LSTSs has a tendency to increase.

[1] These figures refer to the appendices.

A few examples of system breakdowns or cases of dysfunction made the headlines in France and Europe in recent years:

- the partial black out or 'brown-out' of the European electric system, November 4, 2006 deprived some 15M customers of their electricity supply;
- service stoppages of Eurostar during the very cold spells recorded in November 2009 and February 2010;
- disruption of air traffic due to eruptions of the Icelandic volcano, Eyjafjallajökull, in 2010;
- strikes by air traffic controller or by train drivers;
- services accessible *via* Internet blocked by virus attacks that saturate the network and/or servers (*e.g.*, mass spamming);
- the Orange July 2012 mobile phone 'crash' (but it should be added that nearly every telecommunications operator has known the same misadventure!) (2).

The potential danger of these kinds of breakdowns or dysfunctions, in terms of human lives but also in terms of economic factors can be quite considerable and this leads us to address the question of the principal factors of vulnerability for LSTSs and their possible evolution.

LSTSs are becoming increasingly complicated and even "complex"(3). Thus, mobile telephony and more recently, Voice over Internet Protocol (VoIP) have 'complexified' the telephone system, where originally there were only fixed line handsets. The installation of millions of photovoltaic solar panels on Europe's rooftops is increasing the number of production points from the figure of one thousand (main power stations) to millions and even tens of millions of production points. Moreover, these LST systems lead to a set of inter-acting materials, software and sub-systems each with very variable life expectancies, ranging from several years to several decades, which situation, alone, leads to questions of component compatibility, maintainability and/or replacement. These three factors contribute to an increased overall degree of complexity (4 & 5). Having said this, we can easily understand why we assert that the LSTSs are "systems of systems". In addition, the component parts can be replaced, or modified (*e.g.* simply by installing an upgrade version of the software) or new services and or components can be added to the offer without inducing service breaks. Another factor conducive to complexity: the daily, in principle no-break, operation of the LSTSs requires the intervention of thousands of agents each with varying skills and job profiles, applying different specialties, who must all collaborate efficiently, exchanging operational informations in space and time in the context of different organizations and/or authorities. **The increasing presence of ICTs (Information and Communication Technologies) is *per se* an extra factor of vulnerability,** notwithstanding the creation of new services and possibilities, with better resilience and service performance levels. This applies at all levels, in the command/control of the systems, in the services offered or in the relationship between provider and clients/subscribers/users.

It is clear that surveillance, control, modelling and simulation of large systems have all progressed fantastically over five decades, through a multiplication of sensors on one hand and ICTs on the other, and not forgetting space technologies. The latter, notably, have enabled nigh-instantaneous point-to-point connection, geolocation, rapid optimization or more or less real time tariffs. However, it can be noted that when incidents and/or accidents occur, progress is not quite as fast. Moreover, modelling, simulation and studies of situations where a human factor has to be taken into account are difficult, at least not to say beyond reach, generally speaking (7).

Indeed, we must not forget that even if all sorts of automated systems are legion in LSTSs, **there is always a human factor involved somewhere** (6): presence of a human can prevent a situation from getting worse or lead to an accident, but the human factor can itself be a cause of a system failure, where personal responsibility, incompetence, wrong decisions, whether taken singly or by a group can be identified as the cause. Often this relates to the organization or its operational mode (*e.g.*, an organisation in which different parts are not communicating enough); the human may also become a factor of accident if the system was badly designed! More broadly, humans are in the circuit not only in day-to-day operation, but also intervene in the upstream decision levels, system and component design, policy decisions to upgrade, to invest, etc.

Moreover, we should observe that **simulating does not mean designing a system or deciding how a system should evolve!** But in these phases too, **humans are ubiquitous** in both the decisions as to technical options and to investments, for example.

**LSTSs are also becoming more and more inter-dependent, which again contributes to a higher degree of complexity and hence vulnerability:** the telecommunications systems need electricity to function, the control of the transport grid and distribution networks requires operational information relayed from the power stations … A certain number of LSTSs depend on GPS technologies: a breakdown in GPS services would amply demonstrate this point! More generally, we need only cite the growing role of information and communication in control/command systems and the growing role of Internet in the relationships established between LSTSs and client/users (8). This interdependence factor is revealed when an LSTS fails completely or in part only: other systems intimately connected to the failed system tend either to suffer in consequence their own form of failure or may also slow down the main system reset /correction of the failure rather than help solve the issue. Moreover, the information systems that address the clients, especially the real time systems are usually designed and dimensioned for 'normal' operational status and not for degraded or fail modes and this tends to annoy the clients no end. System information is an integral part of the system itself, so the question is: can we guarantee system service — including crises situations — by taking the latter into account at design stage?

**Other factors of complexity, particularly in Europe, deregulation, coupled with "europeanization"** have contributed to the multiplication of the number of participants who intervene with partly antagonistic logics and specific governance modes and protocols: in numerous cases, we have moved from "simple" situation of national companies with national level governance, a relatively stable statute, to a set of companies of varying shape and size, variable statutory situations in a shared governance mode somewhere between a European level and the national level (and, occasionally, regional). On top of this, there are regulatory and technical contexts that are changing rapidly and sometimes in a chaotic manner.

In fact, LSTSs are led increasingly to adopt open approaches, the control of which is highly debated, to enable new and multiple actors to propose new services *via* the systems, and, in a word, to offer them an 'added value'. Frequently these services are implemented on or over the existing infrastructure, on investments made previously by historic actors and even clients (such as on-line trade via Internet or shopping malls that are installed in railway stations): the system then becomes a sort of service platform (9) behind which the infrastructure becomes less and less visible to the users, except when it has a problem!

This subdivision of systems has clearly enabled innovation to foster and to achieve lower unit costs for certain of the LSTSs (telecommunications and Internet!). *A contrario,* it has led to new sorts of necessary investment difficulties (railroad systems or electric grid/network supplies) to the extent that none of the system actors has a sufficiently vested interest to invest, given their mission remits and that the market is not able to engage in long term investment programmes (10 & 11).

Beyond such general considerations, the individual situations of the LSTSs differ considerably because of mission assignments and their own history: thus the telephone systems, followed by the Internet, have always been international in essence from the start as were airline routes, while electric transmission grids and distribution networks tend to be national or regional (10).

Last but not least, the following factors increase complexity: **changing mentalities, as seen in enhanced individualism, higher self-reliance** (in transport choices and energy solutions), increasing distrust in Big Brothers who have the possibility to know far too much (or who already possess this personal knowledge), increased local aspirations and powers, in Townhall or the regional … and this trend is not specifically French. Indeed, there are serious consequences on the evolution of the LSTSs themselves: **should we favour either central or decentralised, distributed solutions? Reworded, the questions are: what balance should be sought and with what degree of co-operation? What should the distribution pattern for the responsibilities and the system's intelligence be?**

What are the keys to satisfactory financing? And, beyond this crucial question, we may also consider possible interference between local decision levels and one or several central authorities.

Observable changes in the electric system are typical, in France and elsewhere. Since the 1900s up to the beginning of the years 2000, there has been a gradual replacement of local networks fed from hydro-electric installations or thermal power stations each rated at several tens of MW, by a more global system (national or regional depending on the country's configuration), with power stations in excess now of 1 000 MW, interconnected by increasingly reinforced grid lines. This wide-spread system has enabled needs and means to be balanced and has induced scale savings. With the advent of renewable decentralised energy sources, such as photovoltaic panels, and in a near future decentralised energy storage facilities, plus a possibility to have local optimization (which notion still remains to be clearly defined!), we can see the premises of a global + local electric system that will enable a number of local degrees of freedom with a certain autonomy while preserving the advantages of cost and system security as can be procured in a globally shared system. Obviously, all of this presupposes that numerous relevant political, technical and industrial options are adopted …

**On a more profound level, we enter into debates about individual freedom and our conception of living in Society.** Internet and the services it offers are both an example of local and global success, but also epitomise, at least in part, these debates.

Having said this, there is an observable increase in the number of actors involved, through internationalization, liberalization, combined with a desire for personal or local self-reliance in a context of constant development of the LSTSs everywhere. Creation of "Authorities" or "Independent regulators" (*i.e.*, independent from political influence) is a new and growing phenomenon and is in keeping with the spread of LSTSs (11). In addition there has been a trend to multiply the number of sectorial policies, as defined by the regulators and/or relevant administrative authorities, and sometimes their actions are not coordinated (in terms of protection of the environment, energy savings, commercial competition). These policies are all justifiably concerning the LSTSs which are themselves multi-sectorial. This often leads to an over-regulation and an observable loss of governance coherency. Lastly, we must take note of a *de facto* **drop in the number of persons who possess an overall view of a given LSTS and this consequently aggravates the difficulties encountered in system governance.**

In this respect, the twenty or so auditions conducted by the NATF-WP showed that the questions of governance are crucial and common to the LSTSs that we investigated and analyzed (12 & 13).

Following these hearings, the NATF-WP was firmly convinced that the growing fragility, the ongoing and planned technical improvements, the operational transformations and above all the changes in governance could in the long run be sources of serious dysfunction. This is all the more true when we note the growing level of our dependence on such systems and an exaggeratedly optimist perception we entertain as to their resilience or 'robustness'. What this implies is not that there cannot be a governance endowing a sufficiently high level of quality to assure sustainable development of the systems, but that the issues to hand must be taken seriously and investigated properly by both the politicians and the industrialists, far more than it has been done this far, especially in the event of system failures or crises chains of events (2, 14 & 15). The NATF-WP is not advocating a return to centralised governance that belongs in the past century ; it just asserts that as in many other areas, besides technical creativity and innovation there is room for innovation in regulatory and organizational matters!

# ACADEMIC PROPOSALS & CONCLUSION

The foregoing considerations led to the formulation of **three academic proposals** that are addressed in a non exclusive manner to public authorities, regulation agencies and industrialist as policy makers, indeed to all parties concerned.

## First Proposal

**A serious twenty years return on experience (ROE) analysis should be conducted for each LSTS, without indulging in lip-service or any *a priori* considerations,** noting the changes that have taken place over these two decades of operation and governance and to identify the possible trends for the coming two decades. **This ROE should present an analysis, notably of:**

a. the evolution of services rendered by a given LSTS, its real and perceived quality, its accessibility and the direct and indirect operating costs (*via* the State budget) to the citizens and by extension to all users, as well as the options among which these customers can choose ;
b. the observed and noted service incidents, crises or dysfunctions, the level of acceptability for such incidents, the processes used to explain the occurrence (*e.g.,* resulting from slow system drift phenomena which means that they were not identified rapidly enough) and those that enabled a resolution

as well as the technical and/or organisational changes and lessons learnt; in particular, how risk analysis was conducted and likewise the process to assess the levels of investment needed;

c. the state of the given system in France, compared with other European countries or in the American and Asian continents, notably in terms of ICT integration as used for internal, functional operation and to accommodate the relationships with the user citizens;
d. the impacts of the system and its development on climate change and on the environment (levels of $CO_2$ emissions, dangerous products, noise generated … ) and the associate social acceptability;
e. the ecosystem formed by the various bodies, authorities, organisms and enterprises that provide system operation, the role of the State and local authorities, plus a comparison with other European and other countries;
f. the level of standardization with its industrial consequences and/or its attested capacity to join either a European or a global system: choices made in terms of standards have their consequences on the development of LSTSs in developing and least developed countries, which is a point that needs to be taken into account if our study on LSTSs were to be extended to cover developing and least developed countries;
g. evolution of direct and indirect employment generated by an LSTS, in operations and depending on location (jobs created in France by industrialists who are involved in international operations of LSTSs is just one aspect of the point made here).

## Second proposal

**In order to better control LSTS phenomena over the next two decades, in terms of the service rendered, quality and cost to the citizen/client/user as generated by the evolution of each LSTS,** the ROE should be completed, for each system, by:

a. **a cartography of the entities and skills available in France (but also in the wider, global context of Europe, the USA, Japan, China …) to ensure that we preserve a global view of the system in question,** for the purpose of observing, understanding, forecasting and modelling the possible evolutions of the system, its strong and weak points, the opportunities it presents and the threats it faces and how, *in fine*, these can be controlled, to better design and guarantee system governance at every level (national, local ...). The scale of the challenges facing our country when the objective is to attain and maintain proper day-to-day operation of the systems, leads naturally to having several skill-intensive locations for each, spread between public and private sector actors, between industrialists and academics, to enable exchanges and 'face-to-face' confrontation about methods to conduct the analyses and to define the options. One target of an inventory approach will consist of determining whether the teams in charge of the systems are sufficiently numerous, if they have proper access to the data needed and if their level of knowledge, know-how and skills is guaranteed, scientifically, technically, economically and sociologically speaking. An in-depth assessment will also be needed for the R&D work, development of new tools to be used in simulations, notably in simulations that include the human factor of men in the field, handling parts of the system. Such an analysis could lead public authorities, in certain instances, to reinforce or recreate new skill-intensive centres, this appearing as an a *minima* solution for the electric and railroad system, if we judge by the hearings the NATF-WP conducted. Enterprise/French or foreign universities/ could also be led **to set up one (or several) Regulation Research Centre(s) (CERR) that would work in particular on the design and implementation of resilient, adaptive and sustainable regulatory processes** (16)!

b. **a prospective thinking, with a projection to 20 years if possible, in a resolutely global context, complying with the tenets of sustainable development, as to the possible system evolutions**, to competing solutions and to the challenges and opportunities whatever their nature that will arise in our ever-changing society, notably in terms of urbanism and urban development;

c. **establishing priorities and sustainable policies orientations at a political level, taking into account past changes and the current situation** (analysed as per the recommendations of proposal No. 1) and also the results of the prospective studies (in 2.b), so asthe parties concerned:
   - can act appropriately, local authorities, regulators, industrialists, not forgetting the citizens and the cost for them (for example, when they insulate their homes, when they purchase photovoltaic panels, or a rechargeable hybrid vehicle ...);

- set creativity free so that newcomers to the LSTSs scene can propose new solutions;
- control quality and costs of LSTSs as needed to keep associate risk down to an acceptable level;
- update the analysis of the risks stemming to LSTSs and their interactions from vandalism or 'attacks' (equipment and/or software) is one of the priorities, whatever the situation; to carry out this kind of investigation with the appropriate level of skills and confidentiality, integrated specialists teams (systems, computer scientists, etc.) from the operators and administration, have to be involved in.

**A few comments on our two first proposals before the third one**

The combination of multiple challenges, the high level of investment needed generally for a LSTS and the associate difficulties of implementation (and lead times in certain cases) justifies that this sort of considerations and analysis be carried out periodically. This is the case today for certain LSTSs — for example the electric system — but in most cases only after a serious incident or even a crisis situation. It would be advantageous to do this on a more systematic basis, using rigorous 'open' methodologies, *viz*., accessible by all the actors involved.

These analyses covering 20 years experience and shedding prospective light on the next 20 years, should be framed with an appropriate level of independence vis-à-vis either the public or private actors, bearing in mind that they generally are powerful entities. These analyses could be entrusted to the one or several "neutral" bodies such as the French Parliamentary OPECST, the CESE (*cf.* Glossary) endowed as necessary to fulfil the remit. The National Academy of Technologies of France (NATF) could be invited to contribute. Whatever the choices made, the visions proposed should embody a principle of public interest and not a form of arbitration between lobbies …

A final thought here is that we must think at least in terms of Europe and not only Franco-French! A joint study could be undertaken by the NATF, with the sister academies of Euro-CASE and the CAETS and could prove extremely useful, given the European and global dimensions involved.

If those two proposals were implemented, our politicians would be in a better position to integrate long-term considerations, systemic risk and inter-system risks, in both design and evolution of the regulations, of the role of the regulators themselves, of the articulation between them and even market-place design (when there is a market.)

We can note that the coherency between the regulations of the various sectors is a factor that facilitates the role of the actors and the cost reduction. In some countries, a single regulator covers several LSTSs: in Germany, for example, BundesNetzAgentur (BNA) is responsible for electricity, gas, telecommunications, postal services and railroad transport.

Thus the industrialists engaged in this sector of activities would be able to invest more intelligently and to take action with more appropriate tie constants.

Such moves (to generate status reports and prospective studies) clearly provide an opportunity to encourage debate in 'main street' on LSTSs and the role they play in the Society: it is manifest that Society would gain through having better informed citizen/consumers who know about Large Scale Systems. Non specialists should be able to access information and comprehend what LSTS are about!

**The preceding remark leads on to the third proposal.**

## Third proposal

**LSTSs should be 'taught' in our education system in order that the next generations know them and appreciate them better.** In this way, the LSTSs, offering, as they do, new forms of employment will enable a better comprehension and appreciation for the underlying sciences and technologies thereby serving to demonstrate that they results from ongoing innovations in real life. Indeed, for all citizens the daily encountered interfaces with a number of scientific and technological disciplines, *viz.,* mathematics, physics, mechanical engineering, materials sciences and engineering, computer and software sciences, economics, social sciences … all of which are at the heart of LSTSs. This observation led the WP to make the following suggestions:

a. **to introduce some basic information about LSTSs in the high schools programmes**, *a minima* in the final year classes to begin with, covering the physics, the geography, the history of LSTSs and adding perhaps some interdisciplinary investigation assignments. There is plenty of scope here to introduce some pedagogical innovation, designed to help young people "think systems" which is very different from introducing them to the outside world of enterprise! These innovative programmes could be based on the local/regional environment with "live" examples of LSTS in operation;

b. **"systemics" and systems engineering studies could be valorised in higher education and research** — the idea here is not so much to create new systems (such as when you design a new aircraft from scratch) but to use new approaches which are in most cases undergoing development, relating as they do to evolution of today's major systems, notably the LSTSs;
c. **starting at school level, the notions of collective work, co-operation and inter-personal communication,** seeking person-to-person (or group) agreements to face and overcome initially divergent positions, can be seen as a dimension needed to ensure a fluid operation of LSTSs (and this statement is not restrictive!), that would help change the face of teaching practice, notably in secondary schools and higher education classes, to better arm young people to handle these situations. Group projects or class-room sub-group organization are part of the means deemed efficient if they are used appropriately;
d. **in more general terms, the challenges embodied in LSTSs should be used to help younger generations to 'dream' up solutions,** new services and to face the challenges as they arise and spread, and this can be partly achieved via the earlier proposals and partly by institutions such as Universciences [Paris], the Futuroscope near Poitiers.

## Conclusion

We are fully aware that the implementation of these three proposals calls for appropriate deployment of means. We are, however, convinced that the outlay is small in respect to the benefits that would accrue and by the very scale of the challenges ahead. If we were to prioritize our proposals, we would advocate the following four fields of specific actions:

a. produce an "atlas" of LSTS governance, their regulation functions and the relationships between levels of regulation (the CAS, *cf.* Glossary, could probably accept to fund this action);

b. make (and maintain updated) an 'awareness' study of the extent to which the operators of a given LSTS are prepared for the risk of other LSTSs failing (in all probability it would be the role of the SGDSN (*cf.* Glossary) to carry out these studies as well as others relating to inter-dependence factors among systems and how they are to be countered) ;
c. prepare LSTSs modules to be included in the final lycée year programmes (this would certainly be the prerogative in France of the ministry of Education's Inspectorate General); the National Academy of Technologies of France should be associated with this point and could usefully contribute to its success) ;
d. propose to the Boards of Euro-CASE and CAETS that they carry out a joint study.

We share the opinion that these thoughts could usefully be extended to address the case of developing and least developed countries.

**We hope the ambition to implement our three academic proposals, will be carried through completely and will thereby favour the development of Large-Scale Socio-Technical Systems operating in networks, for the benefit of French and European citizens alike, in the face of ongoing geopolitical change. We must maintain or recreate the conditions that will definitively enable our children to benefit fully from these magnificent and renewed fruits of human activities with their constant interactions involving Mankind, Society, sciences and techniques, *viz.*, the LSTSs.**

# APPENDICES

*Given the extremely wide scope of the subject matter possible, readers will readily understand that the following appendices do not lay any claim to being exhaustive! Their primary purpose is to illustrate and analyse certain important points somewhat deeper.*

## 1. How should we define LSTSs?

Let us define how we understand our LSTSs and what “limits” should be assigned to each:

- **the electric system** — we can say that the electric system runs from plug outlets at home to the power production stations, including the storage facilities, distribution and transmission networks, not forgetting grid dispatch, control and management centres!
- **the railroad system** — we can say that this system comprises the railroads, the rolling stock and control services and centres ; we may sometimes be tempted to see the railroad system as part of an overarching “transportation system”, especially so when we wish to study questions such as inter-modal transport or door-to-door delivery systems ; but given the inherent difficulties to do the relevant analysis and to carry out implementations of intermodality in this day and age and our Society, it is a justifiably self-standing LSTS ;

- **the air traffic system** — this covers airports, aircraft and air traffic control ;
- **telecommunications** — in 1970 we might have been able to limit the definition to fixed wired telephone networks! But even if we include the mobile phone networks, that would still constitute a too restrictive approach that would have no well-defined frontier with 'voice over IP' — Internet which can no longer be left out either. Probably the right solution is to consider **"the major digital technology system" ;**
- **the road system** — does it merit the term "system" given the connections that exist between roads and vehicles? When "Bison Futé"[2] was launched June 30, 1976 in France, this new road traffic aid symbolized the beginning of a changeover from a "simple" network to a system. The answer here became totally positive when ICT were introduced, and real time intelligence reached the road side, via sensors and cameras ..., was mounted onboard vehicles and enrich the functionalities of the road surveillance centres. This we could qualify as the "5th generation roads" the previous versions being donkey trails, Roman roads, McAdam's[3] surfaced roads and motorways.

System users (*aka* clients, subscribers, consumers or citizens, depending on the given context), act directly connected on the electric system, on the telecommunications system, *via* Internet and on the road system. In contrast, they do not act directly on the railroad system or air traffic system. But in every instance, they do use the "LSTS Information System", which has significantly modified the "customer relationships".

If we now lay out a tentative definition for LSTSs, there is *a minima* a temptation to look for commoncharacteristics !

Let us assert that LSTS provide a "unified service" and that they are:

- **systems** — The links within LSTS are mainly technical, but it will be seen that organisational, economic, industrial and legal questions are largely prevalent. These links are sufficiently strong to state that the parts cannot be studied without referring to the whole system ;

[2] Literally "The smart buffalo" , similar in concept to California's Beat the Traffic facilities–cf. http://www.fhwa.dot.gov/Trafficinfo/ca.htm

[3] Scottish engineer John Loudon McAdam, around 1820.

- **large-scale, in time and spatially (which we sum as 'Large', in the acronym LSTS)** — For those systems that we studied, the spatial scale was France for some, but now it is Europe or even the world. The time scale plays a vital role: LSTSs are designed and "operated" to last, indeed to last forever;
- **socio-** — LSTSs involve **all citizens** and act as major supports to aid Society to function correctly. We can see ourselves as concerned both at national and local levels, but also as clients/consumers/subscribers …
- **technical** — LSTSs are materialized in technical networks where there is a growing fraction occupied by the ICT component.

In fact, this "definition" is more a guide than a definition *per se* … even if we decide what an LSTS is, which corresponds to our "definition"!

Other expressions come likewise to mind, namely:

**Critical infrastructure:** "the physical and information technology facilities, networks, services and assets that, if disrupted or destroyed, would have a serious impact on the health, safety, security or economic well-being of citizens or the effective functioning of governments in EU countries" (Excerpt from: Communication from the Commission of 12 December 2006 on a European Programme for Critical Infrastructure Protection [COM (2006) 786 final –*Official Journal C* 126 of 7.6.2007].

**A vitally important sector of activities** — as mentioned in 1° of II in Art.1 in the French Government decree n° 2006-212 dated February 23 2006 — security factors in vitally important sectors of activity *viz.*, activities that pursue the same aims, which:

- 1° Appertain to production and distribution of essential goods or services:
  a. satisfying the life-sustaining basic needs of populations;
  b. or relate to the powers invested in the State authorities;
  c. or to the proper functioning of the national economy;
  d. or maintenance of an appropriate level of national defence potential;
  e. or national security;
  Where it proves difficult to substitute for these activities or replace them.
- 2° Or represent a serious threat for the populations.

*[It will be noted here that the terms system and network do not appear in this decree].*

These expressions are also to be found in official documents that address the question of our Society's dependence *vs.* LSTSs, notably in the light of the increased role played by ICTs and the multiplication of inter system relationships.

The same type of definitions is to be find for example on the site of the US homeland security department: http://www.dhs.gov

## 2. 'Resilience' of the Telecommunications system, the light and shadows of ICTs

The overall system control of France-Telecom France was organized to be fully automatic and distributed (barring a major crisis event or situation):

- the real time regulation takes place in the routing systems that include auto-limiting traffic devices, working alongside partial outage priorities that apply as a function of the flow demand on the networks (data traffic is less prioritised than voice traffic, etc.);
- the network core is 'oversized' (nonetheless, it accounts for only 20% of total operating costs) and therefore is designed to accommodate daily (and exceptional) traffic demand variations; the extremely high growth rate of traffic (doubling up every year), requires the national Operator to reinvest constantly in terms of handling capacity and for this reason the network was built to meet "peak" conditions, as was the electric grid and networks;
- system surveillance is centralised nationally. In crises and critical events, the interconnected operators are exchanging in real time the useful data and informations. The risk of a total system collapse is very low since an increasing fraction of the interconnections go *via* the world wide web (www), which is a self-healing and meshed network.

Having said this, the system break-down that took place in July 2012 amply demonstrates that the risk of a major collapse is not zero! Other big national or international operators have been faced with similar major collapse situations … or will potentially be faced with them some day!

The July 2012 break-down has its origin in a choice of the regulator to 'improve' service quality, *i.e.*, enabling the customers to keep their former number when changing their service provider (operator). Before and as a function of the number prefix (06, 07 …), the network routed the call directly to the various server stations, placed in a redundant configuration. To ensure the 'portability' of the number, in the case of a contractual change of operator, the servers of the former provider reroute the call to the servers of the new operator: the end-result was to insert an additional layer in the way calls are handled and routed, and moreover to introduce a new interdependence between the networks of competing operators — all of which serves to show that the introduction of a service 'improvement' can sometimes weaken the systems!

More important was the fact that a new real-time, rerouting software package has to be readied and implemented. This software package was developed by a single world-market supplier and had a 'bug' in a new version when installed. The system redundancy factor among the telecommunications operator was made inoperable by this "common operator mode", embodied in the new software!

Since these events, the market place offer for this sort of rerouting software has grown, and the telecommunications operators now take the precaution to ensure that their server stations do not all use the same package.

We can complete this appendix by adding that the return on experience among operators on this and similar problem areas is not made easy by regulation, inasmuch as the latter limits exchange of data and other useful informations between market competing companies.

## 3. Distinguishing between complicated and complex

System studies often use the terms "complicated" and "complex", even though their Latin origins are different: 'complicated' is used to refer to a whole comprising a large number of component parts that is hence difficult to understand, while 'complex' refers more to a system whose behaviour is difficult to predict from the behaviour of the component parts.

In regard to the notion of 'system', there is an abundance of scientific and philosophical literature available. We limit our definition to that given by

J.-L. LE MOIGNE[4], indicating that the notion of 'system' is itself recursive in nature and that any system (at least potentially) is a "system of systems":

"A system is a complex entity, made up of a number of identifiable components that share certain relationships. These component parts can be seen as sub-systems, which implies that they also are to be considered in the same category as the whole systems to which they belong. Again, a sub-system can be subdivided into lower order sub-systems or can be treated (at least provisionally) as an un-decomposable system. The main idea to be retained is that a system possesses a higher level of complexity than the parts, in other words, it possesses properties that cannot be reduced to the sum of the properties of the parts".

To finish this section, an excerpt from a paper authored by Herbert A. SIMON, *"The Architecture of Complexity"*, published in the Proceedings of the American Philosophical Society, Vol. 106, No. 6, December 1962:

"I shall not undertake a formal definition of "complex systems." Roughly, by a complex system I mean one made up of a large number of parts that interact in a non simple way. In such systems, the whole is more than the sum of the parts, not in an ultimate, metaphysical sense, but in the important pragmatic sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to infer the properties of the whole".

## 4. Increasingly complex time-dependent dynamics to coordinate: two examples in electric systems

In May 2012, around 13h00 and for the first time, in Germany , the photovoltaic (PV) output exceeded 22 000 MW, whereas at both 05h00 and at 22h00 this decentralised form of power generation was naturally strictly zero. The PV power generation that day and hour amounted to 1/3 total German power generation. The dynamics of using the solar power source does not match demand patterns, which do not reach a peak at mid-day in Germany. The random characteristic

[4] Jean-Louis Le Moigne is a French specialist on systems theory and constructivist epistemology.

of PV production, *inter alia*, requires the power operators to maintain and even develop conventional power producing capacity: the strongly 'volatile' feature also calls for rapid, flexible change in power output from other generation sources (and storage facilities) ; normally, grid flexibility is obtained by hydroelectric installations, thermal power stations (gas, oil and coal) and also, in the case of France, from nuclear power stations.

Day-to-day coordination of production capacity from 'fixed' units as mentioned above, is not the only area where things have become more complex. Wind turbine output, as exists already and forecast in numerous countries, has an impact on the grids: it in fact needs new network investments. If it is possible to erect a large wind farm of turbines over 3 to 4 years, or a combined gas power station, the reinforcement needed in the grid to accommodate this new production takes from 7 to 10 years, given local opposition just to build new pylons — and to acquire the necessary authorizations! A case in point here is that of securing the electric power supply along France's Mediterranean coastline in the PACA Region. The practical difficulties encountered do not encourage the producers to invest nor does they help make the supply more secure or safer.

## 5. Reconciling the time constants in road haulage

The road transport system has three components:

1. the vehicles, dependent on the manufacturing-assembly automobile industries ;
2. the road infrastructures that depend on civil engineering and operations on authorities such as the [French] 'regions' and/or the 'departments' and/or motorway management companies ;
3. road and traffic operations.

The industrial sector, the civil engineering concerns and road and traffic operators, although obeying different logics are nonetheless interdependent.

If we now consider the interactions that take place between:

- the road transport system ;
- the activities of the society (industry, services, housing ...) ;

in essence the balance of activities between offer and demand, then we can address the question of traffic flow on the network, *i.e.,* to enable the mobility of people (passengers), supply of goods to factories and equivalents and distribution to end-customers.

If we prefer to consider the time constants, the we have three distinct levels:

1. **short-term (daily):** traffic is the immediate resultant of comparing current levels of activity and the current transport system parameters;
2. **mid-term (several years):** the operator can adapt the infrastructure — within certain limits, naturally — and his operational mode to traffic evolving conditions via investments; thus, a variable toll gate policy based on real time tariffs can become a road system tool;
3. **long-term (ten years or more):** volume and rhythm of activities themselves can evolve in accordance with policy decisions, notably decisions as to where installations will be located, which are taken as a function of the service offer made by the operators. Land management and urbanism are policies that require long range planning …

How can we reconcile these three time factors? The bottlenecks and traffic jams, which are so familiar to some drivers at the same times and places, show that it is difficult to reconcile the three factors.

An operator should aim at attaining a business "profitability" but cannot decide alone those infrastructures he needs and even less about where the activities will be located, this being the responsibility of other societal actors (politicians, industrialists, promoters, citizens) who cannot do without technical network operators.

In contrast, the "market-place" alone cannot co-ordinate the three components, *viz*., the vehicles, the infrastructures and operational facilities and services. The final point to be made is that it is not easy at all to simulate globally how such LSTSs actually function …

We might add that this comment applies also to a large extent to the railroad system.

## 6. The human factor in air traffic control

There are two categories of person closely concerned and at the heart of the system: the pilots and the air traffic controllers.

Both categories are engaged in constant dialogue and exchange of information *via* systems that communicate with each other (the onboard flight management system (FMS) and the flight plan followed by the controllers) but are unable alone of ensuring a safe flight path for the aircraft in flight.

One of the main issues for the next few years will consist of providing these two categories of actors with data coming from flight deck — ground exchanges, that will enable the air traffic controllers to have more information to hand and allow the pilots to have a higher degree of flexibility to adjust the flight path (the idea here is that aircraft — like boats — will be able to fly just about everywhere, *viz*., minus no-fly zones, of course!).

This technological progress goal is to raise safety by a factor 10: the increases in air traffic forecast will only be socially acceptable if the number of airline accidents does not increase and will even continue to drop (even as traffic rises, *cf.* appendix 11 below).

Such technological changes bring with them a series of serious ergonomic problems, especially the degree of "imbrication" of professional qualifications that require specific training, both for pilots and air traffic controllers, on one hand, and the industrialists who design, assemble and supply these air traffic systems.

## 7. The move towards modelling and simulation that cover systems including human beings

Over the past 50 years — notably through use of increasingly powerful computers — modelling and simulation of physical and chemical phenomena that accompany man-made systems have become commonplace. Without going into details, which would be superfluous here, applications to Large Scale Systems can still encounter two stumbling blocks:

- the computing power available is still too low to enable fine static or dynamic multiphysical simulations — having said this, computers are gaining in power rapidly;

- non-availability of data, whether we are talking about measurement made on real observable phenomena or data about Society, for example; this unavailability factor can be real or arise as a consequence of specific competition or legal situations.

We can note that measurements on the real world have progressed by several orders of magnitude, both in quality and in quality in many domains over the past 30 years.

Likewise, and more recently, we see considerable progress in gathering data about Society: measurements using space technologies, data mining *via* Internet … and these continue to develop. We shall avoid here addressing the issue of data floods — which is amply covered in other papers, but they do relate to LSTSs inasmuch as the latter are one of the sources for data generation and their everyday operations call for the handling of huge quantities of data.

We may add that questions of uncertainty related to data (notably for physical measurements) call for probabilistic approaches. There are also specific approaches for system failure problems (so-called 'failure tree diagram' …).

There are indeed many other models and simulation protocols, outside the domains of physics and chemistry (OR, *viz*., operational research, for example). We shall not go in any details here.

Taking the human factor into account, that of the user's reactions and associate modelling is a totally different challenge. Models have been forthcoming when only a part of a given human behavior is concerned, where an experimental proof can be given. This is the case, for example, for aircraft pilots and for nuclear power station supervisors.

In order to study deeper the LSTSs, one must find ways to represent human behavioral features that are far more complex (the single person dimension, inter-person exchanges and actions in the case of shared decisions, the organizational dimension to analyze crowds, for instance …). This indeed is a research domain in full expansion, in which:

- the national defence services (notably the Americans) are leading;
- various biological tools (simulation of insect societies) and others used in 'distributed AI' (artificial intelligence) can serve as sources for new ideas and new models;

- methods and algorithms used in multi-player video games are also included in this area of research.

There are already simulation software packages on the market with "agents" that can also represent human beings with 'modelled' behavior patterns. However, we must bear in mind that they are simulations and that when we "run" them, we may see emergent behaviors that simply have not been envisaged by the designers (*cf. Appendix 3*). A doubled-edged question then arises: is this emergent behavior an artefact itself, generated by the model or is it a phenomenon that could be real? And finally, could its occurrence have been forecast?

## 8. Various types of systems interdependencies

A distinction can be drawn between:

- **real-time (or immediate) dependence:** the electric system needs input from the telecommunications system for the control functions; likewise, the telecommunications system — and Internet, more globally (?) –will only operate if there is a proper electric supply; again, for the railroad system (locomotives, signals); practically speaking the control systems of LSTSs depend more and more on recent ICTs and therefore also on electricity;
- **delayed dependence (several hours, days, weeks …):** in many countries, the electric system depends on gas supplies; the road system and air traffic on fuel supplies, again dependent on road tanker transport; a road system can often be saturated when railroad drivers go on strike! Maintenance today is increasingly dependent on GPS data;
- **long-term dependence (several months or more):** these are the dependence situations of LSTSs with respect to the suppliers (e.g., those that provide nuclear fuel needed to generate electricity in nuclear power stations, computer equipment suppliers who sell and install system control servers …

System control centres (control/command) in the case of LSTSs generally are in need of a real time, no-cut power supply and operational data coming in over the telecommunications lines which constitute "transverse" LSTSs.

Network meshing, implementation of double or even triple redundancy factors, storage (gas, for example), back-up facilities (diesel engine generators, for example), are means that can compensate for certain LSTS failures impacting other LSTSs – at least temporarily and sometimes only on a local basis.

Beyond this observation, mutual dependences can lead to a drop in life standards and comfort, when an LSTS in a city fails! All forms of dependence are conducive to higher system vulnerability, notably faced with threats of vandalism, sabotage, terrorism, all threats which require further studies and preventive measures taken by the authorities concerned and the system operators, all of which should be updated on a regular basis.

## 9. The LSTSs as technical platforms to accommodate new actors

Excerpt from: "Regulation of electronic communications in France and Europe"[5], interview of Nicolas Curien[6] drafted by Géraldine PFLIEGER, published in FLUX No. 87, 2012/1:

"This ISO layer [services and utilizations], potentially the most 'open' to competition, lies at the interface with the end-users , the network users. In the sector of electronic communication, it brings together all the applications that can be accessed *via* the network: in the beginning, of course, there was only one application — voice telephony ; today we have a host of off-the-shelf "apps" *via* Internet. This wide diversification of the utilizations, certainly one of most striking phenomena in the ongoing digital revolution, that began at the end of the 1970s, when data transmission services appeared alongside the voice telephone services. The network, with its infrastructure and info-structure, was no longer a unique point to point service, with which there was a confusion of identity, in a highly natural manner, it might be added. But then it became an intermediation locus, a technical

[5] Original title "La régulation des communications électroniques en France et en Europe": interview with Nicolas CURIEN.

[6] NATF fellow.

platform that enables links to be made between suppliers, users of telecommunications services. This radical change, embodied in the ubiquitous and the current explosion of the offer of on-line services, has in fact generated a new paradigm: the network is no longer a service support, and has become a 'place' (akin to a market place) for the exchange of merchant and/or non-merchant goods between socio-economic agents."

## 10. Three types of GSST

We can conjecture that LSTSs can be placed in one of three categories (in Europe, at least):

- the system can be organized as a set of networks (corporate entities) that operate at a European or a global scale. These companies are brought together under a common regulatory frame designed to ensure a fairly uniform European or global service: this indeed is the case for telecommunications systems and for civil aircraft in flight — but with highly different type of liaison in one and the other case;
- it can also be composed of companies that operate essentially until recently in a national frame, yet still complying with European regulations as those above. This currently is the most common situation: the electric supply services or the railroads for example;
- the 3rd case possible – that of a "native" European leadership – has not (as yet) come to be. The Galileo system, under the overarching control of the European Commission and which is currently being deployed is no doubt what we have as close to this category as possible.

The situations in the second category correspond to those that comply with non-stabilised governance and organisation. We can observe that there are sectors where there are successive European directives that endeavour to create European systems using a liberal open market approach. The evolution under way for the railroad system is fully embodied in a statement by NATF fellow member, J.-Cl. RAOUL, when he said at our audition:

"Networks operated and managed by separate authorities in each country and few inter-connections, special appropriately gauged rolling stock to cross the frontiers, a change of driver at the border-line… the European Commission has asserted it would like to see a homogeneous European rail network, open-market in terms of trains and suppliers".

**Seen in this light, the question arises: will the second category disappear? The question is all then more relevant that faced with the national level on one side there is the rising power of local/regional level on one hand and of the European level on the other…).**

## 11. Consequences of deregulation on investments: the case of the electric system

As and when a deregulated market is implemented, short term costs should appear. In any countries, the political dimension of any electricity bill — at least for residential users — implies that regulated kWh prices or even constant pricing policies are maintained that reflects to a greater or lesser extent the average costs over a given period of time.

Moreover, the market-place makes no provision for long term optimization and does not allow you to make development of peak equipment a profitable business. There is where "pluriannual investment planning" comes in, to quote the example of France, the calls to tender by the RTE national grid operator for new production plant, possible creation of a so-called capacity market (to ensure that there is always enough stand-by peak production capacity to hand). These new approaches, alongside others, are being experimented and even implemented in many countries, not only in Europe. Whatever the outcome and development here, this is not yet being done on a European scale and those practices are not yet stabilized rules, which alone does not foster or encourage industrial investments. In comparison, having a local, a national or a regional monopoly is easier to manage inasmuch as it is the same actor who disposes of the consumption and generation data and associate long-term forecasts … but they do not necessarily encourage creativity nor even a need to seek savings if the monopoly in question is not totally "virtuous".

Furthermore, European regulation is based on the 20 th Century electric system with its 4 layers: (generation (centralised), the HV grid network, the MV/LV distribution networks, the electric business *per se*). Current directives enforce increasingly clear boundaries between these four layers. Now, however, with distributed generation (*e.g.*, from photovoltaic arrays) — the same applying in the long term to energy storage — does not fit in well to the model. To be more explicit, the new forms of deployment concern the business and distribution layers, the distribution network must invest to become a safe "circulation" network. Moreover, the tools available for energy control, peak smoothing, for example, by reducing or displacing the load factor, turning on load saving of consumers are also on either side of the business/distribution boundary: the very existence of this boundary hampers the experimentations of smart grid concepts and, more seriously, call the investments on possible smart meters themselves into question, where it is difficult to ensure profitability on only one side of the boundary. "Crossed subsidies" between layers in the model occasionally could be attractive! They enabled the electrical utilities to use their investment potential according to given periods, to adjust their generation capacities or to develop the networks, for example without having to balance their business in either sector. This can be translated by stating that there are real needs for creativity when it come to implementing new forms of regulation.

## 12. Air-traffic control in Europe

European 'airspace management' was derived firstly from the national air control systems. It is currently segmented into sixty-seven air spaces and, what is more, has little integration between civil aircraft and military aircraft systems. This leads to some negative consequences, in terms of safety, total traffic capacity and total cost of planes.

In order to remedy the situation, and also to absorb increased passenger (and freight) traffic, Europe is now supporting the Single European Sky programme, the purpose of which is to establish a "no break" sky. The Programme calls for two regulatory "packets" and on the findings of the EC Research Programme SESAR (Single European Sky ATM Research) run by Eurocontrol (representing thirty-eight

European countries). The introduction of the concept of Functional Airspace Blocks (FABs) should lead to a change in paradigm enabling an air traffic controller to follow an aircraft beyond the national boundaries thanks to a Common Operational Picture that would be accessible to all concerned. The plan is to have nine FABs that will replace the 67 airspace sectors currently used.

The SESAR Programme is subdivided into three rolling phases: the definitions phase (2004-2008), the Development phase (2008-2013) and the deployment phase 2013-2020 and beyond. The last-named phase calls for production in quantity of new systems and also the implementation of the new harmonized and interoperable air traffic management infrastructures that will lend a very high level of efficiency to European air traffic control and system management.

The time scale assigned to the SESAR Programme illustrates the characteristics of airspace LSTSs. There are numerous actors involved: the airline companies, private pilots, civil aviation authorities, ministerial departments, including those in charge of defence questions, airport management, certification bodies, industrialists, defence sector industries and last but not least in our list, obviously, the passengers!

The number of actors, their priorities which are sometimes different even contradictory with respect to the evolutions they would like to see enacted, can act as a brake to technological progress and to their deployment and this factor alone leads to objectives to reduced investment and operational costs that are rarely achieved.

## 13. Impact of governance: the example of the construction of a European railroad area

Historically, national railroad systems were made with different specifications and gauges, because of militaro-industrial reasons. The European Commission at the initiative of several Member States each seeking solutions to endemic rail transport congestion, decided on a programme to create railroad packets, *viz.,* with the aim to build up a (trans) European Rail Network Area that would be integrated technically and from the point of view of the rail traffic operators. The latter and rolling stock manufacturers would thereby have open market possibilities.

We can note in this context:

- the separation between the traffic operators and the infrastructure management authorities with the creation of RFF (Réseau ferré de France) in 1997, to cite the case of France ;
- the opening of the international (rail) services as of 2001.

The objective of attaining network and rolling stock interoperability is obviously technical and industrial in nature, but also includes social and financial aspects that go beyond short term considerations, for instance by the need to replace some rails themselves and some wheels. Likewise for the signals used, for system voltage and frequencies, etc. The first practical work-site for interoperability was that for the high speed trains, facilitated doubtless by the fact that these trains were recent developments. These changes were implemented by way of a directive 96/48 which embodies two principles:

- definition of relevant sub-systems (infrastructures, fixed and rolling stock) ;
- for each sub-system, definition of certain interface conditions requiring compliance, called the "Interoperability Technical Specifications" (ITS), using a certification and assessment system that is independent of the operators and industrialists.

Consensus on the ITSs (issued as EC regulations) was achieved in 2004 after several intense years of activities of some 500 experts representing the operators, the train equipment industrialists, then infrastructure managers, representing all 15 Member State Europe, at that time.

The consensus was attained by:

- addressing the issues more from a technical than from a legal angle and by a relatively restricted perimeter for applications (the high speed train sub-system) ;
- a convergence of interests of the railroad rolling stock providers (Alstom, Bombardier, Siemens, who all have a vested interest in seeing development of the rail market and who represent approx. 50% of the world market) ; this alone encouraged some operators who were somewhat reticent in the early stages of discussions ;
- making sure that the use of the EC Cohesion Fund (for major transportation infrastructures) is compliant with the ITSs.

## 14. The blackout of the European electric system Saturday, November 4, 2006 and the lessons learned

Following an intentional power cut on a VHT line – this outage allowing a large ship to pass a section of the river Ems in North Germany – more than 15 M Europeans customers (5M in France) experienced a 30 min to 1h total power blackout.

The analysis conducted on the blackout showed, notably, that:

- E.on-Netz, who was responsible for this particular section of the German grid, apparently had not complied with the basic rule called "n-1", *viz.*, the grid operator must constantly check that if a key element of the grid, whether it is a power station or a major line, is suddenly placed out of service, the load transfer functions to the remaining grid lines do not lead to a domino effect collapse of the entire system;
- available wind generated power was not precisely known by the grid dispatchers, since the handing over of this information was not a constraint on wind-farm owners;
- the disconnect/reconnect procedure of the wind turbine output resulting from change in grid frequency consequently to the incident made the situation worse and complicated the job of finding a solution. For instance, when you disconnect the wind-farms because of a drop in grid frequency in the case of a drop in generation , then this shortfall is made worse by losing the turbines; moreover, the automatic reconnection procedure following a rise in grid frequency due to excess power being injected, again makes the situation worse!
- the real time communication among the network operators was inadequate to the situation and the training of the dispatch officers in the context of decentralised power production definitely needs to be reviewed and upgraded.

This power system breakdown — the most serious to have taken place in Europe over the past few decades — led the operators of the European power production and transport 'universe' (comprising regulators, grid operators, the Union for Coordination of Electric Power Transport) as well as the politicians (national and European):

- to modify the European organization: with the creation of the Agency of cooperation of Energy regulators (ACER) and the association for European Network of Transmission System (ENTSO-E) with a definition of their role. *Cf.* https://www.entsoe.eu/ ...

- to modify the "grid code" which stipulates exactly the rules and regulations with which the power producers, notably, must comply.

Moreover, five Western European transport operators decided to set up CORESO (at the initiative of RTE) which is a centre for co-operation that has the remit to prevent incidents such as that of 2006 reoccurring. By bringing together the engineers of several countries, CORESO can simulate the operation of the European network as a whole and can propose, if needed, solutions to remove issues of network congestion by using the grid lines of several countries, whereas the national dispatching officers are only authorised to do so using the grid lines of their respective countries. This widening of the scope for handling power congestion situations is analogous to the changes observed in Europe's air-traffic control (*cf.* Appendix 9) to the extent the european electric system is effectively "an aircraft with several pilots in the cockpit".

This also serves to illustrate the process of the consequences of a case of crisis management, that resulted partly from other changes such as the increasing amount of available wind-power that is generated but not dispatched via the grid.

Lastly, it can be noted that E.ON Netz has now been taken to court because of the Nov. 4, 2006 incident and might also find itself indicted by French customers who became victims of the power outage and to whom RTE served the cause as being "unforeseen, unpredictable events" *i.e.*, a force majeure. The responsibility of the national dispatching officers may also be engaged if it can be proven that they did not approve investment proposals that would have made the national grid safer and the power supply secure.

## 15. The fragile aspects of Internet (the world-wide-web)

Notwithstanding its past success and a solid basis — and we can recall that the IUT (International Union of Telecommunication) has always been able to successfully build up a world system in this domain — and even continued investments after the Internet "bubble", the system still has some fragile features and uncertainties that stem from:

- industrial strife in the USA between network and content suppliers ;

- concerns raised in Europe about the strong American influence in terms of Internet governance and on the circulation of contents ;
- the more general question of data pirating and ongoing debates on protection of personal data, etc.: consequences on the creative sector businesses, on Internaut surveillance ;
- even more generally speaking, questions of malware, risks of sabotage *via* the Internet nodes and access points which increase steadily in numbers to all sorts of service, including computer operated client services which when blocked, force an outage on all the associate billing circuits.

On a different level, the observable slowing down of economic growth (in terms of value produced, GDP) in the more advanced countries, consequences of the drop of unit costs of fixed telephony and stagnation of the ARPU (Average Revenue Per Unit) of mobile phones in an already saturated market is not as yet completely offset by revenues from high data flow offers and data transmission and handling services. This might also lead to limited future investments that would in turn weaken certain system components.

## 16. A few thoughts about the actions that could be assigned to a Research Centre on Regulation

**Over and above necessarily long range training schemes, the aim is to feed the LSTS regulation decision processes by a potential for studies and research at a level compatible with the stakes of the challenges.**

Thus, the creation of one or several **Regulation Research Centres (CERR)** would be a way of contributing to creativity and intelligence in regulatory questions. The annual budget that could be allocated, several tens of millions of euros to create a centre would no doubt be several orders of magnitude lower than the profits/savings it would generate!

Through its multidisciplinary and international characteristics, such a centre would be in a position to develop, on one hand, a “system oriented vision” and, on the other, to capitalise on skills and memory as needed for the systems:

- the Centre could acquire or even develop a high level simulation and visualization tool to follow the evolution of LSTSs, issues, vulnerability, options, impacts ;
- the Centre would have an access to LSTS data to conduct its research (excluding all forms of commercial activity) ;
- the Centre would be able to develop an in-house expertise on regulatory questions and simulation of consequences on the decisions and options.

The operational feasibility of the proposals, the financing of the studies and the credibility of such a Centre will be largely enhanced through the implication of the industrial operators themselves, in terms of:

- financial arrangements ;
- access to data sources ;
- certain field experimentations ;
- over and above the implication of the regulatory bodies and the academic institutions, notably the Universities and similar institutes who work on engineering and operation of LSTSs.

The scope of the challenges leaves room to envisage installing several Centres throughout Europe that would thus be able to investigate several LSTSs simultaneously. Thematics related to system security and vulnerability have certainly to be prioritized.

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# SELECTED INTERNET SITES

*The Internet sites of industrial scale suppliers and major system operators, inasmuch as they are easy to find, are not included in this list.*

## GENERAL SCOPE

http://ec.europa.eu (European Commission)
www.strategie.gouv.fr (French Government Strategic Advice Council)
www.dhs.gov (US Department of Homeland Security)

## SPECIFIC TO RAILROAD SYSTEMS

www.rff.fr (France)
www.regulation-ferroviaire.fr (France)
www.rail-reg.gov.uk (United Kingdom)
www.irg-rail.eu (Group of European railway regulators)

## SPECIFIC TO AIR TRANSPORT SYSTEMS

www.iata.org (International Air Transport Association)
http://easa.europa.eu (European Agency for Safety in Aviation)
www.eurocontrol.int (European air traffic control)

## SPECIFIC TO ELECTRIC SYSTEMS

www.cre.fr (Commission de régulation de l'énergie - France)
www.rte-France.com (Réseau de transport de l'électricité - France)
www.coreso.eu (Europe)
www.entsoe.eu (European Network of Transmission System Operators)
www.caiso.com (Californian Energy Operator)
www.acer.europa.eu (Agency for the Co-operation of Energy regulators)
http://ieeexplore.ieee.org (IEEE's electronic library, restricted access)

## SPECIFIC TO THE ROAD SYSTEMS

http://www.bison-fute.equipement.gouv.fr (French Government Road and Travel Advice Information Centre)
www.worldhighways.com (Journal - USA)

## SPECIFIC TO TELECOMMUNICATIONS AND INTERNET SYSTEMS

www.arcep.fr (France — regulation)
http://berec.europa.eu (Body of European regulators for electronic communications)

## SPECIFIC TO RESEARCH AND TEACHING SYSTEMS

media.eduscol.education.fr/file/SVT/16/2/SVT_Fiche1_20916.pdf (French Ministry for Education — fact sheet on sectored teaching)
www.iscpif.fr (Institute for analysis of complex systems in the Île-de-France Region)
www.santafe.edu (Santa Fe Institute, specialised in the study of complex systems)
www.universcience.fr
en.futuroscope.com

# GLOSSARY

## ACER – AGENCY FOR THE COOPERATION OF ENERGY REGULATORS

The Agency for the Cooperation of Energy Regulators (ACER) is the European Union body created by the Third Energy Package to further progress on the completion of the internal energy market both for electricity and for natural gas. *Cf.* http://www.acer.europa.eu/The_agency/Pages/default.aspx

## BLACK-OUT

A black-out is a large scale power failure cutting supplies typically to several million or tens of millions of consumers.

## CAETS – INTERNATIONAL COUNCIL OF AC ADEMIES OF ENGINEERING AND TECHNOLOGICAL SCIENCES

**CAETS** is an independent non-political, non-governmental international organization of the world's engineering and technological sciences academies, one member academy per country.

## CAS – ACRONYM IN FRENCH FOR CENTRE D'ANALYSE STRATÉGIQUE — THE FRENCH GOVERNMENT'S STRATEGIC ANALYSIS 'THINK-TANK'

The CAS is an expert advisory unit that reports to the Prime Minister. Its remit is to advice Government when defining and implementing strategic orientations, in the economy, in social and environmental or technological areas.

## CESE – ACRONYM FOR CONSEIL ÉCONOMIQUE SOCIAL ET ENVIRONNEMENTAL (HIGH COUNCIL FOR ECONOMIC, SOCIAL AND ENVIRONMENTAL QUESTIONS)

CESE is an advisory body [aka the Third Chamber], comprising 233 members, as legally defined in the French Constitution. The Members are representative of the mainstream activities of the country – in economics, in social and environmental areas – and its remit is to ensure that they not only participate in defining national public policies but also in evaluating the effects and consequences.

## CONTROL AND COMMAND SYSTEM

The Control and command system of any system is the system or subsystem in charge of piloting and controlling it.

## CORESO–REGIONAL COORDINATION SERVICE CENTRE

Coreso is an independent company whose engineers come from several European (EU) countries to ensure collectively the proper functioning of Europe's electric HT transmission grids and MT distribution networks (the countries in 2012 are France, United Kingdom, Italy, Belgium and the Eastern part of the German grid).

## E.ON-NETZ

HV transmission grid of the North German E.ON company.

## EURO-CASE – EUROPEAN COUNCIL OF APPLIED SCIENCES TECHNOLOGIES AND ENGINEERING

The European Council of Academies of Applied Sciences, Technologies and Engineering is an independent non-profit organization of national academies of Engineering, Applied Sciences and Technology from 21 European countries. The mission of Euro-CASE is to pursue, encourage and maintain excellence in the fields of engineering, applied sciences and technology, and promote their science, art and practice for the benefit of the citizens of Europe.
*cf.* http://www.euro-case.org/index.php/about-eurocase.html

## EUROCONTROL

EUROCONTROL is an international civilian and military organization for air traffic control, covering mostly the skies over Europe with 39 Member States. EUROCONTROL, with its partners, is working towards a Single European Sky by development of the ATM system (Air Traffic Management), adapted to the 21st Century needs and traffic.

## EUROSTAR–EUROSTAR INTERNATIONAL LIMITED

This limited company is the property of London and Continental Railways (40 %), SNCB (5%) and the French SNCF (55%), Eurostar is the governing company for the Eurostar that provides high speed train services between London, Brussels and Paris, *via* the Channel Tunnel.

## FOND DE COHÉSION (COHESION FUND)

This fund has been created in 1994 by the European Commission with the aim to reduce economic and social disparities on the European territory.

## GALILEO

Galileo is the European equivalent of GPS for satellite positioning technologies and facilities.

## MW

One MegaWatt represents a million Watts.
To give an order of magnitude, a standard nuclear power station has a nominal output electrical power of approx. 1 000 MW.

## OPECST– ACRONYM FOR THE FRENCH PARLIAMENTARY OFFICE OF ASSESSMENT OF SCIENTIFIC AND TECHNOLOGICAL POLICIES

OPECST was created in 1983 with the remit to inform Parliament as to the consequences of policy decisions of a scientific and/or technological nature, and to aid Parliamentarians to make these decisions. This advisory body comprises 18 Lower House Members of Parliament and 18 Upper House Members of the Senate. The OPECST gathers its information, organises hearings, implements its investigations and carries out assessment work for decisions to be taken by the Parliament (it also assess the consequences of decisions already taken).

## PACA

The French Region Provence Alpes Côte d’Azur (French Riviera)

## THE (ELECTRIC) DISTRIBUTION NETWORK

Distribution is that part of the national networks that brings MTV and LV power to the outlets (mainly sockets in homes). It accounts for some 1.3M km of lines in France.

## THE (ELECTRIC) TRANSMISSION GRID

Transmission is that part of the national networks, often called the Grid , that carry HV and VHV electricity from the power generating stations to the transformer stations that feed into the distribution networks. There are some 90 000 km of grid lines in France.

## RFF — FRENCH RAILROAD NETWORK

RFF is a public company responsible for maintenance, development, coherence and valuation of the national French railroads.

## RTE – ELECTRICITY TRANSPORT NETWORK

RTE is a public company that operates the French electric power transmission grid. It is a subsidiary of EDF.

## SGDSN (EX SGDN) —
## ACRONYM FOR GENERAL SECRETARIAT FOR DEFENCE AND NATIONAL SECURITY

The SGDSN is responsible for the secretariat of the National Defence Council, chaired by the President of the French Republic, which body defines the policy orientations in terms of military programming, the deterrent forces, overseas operations, planning to counter possible major crises, critical information gathering, economic issues and energy procurement problems, national security matters and the fight against terrorism.

## UIT–UNION INTERNATIONALE DES TÉLÉCOMMUNICATIONS

ITU (International Telecommunication Union) is the United Nations specialized agency for information and communication technologies — ICTs.
*cf.* http://www.itu.int/en/about/Pages/default.aspx

## VOICE OVER IP

VoIP (voice over internet) is a technique that enables voice communications *via* internet links or on private networks using an IP coding protocol.