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the journey of Bluetooth

van de Kaa, Geerten

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Sacrificing uniformity: the journey of Bluetooth

Geerten van de Kaa

Faculty of Technology, Policy, and Management, Delft University of Technology, Jaffalaan 5, 2628BX, Delft, the Netherlands

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ABSTRACT

A unique aspect of standards is that they define uniformity concerning, e.g., the interconnection between system components. By adhering to these standards, companies know their products can connect to other products when integrated into systems. Therefore, a standard should not be changed, as, consequently, interoperability cannot be guaranteed. At the same time, from the literature on innovation management, we know that companies that make their designs flexible will be able to include user requirements. As a result, these users will be more inclined to choose these designs, increasing the installed base and design dominance. This paper addresses the counterintuitive relationship between standardization and flexibility. Specifically, we study whether standards flexibility will result in more successful standards regarding their installed base. We study the standards battle for short-range wireless communication between IrDA and Bluetooth in the home. The standardization process surrounding the winning standard, Bluetooth, was more flexible. This provides a first indication that flexibility in standardization positively affects standards dominance.

1. Introduction

Standards are defined, among other things, to guarantee uniformity in systems (Brunssen et al., 2000). Companies and other stakeholders come together in standardization organizations to, e.g., agree on how their system components and products can connect. As a result, innovation, in the form of, e.g., new technological systems can be realized (Viardot et al., 2016). When companies introduce new products and ensure that they meet the established standards, they also know that those new products will be interoperable with the old products. So, through standards, the integrity of systems can be guaranteed.

However, we can increasingly observe a tendency for standards to change. And these changes go beyond merely introducing errata or incorporating textual changes in existing standards. Often, completely new versions of standards are introduced (Van den Ende et al., 2012). When firms incorporate these standards into their products, it leads to incompatibility with existing products that still apply the older standard. Companies will instead choose to adopt the old standard because their products can communicate with other products (Hovav et al., 2004). If there is a choice for consumers, they will also often select the old standard because they are used to it and the costs to switch are too high (David, 1985).

When the new standard is technologically better, firms and consumers might switch when switching costs are low. However, there are many examples of situations whereby newer and better standards are introduced that are subsequently not adopted because switching costs are too high. For example, we mainly use the technologically insuperior QWERTY keyboard layout standard introduced in the late 19th century, even though more efficient layouts became available in the 20th century (David, 1985).

The question is why standards are nevertheless often changed. One of the reasons hinted at in the literature (Van den Ende et al., 2012) is that this is done on purpose to increase the standard's installed base. The aim of this article is to further investigate whether flexible standards are accompanied by a higher installed base. Standards are normally developed in standards committees or by (consortia of) companies. If several alternative standards are developed, this can result in a conflict, a standards battle (Gallagher, 2012; Oshri et al., 2008). Committees and consortia may engage in a battle to attempt to set a de-facto standard. Various scholars have studied which strategies standard owners can apply to increase the chances that users, such as manufacturers of complementary goods, will choose their standard. In this paper, we add to this literature by studying the extent to which flexibility in terms of adapting a standard could lead to an increase in installed base.

The research question is: how does the flexibility of standards affect the chances of standards achieving dominance? This question is addressed by performing an exploratory study into successful and unsuccessful standards for short-range wireless data communication in the context of home energy management systems. This research question is studied specifically through the examination of Bluetooth vs. IrDA.

E-mail address: g.vandekaa@tudelft.nl.

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The paper contributes to the literature in the following ways. First, the technology management literature indicates that flexibility facilitates the adaptation of a product to customer requirements and thus has a positive influence on the installed base (Thomke, 1997). We contribute to that literature by showing that this is also the case for standards. Second, although standardization literature addresses the topic of flexibility (Hanseth et al., 1996), it does not link it directly to standard dominance. We contribute to the standardization literature by empirically showing that standards flexibility positively affects standards success. We also contribute to the standardization literature by uncovering and explaining other facets of flexibility related to standardization that positively affect standards selection.

In section 2, we place this study in the context of existing theoretical and empirical contributions that study the determinants of standardization outcomes. Section 3 discusses the methodology that is applied in this paper and section 4 presents the results. In section 5, a discussion and conclusion are presented, including a discussion of theoretical contributions, implications, limitations, and areas for further research.

2. Theory

Many researchers have studied the process of establishing a standard from different perspectives. There are two directions available for a company to arrive at a standard: committee-based standardization (also called pre-standardization (Koski et al., 2004)) or market-based standardization (Wiegmann et al., 2017). For example, scholars have attempted to examine how standards are developed in committees (Backhouse et al., 2006) and how the complexity of the IT standardization process can be reduced (Ngosi et al., 2009). Other researchers have studied why companies become engaged in the standardization process in the first place (Blind et al., 2021), while others look at the effect that participating in a standardization organization has on a company (Aggarwal et al., 2011; Jiang et al., 2024). Some scholars have focused on how nations can influence international standards development (Kim et al., 2020) and other scholars have studied the impact that standards have on innovation (Blind et al., 2017). Scholars have also described different versions of standards (Xue et al., 2014).

The vast majority of academics who research standardization have focused on studying standards battles. Standards battles can be observed when two or more standards are developed for the same application and compete to become the de facto standard. Examples abound, such as VHS vs. Betamax (Cusumano et al., 1992), Blu-ray vs. HD DVD (Gallagher, 2012), Playstation 2 vs. XBOX vs. Gamecube (Gallagher et al., 2002; Schilling, 2003), and X.400 vs. SMTP (Jakobs, 2013). Scholars have studied these and other cases of standards battles and have, e.g., attempted to uncover the underlying reasons why standards reach market dominance.

They stress the fact that standards-based markets are characterized by the existence of network effects. This is the phenomenon whereby the value of a technology increases with the number of adopters (Farrell et al., 1985; Katz et al., 1985). In a market that is characterized by network effects, quickly building up an installed base becomes pivotal for reaching dominance (Shapiro et al., 1999). These network effects can be direct when there are physical connections between products. These connections increase the value of these products for users. Network effects are indirect when complementary goods are available which increase the value of the core technology with which they are combined. This can also be observed in platform-based markets such as video gaming consoles (Dou et al., 2021; Song et al., 2018; Srinivasan et al., 2010).

Therefore, these scholars have studied strategies firms pursue to build up installed base (Gallagher, 2012; Gallagher et al., 2002). They emphasize that, e.g., expectations count for a lot in standards based markets. Therefore, marketing communications is a crucial strategy in order to reach dominance as it may increase both expected and perceived installed base (Schilling, 2020). For example, pre-announcements may stall the adoption of competing technologies and build up expectations surrounding a firm's technologies that may be introduced later. However, not fulfilling the pre-announcements may decrease a firm's reputation potentially decreasing future adoption of its technology (Hoxmeier, 2000) so care is advised in using pre-announcements. A firm's reputation can be further hurt when the firm is not able to live up to expectations by having an insufficient production capacity or an unhealthy distribution system.

Another strategy to increase an installed base of users includes, e.g., attempting to increase the availability of complementary goods (Gallagher et al., 2002). When there are more complementary goods available for a technology, that technology will increase in value, increasing its demand and installed base (Hill, 1997). For example, when more video games can be played on a video gaming console, the value of that console will increase, leading to more demand and installed base. Firms can also attempt to apply a penetration pricing strategy whereby they price their technology intentionally as low as possible which will increase the chances that it will be adopted (Liu, 2010). Sometimes, the price is even decreased below the production costs. This can also often be observed in the video gaming console industry, where the bill of materials for the technology is often higher than the price that people have to pay. Choosing a proper point in time to enter the market is also crucial. On the one hand, early entry will increase the installed base and firms can pre-empt the market, but scholars have also shown that first movers are not always successful (Schilling, 2020). Schilling showed that there exists an inverted U-shaped relation between timing of entry and standards success (Schilling, 1998, 2002).

Some researchers that study standardization focus on factors that affect the chances that standards will become adopted by users (Charalambos et al., 1995). The firm is, often, seen as a blackbox while the installed base of users as a factor affecting adoption of standards is opened up by these researchers. Auriol and Benaim (Auriol et al., 2000) have, e.g., studied characteristics of users that make them adopt standards, and Hovav et al. (Hovav et al., 2004) developed a model with factors that affect the adoption of the IPv6 standard.

Apart from studying factors that lead to dominant standards, scholars have attempted to understand the factors that lead to multiple standards coexisting (Rogante et al., 2022). Scholars have also focused on the role that standards play in the adoption of IT systems (Jia et al., 2022). Also, scholars have looked at standards battles that occur in standards committees (Eom et al., 2021). Finally, various scholars have focused on how the importance of factors for standards dominance change over time (Clements et al., 2005; Den Uijl et al., 2013; Suarez, 2004)

A factor that has received limited theoretical and empirical attention in standardization research is the role of flexibility. That literature addresses the topic of flexibility only implicitly at most. On the one hand, by definition, standards should not be changed. When standards do change, products that implement those standards may not function anymore and it may become difficult to connect different products. Furthermore, it is cumbersome for companies as their processes may have to be adapted when new versions of standards are introduced (Xue et al., 2014). On the other hand, a more flexible standard may add to technological superiority and, thus, ceteris paribus, to standard dominance (Hanseth et al., 1996). The modification of the standard can result in, for instance, better functionality (Cusumano, 2011). Following this line of argumentation, ideally, the standard is adapted to the requirements of every product market involved. This may increase the installed base of the standard.

In some standards battles, that scholars have studied, the relevance of flexibility as a factor for dominance of standards has been empirically demonstrated. Van den Ende et al. (Van den Ende et al., 2012) have studied three battles for a dominant standard and show that changes in standards attract more members, positively affecting their success. Other researchers have also studied the relationship between standardization and flexibility (Garud et al., 2008). However, these studies are primarily conducted in sectors where compatibility standards abound, such as the consumer electronics, telecommunications, and information technology sectors.

Technology management scholars have studied the significance of flexibility in new product development. They have contended that in turbulent environments with high levels of uncertainty, firms should adopt a flexible new product development process (Garud et al., 2008; Ianisiti et al., 1997; Iansiti, 1995; Kamoche et al., 2001; MacCormack et al., 2003; Moorman et al., 1998; Thomke et al., 1998). This may speed up development time (Eisenhardt et al., 1995), improve product quality (MacCormack et al., 2003), and improve project performance (MacCormack et al., 2001; Thomke, 1997). Flexibility facilitates the adaptation of a product to customer requirements (Thomke, 1997). Ideally, a match with user requirements can be reached. For instance, in the Internet software industry, product quality can be increased by incorporating customer feedback into the software early on in the product development process (MacCormack et al., 2003).

3. Method

A case study design was followed to answer how the flexibility of standards affects the chances of standards achieving dominance. The case study involves a standards battle. Criteria for the choice of a standards battle to study include the following. First, the focus lies on standards that enable interoperability between systems within the house. Second, it was ensured that a clear winner and a loser could be designated for the battle. Finally, standards are chosen for which information exists concerning the number of revisions introduced.

For this study, it is determined which standard has become dominant and which standard has not. In addition, it is determined to what extent the standard has been adjusted throughout its lifetime. The rate of change of the standard refers to the extent to which the standard is changed through time. One way to increase a design's rate of change is by developing multiple iterations of the design that may be new and or build upon each other (Eisenhardt et al., 1995). The standard's flexibility is measured by the number of new versions released yearly. Whenever it was reported that a new standard specification was released, we regarded this as a new version. We investigated the nature of the changes by analyzing their description meaning that we could primarily focus on changes that go beyond editorial changes or corrections of mistakes.

The data to assess the dominance of standards comes mainly from academic articles that have described the battles. Secondary data sources that were used to collect information about the standard's rate of change include various websites (websites reporting on standards in general, such as https://www.consortiuminfo.org/; industry-specific news websites, such as https://www.telecompaper.com/), press releases, academic papers, and grey literature. Furthermore, the internet pages of the consortia that developed and promoted the standards provided a rich source of information and were consulted. That data was collected by performing a retrospective search using the internet archive (https://web.archive.org/), an online library consisting of archived versions of websites that researchers can use freely. Each year, at multiple times, the internet archive scans the websites for changes. By consulting the part of the homepage of each standards consortium that reports on the standard, the revisions could be reconstructed over time from when the standards consortia was founded until the moment it was dissolved. The data was collected and analyzed in July 2024. The standards battle that is studied in this paper is the one that defines interoperability related to short-range wireless communication between Bluetooth and IrDA (winner: Bluetooth).

4. Results

4.1. Case description

In 1994, the Infrared Data Association was founded. That organization intended to develop standards for wireless short-range data communication based on infrared technology, which was discovered at the end of the 19th century by William Hershell. In the late 1990s and the beginning of the 2000s, the Infrared Data Association developed many standards that use infrared technology and are intended for applications such as connecting peripheral devices (such as keyboards) to PCs, transporting photos from digital cameras to PCs, and digital payment options. These applications are based on the basic standard, IrDA, that is the focus of our research. This standard consists of various parts, such as the specification of the physical layer but also test protocols. These parts are released in different standard versions (see Table 1). At the start, the consortium was quite diverse and consisted of consumer electronics and information technology technologies such as Hewlett-Packard, IBM, Vishay, and Sharp.

The first version (1.0) was approved in an IrDA meeting on April 27th, 1994, and the second version (1.1) was approved on October 17th, 1995. The third version (1.2) was approved on October 16th, 1997, and included a low-power option. The option meant that costs for implementing the standard were reduced. Connecting devices that implemented IrDA receivers using low amounts of power (albeit over a shorter range (0.2 m)) became possible. In 1998, the fourth version was approved at the IrDA meeting on October 15, and this version supported a maximum data rate of 4.0 Mbit/s, and the low power option was extended for each supported data rate. In these first four versions of the standard, two representatives of Hewlett Packard were heavily involved as the primary author and editor of the standard. On February 6th, 2001, the final version of the standard, version 1.4, was approved. At this stage, more people were involved as editors, representing companies, including Agilent Technologies, Sharp, and Vishay Semiconductor. Various changes were included, such as an improved data rate of 16 Mbit/s. Fig. 1 shows the installed base of the standard over time. As can be seen in the beginning when changes were released relatively frequently, the installed base did not decrease that much. However, after 1999, the installed base decreased rapidly possibly because of the lack of changes incorporated into the standard after version 1.4.

The Bluetooth special interest group was founded in 1998. This consortium intended to develop wireless communication based on ultra-high frequency radio waves. Using radio waves as a means of communication dates back to the late 19th century. Several large companies from the IT and telecom sectors were involved from the founding of this group, including Ericsson, IBM, Intel, Nokia, and Toshiba. The Bluetooth special interest group's standard is called Bluetooth, and over the years, many versions of that standard were released (see Table 2). The first versions of the standard were introduced in 1999 and 2000 (versions 1.0A and 1.0B) and guaranteed a data rate of 732 kb/s over a maximum range of 10 M. In the following years, various changes related to e.g. improved encryption, signal strength, and data range of 1 Mb/s were

Table 1
Chronology of changes in IrDA and its consortium.

Year	Version	Description	Changes that occurred in the consortium
1994	1.0		
1995	1.1		
1997	1.2	This version included a low-power option to reduce costs	
1998	1.3	A maximum data rate of 4.0 Mbit/s was supported, and the low-power option for data rates was extended	
1999			Siemens and Texas Instruments left.
2000			IBM left.
2001	1.4	The main changes included an improved data rate of 16 Mbit/s, a new modulation code, a signaling rate, and encoding and decoding examples	Apple left.
2002			Nokia left.

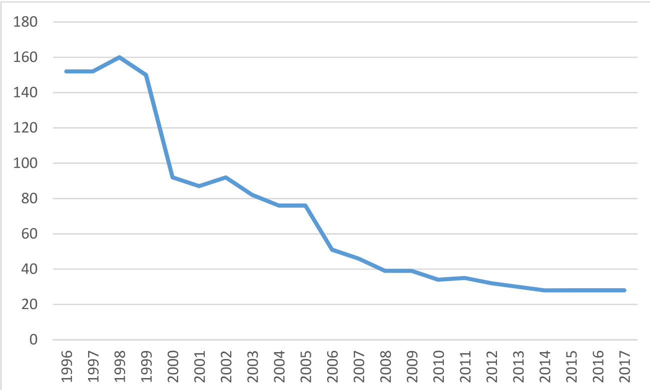

Fig. 1. Installed base of IrDA from 1996 to 2017.

incorporated. Ultimately this led to the introduction of version 2.0, which was introduced in 2004. The Enhanced Data Rate (EDR) technology was implemented in that version boosting the maximum data rate to 2.1 Mb/s. Also, it came with a lower power consumption and, therefore, an increased battery life for devices that implemented the standard. In 2007, additional changes were incorporated related to improved security and new features, such as support for near-field communication.

Version 3.0 was introduced in 2009. A significantly higher data rate became available (24 Mb/s), allowing transmission of audio and video data. However, that version of the standard was implemented little in devices as the high data rate meant that large amounts of power were required, significantly reducing the battery life. Presumably, therefore, in the same year, a new version of the standard (version 4.0) was introduced, which, amongst others, defined a low-power specification called Bluetooth Low Energy (BLE) or Bluetooth Smart. In the BLE variant, the Bluetooth smart ready technology was included, which made it possible to turn laptops into smart hubs to send and receive data to smart devices. By incorporating the smart ready technology, using the Bluetooth standard in a home networking environment became possible.

In 2013 and 2014, horizontal compatibility with other standards was improved. Furthermore, in 2016, Bluetooth 5 was introduced, which guaranteed a data rate of 2 Mb/s for the low-speed variant and 50 Mb/s for the high-speed variant. The maximum range was increased to 240 m. Connectivity with IoT devices was further improved. From 2016 to 2021, various new versions were introduced, accompanied by multiple new features, including better encryption and enhanced accuracy. Fig. 2 shows the installed base of the standard over time. A detailed overview of the changes incorporated in the Bluetooth and the IrDA standard is available upon request.

4.2. Case analysis

Both standards organizations intended to develop short-range wireless communication standards, but they based those standards on different underlying technologies (radio waves and infrared data communication). As we know, Bluetooth has become dominant, and IrDA is only used in niche applications. This is striking as there are many success factors for standards in favor of IrDA. For example, the Infrared Data Association was founded earlier, and its standards were introduced much earlier than Bluetooth standards. Therefore, IrDA could reap first-mover advantages related to securing an installed base and starting a bandwagon. Also, when first introduced, the data rate of Bluetooth was 732 kb/s compared to a data rate of 4 Mbit/s for IrDA. Therefore, at the time of its introduction, Bluetooth was technologically inferior compared to IrDA concerning its maximum data rate. Furthermore, early on, the IrDA standard included a low-power option, and IrDA was, therefore, also technologically superior in that aspect. The Bluetooth

Table 2
Chronology of changes incorporated in Bluetooth.

Year	Version	Description	Changes that occurred in the network
1998			IBM joined.
1999	1.0A	This version allowed a connection speed of 732 kb/s and a connection range of 10 m.	
2000	1.0B		Motorola and Microsoft joined.
2001	1.1	Various improvements were added, e.g., improved encryption, signal strength, device discovery, and pairing.	Nokia joined.
2003	1.2	This version includes various improvements, including a faster connection of 1 Mb/s. Furthermore, extended synchronous connections and adaptive frequency hopping were implemented.	
2004	2.0	The Enhanced Data Rate technology was implemented, boosting the data rate from 1 Mb/s to 2.1 Mb/s. A lower power consumption was incorporated. The connection range increased to 30m.	
2007	2.1	The secure, simple pairing technology was implemented, significantly improving security. Also, near-field communication support was added to the standard.	
2009	3.0	This version enabled consumers to use significantly higher data rates (up to 24 Mb/s). Enhanced power control was implemented, which allows devices to change the power level depending on their needs. This improved the stableness of the connection considerably	
2009	4.0	The range increased to 60 m. Furthermore, the aptX codec was implemented, improving the compression algorithm. Improvements were also made to decrease interference between Bluetooth and other signals (e.g., 4G or long-term evolution). (re-)pairing of devices was also improved, and the packet capacity and range for IoT devices increased. Furthermore, two standard variants became available: the low-speed variant, also called Bluetooth smart (which required low energy supply), and the existing high-speed variant that utilized the Enhanced Data Rate technology.	
2011			Apple joined.
2013	4.1	This version added support for the internet protocol version 6, improved co-existence with 4G, and enhanced encryption technology to make the connection even more secure.	
2014	4.2	This version further improved IoT and internet protocol version 6 connectivity.	
2016	5	The data rate increased to 2 Mb/s for the low-speed variant and 50 Mb/s for the high-speed variant. Furthermore, the maximum range increased to 240 m. Other improvements were made related to improved connectivity to the Internet of Things devices, Dual Audio, and better co-existence with LTE signals.	
2019	5.1	This version enhanced the accuracy even more.	
2019	5.2	This version increased the support for LC3 Bluetooth codecs.	
2021	5.3	This version was accompanied by various improvements related to, e.g., better classification of channels and improved encryption.	

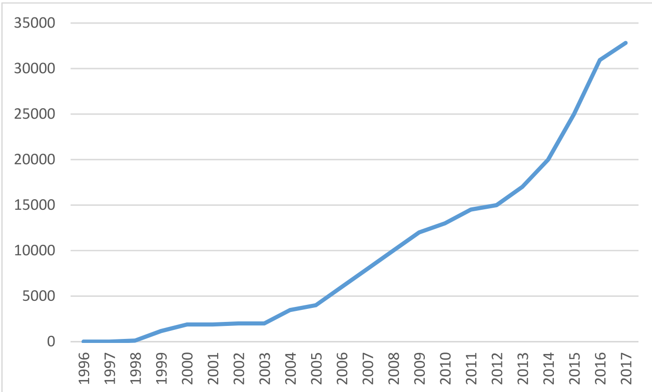

Fig. 2. Installed base of Bluetooth from 1996 to 2017.

standard incorporated such an option much later. To explain standards' success, we, therefore, have to search for another explanation.

Three observations related to flexibility and standardization that might have led to the dominance of Bluetooth can be inferred from this case. Firstly, we can observe that both standardization organizations introduce new versions every 1–4 years. However, we can also observe that the number of Bluetooth changes is clearly higher than the IrDA standard. In addition, we can observe that Bluetooth continues to make changes and that the IrDA standard remains basically constant after version 1.4, which was introduced in 2001.

Second, in 2009, the Bluetooth special interest group introduced version 3.0, but the group itself was flexible enough to quickly come up with a new version of the standard. This was probably done in response to the low adoption rate of the standard among companies because of the disadvantage related to power usage for smaller devices. Therefore, we may also infer that the Bluetooth special interest group is a flexible organization and can easily cope with changes encountered.

Furthermore, from 2009 onwards, a flexible implementation of the standard was possible in that users could choose their preferred variant of the standard. They could choose the low-speed variant if they are interested in a solution that guarantees a low data rate but a high battery life. Alternatively, they could choose the high-speed variant when a high data rate is needed and low battery life is not an issue. These flexible implementation possibilities led to more companies adopting the standards for multiple purposes, leading to a higher installed base and standards dominance. Based upon this one example, we could infer that standards that leave open the implementation choices may have a higher chance of reaching success.

Besides the fact that the Bluetooth standard is more flexible than the IrDA standard, we also see that companies are leaving the IrDA group from 1999 to 2001. Other companies are joining the Bluetooth group in that period. In this period, two versions were introduced for Bluetooth while only one new version was introduced for IrDA. For example, Siemens and Texas Instruments left the IrDA group in 1999, and Motorola and Microsoft joined the Bluetooth group in 2000. Interestingly, three companies even switched sides. For example, IBM left the IrDA group in 2000 and joined the Bluetooth group in 1998, Nokia left the IrDA group in 2002 and joined the Bluetooth group in 2001, and, finally, Apple left the IrDA group in 2001 and joined the Bluetooth group in 2011.

5. Discussion

After analyzing the case study, we can conclude that two aspects surrounding flexibility and standardization can be distinguished. On the one hand, we see that the successful consortium is flexible with regard to admitting new members and with regard to responding to needs that occur among the users of the standard. This can be seen as one dimension: flexibility in standards development. In addition, the successful consortium developed multiple variants of the standard. In this way, users had the opportunity to choose a specific variant of the standard that matches their needs. This can be seen as another dimension: flexibility in standards implementation.

We define flexibility in standards development as the extent to which a standardization organization is structured in such a way that changes can easily be made to the standard if external events make this necessary. Flexibility in standards implementation can be defined as the extent to which users of standards can choose the standard (or component therein) that best fits their requirements. In that case, the standard does not specify one solution to a matching problem but multiple depending upon the preferences of users.

The remainder of this section will discuss the potential choices standards organizations may take in considering flexibility. They can select four modes of flexible standardization (see Fig. 3): (1) full flexibility, (2) flexible process, standard implementation, (3) standard process, flexible implementation, and (4) no flexibility. These modes may be especially suited for particular environments, the particular composition of the standards committee, specific types of standards that are being developed, and a specific type of installed base. This will be discussed below.

When committees in standards organizations are developing standards for environments that are characterized by a high rate of technological change it may be especially suited to adopt a flexible standardization process. Then, the process is flexible enough to allow changes to be incorporated into standards in response to the events taking place in the environment. Also, in these turbulent environments, user needs change more quickly, resulting in a demand for more flexible standard implementations.

Furthermore, it may be argued that in a diverse committee in which actors represent diverse sectors and industries, there might be more (diverse) change requests during standards development (Van den Ende et al., 2012). If, in diverse committees, the diverse demands can be met then the process can reach a consensus more quickly. However, sometimes, parties come up with different conflicting proposals, and the process is delayed. Occasionally, it is decided to implement both proposals to prevent delay. This happened, e.g., in the development of the WiFi standard where in one of the meetings, two groups of people were voting for two different technologies to be incorporated into the standard; direct sequence spread spectrum and frequency hopping. Since no sufficient support could be gathered for either technology, both technologies were incorporated into the standard (Van de Kaa et al., 2015). This is a form of unintentional flexibility in the standardization process that helped the process to continue, and, therefore, to achieve a standard.

When standards are used to connect a highly diverse number of products to each other then it can help for those standards if they allow multiple implementations. In this way, multiple configurations of systems can be realized, and in this way, horizontal compatibility is improved, which increases the usability of the standard. This is also a means to increase the reusability of components (Duncan, 1995; Egyedi et al., 2005).

Finally, the installed base is heterogeneous when users from different industries and sectors may potentially adopt the standard. These users have diverse requirements, and when the standard is flexible and facilitates such requirements, it will potentially be adopted by a larger group of people, increasing its installed base and dominance.

Bluetooth is a typical example of a type 1 standard. Another example is Zigbee, as it changed considerably during its development, and it supports multiple configurations, which increases usability (Muthu Ramya et al., 2011). IrDA is a typical example of a type 2 standard. Another example is HDMI; although different versions of that standard have been released, the physical layout of the connector has never changed. A typical example of a type 3 standard is GSM, which did not change that much during its development but intentionally supported

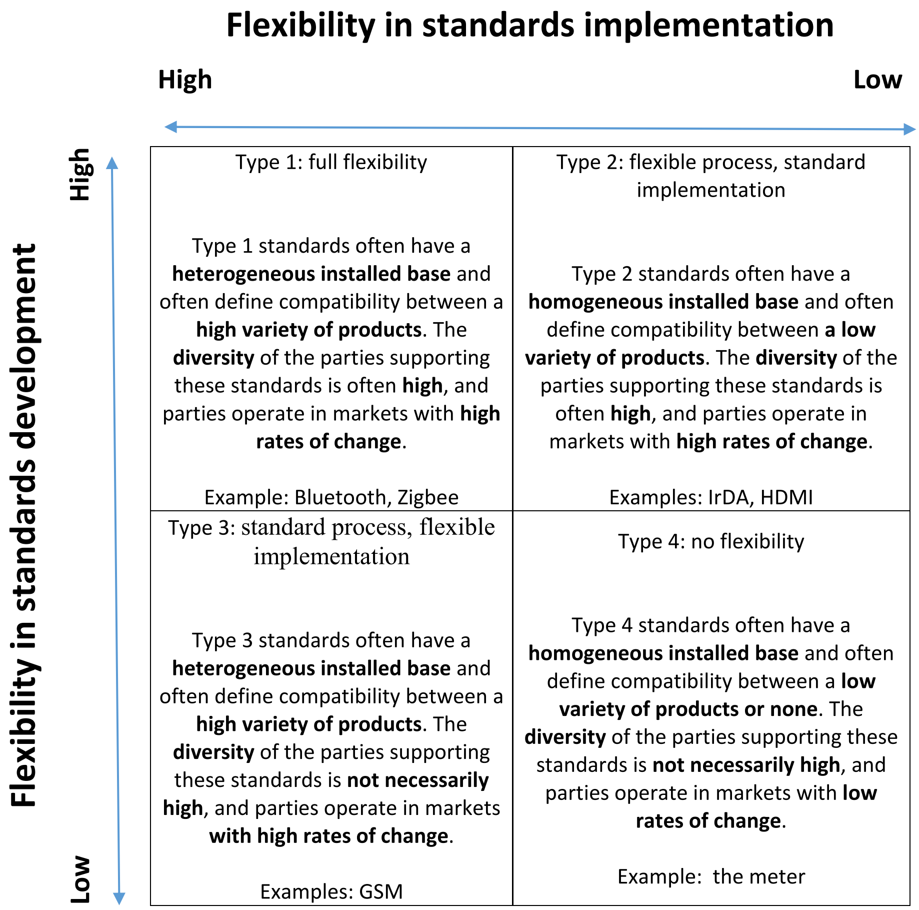

Fig. 3. Flexibility in standards development and implementation.

three communication protocols (three bands) so that it could be used on multiple continents (Van de Kaa, 2015-a). Finally, a typical example of type 4 standards is a measurement standard such as the meter.

5.1. Theoretical contributions and practical implications

We add to the technology management literature by providing more empirical evidence that the flexibility of designs contributes to their success while also introducing a new type of design in this literature: the standard. Furthermore, while most studies on flexibility in new product development focus on the point until market introduction, it may still be important after that point. We show that the IrDA standard was changed a bit after market introduction but did not become dominant, while the Bluetooth standard was changed throughout its lifetime. Presumably, users will preferably adopt a product that implements a standard in which their requirements have been taken care of, requirements that may only be known after the product launch. We found that flexibility after the launch of a standard might be as necessary as before and we thereby contribute further to the literature on technology management concerning the role of flexibility.

Finally, this study contributes to the literature on standardization in several ways. We contribute to that literature by addressing the role of standard flexibility on the chances that the standard will become dominant. This research extends previous work (Van den Ende et al., 2012) by emphasizing the importance of standard flexibility in standards battles and relating it directly to its success. We show that it is essential for a standard to be constantly adapted to enable communication between different products. This increases standard success. Furthermore, we contribute to the standardization literature by empirically illustrating two other types of flexibility in the context of standardization: flexibility of the standards organization and flexibility concerning the implementation of the standard. We contribute to the literature by illustrating that flexibility can occur intentionally and unintentionally and by combining the two types of flexibility to form four modes of standardization related to flexibility.

Companies and public institutions that want to influence which standard becomes dominant can use the results from this research by pushing for changes that respond to users' wishes of the standard. In this way, they can ensure that the standard they prefer has a higher chance of success.

6. Conclusion

In this study, we explored the influence of the flexibility of the standard on the chances that the standard becomes dominant. The data provides a first indication that if the standard is more frequently adapted, the chances of it becoming dominant increase. It would seem that a standard should not be too 'standard' but should be flexible enough to be changed to realize communication with other systems, resulting in a higher chance that the standard achieves dominance.

Our findings do not allow us to conclude with certainty that the changes were made *intentionally* to attract certain user groups and expand the installed base. To investigate that, future research could analyze the motivations, stakeholders, conflicts and processes surrounding each version (through, e.g., interviewing the stakeholders that were involved in developing that version). That research could also discuss and explain how significant each version is and whether significance of the chances incorporated may lead to certain firms adopting the standard. Also, researchers could study to what extent the type of change influences whether firms will join the organization. For example, in our cases, a distinction can be made between three types of changes; enhanced data rate, extended range, and increased functionality. It could be argued that the increase in the installed base of the standard may differ depending upon the type of change incorporated. For example, an increase in data rate might lead to more increase in installed base as compared to an increase in functionality such as better encryption and enhanced accuracy. These are interesting topics for future research.

One limitation of this research is that we have focused on a single case study. The question is whether our results would also apply to other cases. To study the generalizability of our findings, we recommend that scholars study more cases of standards battles focusing on the role of flexibility in standardization in reaching standards dominance.

Another limitation of this research is that we measured flexibility by counting the number of new versions of the standard released and the content of those revisions as communicated in the standard's specifications. Since this data, in part, comes from the standards organization itself, this source might be distorted, resulting in a possible limitation of this research. Furthermore, when a new version of a standard is released, this does not always mean that the contents of the standard have been changed. Therefore, one should consider whether changes have been incorporated into the standards. This has been done for 16 of the 19 specifications. However, three specifications were not freely accessible. The changes incorporated into these three specifications could be related to merely fixing problems with the previous version of the standard.

Interestingly, we see that IBM was involved in both the IrDA and the Bluetooth Special Interest Group until 2007 as a board member. Maybe IBM was unsure which standard would win, so it bet on both sides. However, this behavior results in a lower commitment to each standard. It would be interesting to study to what extent this behaviour can be observed in other standards battles.

Bluetooth is still being used, which is interesting as it is quite an old standard. Most standards are replaced by other standards (such as CD, DVD, and Blu-ray). The Bluetooth standard keeps being updated every once in a while and it is still being updated to this date. That may be the main reason that this standard still exists. Studying factors for the longevity of standards is an exciting area for future research. In that respect, flexibility could be studied.

It can also be observed that changes were not incorporated into the IrDA standard after 2001. Future research could investigate the reasons why consortia or committees make the decision to stop with further adapting standards. Reasons might include that they believe that the standard is finished and that further revisions are not needed. Alternatively, revisions were planned but not incorporated due to a lack of interest and input by members or conflicts between members. A third possibility is that the consortium that develops the standard realizes that the competing standard has won and that it then focuses on a specific niche application. This might be the reason for the IrDA specification in that the standard is now used for a niche application, short range wireless communication that requires low bandwidth capacity such as remote controls.

One other way to increase flexibility in standards is to allow users of standards to develop extensions for the standard (without changing its core specification so that compatibility between devices is ensured). This would allow greater applicability of the standard. This is a form of 'open standardization' and could potentially open up a new research line within the area of standardization. It would, e.g., be interesting to study whether open standardization is possible to implement for standardization organizations. Interested scholars could fruitfully use the research of Jakobs (Jakobs, 2006) on users and standardization. Also, does open standardization lead to inclusivity and responsiveness and, therefore, more responsible standardization (Wiarda et al., 2022)? Finally, it would be interesting to study whether and how open standardization could potentially lead to the success of standards. Arguably, it would allow the standard to better incorporate the requirements of the users of the standard as they will become involved in the standards development process.

The two dimensions distinguished in this paper can possibly also influence each other. The underlying argument is as follows. More flexible standardization organizations might leave open room for developing multiple versions of standards that can be applied for multiple purposes. And as there are more possibilities to implement a standard, this will, possibly, also attract new actors in the standardization process. Consequently, this leads to a more diverse group of parties within that process. As we know from previous research (Van den Ende et al., 2012), a more diverse network of actors that are involved in the development of the standard leads to more changes that are implemented within that standard. Future research can further study this potential interrelation.

Data availability

Data will be made available on request.

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