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### **Incorporating a New Technology Into Agent-Artifact Space. The case of Control Systems Automation**

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# **Incorporating a new technology into agent-artifact space. The case of control systems automation<sup>1</sup>**

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## **Abstract**

We contribute to the debate on innovation theory and policy by exploring, through the interpretative framework provided by Lane and Maxfield's theory of innovation (1997; 2005), a set of case studies concerning the implementation of a new technology for system automation and its incorporation into the structure of agent-artifact space (Lane and Maxfield, 1996). Our purposes are, on the one hand, to illustrate to what extent this theoretical approach can help us make sense of innovation processes, and, on the other, to derive some general implications for innovation theory.

**Keywords:** innovation, technological systems, complex systems, innovation networks, control systems automation

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## **1. Introduction**

We contribute to the debate on innovation theory and policy by exploring, through the interpretative framework provided by Lane and Maxfield's theory of innovation (1997; 2005), a set of case studies concerning the implementation of a new technology for system automation and its incorporation into the structure of agent-artifact space (Lane and Maxfield, 1996). Our purposes are, on the one hand, to illustrate to what extent this theoretical approach can help us make sense of innovation processes, and, on the other, to derive some general implications for innovation theory. By focusing on agents that are involved in different kinds of interactions around the same technology, we introduce and compare different practices according to which a new technology can be incorporated into the existing structure of agent-artifact space, and we highlight some of the complexities involved in processes of technological adoption and diffusion, which are often modelled in excessively simplistic terms.

After a brief introduction to the technology and to the issues that we attempt to confront (section 2), we describe the technology provider's efforts to construct a market system for its technology in Europe, and the difficulties it encountered when it attempted to modify established market system structures (section 3). In section 4 we describe a small German company that builds integrated control systems using LonWorks technology; this company adopts a project-based approach and relies on a web of interactions in order to carve out niches for its complex products. In section 5 we describe an innovative remote metering project jointly carried out by the technology provider and Italy's largest electric utility; in this case, the technology has been incorporated into an existing market system without substantial changes to its organization. Section 6 draws some theoretical implications from the comparative analysis of these case studies and presents some concluding remarks.

## **2. LonWorks: the 'rise and fall' of a market system program**

LonWorks, officially launched in the US in 1990, is a technology that implements communication and control functionalities among individual devices and sets of devices; it enables the construction of control systems which connect different artifacts, whether in a factory, a building, or a residential environment. Its creator is a small company based in

Silicon Valley, Echelon. One of LonWorks' most innovative features is that it permits distributed control architectures: that is, it can be used to build control systems whose nodes communicate with each other as peers rather than in a master-slave configuration. The technology's basic building block is the Neuron Chip: a microprocessor, provided with a unique identification number, which is able to run control algorithms and can thus distribute the intelligence of the system to the level of individual nodes<sup>2</sup>. Compared with pre-existing hierarchical systems, a distributed control system is more reliable, because the malfunctioning of a single node does not impair system functionality, less expensive in terms of cabling, and extremely flexible, because the system's configuration is logical, not physical. The individual nodes' 'intelligence' allows for the network's topology to be free, and transmission of information can take place over a variety of media (infrared, twisted pair, powerline, and others). LonWorks is a 'general purpose' technology (David, 1991) since it provides, at least at an abstract level, a general solution to the problem of control; so much so that, when LonWorks was first introduced and for a long time afterwards, many novel applications, unforeseen at the time that LonWorks technology was first launched in the market, began to emerge in a variety of different contexts (Lane and Maxfield, 2003).

In principle, it may have been possible for LonWorks to catalyze the creation of a new market system for distributed control technology, crossing existing industry boundaries, where different companies would provide hardware and software for the construction of distributed networks connecting devices of the most varied kinds, from industrial machines to heating systems to home appliances. The distributed control architecture is, in principle, compatible with a structure of agent roles conforming to an 'open system' model of integration, whereby independent system integrators build and configure networks by combining interoperable devices and network integration products (such as routers, gateways, servers) that are made available 'off the shelf' by numerous competing companies, thus ensuring low prices and ease of installation. The early documents that describe LonWorks show that such was precisely Echelon's vision.

Instead, this process has not taken place according to Echelon's expectations. The widespread diffusion of LonWorks as a general purpose technology, able to flatten hierarchical control networks, and leading to the creation of a single market system for distributed control systems in different applications, has not materialised, for reasons that we explore in section 3.

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<sup>2</sup> For a detailed description of the Neuron Chip and LonWorks technology see Lane and Maxfield (2003).

LonWorks has entered different market systems that to a large extent have remained separate, each maintaining its own physical and cognitive scaffolding structures, role structures, conventions, and each involving different actors. LonWorks artifacts have found their niches in specific applications like building automation (especially integrated building automation systems where LonWorks' market share is currently estimated at about 65%<sup>3</sup>), industrial automation (although the technology's presence in this sector has been very modest), local control networks (we present some examples in section 4), remote metering (we describe a very important application in section 5), and numerous other applications, quite unrelated to each other, such as pumps, robots, and train braking systems. The use of LonWorks in different environments seems to be even leading to a 'speciation' of the technology, which is developing in different directions according to the applications for which it is used, while the technology's basic building blocks remain largely the same - although in time these may change as well.

### **3. Distributing control in agent-artifact space: Echelon**

From the start, the technology provider was aware that the creation of a market system around LonWorks required the involvement of many other agents. Echelon would need to interact with numerous companies in order to enlist their cooperation, so that they would agree to supply the products and components necessary to build distributed control networks: in a way, Echelon would need to 'distribute control in agent space', almost in parallel with its efforts to distribute control in artifact space. In particular, manufacturers of control systems for different applications (the so-called Original Equipment Manufactureres, or OEMs) would have to be convinced to expand their offer of interoperable components implementing the Neuron Chip and the LonTalk communication protocol; system integrators would have to be persuaded of the superiority of LonWorks over its competitors; hardware and software suppliers would have to be recruited in the production of network integration products.

At the beginning, Echelon thought that this would be a straightforward process, and that the superiority of their technology in terms of reliability, flexibility and openness would suffice in

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<sup>3</sup> This figure was published in a report commissioned by a Japanese firm, which estimated LonWorks' worldwide market share in the area of integrated, high-end building automation applications to be approximately 65%. The figure therefore refers to a very specific market segment which includes a small share of building automation installations, many of which consist instead of simple non-integrated systems (HVAC, lighting, access control and so on). Because the building automation industry is transversal with respect to other more established industries, it is in general quite difficult to obtain precise data at industry level in each country, and even more difficult to provide international comparisons.

order to persuade their interlocutors to share their ‘distributed control network’ vision. But innovation processes are complex and multilevel; market systems rely on specific structures (cognitive and physical scaffolding structures, competence networks) that allow interactions to take place and to continue over time, and create and spread shared narratives which communicate shared attributions about the technology’s identity and the roles and prerogatives of the agents involved (Lane and Maxfield, 2005). Overcoming the resistance posed by the structures supporting established market systems would prove to be far more difficult than Echelon originally expected.

When LonWorks was first commercialized in Europe, in the early 1990s, different control industries were characterized by very different features and histories. Established market systems existed for control systems in building environments - mainly for the control of heating, ventilation and air conditioning units (HVAC) – and for the control of production processes in industrial settings.

As it did in the United States, Echelon immediately sought to establish contacts with the large European OEMs in the building automation sector. In the early 1990s, most large OEMs still sold systems based on proprietary control software and communication protocols, and their interests, as they perceived them, conflicted with the ‘open system’ model promised by LonWorks. These companies worked with consolidated networks of relationships and well defined roles; they had their trusted technicians and single-brand integrators, and the exclusive maintenance contracts generated large profits. The possibility to ‘lock in’ their clients for the expansion and maintenance of their systems was a privilege that they did not want to relinquish, and so, generally, they were not willing to make their products easily interoperable with products manufactured by their competitors.

However, LonWorks also had numerous advantages: it was robust and - since it comprised a powerful chip and a range of tools that simplified communication among devices - it solved numerous communication problems within the control system, which the large companies that produce controls and ‘big iron’ (chillers, boilers and so forth) would prefer not to have to confront. Since the mid-1990s, the largest OEMs, particularly in the HVAC industry, began to use LonWorks as a communication protocol within their systems, while, often, they continued to offer one or more alternative product lines that used proprietary protocols. Several

companies even inserted LonWorks in systems that were then closed to the outside, preventing communication with other systems<sup>4</sup>.

Although sales to large OEMs were, and remain, one of the principal sources of revenue for Echelon<sup>5</sup>, this was not very publicized: large companies were not particularly interested in promoting LonWorks, which they considered as a simple component, and the fact that most chips became part of closed systems contrasted with the ‘open systems’ integration model that was actively pushed by Echelon, especially during the 1990s<sup>6</sup>.

In order to build a market system for distributed control, Echelon could not simply passively rely on the large OEMs’ cooperation; it needed to recruit allies that were more interested in open systems – smaller OEMs and independent system integrators, in particular, that would gain the most from a transition to a market system characterized by greater competition around interoperable products. LonWorks appeared particularly suited to these companies’ needs not only because it allowed peer-to-peer communication among devices via a standardized protocol, but also because it was already implemented in a range of commercially available hardware and software tools that made it easy to design, install and configure distributed control networks.

In the course of the 1990s other technologies had been launched which promised to facilitate communication among control systems produced by different manufacturers, and hence to enable the construction of ‘open’ control networks in building automation. Those that drummed up greater industry support were BacNet and EIB, both promoted by OEM consortia<sup>7</sup>. However, LonWorks and BacNet or EIB were not equivalent. The latter two were simple protocols that enabled communication among control subsystem and therefore, while

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<sup>4</sup> As late as 1998 Echelon complained that: “While major manufacturers of control systems continue to adopt LonWorks technology at an accelerating pace, many are worried about the market changes that will be brought about by adoption of a standard network protocol and implementation of truly open architectures. Open architectures are viewed as a possible Pandora’s Box to larger companies with substantial market shares; they prefer to maintain the status quo, which keeps their customers boxed in (...) Many of these manufacturers have found the use of LonWorks technology to be a cost-effective way to allow their proprietary devices to share information within their own closed system and wish to leave it at that” (Echelon, 1998a).

<sup>5</sup> According to information gathered in the course of several interviews, the main manufacturers in the HVAC field all use LonWorks: the ‘big five’ sharing more than 50% of the market for HVAC installations (Honeywell, Johnson Controls, Siemens, TAC, Satchwell Invensys) but also Philips, Trend, and others. Always according to our interviews, the producers that have adopted LonWorks to a greater extent are TAC and Honeywell.

<sup>6</sup> Publicizing LonWorks as the technology that makes it possible to create open, interoperable networks, constituted Echelon’s principal communication strategy toward the outside (Echelon, 2000,1999, 1998a, 1998b).

<sup>7</sup> BacNet, published in 1995, was promoted by the American HVAC trade association (ASHRAE), while EIB, launched in 1990, was promoted by a European consortium (EIBA) led by Siemens, the leading European HVAC controls producer.

allowing system architectures that were more flexible than strictly hierarchical ones, they were not designed to support peer-to-peer communication among devices, as LonWorks did; furthermore, each subsystem in the control network still had to be configured using the proprietary software tools offered by its producer. These technologies were designed to enable communication among systems without opening up the control systems themselves to competition.

Echelon began to realize that the construction of a new market system for distributed control technology would entail something more than simply convincing potential users of LonWorks' superiority. Rather, it would require the creation of new scaffolding structures sustaining numerous processes necessary for the market system to function and persist over time: providing training for interested users, verifying the compliance of products to LonWorks' standard specifications, lobbying for the promotion of LonWorks as an international standard and confronting other lobbies with contrasting interests, and, in general, supporting the many interactions needed to reshuffle roles in agent space and create new competence networks. To achieve this, Echelon acted on various fronts: it set up an internal standards setting organization (LonMark Interoperability Association) and an annual trade fair (LonWorld), it supported the creation of European user groups (the LonUsers associations), and opened up key elements of the technology so that other agents would be able to construct compatible devices (in particular, the LonTalk communication protocol was published as an ANSI standard, and Echelon issued royalty-free licenses to all who wished to implement it)<sup>8</sup>.

In the early 1990s, in order to promote interoperability between LonWorks-based products and to create consensus around the distributed control movement, Echelon set up, in the US, the LonMark Interoperability Association (LIA), a voluntary standards organization whose members included Echelon and a large number of user companies, mostly OEMs, system integrators and software developers. LIA members organized into task groups whose main objective was to develop standard specifications to which products based on LonWorks technology would have to conform in order to ensure interoperability with other products. As a scaffolding structure, organized as a quality promotion and standard-setting association, LonMark has promoted interactions around the technology and has supported the expansion of artifact space: currently, LIA associates about 300 firms worldwide, for the most part

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<sup>8</sup> At the same time, Echelon tried to preserve exclusive rights to other key elements of the technology (more often through secrecy and technological barriers rather than enforcement of proprietary rights), in order to safeguard the possibility to maintain some control on the innovation process and to derive some revenue from its activities.



located in the US and Canada, while the LIA Product Database includes over 1300 products, of which about half are offered by European firms<sup>9</sup>.

Echelon also set up a trade fair, LonWorld<sup>10</sup>, in order to promote interaction and exchange among LonWorks users and to strengthen the consolidation of the market system. LonWorld provided an important meeting place for those users - small OEMs and integrators in particular – which were interested in realizing open control networks able to integrate different functions. From the mid-1990s, several of these users, in different European countries, began to organize into user groups, called LonUsers<sup>11</sup>. Echelon played a key role in supporting their formation, involving people who committed to its concept of distributed control rather than to its products in a narrow sense. Interestingly, LonUsers were specific to Europe: we may suppose that, in the United States, the companies that were more active in promoting LonWorks relied on the US-based LIA as a scaffold for meeting and exchange; furthermore, US system integrators working with open systems already had their own professional organizations, such as CSIA (Control System Integrators Association), which instead were absent in Europe.

With the support of these scaffolding structures, Echelon enjoyed some success in recruiting numerous agents to the complex task of creating a market system for LonWorks, and the zone of artifact space around this technology expanded considerably. During the second half of the 1990s the LonUser groups were the most active agents engaged in promoting distributed control and LonWorks technology in Europe. LonUsers associations became the privileged channel for the forming of expertise, and for the forging of stable relationships between Echelon, the system integrators and the smaller OEMs.

In the meantime, however, important changes were taking place in the zones of agent-artifact space around control systems for building and industrial automation.

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<sup>9</sup> The database (<http://www.echelon.com/productdb/>) however does not provide a complete overview of existing LonWorks-based artifacts, since it includes only those products that have been certified as interoperable by LonMark, but many other noncertified products are also commercially available.

<sup>10</sup> The first trade fair, called LonUsers, was convened by Echelon in California in November 1991, with around 65 attendees representing over 40 companies. From then, until 2000, two LonUser trade fairs were held each year, one in the US and one in Europe. In 2000, the fair's name was changed to LonWorld, responsibility for its organization was contracted to a German marketing company, and the number of fairs was reduced to one per year.

<sup>11</sup> The largest users groups are the German LonNutzer Organization (LNO) founded in 1993, and LonUser Sweden, founded in 1992; a few years later LonUsers Italia (1999), LonUsers UK (2000) and LonUsers France were formed, together with other user groups in smaller countries (Finland, Denmark, Norway, the Netherlands, Belgium). The most recently founded groups are LonUsers Espana and LonUsers Poland.

Let us first consider industrial automation applications, where LonWorks' penetration has been, over time, very modest. While some commentators claim that it was LonWorks' technical features that made it unsuitable for applications where precision of execution and rapid reaction times are fundamental (such as most industrial processes), other more convincing reasons have to do with the structure of the entire 'sociotechnical system' (Ropohl, 1999; Mollerman and Broekhuis, 2001) surrounding industrial automation technologies. When LonWorks arrived on the market, in fact, open system architectures for industrial control systems had already consolidated.

System integrators, building industrial control networks by integrating control subsystems via standard protocols, had started to appear already in the early to mid-1980s. Independent software companies had begun to specialize in supervision and control software (SCADA) for managing complex networks of industrial machines; over time, a few widely used standards (Profibus, CAN, OPC), developed by industry consortia, had become the dominant communication protocols. In the course of the 1980s, this 'open system' model of integration had the better of the 'closed' model based on proprietary control systems<sup>12</sup>. Because of the consolidated presence of integrators able to build control systems from commercial 'off the shelf' components using already standardized interfaces, LonWorks could more easily be accommodated into existing networks instead of precipitating dramatic changes in agent-artifact space. According to one of our informants, nowadays "companies that are making solutions with Profibus, Allen Bradley all these PLC manufactures... have 99,9% of the market share, and the industrial Lon is probably sold only by about by 20 companies worldwide".

The evolution of building automation systems, from proprietary to more open systems, may prove not too dissimilar from that followed by industrial controls. Compared with industrial automation, however, the movement toward open systems in building automation has been extremely slow. Demand for integrated control networks in buildings has grown very slowly, due in part to the less pressing need to drive down costs and increase safety standards in a building rather than a factory environment, and in part to the different nature of the users – property owners are typically less technically informed than managers of industrial plants,

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<sup>12</sup> "The manufacturers' representatives, distributors and electrical contractors who had been doing PLC-based integration projects were now able to compete directly with the major control system manufacturers [such as, in the US, Foxboro, Fisher Controls, Fischer & Porter, and Bailey Controls] ... That they did so successfully is clear as evidenced by the fact that Bailey, Fischer & Porter, Foxboro and Fisher Controls are no longer independent companies, and Honeywell is recovering from a failed merger attempt with General Electric" (CSIA, 2002).

and rely on the advice of consultants to solve their technical needs. Established conventions in the construction industry generally assign the responsibility for control systems to ‘mechanical contractors’, who are responsible for the HVAC system and for all the systems that, in the words of one of our informants, “have to do with water and cooling”; their competencies lie in heating and refrigeration rather than in electronics and informatics, and their understanding of innovative communication and control systems is often poor. The use of standard contracts and the reliance on established tender requirements, which rigidly assign responsibilities for different systems to different contractors, also imply that only a very small fraction of building automation projects explicitly require integration among control systems, and even less specifically provide for open technologies. In addition, the market for home automation systems, which has been considered very promising by many industry spokesmen for decades, has so far failed to materialise, for reasons mainly connected to these systems’ high cost and the lack of specific control competences on the part of electricians.

Despite slow growth in the demand for building control systems - which is also strongly constrained by the vicissitudes of the construction market - since the early 2000s some important changes have taken place in the industry. These are connected, in the first place, with changing attitudes and strategies on the part of control systems manufacturers. Since the beginning of the new century, several large OEMs have abandoned their closed product lines in favour of products that use standard communication technologies<sup>13</sup>. At the same time, in order to win the most innovative and complex projects - integrating different functions like lighting, access control, fire protection, HVAC - many large OEMs are trying to extend their expertise to system integration. Although to some extent there has always been a conflicting model within OEMs that do both manufacturing and installation, this ‘double role’ has become more commonplace in the last 4 to 5 years<sup>14</sup>. The OEMs’ efforts to position themselves as system integrators, as well as providers of open systems, modify role structures in ways that do not match Echelon’s expectations nor those of many of its small allies: if large OEMs acquire the necessary skills in order to perform complex integration projects, their strong brand visibility and their ability to drive down prices may undercut specialized

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<sup>13</sup> An example is the agreement, signed in 2000, between Echelon and Honeywell, according to which the latter adopted LonWorks as standard in its own products, and it undertook to acquire them mainly from Echelon. In the same year, TAC and Echelon signed an agreement according to which TAC and its integrators became authorized retailers of Echelon software products.

<sup>14</sup> According to one informant, “In the last 4 to 5 years the big controls companies have increasingly been moving into systems integration ... these guys quite often play two roles, they are consultants at the beginning and potentially they also provide the system integration... Over the last 5 years we have seen increasing development, in our controls clients, of business entities that will do the whole thing”.

LonWorks integrators. Among the small OEMs and integrators that specialize in LonWorks networks, some have moved towards even more complex networks, not necessarily in building automation, widening their technological competencies; others have successfully defended their market niches by maintaining consulting relationships with large OEMs, providing specialized LonWorks-related skills in the execution of technically advanced building automation projects.

Furthermore, while traditional OEMs are trying to grab a larger slice of the market for integrated projects, innovative system architectures and new competence networks are also appearing. As projects become more complex, involving the seamless integration of different subsystems, other integrators, specialized in industrial information systems and with highly sophisticated IT skills, entered the building automation industry, bringing with them technological architectures and 'cognitive schemes' typical of industrial automation.

Complex building automation projects are increasingly structured in ways that mirror the communication and control architectures that are now commonplace in industrial automation: while standard communication protocols such as LonWorks, BacNet and/or EIB are used for communication *within* subsystems, communication *among* subsystems takes place through widely used data transmission protocols, such as Ethernet, and thanks to generic supervision software. An example is the Atari building in Lyon, completed in 2001. The integration project was jointly managed by the system integrator Meta Productique and by the software developer Newron Systems. The latter is a small company with advanced LonWorks software competencies that often provides consulting services to other companies, OEMs and integrators, which wish to use LonWorks in complex projects for which they do not possess specific expertise. Meta Productique, with a background in industrial automation, realized a system with mixed hierarchical and distributed architectures, all based on open communication protocols: communication between the various devices within the offices (lights, air conditioning, heating) relied on LonWorks technology, while the general supervision of the general building control subsystems (which included automated reconfiguration of office spaces, access control, remote metering of energy consumption) was performed through an industrial supervision software, installed on a server; communication between the subsystems and the server occurred via the OPC protocol on Ethernet-TCP/IP. Like in industrial automation, structures such as these may limit LonWorks' scope of

application to subnetworks or ‘islands’ of distributed control within complex networks that have an overall hierarchical structure.

The movement toward new, more complex system architectures that include both hierarchical and distributed control and merge different technologies, is also facilitated by a phenomenon that trade magazines call ‘convergence’, that is, the tendency to integrate control systems – including building automation systems - to a higher level within the company’s information technology system. Many in the control industry express concern about this trend. The trade journal *Automated Buildings* (Gowan, 2002; Hartman, 2003) warns that it may bring about a reshuffling of roles in agent space, whereby those system integrators with an electric engineering background (as it is currently the case for the majority of integrators in the building automation sector) may be confined to the role of simple installers, unless they quickly upgrade their skills to IT.

These processes have hampered the emergence of a single market system for distributed control. As LonWorks has found applications in different and often separate market systems, the LonWorks scaffolding structures, in particular the user groups that were very active in the second half of the 1990s, have lost importance and associates. LIA, now called LonMark International, has incorporated many of the European LonUser groups, but membership growth has nonetheless stalled in the last three/four years.

We can interpret LonWorks’ story throughout the 1990s and in the first years of the following decade as an example of the ‘rise and fall of a market system program’. Echelon set out to build a market system for its technology by supporting a set of scaffolding structures that would sustain interactions and promote shared narratives centred on distributed control networks and open systems. However, the inertia of existing market systems structures, as well as defensive actions undertaken by the large players in order to protect their technologies, has proved instrumental in slowing down the growth of innovative applications and in hampering LonWorks’ diffusion. In the meantime, the existing market system structures have endeavoured to – and have eventually succeeded in – confining LonWorks to marginal roles that they could incorporate, instead of breaking down boundaries between them.

Echelon has successfully adapted to these changes: it has reduced its ambition to establish itself as the provider of general purpose distributed control technology, and it has started to focus on system-level artifacts suited for specific applications – such as street lighting

systems and, especially, remote metering systems<sup>15</sup>. Echelon is well-positioned to benefit from the new global focus on energy conservation resulting from global warming and energy crisis fears. Sales of LonWorks products have in fact picked up and have continued to grow over the last 3 years.

#### **4. Innovation through networking: Tlon**

Tlon is a small company actively constructing an environment favourable to the application of its exclusive competencies. It operates in market systems that are different but complementary and constitute a context where it can carve out a specialized niche. This case exemplifies how LonWorks technology provides the opportunity for individual entrepreneurs, working together within generative relationships (Lane and Maxfield, 1997) and through scaffolding structures, to weave together projects that cut across existing market system boundaries. Generating these new ‘interstitial zones’ in agent-artifact space – which involve the integration of the focal technology with other technologies, some general purpose, some specific to the particular market systems that the projects link – may produce numerous difficulties but also potentially high rewards.

Founded in 1997, Tlon has headquarters in Schwaebisch Hall, in the Baden-Wurttemberg area. In many ways, it is a typical small European firm: the company coincides with the life and business objectives of its founder and of his closest collaborators; most investment is self-financed; return on research is modest and return on investment takes place in the medium-long term. Innovation is mostly incremental, based on the application of existing technologies to new contexts; however, the company also takes part in sophisticated projects that may deliver relevant innovations.

Tlon is headed by an entrepreneur, VT, an electronic engineer with a long experience in the control industry. VT started to experiment with LonWorks technology in 1995, when he was managing the electronic controls department of a company that produced dyeing machines for the textile industry. After a couple of years’ experience he realized that his newly acquired competencies could be profitably applied to a wide range of control problems, and decided to start a ‘technology consulting’ company for customers interested in innovative electronic controls.

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<sup>15</sup> Some informants have identified 2003 as the year in which Echelon has decided to invest heavily in remote metering applications and in powerline communication, one of Echelon’s technical strong points; the ENEL project, which we describe in section 5, has been instrumental in bringing about this change of direction.

The project that boosted Tlon's reputation was commissioned by a coffee machine manufacturer. This company was not satisfied with the controls produced in house: the software was too complicated, it was unable to simultaneously manage all the functions it was supposed to perform, and it was hard to reconfigure. Tlon set up a system that constituted a textbook example of what it means to move from centralized to distributed control in manufacturing. The software was destructured into elementary components, which were then inserted into different Neuron chips and configured into a communication and control network. This system integrated different functions in flexible ways, allowing for easy and continuous upgrading. Between 1998 and 2001, Tlon introduced in the same company three successive incremental innovations, all based on LonWorks technology<sup>16</sup>.

In the first period of his entrepreneurial career (1998-2003), VT consolidated his relationship with Echelon. Participation in the relevant LonWorks scaffolds (LIA and the German LonUsers association, LNO) and the setting up of Infranet Partners (a consortium of firms interested in developing control network infrastructure, set up in 1999 by VT and a British colleague whom he had met through LonMark) enabled Tlon to remain close to the circle of companies performing the most complex LonWorks-based projects. Tlon also started to cooperate with local agents that were interested in applying distributed control functionalities to other fields. Local technical schools contacted Tlon to carry out case studies and dissertations about problems that could be solved with LonWorks technology. From all these relationships, Tlon gathered new business ideas and human resources.

When Echelon decided to concentrate on remote metering, focusing their attention on powerline communication and on solving large network problems, integrators working on complex projects had already begun to move toward new technological solutions, including wireless technologies such as ZigBee (for which, according to VT, Echelon has no specific expertise). As we have noticed in the previous section, system integrators and software developers, while still using LonWorks at the field level, for communication among devices within control subsystems, have now begun to use TCP/IP and software developed on an open source basis for integration at higher levels.

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<sup>16</sup> The first consisted in the development of a new system for the control of individual machines; the second concerned the creation of a control network polling payment information from vending machines and transmitting it to the company's accounting system; the third was the implementation of a remote control functionality for the network of vending machines, in order to reduce maintenance costs and enable the producer to monitor the machines' state in real-time.

VT thinks that LonWorks is unlikely to become a popular choice for communication and control within simple systems, such as home automation or simple building automation projects: although the technology works well, it is expensive, and the market is already dominated by electricians and distributors working with large companies, like Siemens and Honeywell, which enjoy a strong reputation with final customers. Instead, Tlon has decided to concentrate on complex projects that only very skilled integrators can undertake. In particular, it focuses on complex networks, often comprising geographically dispersed devices, aimed at reducing energy consumption and improving device management. They have realized, among other projects, a network for the management of cooking devices in order to reduce energy consumption, a network for the remote management of HVAC systems in private homes, and a network for the management of photovoltaic panels in schools and government buildings.

These projects, all developed locally, are conceived as components of a broader project, called ‘Infranet Valley’, which VT hopes to realize in Schwaebisch Hall, and maybe to replicate elsewhere. The Infranet Valley project should extend the distributed control framework to networks that are geographically dispersed, in order to deliver functionalities to the individuals living and working in a certain territory<sup>17</sup>. Initially (2000-2002) the plan was to construct a very large local network based on LonWorks technology, comprising around 5 million devices. The network would allow the local government to optimize energy consumption in local schools, swimming pools and administrative buildings. Later (since 2003) the project has been reframed in terms of integration of specialized sub-networks, where communication is based upon LonWorks and other protocols. Although VT continues to use LonWorks for device-level communication and wherever it provides the best communication solution, he has decided to acquire skills in the development of open-source software that he considers to be strategic for the realization of future projects. This change in perspective has happened, not by chance, when Echelon re-oriented its activities toward metering technologies and decided to privilege research on powerline rather than on wireless communication.

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<sup>17</sup> Tlon’s brochure clearly introduces this concept: “What is Infranet? Infranet is the information exchange highway between equipment and machines through their sensors and actuators. The future belongs to this network of decentralized, intelligent automation: worldwide long-range observance and long-range control of buildings and others; automatic control and observance of energy flow; networking of household devices, networking of actuators and sensors from the heating, ventilation and climate technology; long-range control of production processes. Control systems previously based on PCs are now moving to a lower level: decentralized intelligent sensors and actuators. The Tlon solution is based on a twisted wire network and all the devices have their own local intelligence. It allows the devices to talk to each other directly rather than referring each time to a central computer”.



Infranet Valley is a long-term project, which builds upon many small local initiatives. VT continually attempts to build generative relationships with local actors (local officials, training and academic institutions, industrial associations), trying to create networks of operators interested in solving community problems, not specifically connected with distributed control. Tlon relies on numerous scaffolds: besides LIA, LNO and Infranet Partners, it also takes part in associations and projects related to energy management, integrated management of public services, and in initiatives promoted by local or national public bodies. VT thinks that networking at the local and international level can help his firm actively construct a market niche for complex local networks that is more promising than the market share or profit results that could be obtained by trying to position Tlon within the more established market system for simple automation projects. The cost of participation in the different relationships networks and scaffolds is high, but the positioning in the high end of the market guarantees the resources necessary to continue investments of this kind.

## **5. Maintaining hierarchical control: ENEL**

In the late 1990s, a new application opened up for LonWorks technology that has proved instrumental in reorienting Echelon's activities: the remote control of utility meters. The first, and so far the largest, application is ENEL's 'Telegestore' project, involving the installation of electronic meters in 27 million Italian households, which in recent years has constituted Echelon's main source of revenue<sup>18</sup>. At its inception between the spring of 2000 and early 2001, the Telegestore project was extremely innovative. It was the first large-scale installation of this kind and has since become an important 'cultural' reference for many agents, opening the way for similar installations. In addition, at that time many in the industry anticipated that the electricity meter could be transformed into a 'residential gateway', connecting, through power lines, the electricity provider upstream with any intelligent device downstream, including other meters, local plants, even home appliances. Some hoped that this innovation would leverage the launch of a radical change in the provision of user services through powerline communication, and, in particular, that it would finally launch the long anticipated and much coveted home automation market. As it turned out, though, the Telegestore project developed along more conservative lines, without spurring radical innovations in the provision of user services via the electricity grid. While it is interesting to investigate what prevented the process from going ahead according to the initial expectations, our main focus

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<sup>18</sup> Between 2001 and 2005 ENEL has been by far Echelon's main customer; for example, in 2004 it has brought in \$64.1 million out of \$109.9 million of total revenue.

is on how LonWorks technology has been incorporated into existing structures in agent-artifact space, so that the realization of new functionalities has been carried out by existing competence networks under the control of a central agent, ENEL.

Founded in 1962, ENEL (Ente Nazionale per l'Energia Elettrica) is a large enterprise with public capital<sup>19</sup>. For almost four decades, it was a de jure monopolist in electricity generation and distribution. Its position began to weaken during the 1990s with the introduction of provisions aimed at liberalizing the energy market, in particular the so called 'Bersani Act' (March 16, 1999) which established that, from January 1st 2003, no company could produce or import more than 50% of the total electric power produced or imported in Italy.

At the beginning of the current decade, therefore, ENEL was forced to give up an important share of its business. ENEL's management devised a new role for the company as a 'multi-utility', diversifying into other networked services thanks to the reallocation of the large proceeds accrued from the mandatory sale of parts of its activity. ENEL tried to expand into water distribution, with Acquedotto Pugliese, but the initiative was not successful. It also acquired the gas distribution network Camuzzi SpA, the second largest gas supplier in Italy. Telecommunications were considered as particularly important: between 1999 and 2001, ENEL became the second Italian telecommunications provider, through the acquisition of part of the mobile telephony operator Wind and the acquisition of the fixed telephony operator Infostrada. In this context of convergence among electricity distribution and telecommunications, a large remote customer management project started to take shape.

Many large European utilities had performed experiments in remote management in the 1990s. ENEL had carried out a pilot project called SITRED, experimenting with meters that recorded information about consumption and about the state of the network, sent it to a control centre through power lines, and received instructions through the same means. The main technical difference between SITRED and the successive Telegestore project was the use of an electromechanical meter and the simultaneous data accumulation by an electronic support connected to each meter, which could be remotely controlled. The project involved several of ENEL's established suppliers: Siemens, Landis & GYR, Schlumberger, Copeco, Ducati, ABB Elettrocondutture, Feme and Bticino. The system was tested, quite successfully, on 70,000 households in and around Rome.

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<sup>19</sup> ENEL was formed from the merger of over 1,200 private and public local companies, and was for a long time the second largest Italian group, after FIAT, in terms of revenue and employees.

By the mid-1990s the group of engineers in charge of this and other projects was convinced of the technical feasibility of a meter that could become a ‘user interface’. This project moved to the forefront shortly after the appointment of Franco Tatò as ENEL’s CEO in 1996. Tatò, a manager with international experience, had a background in communications, and it was under his direction that ENEL undertook a strategy of diversification into other sectors.

We can identify several reasons behind ENEL’s decision to venture into a large project such as Telegestore. In 1997 an economic feasibility study highlighted the possibility of large savings for ENEL, both in meter reading (which could be performed automatically instead of manually) and in the control of energy flows, reducing the revenue losses due to network failures and to misreporting or tampering on the customer’s part.

More generally, in the strategy of transformation into a multi-utility, the opportunity to maintain and reinforce the relationships with the final customers and to increase the range of available services (from the provision of customized energy distribution, to the remote management of customers’ accounts, to mobile telephony) could provide a remarkable advantage vis-à-vis the competitors and could hinder the entry of other providers.

Finally, the importance of being the first utility worldwide to activate such a cutting-edge service did not escape ENEL’s management. This might enable ENEL to sell the service to other providers, whether in Italy - where the local utilities were buying a large share of the electric distribution network - or abroad.

ENEL decided to disband the group that had worked on SITRED and to use internal capabilities more substantially. Unlike in SITRED, it was decided to use a fully electronic meter able to manage information directly. This decision seems to have involved a direct intervention on the part of Tatò, who wanted a radically innovative project, without the electromechanical/electronic technological compromise that could hamper further innovation<sup>20</sup>.

First, through an international tender, ENEL selected the British company AMPY to design an electronic meter with features meeting their current needs. To enable communication between the meter and the concentration and data processing centre, ENEL could use its own

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<sup>20</sup> It has been said that Tatò’s radically innovative approach – implying the complete substitution of electromechanical technology with electronic technology, rather than their complementary use – came from his experience in Olivetti. Tatò, in fact, was Olivetti’s manager during the complicated transition from typewriters to calculating machines.

electricity network and the mobile telephony network of its controlled company Wind. It was decided that communication between the concentration centres, each of which serves about 200 users, and the processing centre would happen via GPRS, while communication between the meters and the concentration centres would be enabled by Echelon's LonWorks technology, over powerline. This choice seemed to have been motivated, according to sources internal to ENEL, by technical reasons: in fact, Echelon had developed a very efficient system for data transmission over powerline, and it would be able to rapidly resolve any communication problem using its own products.

Echelon and ENEL collaborated for about three years, from 2000 to 2003. In the first period, ENEL's internal team and two technicians from Echelon worked together in developing the devices. After this technical collaboration, kept behind closed doors, a preparatory agreement, dated May 10<sup>th</sup> 2000, was jointly presented by the two companies. The press release stated that: "Through this technology numerous value-added services can be offered for the remote management of homes and offices, such as monitoring, use and reparation of home appliances and of security systems, control of air conditioning and lighting devices. The services offered can be accessed by customers through the Internet, fixed or mobile telephone, and will be managed by the ENEL group".

Therefore, at least in the initial phases of the project, the LonWorks-enabled meter was interpreted by ENEL as a tool that could launch a radical innovation in the relationship with the final customer, which may eventually lead to a revolution in the utilities' market system, allowing the implementation of a wide range of services. The performances expected for the Telegestore system were not limited to the remote management of energy consumption, however; through the Neuron chip and two transceivers it would be possible to connect, via powerline, the devices already present in the home (heating system, home appliances, access control) and transmit and receive data to and from a control centre. This seemed the right opportunity to jumpstart – especially in Italy – the so far elusive home automation market.

In addition to ENEL and Echelon, another partner at the beginning of the project was Merloni Industries, the third largest European manufacturer of home appliances. The official agreement between ENEL and Merloni Elettrodomestici was dated October 19, 2000. The two companies agreed to cooperate in order to experiment with innovative forms of payment for home appliances connected via powerline to the intelligent meter. In the same period, Merloni consolidated its relationship with Echelon, with whom they had their first contact

back in 1993. The two companies issued statements announcing the deployment of Echelon's powerline transceivers within Merloni products (although the product under study, Leonardo, has never been commercialized). At the 2001 SMAU fair, Merloni presented the pay-per-use washing machine that communicated with the electronic meter: it would be rented and paid according to effective use. At LonWorld 2001 the most popular debate was The Residential Gateway – Gateway Challenges, where the first speaker was the manager in charge of the Telegestore project. The home automation revolution seemed to be about to happen.

In 2001, the Telegestore project began. Thirty million meters had to be produced and installed, the network of concentrators and the information network had to be set up. The meters were produced in different countries, mostly in Eastern Europe and in China, where relationships with the various sub-suppliers were mediated by Shenzhen Kaifa Technology Co.

The start of the Telegestore project in Italy was not painless. Many critics, within the Competition Authority and especially within the trade unions and among the environmentalists, were sceptical that ENEL could manage such a complex innovation as Telegestore. These suspicions were fuelled by the fact that the meters showed a worrying tendency to immediately disconnect customers that exceeded their contractually established wattage, unlike the old electromechanical meters that had elevated tolerances: this provoked harsh reactions from some consumers' associations.

Another source of controversy concerned Echelon's involvement as a supplier. The contract for the communication system – with a value of approximately 300 million Euro – had been assigned to Echelon without a competitive tender, and the agreement had been followed with the acquisition by ENEL of a share of about 9% in Echelon, through which ENEL gained a seat in Echelon's board. This close association with an American company was criticized by the new center-right government formed in 2001, particularly by the right-wing nationalist Alleanza Nazionale party<sup>21</sup>.

Tatò resigned on May 24<sup>th</sup> 2002 - for numerous reasons, mainly political, probably not

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<sup>21</sup> The parliamentary interrogation presented on 2/19/2002 by the Apulian MPs Ivano Leccisi and Ugo Lisi affirmed, "how could it be that Echelon was chosen without public tender as supplier of ENEL, when the ENEL purchases will cover a share superior to half of its revenue," and it was asked "if the government thinks it admissible that an operation of this kind can be financed with public money; if the government does not think it appropriate, once possible responsibilities have been ascertained, to adopt immediate provisions vis-à-vis ENEL's current management."

directly related to the Telegestore project - and Paolo Scaroni, another internationally renowned manager but with a background in manufacturing rather than communications, was appointed in his place. Under the new management, the project to transform ENEL into a multi-utility was abandoned, and in particular it was decided that ENEL would not engage in sectors different from energy distribution.

After Tatò's resignation, the relationships between ENEL and Echelon became difficult, as they had not consolidated any network of relationships below the CEO level, neither among the staff of the two groups nor in collaboration with external actors. There was not a shared clear vision of the route that the project could follow, nor a group that could build it. Moreover, evident contrasts between ENEL and Echelon appeared, concerning the promotion of the project to other utilities in Italy and abroad. Despite the continuation of the supply relationship, collaboration between ENEL and Echelon ceased in 2003: the controversy was brought before an international arbitration and was resolved in September 2005<sup>22</sup>.

ENEL decided to restructure the project's organization. In meter design, Ampy was replaced by Kaifa, which, together with ENEL, quickly perfected a replacement electronic meter; the communication protocol, appropriately modified, came from the SITRED project.

STMicroelectronics adapted a chip kit capable of running the software. The announcement was made at the end of 2004, after the deal had been done. In order to sell Telegestore to local energy distribution firms, ENEL formed an external alliance with IBM, signed in March 2004.

In an article published in *Metering International* magazine (2004), Telegestore was presented as a service for managing electricity users and collecting and transmitting information, while the article was silent on the possibility of downstream connection<sup>23</sup>. In fact the electronic meter, as it was installed in Italian homes, did not, and could not, connect the downstream appliances to the electricity provider's communication system. We can advance some hypotheses concerning the reasons why the project did not achieve all the functionalities that were initially expected. It is plausible that, at the start of the project, a communication technology that allowed connection with downstream devices or systems was still not

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<sup>22</sup> The International Chamber of Commerce to a great extent swayed towards ENEL, however it established much lower compensations than those that were demanded.

<sup>23</sup> There was only a brief, vague mention: "The Telegestore system opens an outdoor-indoor communication channel. ENEL is technically evaluating the co-existence of the metering services with energy-related value added services."

available, or that it was not sufficiently reliable or convenient. The decision was probably made to start with the technology that was available at the time, and in the meantime to continue to research a solution capable of providing more advanced communication performances. However, for various reasons (reshuffling of ENEL's top management and strategic priorities, problems in the ENEL/Echelon relationship) this process stopped, the 'new generation' Echelon/Ampy electronic meter was never realized, and the efficiency of rapid installation was prioritized.

Today the Telegestore project has come to a rapid completion. Sales to other Italian providers have been mediated by IBM: most local utilities in Italy have bought the Telegestore system, while another installation has been made in Cantabria, Spain.

Echelon independently launched its NES – Networked Energy Services – division in 2003, after carrying out experiments in Holland and New Zealand. At the end of 2004, it commercialized an electric meter capable of collecting information and receiving and sending commands<sup>24</sup>. However it was only at the end of 2005 that Echelon began to receive some reward for its efforts in terms of sales, thanks to a project with Swedish utility Vattenfall. The Vattenfall project too seems exclusively directed at meter reading and remote customer management, not differently from Telegestore. Since then, Echelon have received several very large orders, they have begun trials in various countries, and have set up a growing network of NES Value-Added Resellers. For the first quarter of 2007, Echelon reported revenues of \$25M from the NES product line.

The Telegestore example highlights an altogether different way in which a technology can be incorporated into a potential market system, based on a specific new functionality that the technology helps make possible. Few relationships developed around the Telegestore project, and they were mostly mediated by ENEL: cross-cutting relationships among the other participants did not develop if not minimally and in no way did these relationships consolidate into a competence network. ENEL was probably responsible for this situation since it maintained tight control of collaborations, keeping the option to discontinue them at any time, and this way it fully controlled the process and the results. In carrying out this project, ENEL did not rely on external scaffolds. Its involvement in LonUsers was minimal (ENEL joined in

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<sup>24</sup> The meters have been designed by a team of engineers that Echelon hired from a failed startup in the Silicon Valley area; they are manufactured by subcontractors in China and Hungary, and marketed by a number of NES Value-Added Resellers around the world.

the LonUsers Italia association in 2001, but it left a short time later, in 2003), and the relationship with Merloni did not produce any tangible results. With respect to LonWorks' market system, ENEL was not interested in distributed control per se. Rather, it used LonWorks technology as a competitive tool in order to attain better control of the existing market. Although an initial convergence had taken place between Echelon and ENEL's management's attributions – concerning the possible use of the electronic meter as a residential gateway enabling communication between devices inside and outside the home – this process was interrupted, for reasons that we described above. The ENEL contract gave Echelon substantial revenues for several years, but it did not catalyze the launch of home automation nor did it boost the growth of a market system for distributed control. However, it convinced Echelon of the importance of orienting its activities towards remote metering applications and network-based services. That is, Echelon's attribution of its own role transformed from that of technology provider and market system coordinator to system - bundles of products and services - provider.

## **6. Lessons from LonWorks**

Our analysis of several case studies confirms the interpretative power of the theoretical framework that we have adopted, and it allows us to derive some useful implications for innovation theory.

Very often, when a new artifact is produced, it enters a pre-existing socioeconomic system characterized by established competence networks, physical scaffolding structures, consolidated role structures, whose interactions with the new artifact strongly constrain the process of adoption, the ways in which the new artifact is used and how its technical characteristics evolve. The production and commercialisation of a new artifact does not simply trigger a cumulative diffusion process, statistically representable with a logistic curve, but it catalyzes a variety of complex processes through which the artifact itself evolves, the set of other artifacts in conjunction with which it is used, installed, maintained, developed changes, sometimes spawning an entirely new artifact family. The cognitive attributions that agents make about the artifact's functionality change over time too, as well as the identities of the agents that are somehow involved in its supply and use.

The diffusion of LonWorks technology cannot be modelled as a simple 'epidemic diffusion' process, since the technology is changing over time and the artifact family is expanding. Even



if we consider only the relatively unchanging building block, the Neuron Chip, the fact that the applications are so varied and that new ones are discovered over time implies that the size of the possible market for Neuron Chips keeps expanding, so that it becomes difficult to understand when the market may be 'saturated' by the new technology. Further, the population of adopters in different applications is heterogeneous and geographically dispersed, and it is hard to imagine that the diffusion process may happen with any regularity. Quantitatively, the diffusion of LonWorks artifacts seems to be characterized by major discontinuities, corresponding to important sale agreements being signed or called off, rather than a process of gradual technological contagion following the spread of information about the new technology.

Innovation processes are not simply driven by the technical characteristics of certain artifacts: the interpretations that different agents make of them are also crucial in driving their actions and hence in determining the overall shape of the process (Bijker, Hughes and Pinch, 1987). From our examples, it is apparent that the technology had different meanings for different agents. While Echelon, at least initially, saw its technology as a general purpose solution to control problems, large OEMs saw it first and foremost as a way to simplify communication within their systems and, at a later stage, as a tool that would allow them to access more sophisticated integration projects. For ENEL, LonWorks was an efficient solution to contingent communication problems; only few actors within ENEL shared Echelon's view of LonWorks as a technology enabling communication with the wider world of 'intelligent devices'. Tlon sees LonWorks as a technology that permits the realization of complex territorial networks: it does not only replace traditional products, it can also allow networking among artifacts that in the past were neither 'intelligent' nor integrated.

Issues of technological superiority and price advantage are negotiated in the social domain and perceived or actual technological superiority does not immediately guarantee the success of a technology over its competitors. Rather than being known to everybody in the market system, even the technology's basic features are the object of negotiation and debate.

The process of construction of a market system for the new technology often requires the creation of new role structures and new scaffolding structures, or the re-orientation of pre-existing ones. Often, the process develops across established industry boundaries and over a very long time span. For example, changes in role structures were necessary in order to sustain the creation of a market system for distributed control networks based on LonWorks

technology: the creation of such networks would require the presence of independent systems integrators buying components ‘off the shelf’, made available by OEMs who would agree to make their product conform to certain interoperability standards. In practice, the two roles of OEM and system integrator are not clearly separated and this has given rise to different kinds of possible interaction schemes and different efforts on the part of the various agents to protect their own technologies and sources of revenues, hampering the development of a market system along the lines originally envisioned by Echelon.

The consolidation of competence networks able to carry out the system’s functionality is also very important in order to allow market systems to operate in practice: for example, it has taken a very long time for LonWorks competence networks to get established in building automation, and this has hampered the diffusion of the technology, so much so that it may have missed its ‘window of opportunity’ in favour of other technologies, imported from industrial automation via different competence networks. Another example is the lack of control competences on the part of electricians, which has certainly hindered the diffusion of home automation products.

The processes that construct a new market system result from a combination of innovation projects, that trigger subsequent cascades of changes, but that are not lined up along a ‘natural’ trajectory (Nelson and Winter, 1982) determined by the artifact’s intrinsic features. Each of the agents that we encountered developed its own course of action in conditions of ontological uncertainty (Lane and Maxfield, 2005) on the basis of personal evaluations, attributions and narrative structures, independent of those produced by Echelon: the sum of these individual actions cannot be considered as the predictable consequence of certain events. While the concept of ‘technological trajectory’ (Dosi, 1982; Nelson and Winter, 1982) may be useful to describe, retrospectively and with the benefit of hindsight, the evolution of a broadly conceived technological system, it is not useful in order to interpret innovation processes in the making, since they are characterized by constant novelty, idiosyncrasy, path dependency, and they are affected by the ‘hierarchically tangled’ (Lane, 2005) actions and interactions of agents located at different levels of social organization.

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