The AgentLink III Technology Diffusion Model

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1. Introduction

This report describes the technology diffusion model developed by the AgentLink III project. AgentLink III[1] is an EC-funded Co-ordination Action to support European research and development in agent-based computer technologies running from 1 January 2004 to 31 December 2005. Workpackage 6 of the project involves the development of a community roadmap (Luck *et al.* 2005) presenting the current status and likely future developments of agent technologies, which was a major revision of an earlier agent technologies roadmap (Luck *et al.* 2003). For the purposes of this roadmapping exercise, a computer simulation model was developed by the authors in order to consider different trajectories for the adoption of agent technologies, with trajectories based on various assumptions regarding industry structure and the existence of competing technology standards. This document presents details of the model and assumptions, along with the results of the simulation exercises. The document begins with a discussion of the marketing theory of the diffusion of innovations, in order to establish the theoretical context of model development.

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2. Diffusion of Innovations

In order to understand the current commercial position of agent technologies it is useful to know something about the diffusion of new technologies and innovations. This is a subject long-studied by marketing theorists (e.g., Rogers 1962, Midgley 1977) drawing on mathematical models from epidemiology and hydrodynamics. We begin by considering the concept of the Product Life Cycle.

Most marketers believe that all products and services are subject to life cycles: sales of a new product or service begin with a small number of customers, grow to a peak at some time, and then decline again, perhaps eventually to zero (Levitt 1965). Growth occurs because increasing numbers of customers learn about the product and perceive that it may satisfy their needs (which may be diverse). Decline eventually occurs because the market reaches saturation, as potential customers have either decided to adopt the product or have found other means to satisfy their needs, or because the needs of potential customers change with time. Most high-technology products are adopted initially only by people or companies with a keen interest in that type of new technology and the disposable income to indulge their interest. Thus, early adopters are often technologically-sophisticated, well-informed, wealthy, and not averse to any risks potentially associated with use of a new product.

Why does a product life cycle exist? In other words, why is it that all the companies or people who will eventually adopt the technology, product or process do not do so immediately. There are several reasons for this:

[1] www.agentlink.org

- Potential adopters must learn about the new technology before they can consider adopting it. Thus, there needs to be an information diffusion process ahead of the technology diffusion process.

- In addition, for non-digital products and services, the supplier needs to physically distribute the product or service. Establishing and filling sales channels may take considerable time and effort, and thus delay uptake of the product or service.

- Once they learn about a new technology, not all eventual adopters will have the same extent of need for the product. The early adopters are likely to be those with the most pressing needs, needs which are not currently satisfied by competing or alternative technologies. The early adopters of supercomputers, for instance, were organizations with massively large-scale processing requirements, such as research physicists, meteorologists, and national census bureaux; later users included companies with smaller, but still large-scale, processing requirements, such as econometric forecasting firms and automotive engineering design studios.

- Of those potential adopters with a need, not all will have the financial resources necessary to adopt the new technology. Most new technologies, products and processes are expensive (relative to alternatives) when first launched. But prices typically fall as the base of installed customers grows, and as new suppliers enter the marketplace, attracted by the growing customer base. Thus, later adopters typically pay less than do early adopters for any new technology. Likewise, the total costs of adoption also typically fall, as complementary tools and products are developed in tandem with a new technology. If a company's needs are not pressing, the company may benefit by waiting for the price and other adoption costs to fall before adopting.

- Similarly, not all potential adopters share the same attitudes to technological risk. The risks associated with adopting a new technology also typically fall, as bugs are eliminated, user-friendly features added, and complementary tools and products developed. Each subsequent release of an operating system, such as Windows or Linux, for example, has entailed lower risks to users of unexpected losses of data, obscure hardware incompatibilities, exception conditions, etc.

- Finally, for many advanced technologies and products the value to any one adopter depends on how many other adopters there are. These so-called *"network goods"* require a critical mass of users to be in place for the benefits of the technology to be fully realizable to any one user. For example, a fax machine is not very useful if only one company purchases one; it will only become useful to that company as and when other companies in its business network also have them.

These reasons for the existence of product life cycles mean that companies or people who adopt a new technology or purchase a new product later in its lifecycle may do so for very different reasons than do the early adopters; later adopters may even have different needs being satisfied by the product or technology. For example, in most countries the first adopters of mobile communications services were mobile business and tradespeople, and wealthy individuals. Only as prices fell have residential consumers, non-mobile office workers, and teenagers become users, and their needs are very different from those earlier into the market. The changing profile of adoptees creates particular challenges for marketers (Moore 1991).

How quickly do new products and technologies reach saturation? If one considers an innovation such as written communication, which began several thousand years ago, diffusion has been very slow. Perhaps as many as half the world's population have still to learn to read and write. In contrast, cellular mobile telephones are now used by 1.7 billion people, a position reached in just over two decades from the first public cellular networks (IDC 2005).

3. Standards and Adoption

The fact that many technology products and processes are network goods means that the presence or otherwise of technology standards may greatly impact adoption. If a standard exists in a particular domain, a potential adopter knows that choosing it will enable access to a network of other users. The greater the extent of adoption of the standard, the larger this network of users will be. Thus, one factor inhibiting adoption of Linux as an operating system (OS) for PCs was the fact that, until recently, most users had adopted the *de facto* standard of Microsoft Windows; while the user of a stand-alone machine could use any operating system he/she desires, installing an uncommon OS would mean not having access to the professional services, software tools and applications which support or run on the operating system. If adopting a technology is viewed as akin to choosing a move in a multi-party strategic game, where the potential adopter wishes to select that technology option which will be also chosen by the majority of his/her peers, then the existence of a standard may weight the payoffs in favor of a particular option and against others (Weitzel 2004).

Where do standards come from? Standards may be imposed upon a user community by national Governments or international organizations, as with the adoption of GSM by all European and many other nations, for second-generation mobile communications networks; the communications regulatory agencies of the United States, in contrast, decided not to impose a particular technology standard in this domain. Or, standards may be strongly recommended to a user community by a voluntary standards organization, as in the case of many Internet standards; two machines connected to the Internet may use any interconnection protocols they themselves agree on, for example, not necessarily the standard protocols, such as TCP and UDP, defined by the Internet Engineering Task Force.[2] Finally, standards may emerge from multiple independent choices of one particular technology over others made by many individual adopters; the common *QWERTY* typewriter layout is one such *bottom-up* standard (Gomes 1998).

However, if standards are not imposed by some Government or regulatory agency, then scope exists for multiple voluntary organizations to recommend competing standards and/or for competing standards to emerge from user decisions. To some extent, this may be occurring in the agent technologies domain, with several organizations having developed or aiming to develop standards related to the inter-operation and interaction of intelligent software entities: The Foundation for

[2] www.ietf.org

Intelligent Physical Agents (FIPA),[3] the Global Grid Forum,[4] the Object Management Group,[5] and the WorldWideWeb Consortium.[6] The view has even been expressed that having multiple competing standards may be in the interests of major technology development companies, none of whom wishes to see a standards body adopt a standard favorable to a competitor's products; in this view, large development companies may actually act so as to “divide and conquer” the various competing standards bodies, by, for example, participating intensely in one standards organization at one time and another organization at another time.

Faced with competing recommendations for standards, what will a potential adopter do? One result may be decision paralysis, with a user or company deciding to postpone adoption of a new technology until the standards position is clearer. Thus, in this case, multiple competing standards may inhibit uptake of a new technology and hence inhibit market growth. On the other hand, the proponents of competing standards each has an interest in promoting their particular solution, and so the presence of multiple standards may lead to faster and more effective dissemination of information about the new technology than would be the case if there was only one standard. On this view, therefore, competing standards may actually encourage uptake of a new technology and hence of market growth. Which of these countervailing pressures actually dominates in any one situation will depend on the other factors influencing the decision processes of a potential adopter, for example, the extent to which the proposed technology satisfies an unmet need, the criticality of the need, and the extent of network effects.

Related to the issue of standards and network effects in adoption decisions by potential users of new technologies is the issue of business ecologies. Most companies and organizations are enmeshed in a network of business relationships, with customers, suppliers, competitors, and other stakeholders. If a downstream customer or an upstream supplier insists on adoption of a particular technology or standard as a condition of business, then a company may adopt it much sooner than they would otherwise. Thus, for example, the US company GE, has insisted that most of its suppliers, including even law firms providing legal advice, bid for its business through online auctions. Of course, such pressure along a supply chain or across a business network may also greatly reduce the risks and costs associated with a new technology; thus, adoption decisions under such circumstances are not necessarily irrational. Recent research has considered the impact of networks of influence in business ecologies on software adoption decisions, e.g., von Westarp 2003.

4. Agent Technologies

With this marketing background in mind, it is useful to consider the position of agent-based computer technologies. Adoption of agent technologies has not yet entered the mainstream of commercial organizations, unlike, say, Object-Oriented Technologies. The majority of commercial organizations adopting agent technologies would, in our opinion, be classified as *early adopters*. We believe this because we know of only a small number of deployed commercial and industrial applications of agent

[3] www.fipa.org
[4] www.ggf.org
[5] www.omg.org
[6] www.w3c.org

technology, and because we believe considerable potential exists for other organizations to apply the technology.

What is the range of applications? To date, deployed applications of agent technologies have been concentrated in a small number of industrial sectors, and for particular, focused, applications. These have included: automated trading in online marketplaces, such as for financial products and commodities; simulation and training applications in defence domains; network management in utilities networks; user interface and local interaction management in telecommunication networks; schedule planning and optimization in logistics and supply-chain management; control system management in industrial plants, such as steel works; and, simulation modelling to guide decision-makers in public policy domains, such as transport and medicine.

Why are agent technologies still only in the early-adopter phase of diffusion? There are a number of reasons for this. Firstly, research in the area of agents technology is also still only in its infancy. Here, a reasonable comparison is with Object-Oriented Programming (OOP) approaches, where the initial research commenced in 1962 (Dahl 2002, Dahl & Nygaard 1965), some 32 years before the public release of the first version of Java and the widespread commercial adoption of OO technologies, and 39 years before the two original researchers, Ole-Johan Dahl and Kristen Nygaard, received a Turing Award for their work. As a consequence of this, knowledge of agent technologies is still not widespread among commercial software developers, although of course projects such as AgentLink have tried to overcome this.

Secondly, as a result of the immaturity of research and development in agent technologies, the field lacks proven methodologies, tools, and complementary products and services, the availability of which would act to reduce the costs and risks associated with adoption. We discuss this issue elsewhere in this report.

Thirdly, the applications for which agent technologies are most suited are those involving interactions between autonomous intelligent entities. While some applications of this sort may be implemented as closed systems inside a single company or organization – for example, agent-based simulation for delivery schedule decision-making – most potential applications of agent technologies require the participation of entities from more than one organization. Automation of purchase decisions along a supply-chain, for example, requires the participation of the companies active along that chain, so that implementing a successful agent-based application will require agreement and co-ordination from multiple companies. In other words, the application domains for which agent technologies are best suited typically exhibit strong network good effects, a factor which complicates technology adoption decisions by the companies or organizations involved.

It is for this reason that the agents community has expended so much effort on developing standards for agent communication and interaction, as undertaken by FIPA, so that agent systems may inter-operate without the need for prior co-ordinated technology adoption decisions. However, as noted above, the agent technology standards landscape is currently one in which multiple organizations have developed or are developing standards for the inter-operation and interaction of intelligent software entities. In these circumstances, adoption of agent technologies are not necessarily promoted by the presence of competing, and subtly-different, standards.

5. Modelling Diffusion of Agent Technologies

AgentLink III developed a simple computer simulation model to study the diffusion of agent technologies. Our model uses assumptions about adoption decision processes and the relationships between different companies, and has not been calibrated against any real market data. It is intended only to provide a means for exploration of relationships between relevant variables and indicative information about these relationships. We fully recognize that the results of a generic model such as this will be highly dependent on the structure and assumptions used to create the model. Moreover, the features of specific markets, such as that for agent technologies, may result in very different outcomes from those described here. Thus the results described here should not be considered as guidance for specific marketing strategies or industrial policies in the agents domain.

5.1 Model Design

Organizations potentially adopting agent technologies were represented as individual nodes in a graph. Directed connections (edges) between nodes were used to represent the influence of one organization over another in a decision to adopt or not adopt agent technologies. Thus, for example, a large company may be able to influence technology decisions of its suppliers. Because different industries have different degrees of concentration and different networks of influence, our model incorporated several different graphical structures – network topologies – which we believe to be representative of the diversity of real-world industrial and commercial networks:

- A: 50 nodes not connected (i.e., no influence from one node to another). This topology models an industry which is highly disaggregated, with independent technology decision-making.
- B: 50 nodes with a dense set of connections, and influence in one or the other direction. This topology models an industry which disaggregated, but where peer relationships are important in technology decisions.
- C: 5 major nodes (parents), each connected to and influencing 9 subsidiary nodes (children), in a cluster formation. This topology models an industry where supply chains are not deep.
- D: 5 parent nodes, each connected to and influencing 9 subsidiary nodes linked together as in a linear supply chain. This topology models an industry where supply chains are deep, and downstream companies have distinct supply chains.
- E: 5 parent nodes, each connected to and influencing 9 subsidiary nodes linked together as in a linear supply chain, with at least one child node also influenced by a second parent. This topology models an industry where supply chains are deep, and downstream companies have overlapping supply chains.

Nodes were then modelled as independent and autonomous decision-makers, each making decisions to progress (or not) through a technology adoption life-cycle. The five stages in this life-cycle were:

- Agent technology not adopted

- Agent technology under consideration
- Agent technology being trialed
- Agent technology partially adopted
- Agent technology fully adopted.

Time in the model is assumed to be discrete and linear, with nodes making decisions between timepoints, based on the status of variables at the most recent timepoint. Each timepoint may be considered as a generation in the adoption lifecycle.

At each stage in the life-cycle, a node may decide to proceed to the next stage, remain at the current stage, or to return to the previous stage. The mechanism used by each node at each stage to make these decisions depends on a number of relevant factors, which were drawn from a study of the marketing literature (Lilien *et al.*, 1992, Mahajan *et al.* 1993, Urban and Hauser 1993) and the economics literature (Weitzel 2004, von Westarp 2003):

- The current need of the organization for the technology. This was assigned randomly to nodes.
- The costs of adoption. These costs fall as the number of nodes progressing through the adoption lifecycle increases. Nodes are assumed randomly to be able to afford the technology at the current level costs.
- The availability of complementary software tools. These are increasingly available as more nodes move through the technology adoption cycle, and thus encourage adoption of the technology.
- The presence of a technology standard. The existence of a single standard is assumed to encourage technology adoption by nodes, while the presence of more than one standard encourages adoption in some nodes and discourages it in others.
- The success of a technology trial. Not all trials are successful. However, an unsuccessful trial does not necessarily lead to non-adoption of the technology, since an organization may have pressing needs for the technology.
- The extent of influence of other connected nodes over each node. Thus, downstream customers may strongly influence upstream suppliers in their choice of technologies. It is through this factor that the network topology impacts upon the decisions of individual nodes, and therefore how the model demonstrates the effect of the technology being a network good.

For each node and for each decision, these factors were then combined through a factor-weighting mechanism; the outcome of this combination is a decision: to progress forward to the next state; to remain in the current state; or to revert to the earlier state, in the technology adoption lifecycle. The weighting mechanism differs across the states of the technology adoption lifecycle to better represent the real-world decision processes. The weights and weighting mechanism used in the model were developed on what are believed to be reasonable assumptions regarding real-world decision processes, informed by the marketing literature. It is important to recognize that the factor-weights and the decision mechanism has not been calibrated directly against any real-world agent technology adoption decisions in companies or organizations. The AgentLink III model allows the weights to be set by the user, and so it may be possible to calibrate the model in this way in future work.

5.2 Simulation Results

One thousand simulation runs with random starting values were undertaken for each network topology and assuming different numbers of technology standards (zero, one and two). In each simulation run, the diffusion model ran until all nodes had adopted the technology, and the number of generations required to reach this end-state was then recorded. These measurements were than averaged across the 1000 simulation runs, and the results are shown in Table 1 below.

Network Topology	No Standards	Single Standard	Two Standards
A: Disaggregated industry (non-connected nodes)	66.9	26.5	48.4
B: Disaggregated industry with peer relationships	66.7	26.8	48.7
C: Industry with shallow supply chains	25.0	17.6	22.1
D: Industry with deep, independent supply chains	76.5	26.6	49.1
E: Industry with deep, overlapping supply chains	67.6	19.8	48.7

Table 1: Numbers of Generations to 100% Adoption
(By Network Topology and Numbers of Standards)

As would be expected, the network topology can have a major difference in the numbers of generations needed to reach full adoption. Likewise, for any given topology, the presence of a single standard may reduce the time steps needed for full adoption by more than half. Interestingly, having two competing standards inhibits full adoption, but not as greatly as having no standard at all. Thus, the model provides indicative support for the positive impact of standards on technology adoption decisions. It is also noteworthy that this impact is seen regardless of the network topology, in other words, regardless of the industry structure, at least for those topologies included in the model simulations.

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