# Future Diffusion of PKI-Technology - A German Delphi Study

Michael Gaude

Daimler AG, Sindelfingen, Germany
Vehicle Change Management
Michael.Gaude@Daimler.com

## Abstract

This article provides a contribution to innovation research in the field of electronic signatures, particularly to the future development of the aspects of diffusion throughout the IT-technology of the "Public Key Infrastructure" (PKI). In the modern Internet economy, PKI-technology is generally seen as the basis for obligatory authentication and safe communication. Nowadays, large scale enterprises in particular want to reach concensus concerning this security technology. In this article, the key factors for the future development of PKI are examined. The key factors will then be transferred into a diffusion model consisting of the primary PKI services, the secondary technologies, the process level, the user populations and the markets. Different qualities of a PKI will be distinguished. The qualified electronic signature, according to the German Electronic Signature Act (SigG), is also taken into account. With the results of a Delphi study by 69 experts, the PKI diffusion model will be filled and calibrated with real data. The study's board of participants consists of users, suppliers and scientists in the field of PKI. All participants are designated experts in their field and worked through the Delphi questionnaire twice, thereby judging, commenting and replenishing the study.

# 1 Introduction

Due to global competition, there is heavy pressure on the economic system and its protagonists to adapt its products and services to the quickly changing requirements of the worldwide markets. In light of this scenario, safe communication and agile electronic transactions between the participants of the development and supply chains are accorded a fundamental importance.

The basic IT technology for these demanding network transactions is the Public Key Infrastructure (PKI) [KaLP05]. A PKI can fulfill basic requirements concerning comprehensible and safe communication, as well as transactions. PKIs of the highest class allow the creation of so-called “qualified signatures” and, therefore, the origination of all types of proof-worthy documents. Moreover, a PKI is the basis for efficient authentication in open networks.

The use of PKI technologies and services is not widespread in German enterprises. Today only a very low distribution of the use of electronic signatures can be seen in business processes, at public authorities and at on the private level, as well. Nevertheless, many single PKI projects have been started [LMM+06] as well as bigger initiatives, like the already established German "Signaturbündnis". There is an uncertainty concerning the future dissemination and availability of PKI services among executive managers in Europe.

The analysis of relevant influencing factors based on the innovation theory is a green field in terms of the scientific based analysis of PKI-technology. This concerns the spreading and the

adoption of PKI-technology and particularly the extrapolation of the development of PKI into the future. The need for a technology forecast of PKI-technology is thus revealed, as well. This ought to concern Europe as well as the whole world.

This contribution provides a diffusion model for the future dissemination of the use of PKI-technology. This aims to theoretically and practically describe the process of diffusion of PKI-technology in the economic system, in the past and the future. The aim is to give decision-making advice for entering into PKI-technology and to provide a contribution to the theoretical analysis of PKI development.

The underlying parameters of the diffusion model are filled with estimated values by the instrument of a Delphi study. Based on a board of 69 German experts, several aspects of the future development and dissemination of the PKI-technology in Germany and Europe will be presented indicating the central research result of this contribution.

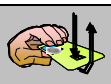
# 2 Explanation of PKI and Innovation Theory

## 2.1 PKI - Special Infrastructure for Electronic Signatures

The PKI-technology enables us to replace the personal signature (given by one's own hand) by an equivalent electronic signature. The possibility arises to replace almost all paper based and also all legally relevant documents and therefore to utilize all advantages of the virtualization [Heus04].

Table 1 defines three categories of the PKI-technology that are relevant for the Delphi study presented in this paper [LoOP05].

**Table 1**: Bundling of PKI-technology in three categories of different quality

| Elements of PKI | Q-Sig  Qualified signature | A-Sig  Advanced signature | M-Sig  Machine signature |
|---|---|---|---|
| Accreditation by German BNetzA | Yes, obligatory | Not necessary | Not necessary |
| Announcement against German BeNetzA | Yes, obligatory | Possible | Not necessary |
| Certificate Class 4 | Yes, obligatory | Not necessary | Not necessary |
| Certificate Class 3 | No | Yes | Not necessary |
| Owner: Natural persons | Yes, obligatory | Not necessary | Not necessary |
| Owner: Legal entity | No | Yes, possible | Yes, possible |
| Owner: Machine - Clients | No | No | Yes, possible |
| Owner: Machine - Server | No | No | Yes, possible |
| Owner: Services of Software (SOA) | No | No | Yes, possible |
| Storage of secure keys | Cert. smartcard | Softtoken or higher | Server |
| Registration | Cert. trusted Org., Official ID-Card | Trusted Org., email-ID | Prog.-ID, UID. |
| Proof of identity | PIN or Biometry | PIN or Biometry | - |
| CPS available | Yes, obligatory | Unstructured | Not necessary |

A PKI allows the user to execute different services: registration of certificates, directory services, certificate checks, authentication in open networks, digital signature, encryption as well as time stamping. These basic services together with the technical surroundings and the accompanying legal regulations are called PKI-technology below.

## 2.2 PKI-Technology in Reflection of Innovation Research

With regard to PKI-technology the so called phase of invention, where new ideas are generated, has reached a high degree of performance. Those inventions are namely the develop-

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ment of the asymmetrical cryptography and the legal equality of personal and digital signature. In opposite to this the situation of the innovation shows generally an expandable level. Moreover, the development of the diffusion, or in other words the distribution of the PKI-technology into markets, is regarded as considerably low [PeOL05].

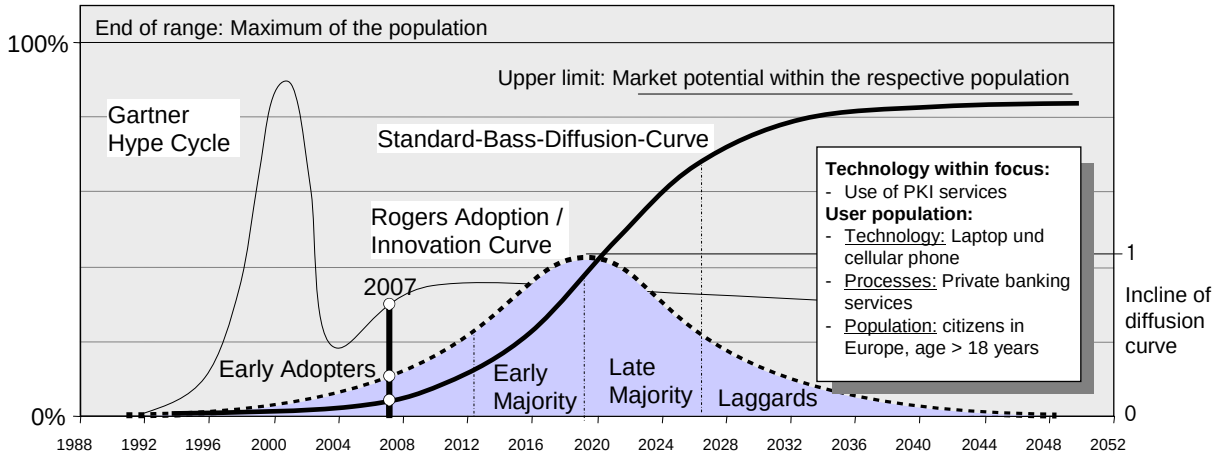


**Figure 1**: Hypothetical diffusion of PKI-services into banking processes.

It is called *adoption* when individuals decide to step into a technology and use it [MaPe85]. The aggregate analysis of many processes of adoption is described as *technology diffusion,* being described in the context of the diffusion theory. The most important dynamic model in this area is the so-called diffusion curve which describes the distribution of a technology over a specific period of time [Bass69, PuSr00]. This is illustrated by the fictitious example of the use of PKI in figure 1.

The gradient course of the Standard Bass Diffusion Curve leads to the Innovation Adoption Curve from Rogers [Roge95]. Finally the Technology Hype Cycle of the Gartner Group, which is based on subjective factors, has to be put into the period of early adopters of the PKI-technology's innovation curve. Thereafter, the PKI-technology is actually in the stage of "Climbing the Slope" [Whea06].

The diffusion theory represents a good basis for the preparation of a Delphi study. Moreover, the model is capable of expressing the special features of the PKI diffusion.

# 3 Evaluation of a PKI Diffusion Model

Chapter 3 presents the procedure of the PKI-Delphi study and its results. At first a theoretical model of the diffusion of the PKI technology is set up followed by the presentation of the research approach.

## 3.1 Conceptual Framework: T2D4 Diffusion Model

The T2D4 model describes the system of adoption and diffusion of the PKI-technology from a general viewpoint. It contains two technical levels: PKI categories and members of the PKI-value chain, furthermore, four diffusion subject levels: secondary technologies, business processes, user populations and economic sectors.

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The model follows the assumption that the experts know the inner connections between different issues of PKI intuitively. The model describes defined cuts through the complex and dynamic scenario of the technology diffusion of the PKI.

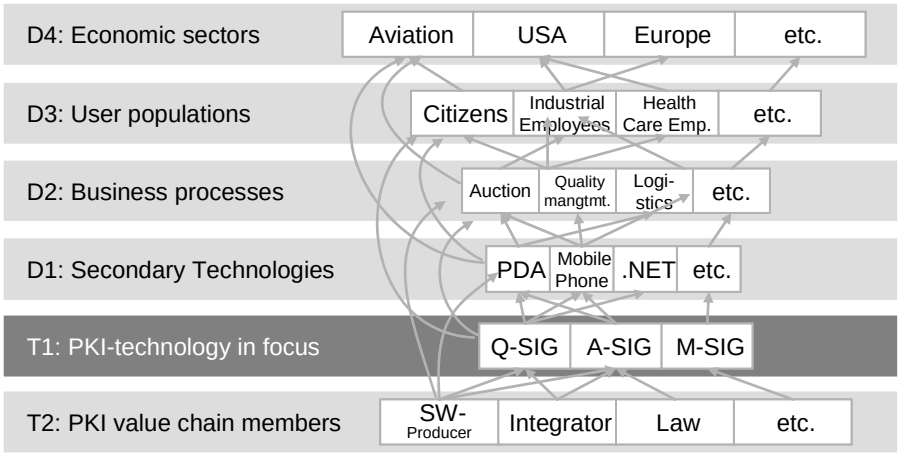


**Figure 2:** Model T2D4 of the PKI-Diffusion

It is posited that it is not necessary to ask for the respective causalities between the layers but to question the experts about snapshots of the effect system along these certain cutting layers (see Figure 2). From those an overall picture can be reconstructed that allows understanding the effective causalities between the layers.

## 3.2 The Approach: Progression of the PKI Delphi study

In order to forecast diffuse future facts from the field of PKI-technology, a certain research instrument, the so-called Delphi study, exists [Häde02]. In a multistage process of interviews experts are questioned about their personal assessments of developments in their respective expert areas. The total design method and the "Theory of Facets" describe how to break down a complex topic to a questionnaire with several simple multiple-choice questions [Häde02, Dill78].

The questionnaire of the PKI Delphi study is based on the PKI-T2D4-diffusion model. It is subdivided into a main study (chapters 1-6) with 243 questions and a deepening study (chapters 7-8) with 233 questions. More than 1700 comments and 73 new questions were given in the initial round one, allowing the experts to understand possible divergences between their own answers and the average results. The feedback rounds no. 2 and no. 3 aimed at providing an improvement concerning the quality of the content and the convergence of the experts´ opinions.

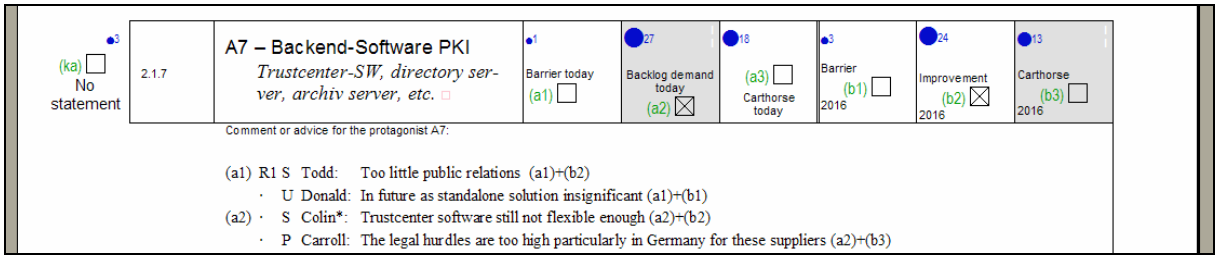


**Figure 3:** Clipping from the questionnaire of the 2nd round of the PKI-Delphi study

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The medium of the questionnaire is a word document. **Figure 3** shows the presentation of a question about the members of the PKI value chain. In order to make a series of comments traceable, each participant gets a pseudonym, which can be found among the compendiums of comments in the feedback round.

The participants of the PKI-Delphi study recruit themselves with one third each from the professions science, users and technology provider. They are chosen experts with a distinct reputation in their field of work. It may be assumed that the experts of the Delphi study are adequately qualified, so that the results of the study can reach a solid level. The Delphi study was performed in three rounds between 03/05/2006 and 01/11/2006. 75 experts have personally confirmed their participation. In the end 69 experts fulfilled the study.

In this contribution the first results of the main study are published.

## 3.3 Results: Adoption and Diffusion of PKI-Technology

Among the five big topics of the main study, 110 questions can be found. Within those, 199 facet questions are defined containing all in all 925 answer choices. The average answer quota per question is numbered to 87%. That means that apart from 13% of the participants who selected the field "no comment" or who gave an invalid answer or no answer, all other participants gave a correct answer to the questions they had been confronted with. The loss rate in the feedback round was numbered on an average of 29%. That leads to the statement that all questions were processed twice with an average of 49 participants.

### 3.3.1 T2: Performance of Members of the PKI Value Chain

In chapter 2 of the questionnaire the participants of the study were asked for their opinion concerning 11 special members of the value chain of the PKI-technology. These questions aim at layer T2 of the diffusion model. Two facet-questions ask the participants' rating of the value chain member about its standing today (year 2006) and in future (year 2016).

The boxplots (see **Figure 4**) show the min/max values (brackets), the arithmetic average (in the centre of the box) and the median (with point). Grey circles behind the boxplot show the number of votes for this category. Thin lines make it possible to pursue the ways of every single voice. The lines are encoded by colours (with regard to their length), so that unusual deviations can be identified easily.

*International organisations* (A1, rank 11 in 2016) are described as "sluggish" and "very slow" in the comments by the study participants. They are "by definition very active", but would not advance the topics from their "passive position", however. It is frequently pointed out that organisations like CEN, ETSI and W3C lack legal and procedural unification.

The *German legislator* (A3, rank 9 in 2016) is appreciated as a "forerunner" and seen in this role in future, too. The German Digital Signature Act (SigG) is described as "restrictive", particularly the obligations for supervision. Initiatives for more pragmatism in the design and interpretation of the laws (e.g. in the area of electronic invoice) would be blocked. The Digital Signature Act is mentioned positively because by this the construction of the trust centre infrastructure was advanced. Nevertheless, this law would not fulfil the current needs of the real business processes at the moment.

*Software producers* (A4-7) are generally advised in the comments of the participants to improve the user-friendliness of their products. The lack of consistency and low compatibility with each other are frequently called an "underlying evil".

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In the target group of the *producer of mainstream-software* (A4, rank 5 in 2016), mainly producers of e-mail programmes and programmes for word processing are observed by comments. Reaching a critical mass was multiply annotated as an important aim.

It is advised to the *producers of enterprise software* (A5, rank 3 in 2016) to integrate the PKI-technology to the software product, so that the final user can use it "without thinking about it". The *backend software* (A7, rank 6 in 2016) gets respected as mature. Deficits are still seen, however, in the area of archival storage.

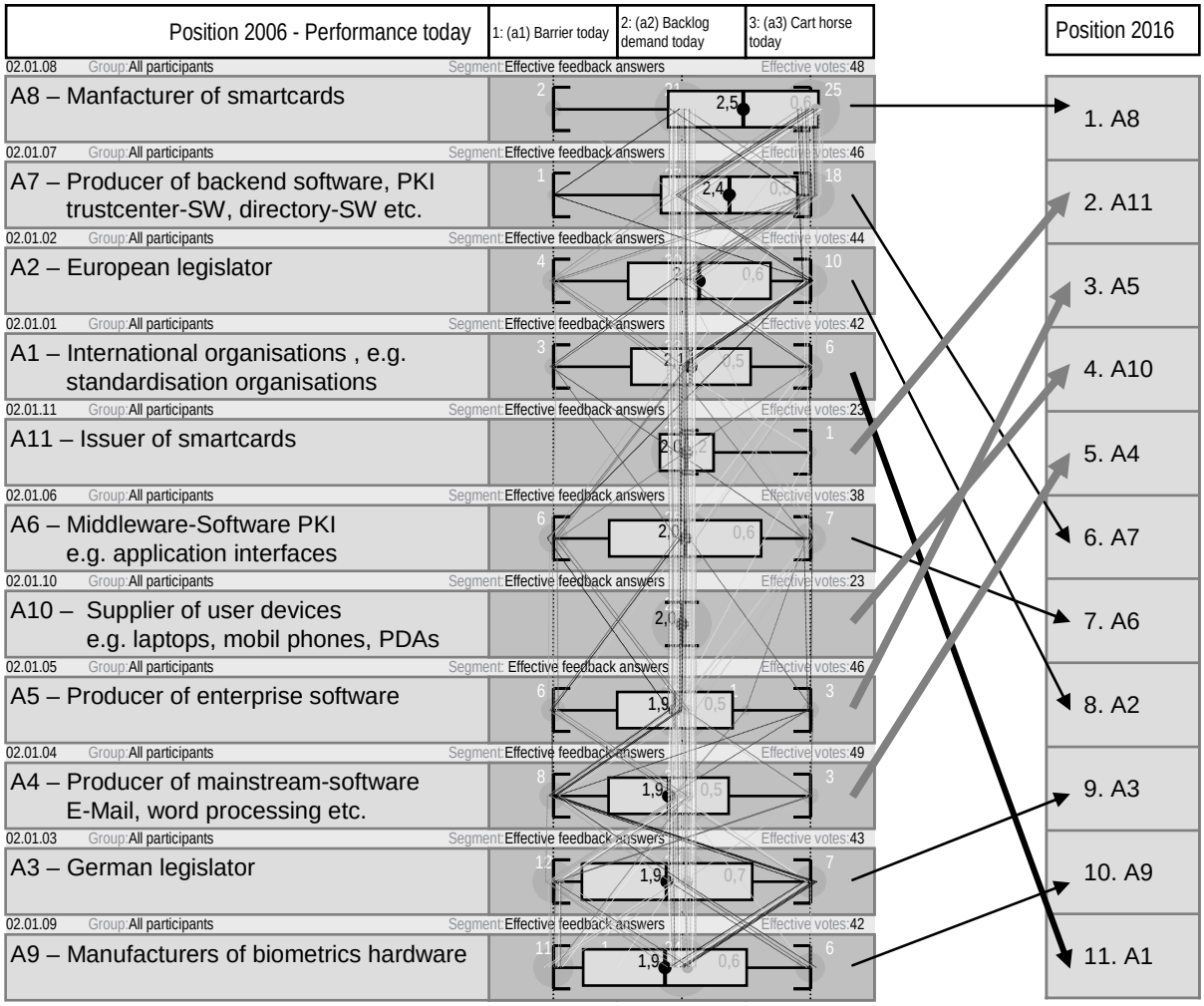


**Figure 4:** Position of the player in the value chain of the PKI-technology today and 2016

A difficult situation is certified to the *manufacturers of smartcards* (A8, rank 1 in 2016). On the one hand they are dependent on the existence of card readers, which could lead to the situation that the smart token or USB token will take a dominant role in future. On the other hand the manufacturers are dependent on the *issuer of smartcards* (A11, rank 2 in 2016) such as banks, certificate service providers or the government itself.

The issuer becomes ascribed a more important role at the distribution of the PKI only in the future. The issuers would primarily see their respective cards as one of the customer loyalty's instrument and therefore, it would have come to a number of spot solutions today. It is not forgotten that this group has already experiences in the area of PKI namely with HBCI and that it turned out that it is very hard to develop a cost-covering business model in the PKI area.

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*Manufacturers of biometrics hardware* (A9, rank 1 in 2016) are confronted with the opinion that their technology has a "low reliability" and a "high failure rate". Positive votes consider the reached level "sufficiently reliable". Biometrics, as can be gathered from the comments, is decoupled of the question about the use of a PKI generally. Particularly governmental activities, such as the USA in the fight against terror or different projects with passports, become the strongest trigger for the use of biometrics and will be entirely thorough - at first without PKI.

The group of the *suppliers of user devices* (A10, rank 4 in 2016) is subdivided by the participant field into two groups: A10a: *Wireless carriers* and its partners for mobile telephones and A10b: *Manufacturers of PDAs and laptop computers*. A good "form factor" is ascribed to the TPM (Trusted Platform Module) and SIM (Subscriber Identity Module) cards. Having a great market volume, one more important reason appears why wireless carriers are considered as keyplayers in the future. Proprietary standards and concepts as well as missing integration of card readers are mentioned as obstacles of the PKI for spreading into the devices.

### 3.3.2 D1: Adoption by secondary Technologies

The participants of the study were questioned about their assessment of 20 special technologies in chapter 4. These questions are aiming at the level D1: "Secondary Technologies" of the T2D4 diffusion model. In a first facet question the study participants gave their judgement of today's potential of PKI for the respective technology (low, medium and high potential benefit). The second facet question refers to the integration of PKI in general in this technology in the year 2016 (barely, inferior or leading dissemination).

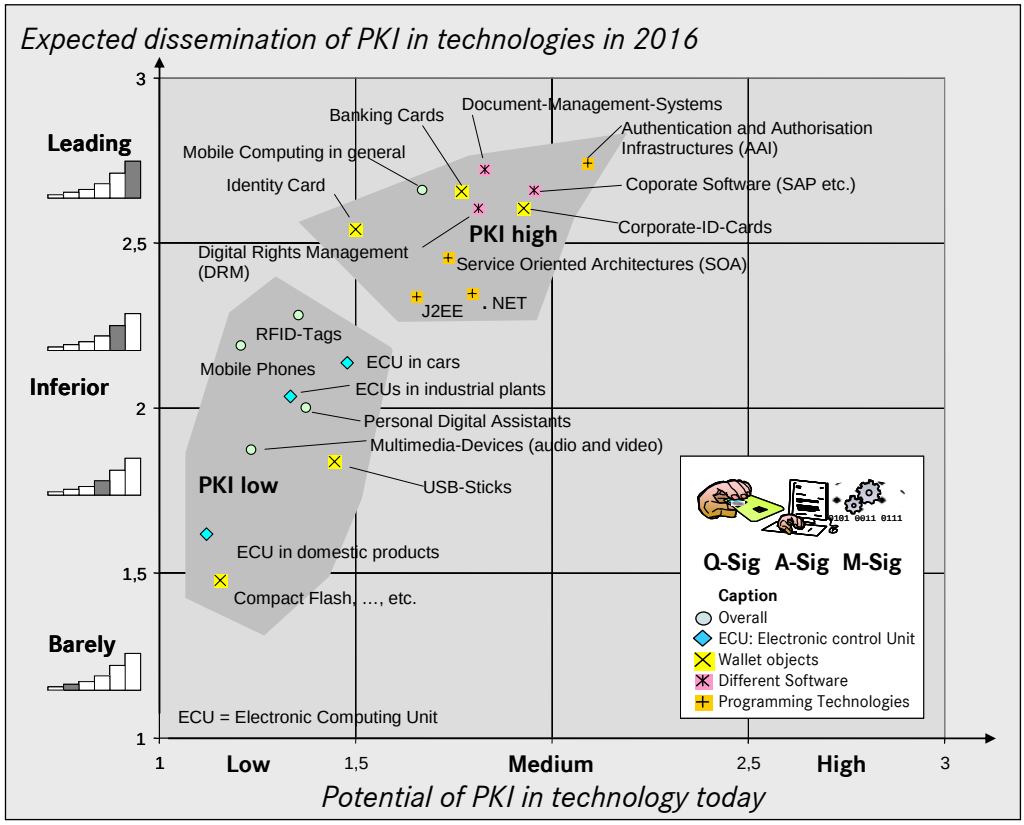


**Figure 5**: Overview of the potential today and the expected dissemination of PKI in technologies

Two clusters have been identified from the graphic cluster analysis of 2D representation of the average answers of both facet questions (see Figure 5): PKI low and PKI high.

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### 3.3.3 D2: Advantages for Business Processes

A cluster analysis (see Table 2) on the basis of the average values and its standard deviations of the facet answer (1. PKI hinders the process, 2. No use effects to be watched, 3. Easy efficiencies, 4. Clear efficiencies, 5. There is nothing like PKI) subdivides the 42 most popular e-business processes into four areas with respectively clear statements concerning the use of a PKI and into two areas with comparatively disproportionate answer pictures.

**Table 2:** Overview of 42 processes and its affinity to the PKI-technology

| | PKI unhelpful | A1 | B 1/2 | A2 | A3 | B 3/4 | A4 |
|---|---|---|---|---|---|---|---|
| | PKI almost indispensable | | | | | | |
| | Superiority of PKI not clearly evident | | | | | | |
| | Advantage of PKI | | | | | | |
| | Slight benefit from PKI | | | | | | |
| | Nonspecific benefit from PKI | | | | | | |
| **1.1 Generally: Electronic correspondence; E-Mail** | | | | | X | | |
| 1.2 Communication inside social associations | | | | X | | | |
| **2.1 Generally: Signing of contracts on the internet** | | | | | X | | |
| 2.2 B2C – Auctions: Business to Consumer | | | X | | | | |
| 2.3 B2B – Auctions: Business to Business | | | | | X | | |
| 2.4 C2C – Auctions: Consumer to Consumer | | | X | | | | |
| 2.5 Stocktrading | | | | | X | | |
| 2.6 Insurance contracting | | | | | X | | |
| 2.7 Credit agreements | | | | | X | | |
| 2.8 Travel booking | | | | X | | | |
| 2.9 Media purchasing - Books, DVDs, CDs etc. | | X | | | | | |
| 2.10 Electronic products - MP3s, videos, pictures etc. | | X | | | | | |
| 2.11 Authorization purchasing - Tickets, bonus coupons etc. | | | X | | | | |
| 2.12 Catalogue selling | | X | | | | | |
| 2.13 Mobile transaction – purchasing with cellular phone etc. | | | | X | | | |
| **3.1 Generally: electronic invoice** | | | | | X | | |
| 3.2 Electronic payment - paying with digital check | | | | | X | | |
| 3.3 Electronic money | | | | | | X | |
| **4.1 Generally: Activities in the "Virtual town-hall"** | | | | | X | | |
| 4.2 E-Election | | | | | | X | |
| 4.3 Electronic official notifications | | | | | X | | |
| 4.4 E-Certificates – e.g. Certificate of birth | | | | | | | X |
| 4.5 E-Cadastre | | | | | | | X |
| 4.6 E-Bafög (Governmental credit agreements for German students) | | | | | X | | |
| 4.7 E-Tax return | | | | | X | | |
| 4.8 E-Personal ID-Card | | | | | | | X |
| 4.9 Electronic governmental bid invitation | | | | | | X | |
| 4.10 E-Registration of vehicles | | | | | X | | |
| 4.11 E-Announcement of alienation (Vehicles or real estates) | | | | | X | | |
| 4.12 Electronic trade register | | | | | X | | |
| 4.13 Governmental registration of individuals | | | | | X | | |
| 4.14 E-Employment office | | X | | | | | |
| **5.1 Generally: Business Processes in Enterprises** | | | X | | | | |
| 5.2 Order completion by e-Contract | | | X | | | | |
| 5.3 E-Order handling | | | | X | | | |
| 5.4 E-Delivery schedule | | | | X | | | |
| 5.5 E- recipe of goods | | X | | | | | |
| 5.6 Stock and capacity queries with the supplier | | X | | | | | |
| 5.7 Quality documentation | | | | | X | | |
| 5.8 Electronic transport supply note | | | X | | | | |
| **6.1 Electronic patients files** | | | | | | | X |
| 6.2 Electronic doctoral notice | | | | | | | X |

It often happens that the benefit is divided unequally between the parties which are involved with the processes. This situation can lead into a blocking. A solution would be the compensation between the involved process parties. This must, however, be examined in each case.

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### 3.3.4 D3: Diffusion into User Populations

The participants of the study were questioned about the assessment of 10 special user populations in chapter 6. The results of the respectively third facet question (distribution in 2016) are shown in Figure 6 as a rank representation within the answer categories of the facet question.

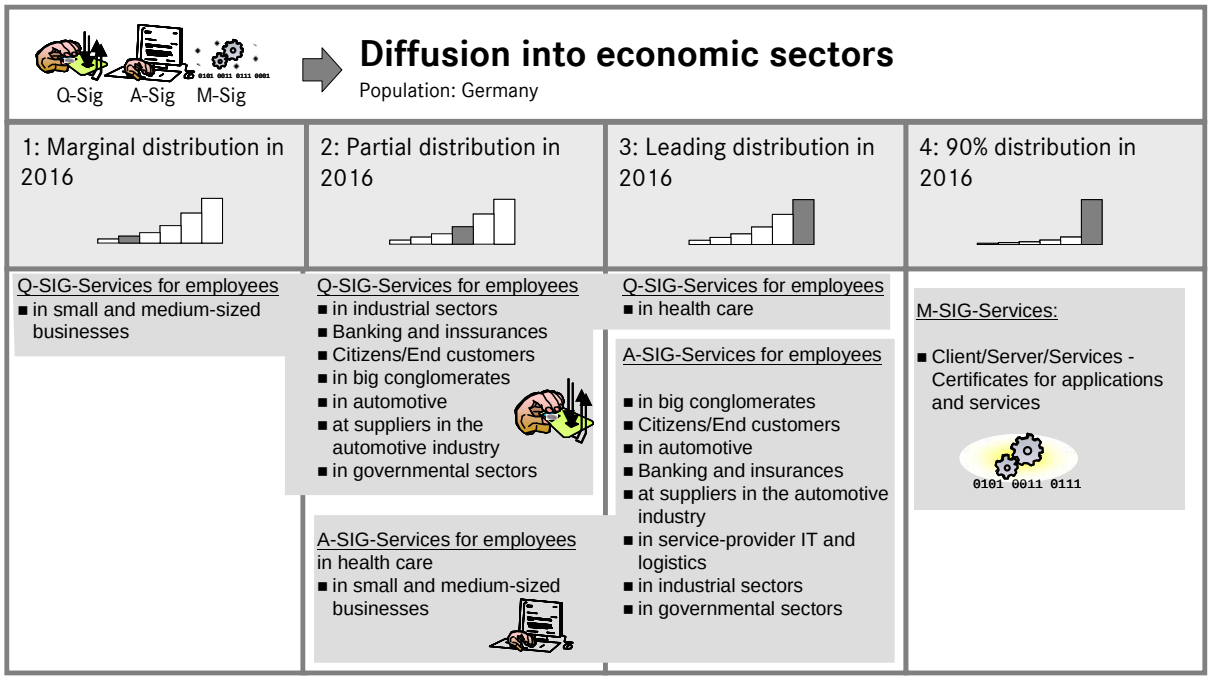


**Figure 6:** Diffusion of PKI-technology into economic sectors

It can be recognized that a leading role is ascribed to the area of "Health care" concerning the use of the qualified signature. The spread of the Q-Sig in other sectors, e.g. the area of citizen/end consumer, shows a comparatively low distribution.

### 3.3.5 D4: Dissemination into Markets and Branches

The participants of the study were questioned about the assessment of 17 business branches in chapter 6.2 of the questionnaire. The result suggests that the PKI will have found a leading spreading in pharma, financial services, aeronautics and automotive - on a basis of minimum A-Sig in 2016. At least a partially spreading is predicted for the branches chemistry, electronic, food, electrical engineering, engineering & tooling, printing, building, iron & metal, mining and ceramics (spreading intensity in a descending order).

## 4 Conclusion

A diffusion model of the PKI-technology was introduced consisting of the layers of secondary technologies, business processes, user populations and economic sectors. Three significant qualities of the electronic signature were defined and integrated into the model. By means of a Delphi study, the model parameters were described and afterwards filled in and judged by experts. The given results confirm the model construction.

Further steps within this research project will be the evaluation of the deepening study as well as the factor analysis of the whole survey. An extension of the diffusion model to additional socio-economic factors is planned, as well as the interpretation of the inner causalities between the given model layers.

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Further areas of study can be identified in the quantitative research in order to capture real diffusion curves from the area of PKI. An extension of the study's underlying population towards European experts as well as a repetition of the Delphi study after an adequate period of time are research opportunities for further deepening the results.

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## Acknowledgements

I would like to gratefully acknowledge the support and advice of Prof. Dr. Günther Pernul from the University of Regensburg in planning and executing the PKI Delphi study.

## Index

Gaude, M.: Future Diffusion of PKI Technology - A German Delphi Study. Pohlmann, N., Reimer, H., Schneider, W. (Hrsg.): ISSE/SECURE 2007 Securing Electronic Business Processes - Highlights of the Information Security Solutions Europe/SECURE 2007 Conference, Vieweg, 2007, S. 386-395.

Innovation Management, Electronic Signature, Public Key Infrastructure, Diffusion of Innovation, Delphi study, Technology forecast.

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