Design of the ICT infrastructure of an educational system

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Abstract: In this paper we expose the design process in engineering an information and communication (ICT) infrastructure. We have based on the Viable System Model for decomposing the ICT infrastructure. A different framework for managing complexity has been applied to each subsystem and a special treatment for the design of the ICT Center has been carried out. ICT Center has the responsibility of guaranteeing the quality of service of the whole system.

Keywords: ICT infrastructure, Viable System Model, Quality of Service, Microsimulation.

Introduction

The information and communication technologies (ICT) infrastructure is a key element in many organizations. This infrastructure is composed by a set of hardware, software, services, procedures, processes and persons. Our vision considers ICT Infrastructure as an organization, with a great number of elements, with persons that interact with these elements and with other persons, with complex processes, with a great number of procedures, etc. This infrastructure should interact with its environment, should adapt to it and should evolve. With this vision we have consider the ICT infrastructure as a complex system. In our work we have developed a methodological framework to model and to design this ICT infrastructure concept.

This work has been applied to a concrete case: the ICT Infrastructure of the Canary educational system. The result has been a basic technological architecture with three evolutionary projects: the Individualize Networks of Schools, the Integrated Broadband Network and the Management System. From a common strategy, each one of these projects has their own evolutionary strategy. This basic technological architectural has been designed considering that at the same time we are planning, designing, building, using and operating. This study has been framed inside MEDUSA and MEDUSA PRIMARIA projects. These projects are an initiative of Government of Canary Islands (Spain) to extend the ICT use in the educational system. The complexity of this ICT Infrastructure is increased since only a little number of persons is the responsible of managing the design, the planning, the acquisition, the installation and the administration. In this sense a framework to reduce its complexity has been design.

Our framework consists of the decomposition this ICT infrastructure in different subsystems. This decomposition has been based on the Viable System Model (VSM). VSM permits to manage the decomposed parts in an integrated way. Each subsystem can be considered as a system with less complexity than the whole system. For each subsystem has been designed an appropriate framework that permits to manage its particular complexity. These frameworks use specific methodological techniques, also simulation techniques based on microsimulation has been applied to a specific system. The framework of this work can be generalized to the design of other ICT infrastructures.

As any system, ICT Infrastructure can fail or can not operate correctly. Thus, a specific treatment has been realized to design this system with a controlled quality of service (QoS). For example, when an element fails it must be repaired, or when a teacher needs a specific service, it should be provided. If the repair or provision time is high, QoS is low. More and more the organizations demand bigger QoS for their ICT Infrastructure. Traditionally, the assessment of fulfilling a certain QoS is carried out based on the designer's experience. We have designed a framework to predict QoS of an ICT Infrastructure. In our model there is a subsystem that is responsible of guaranteeing QoS. This subsystem is the most complex of the whole system. For this system a framework based on microsimulation techniques has been used.

Firstly, summary of our case study is made. Secondly, we develop the concept of ICT Infrastructure and how its complexity is managed. Thirdly, we expose the design of the ICT Center. ICT Center is the responsible system of guaranteeing QoS. In that section a framework based on microsimulation has been described. Finally conclusions are exposed.

Case study

Canary Islands is a region of Spain formed by seven islands. It is located in the Atlantic Ocean, 1,250 km from Europe and 210 km from the African coast. It has a population of 1,694,477 inhabitants, being 40% of them concentrated on the metropolitan zones of the two main islands. The territory is strongly fragmented due to its insularity and orography. The non-university educational system is formed by 850 administrative workers, 301,622 pupils, 19,660 teachers and 1,264 schools. At the beginning of year 2001 the penetration was 23.6 students per computer with an important number of obsolete computers. On the other hand, the available computer material in the schools was used to cover the derived necessities of the ICT conception as a curricular subject, not being approached the ICT use as a didactic instrument in the different areas and curricular subjects. Neither the schools had an infrastructure of data cabling that facilitates the installation of ICT equipment. In year 2000 the number of schools with Internet access was about 24%, and only 2.2% had a WEB site. On the other hand, while there were some teachers with positive ICT attitudes, there were other teachers who had resistances of different intensity toward the ICT use.

The Canary Islands educational system is framed inside Spanish educational system characterized by a decentralized model of administration that distributes the responsibilities mainly among National Government, Regional Governments and the educational centers. National Government has reserved exclusively the exercise of the responsibilities that safeguard the homogeneity and the substantial unit of the educational system. Regional Government deals with, among other duties, the administrative ownership in their territory, administration of personal, orientation and attention to the pupil, helps and grants, etc. Regulations have been establishing the principle of autonomy of schools. They have capacity for the decision-making in curricular aspects. Educational centers or schools should elaborate three different documents where their pedagogic and curricular organization is reflected: the educational project, the curricular project and the didactic programming. It is therefore at the school where the initiative is focused on including ICT for support for the educational project. Regional Governments will be able to motivate and to support this type of initiatives.

At the present time, Government of the Canary Islands, through Department of Education, Culture and Sports, is developing a specific ICT project for non university education. It is basically conceived as an integral programme where all the educational elements are identified. This project is bounded to the educational administration and the public schools of Canary Islands. These are projects with very wide objectives. This project is developed in two Phases: Phase I (2001-2004) and Phase II (2004-2006). At the end of Phase II all schools will have Internet connection and WEB site and there will be a ratio of less than 12 pupils per computer. At the present time this project is at the beginning of Phase II and it is at a level which allows its evaluation.

The ultimate and general aim of these projects is to integrate ICT in educational non university environments in the Canaries in an effective way. This integration should lead us to qualified teachers and students in a short/middle-term period of time, so that they are used to logical and critical use of tools and technological resources, and that will permit new ways of teaching and learning, and that will also help to establish new ways of communication and contribution with other educational agents.

Projects of this dimension require a set of actions that become the basic pillars for a correct execution of it, and these actions are carried out in a coordinated and complementary way. The first action initiated is the creation of infrastructures and equipment in the whole educational system.

The connectivity between schools equipments to each other is possible thanks to the Local Network that is created in each school. Each Local Network contains all the equipment and network electronic elements that permit to share resources, applications, contents and forums of communication. At the same time, they facilitate the exchange with the outside in a safe way, from each endowed area. Each Local Network consists of connecting points distributed all over the school (management department, computer science classrooms, “Classrooms Medusa”, "classroom corners", library, departments, “Special Education” classrooms and laboratories).

The local area networks as a whole make up the second level of network (Educational Intranet), with the same philosophy as the local network. Servers and specific tools permit the Network management, sharing resources, applications, etc., and they are also improved with new functionality such as the distribution of applications, backups, virus shields, among others. The Intranet configuration enables the maintenance of interconnected machines through the corporate network of the Government of the Canaries.

The second basic pillar consists of training teachers, students and other agents involved in the execution of the Project. Users training is conceived as functional, practical and adapted to the contexts, to the materials and environment in which the Project develops. Training contents and offers are flexible. They are collected in an annual Training Plan, provided with a modular structure to facilitate teachers the make-up of their training itinerary. This Plan is continually updated and improved.
The provision of contents is another strategic focal point of the Project. The shortage of educational and specific contents related to ITC, or borne by them, has not favored the approach to ICT in schools, as well as integration and use of ICT as instrumental support in the different subjects. The policy of contents provision is undertaken in different ways. In this sense, the promotion and support to innovation and educational research projects will be another source of provision, with the added value that these materials are already contextualized in specific classroom situations, so that the level of motivation is very high, because they will be suggested by teachers that work with them.
The strategic bases for the design of the ICT infrastructure have been that the basic necessities of the educational community and the deployment of ICT infrastructure should be synchronized with the objectives for transforming the educational system. Thereby, in our vision of the global design, the different parts of ICT infrastructure have been integrated together with the processes that eliminate the obstacles for the ICT integration in education. As reported in Pelgrum (2001) the top 10 obstacles consisted of a mixture of material and non material conditions. The material conditions were the insufficient number of computer equipments and of Internet accesses. As non material conditions were the lack of skill of teachers and the lack of supervisory and technical staff. While the material conditions are fulfilled with the deployment of equipment and Internet accesses, the non-material conditions require the "deployment" of human resources, services and management processes. The result has been an ICT educational, human and technological architecture that we have denominated ICT infrastructure.
This ICT infrastructure is composed (approximately) by 25.000 PCs, 1.200 servers, 3.000 peripherals, 4.000 switches, 3.000 access points (WI-FI), 1.200 routers, 50.000 network points, 1.000 cabling infrastructures, 1.100 ADSL lines, 100 satellite lines, central services (as software deployment, security copies, monitoring services, etc.), corporate applications, 1.200 cooperative environments in each school, an ICT coordinator in each school, etc. In this ICT infrastructure the human infrastructure play a very important role and is composed approximately by 20 technical operators, 20 software developers and a technical office with 8 persons. Also, we can consider that the 20.000 teachers are inside of this ICT infrastructure when they are considered as an element to fulfill the educational activities.
This basic technological architectural has been designed considering that at the same time we are planning, designing, building, using, operating and redesigning, and only five persons are responsible to manage this ICT infrastructure.
The requirements of this ICT infrastructure are basically: it should have a good quality of service (QoS), should be economically efficient and should be changing and evolutionary. QoS should guarantee a good service to the users: when the ICT infrastructure fails the service should be repaired or when a user needs a service it should be provided.
The process of optimal design for guaranteeing a specific QoS in a changing environment is not direct from a deterministic viewpoint. QoS depends of the quality of ICT equipment, a good installation and a correct assessment of the human infrastructure.

Concept of ICT infrastructure

Our concept of the ICT infrastructure is not only a set of equipment or elements. The ICT infrastructure enables to share the ICT capabilities which provide services for other systems of the organization (Broadbenta et al, 1999). For Broadbenta et al these capabilities require the complex combination of the technical infrastructure (cabling infrastructure, hardware platform, base software platform), ICT shared services (as communications services), ICT applications (as WEB services), the human operators and the managerial expertise to guarantee reliable services (see figure 1). All these resources are designed, developed and managed over time. In our system ICT infrastructure does not include the specific computer applications, but the teachers or other users should experience and innovate using specific computer applications on the ICT infrastructure.

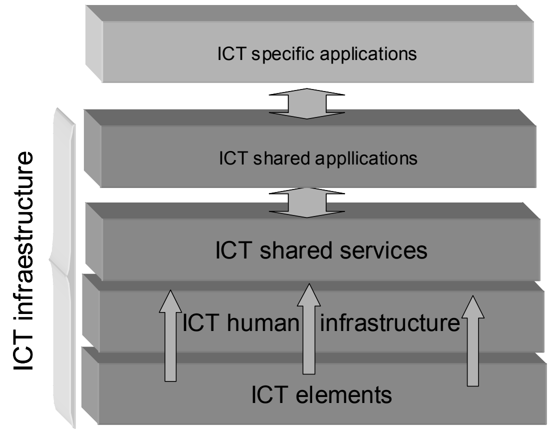

Figure 1 – Concept of ICT Infrastructure

The ICT infrastructure must be flexible to support the operation among different applications and to facilitate the communication of the information inside and outside of the enterprise. Thus, it must be flexible and integrated:

- Building a flexibility infrastructure implies cost and complexity because that supposes to add a characteristic that may be exercised in the future, and must consider the variety of user necessities that an organization can handle without modifying the infrastructure significantly. An organization can take different approaches to invest in the ICT infrastructure investments. ICT infrastructure needs to respond more rapidly to changes in the environment and between the different functional units.
- The integration increases the importance of relations among services and information. This integration implies the capability of exploiting resources shared across services, locations and departments. In this way, an ICT infrastructure must be unique and shared rather than separate ICT platforms.

Other aspects that permit to have a flexible and integrated infrastructure include the knowledge, the skills and the experience embodied in the human infrastructure.

This conception of ICT infrastructure in a large organization can be considered a complex dynamic system (variable environment, organizational system, a great number of elements, etc) in which deterministic and mathematical rules representing all the details of the models can not be easily formulated.

Methodologically, the first step in our analysis of this complex system has been to use the method of decomposing the whole system in subsystems with a smaller complexity degree. In our framework each subsystem can be treated independently, although in each subsystem the whole integration and the synergy with the other subsystems have been considered and one subsystem is the responsible of the integration of all the parts. The decomposition of this system has been based on the Viable System Model (VSM) (Beer, 1984). The Viable System Model considers an organization interacting with its environment. Beer pointed out that a system is only viable if it has a specific management structure. According to the proposed VSM a set of management tasks is distributed to five systems ensure the viability of any social system. The five systems are Operation, Coordination, Integration, Intelligence and Policy. These five systems can be summarized as follows: Operation realizes the primary activities; Coordination regulates and coordinates the different subsystems of Operation; Integration is the controlling unit of the operational level (Operation, Coordination and Integration). It has to ensure the operation of all the system and to optimize the allocation of resources; Intelligence is the link between the primary activities and its environment. On this level the future developments according the systems capabilities and changing of the environment (customer demands) are planned; and Policy is the main decision level of the whole system. The main roles of Policy are to provide clarity about the overall direction, values and purpose of the organizational unit.

Figure 2 shows the VSM model where an organization is composed by two elements: Operation which does all the basic work and Metasystem which provide services to Operation by ensuring the whole organization works in an integrated and viable way. Operation contains the productive units (in our case, schools). Metasystem procures cohesion, optimization, synergy, cohesion, stability and future planning to ensure adaptation to a changing environment. Both Operation and Metasystem must be in contact with, and interacting with, their environment. In our case the set of students (and their parents) is the environment.

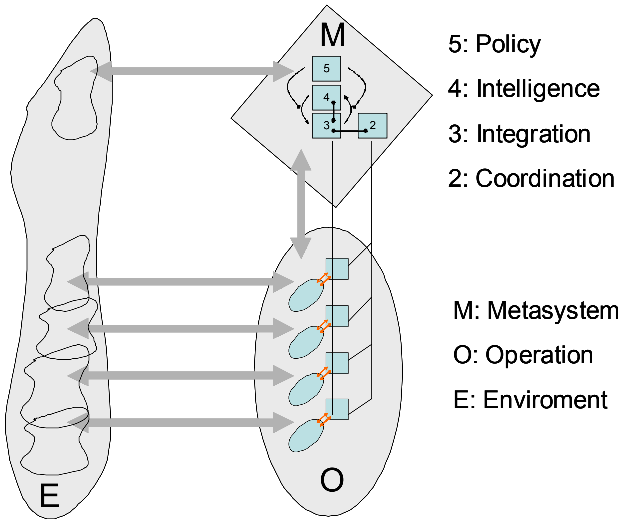

Figure 2 – Viable System Model

We have considered our ICT infrastructure as an organization. Thus, VSM model has been applied to the ICT Infrastructure and, moreover, Operation, Coordination, Integration, Intelligence and Policy have been identified. ICT infrastructure as a viable system is shown in figure 3. In our model each subsystem has a specific framework.

We have decomposed Operation in other VSM systems: the corporate applications and all the schools (ICT infrastructure of schools are considered as a VSM system). The number and the situation of all ICT elements can be seen in figure 3. To reduce the complexity of Operation a uniform solution has been designed for all the schools. Thus, important scale economies will take place with the centralized acquisition of ICT equipment. The uniformity of equipment has important economical profits, also, facilities and simplifies the operation, administration and centralized maintenance. Also, the selection of a uniform technological solution is the only viable way of executing a project that embraces all the great quantity of centers from a unique technical project office. In Operation teacher play two roles: one role as human infrastructure and the other one as environment. The complexity due to the great number of teachers has been managed identifying three types of teachers in function of their ICT skills. Each school ICT Infrastructure has synergies with the whole system, Intelligence subsystem is supported by Intelligence of the whole system (for example, backup copies are realized centrally). Thus, technical staff and technical knowledge are not necessary in schools. There exists an ICT coordinator in each school that is a teacher (without high technical knowledge) dedicated to promote ICT use.

On the other hand, the complexity of Metasystem is completely different to Operation. While in Operation ICT elements are the basic elements, in Metasystem the human infrastructure plays an important role. The number of persons in each subsystem is shown in figure 3. This system should fulfill the functions of the Metasystem: integration, monitoring, control, optimize and resolve conflicts inside the whole organization and realizes future planning to ensure adaptation to a changing environment. Thus, we have decomposed the Metasystem in four systems (based on VSM): Coordination (including the communication network), Integration (software developing, infrastructure deployment, educational support and the ICT center) and Intelligent and Policy (as management system):

- Coordination guarantees a correct interaction of all the parts of the system and with other systems (i.e, Canary Government Network). Its complexity is managed with the help of outsourcing and choosing few types of broadband accesses. Also Coordination guarantees the security of the system, avoiding that an element can damage all or a part of the system. This function is realized with security policies and specific security systems. This subsystem avoids that an element, teacher or student can suppose a risk for the whole system.
- Integration permits the adaptation of all the system and guarantees the continuity of service. Also it guarantees QoS (quality of service) of the whole system. Its complexity can be reduced decomposing it in four subsystems. The integration and the synergy of these subsystems are mainly realized by

Intelligence. The four subsystems are Infrastructure Deployment Office, Software Development Office, Educational Support Office and ICT Center. Infrastructure Deployment Office is the responsible of the infrastructure endowment of the whole system. This office designs specifics solutions and manages and controls to the suppliers. Software Development Office is the responsible of the continuous software development of the corporate and cooperative environments. Educational Support Office is the responsible of training teachers and promoting the use of the ICT infrastructure. And ICT Center is the responsible of guaranteeing the correct operation of the ICT Infrastructure.

- The management system (Intelligence and Policy) guarantees a unique vision of the project, following the VSM model, the management system carries out a centralized control. Also it is the responsible of assessing the whole system.

With the exception of ICT Center, all the subsystems can be designed using deterministic approaches. For example, the human endowment of Infrastructure Deployment Office can be easily estimated knowing the average time to visit a school, to project an ICT Infrastructure of a school, to check it, etc.

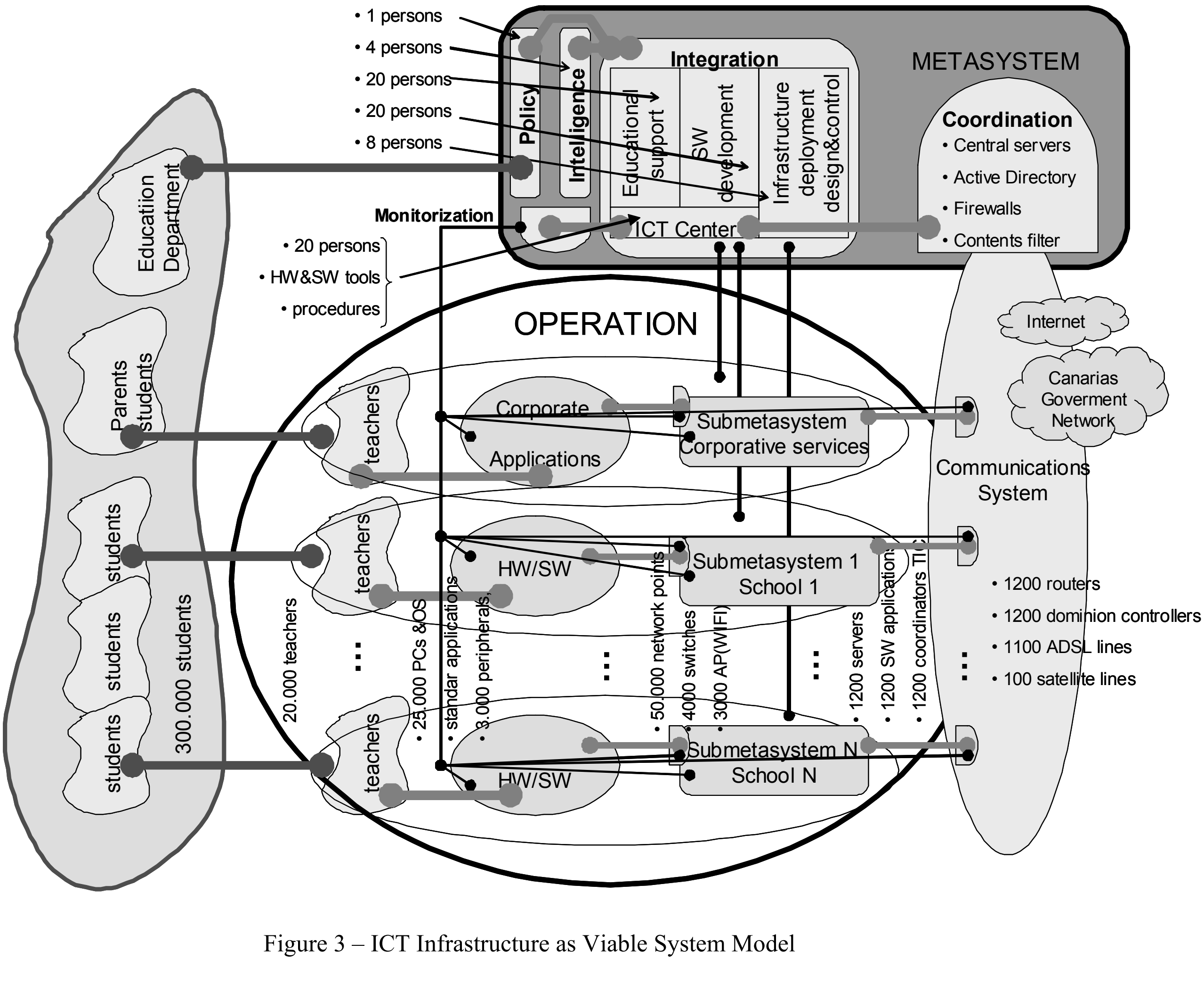

Figure 3 – ICT Infrastructure as Viable System Model

Design of the ICT Center

In this work we have focused our analysis on a specific subsystem: the ICT center. This subsystem is the responsible of guaranteeing QoS of the whole system and plays an important role to permit the integration of all the parts. ICT Centre administrates the whole ICT infrastructure, as well as the attention and service to all users. While the other subsystems can be easily designed using project programming techniques, the

design of ICT Center should use other types of approaches since it can be considered as a complex system where deterministic techniques cannot be used. ICT Centre should be endowed with an organizational structure and technological tools to carry out the centralized administration of ICT resources. All kind of inquires, problems, petitions or mishaps are managed until their complete resolution. And it is constituted as a unique point of direct attention. ICT Centre is organized in a similar outline as recommended by the methodology ITIL. ITIL (IT Infrastructure Library) is a broadly grateful methodology and adopted in the sector of the IT and that it supports and it reinforces standard of quality like the PD0005 (British Standards Institution's Code of Practice for IT Service Management) and the ISO9000.
Figure 4 shows an outline of the ICT Center. ICT Center is composed by tools that permit to monitor the elements, the network, the computer systems, to make an inventory of all the hardware and software, to provide services (SW deployment, remote control of computers and servers, realizing backups, etc), and to administrate the network, the active directory, the routers, the switches, etc. Also a human infrastructure that interacts with these tools is necessary. The human infrastructure is composed by Level 1 and Level 2. Level 1 is composed by phone operators with little ICT knowledge and their cost is low. Level 2 is composed by engineers and their cost is very high. Level 2 can be divided in specialized teams. Also, there is a Level 3 that is composed by the maintenance service of the suppliers.

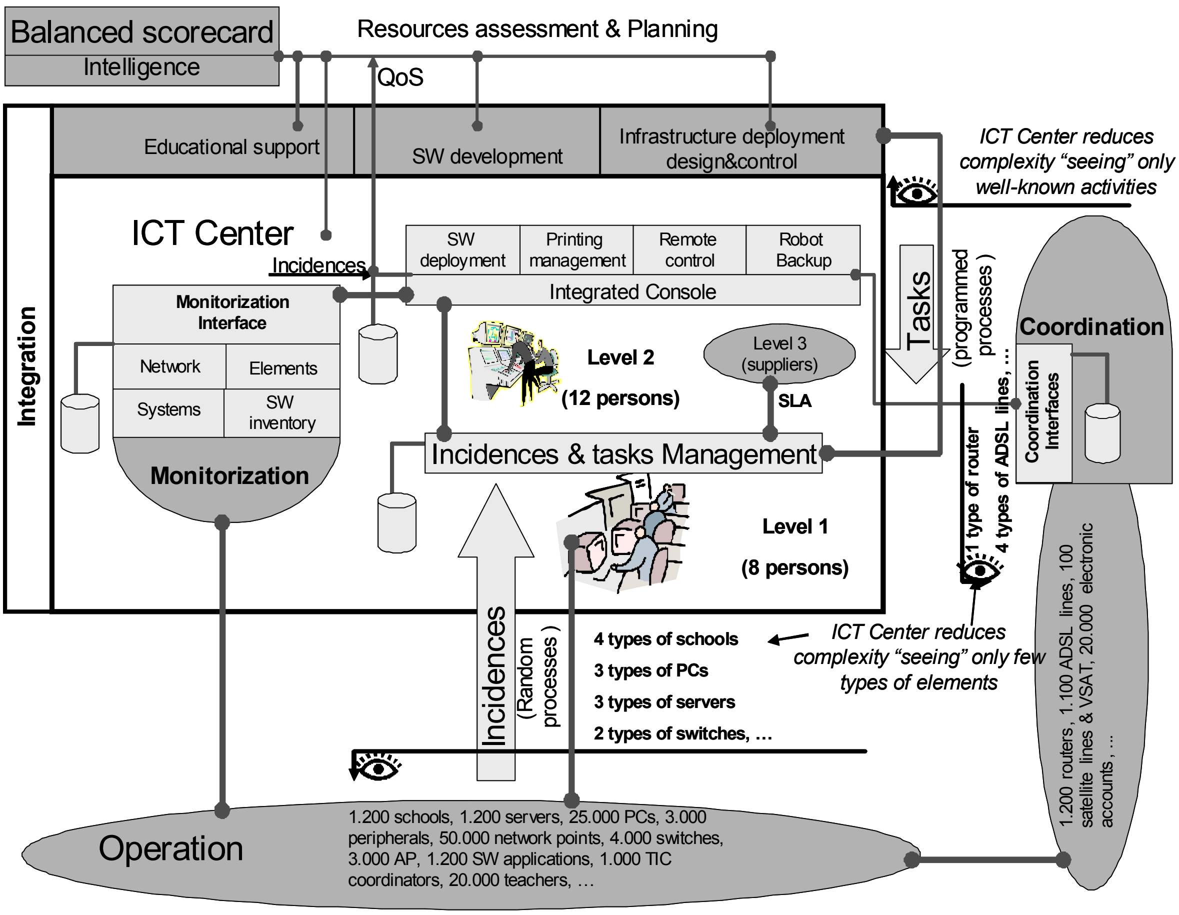

Figure 4 – Outline of the ICT Center

When an element or system fails or does not function, ICT Center is the responsible of its repair or reconfiguration. When a teacher needs a specific service (for example, a new electronic account), ICT Centre is the responsible of providing it. These fails, problems, petitions or mishaps are denominated *incidences*. The incidences can be reported by teachers or by the monitoring system. Incidences are mainly generated in Operation and Coordination System where there are a great number of elements. As shown in figure 4, ICT Center only “sees” few types of elements, thus ICT Center can reduce the complexity of its operation. The incidence rate is a random process.

Also ICT Center is the responsible of the operation of the systems, for example, realizing backups, configuring elements and systems, etc. Also, ICT Center should carry out different activities requested by other subsystems (Infrastructure Deployment Office, SW Development Office, etc). These activities are denominated *tasks*. A task can be accepted if it has been previously defined: ICT Center only “sees” well-known activities. This way also contributes to reduce the complexity of the operation of the ICT Center. The task rate can be considered as programmed processes.

The requirements of the design of this system must guarantee a good quality of service (QoS). QoS depends of the assessment of human resources. This assessment must consider both the number of persons in each level (Level 1 and Level 2) and their knowledge. The assessment of these resources can not be realized using deterministic approaches due to: ICT Center can be considered as a human organization, the duration of each activity realized by the human infrastructure is random, incidences rate is random, each incidence has a different treatment, there is an important number of type of incidences and activities, etc. Thus, ICT Center can be considered a complex system.

With the purpose of simulation and design, ICT Center has been decomposed in other subsystems. In figure 5 shows the ICT center decomposed in four subsystems: subsystem 2 (where its Level 2 operates the technological tools), subsystem 3 (composed by the technical staff), subsystem 1 (that manages incidences) and subsystem 4 (Intelligence) that controls all this system:

- Subsystem 3 does not process incidences or tasks. It is a static system where the number of elements can change and the knowledge of each element varies with the time. Subsystem 3 feeds with human resources to subsystems 2 and 1. These human resources are shared by these two subsystems.
- Subsystem 2 processes programmed tasks, thus the occupation of the human resources (Level 2) can be easily predicted. The output of subsystem 2 is the operation state of the systems.
- Subsystem 1 processes random incidences. The occupation of its resources cannot be easily predicted. The output of subsystem 1 is QoS of the whole. QoS is mainly measured by the resolution times of the incidences.
- Subsystem 4 indicates the assessment of human resources that subsystem 3 should have.

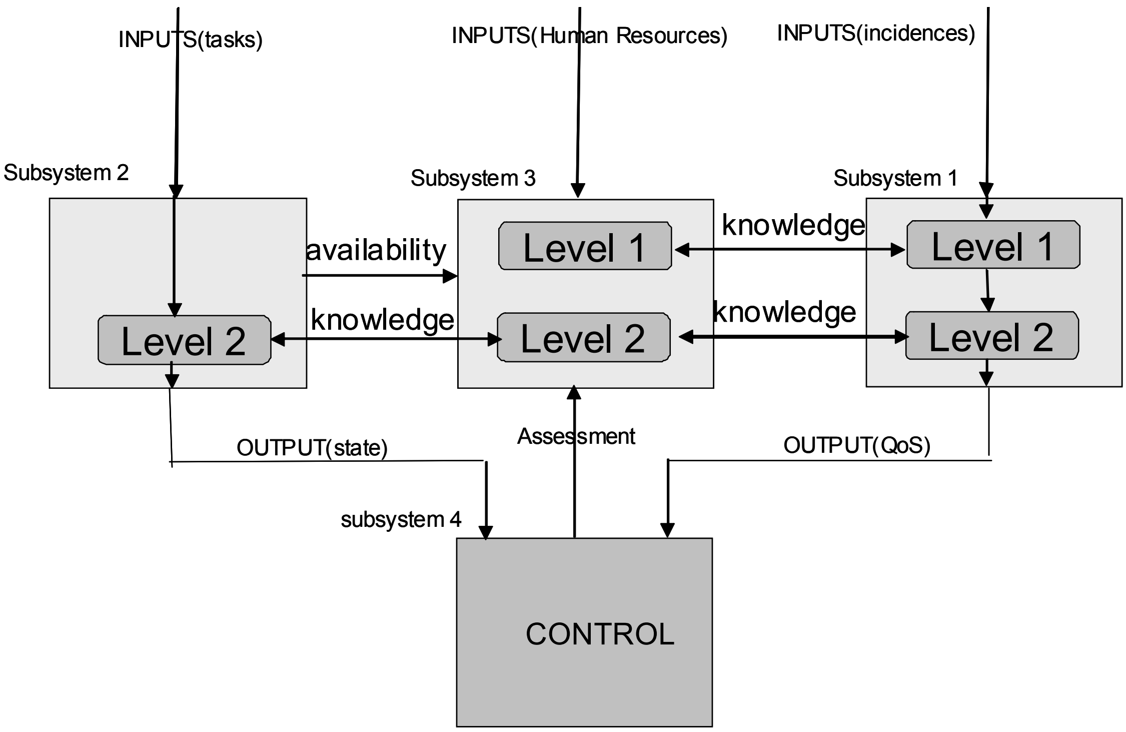

Figure 5 – Model of the ICT Center

Despite the fact that subsystem 1 can be analyzed as a discrete events system that change their condition each time a new event happens (new users, new necessities, new skills, new services,…), complex organizations as this ICT center are modeled more efficiently if we consider the system components as entities that flow throw them (process oriented simulation). A process is an ordered time sequence of interrelated events. This sequence describes the pass of an item throw the system. Other typical feature of this kind of models is the appearing of the transaction concept. An actor of the system requires a particular resource and its action is determined by this fact. Transactions in process oriented simulations have to be defined as a sequence of steps. Studying transactions in complex organizations involves the concept of microsimulation: all the actors involved in relevant transactions are included in the model and they are simulated. These actors behave according to established rules that can be deterministic, stochastic or a mixture of both. In the framework of process oriented simulation each actor is a process and in this ICT Center we can have hundreds of processes competing for resources. This is the typical situation of incidences waiting for being resolved by this ICT center.
With this approach the resolution time of the each incidence can be predicted over the time, and thus can be assessed with the human resources to fulfill a certain QoS. In figure 6 shows as incidences are resolved. The resolution time has been simulated using an available tool that uses the previous concepts. Initially this tool was developed for the process simulation in a hospital. A discussion and justification of this tool can be found in Moreno et al (1999) and Moreno et al (2001). Other frameworks can be found in Unger & Cleary (1993) and Gilbert & Doran (1993). Adaptation of this tool for simulating ICT Center has been direct.
In this system, the concrete resource (human operator) that resolves incidences also fixes the quality of service, due to their experience the resolution is carried out in more or less time. An analytic approach of the problem would not allow us to discriminate the specific performance of each resource and each incidence, while we can carry out this analysis centered in the resource with a modeling oriented to the process. This is due to each element (resource and incidence) that flows for the system is simulated in an individualized way: we carry out a microsimulation.
Figure 6 shows the average resolution time of all the incidences. Other results could be represented easily (for example, average time of each incidence type). Also, with the simulations realized we could predict the occupation of the resources and thus their efficiency can be measured. One advantage to choose this approach is that with a process oriented modeling we focus on the local problems that are not only important in their own, but also because sometimes they are in the origin of emergent behaviors that affect the complex system as a whole (Harding, 1990). Also, this methodology allows us to know the influence of the peaks of incidences on the QoS of the whole system: a massive arrival of incidences can be simulated (for example, a widespread propagation of a virus can imply personalized actuation in each PC) and it can be analyzed the influence of the resolution time on the habitual incidences.

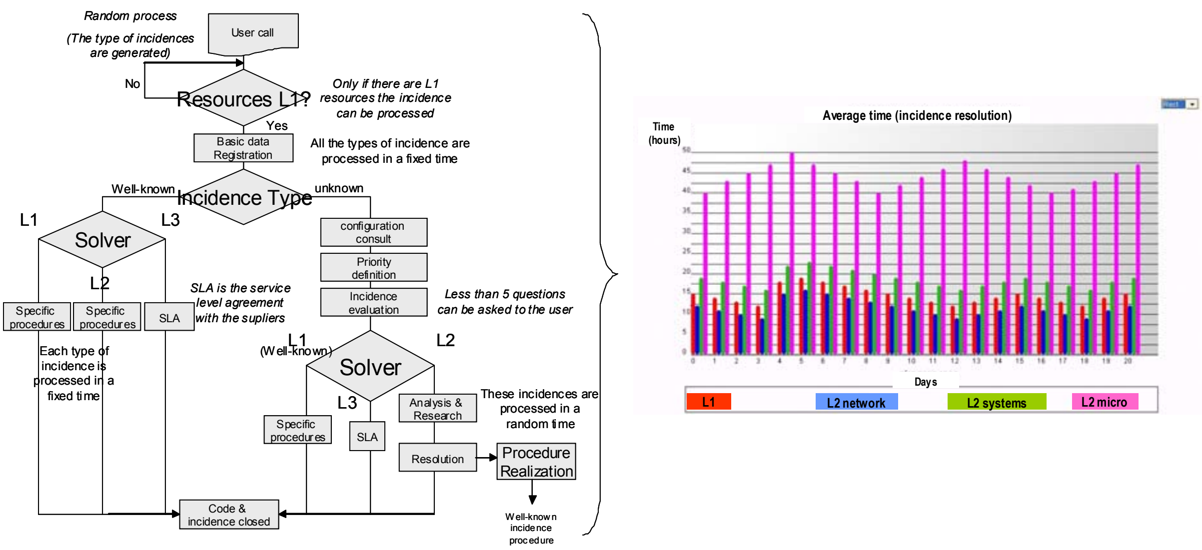

Figure 6 – Simulation of the resolution process of incidences

This ICT Center has been operating since two years ago (during Phase I), thus we have been able to use the previous experience to establish parameters in our simulation, for example, resolution time of well-known and unknown incidences and types of incidences. Due to that other parameters have not been measured, in our simulation we have realized some simplifications (human knowledge has been considered as constant, i.e., it does not change with the experience and we have considered that the well-known incidences and processes are processed in a fixed time).
In a real ICT Center there are other many QoS indicators (for example, waiting time of the user to be assisted). With the microsimulation it is possible to predict these types of indicators, although it is not possible to predict other indicators as the perceived quality for the user. These indicators are measured using surveys to the users.

Conclusions

We have seen as an ICT Infrastructure can be considered a complex system and it should work with a certain QoS. Also we have seen as applying a framework based on VSM facilitates the analysis and the design of a complex system as this ICT infrastructure, and that inside this system ICT Center is the responsible of ensuring that the whole system works correctly.
Unfortunately we have not found works that have approached neither the treatment of an ICT infrastructure like a complex system, nor the QoS prediction in an ICT Center that allow us to be carried out a comparative discussion with our framework.
Our focus based on VSM has allowed us to design an ICT Infrastructure solution that can be managed by few people. QoS is a key aspect of this system and a good design should consider it. Using microsimulation adapts quite well to model the QoS performance in an ICT Center since it is possible to predict easily different indicators that measure the QoS of the ICT Infrastructure. As inconveniences we have that it is not possible the prediction of other important indicators as the perceived quality of the service for the user. Another inconvenience is the difficulty to extrapolate the experience of a specific ICT Center to other one, since the QoS performance depends on many factors, like a correct installation of the administration tools, the knowledge of the users, the grade of stability of the ICT Infrastructure, etc. This implies that to carry out a better assessment it is necessary to have real data of the history of an ICT Center. For it, it becomes necessary a previous period of time operating before carrying out a final design of the necessary resources in an ICT Center. Once there is a previous experience it is possible to carry out predictions of the QoS performance simulating different situations and resources.
Finally, we indicate that the framework developed in this work can be applied to other ICT Infrastructures since all these have similar structures.

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