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Standards in transitions: Catalyzing infrastructure change

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Abstract

Infrastructures are difficult to change in response to new societal demands. They are entrenched, materially and socio-institutionally, and seem to be 'locked-in'. Scholars have addressed this problem by, for example, devising strategies for de-entrenchment, alternative path creation and transition management that focus on the process of change (emphasis on 'how'). In this paper, we take a novel and counterintuitive approach, and focus on standards as a starting point for change (emphasis on 'what'). We analyze in what manner standards can play a catalyzing role in infrastructure transitions and which standards characteristics facilitate in doing so.

Central to our framework are the concepts of gateway technology and compatibility. We analyze three cases, i.e., the modal shift in freight container transport; the transition from barcode to Radio Frequency Identifier (RFID); and the possibility of a Dutch energy transition from natural gas to hydrogen.

The article concludes that standards can catalyze infrastructure transitions if, first, their content well-reflects relevant stakeholder interests; and, second, if standard specifications are simple and performance-oriented. Their impact is highest in stable markets and for expanding infrastructures. Under these conditions standards can exploit the forces of entrenchment and socio-technical lock-in to bring about change.

1. The problem of entrenchment

Large technical systems (LTSs), infrastructures included, are often difficult to change. A lock-in of these socio-technical systems seems to occur. This is at least partly due to their sheer complexity, that is, to the countless number of interdependent components they comprise and to the technological, institutional and regulatory contexts in which they develop and operate [1]. Companies and organizations emerge that develop and sustain the system. Experience is gained with operating and using the system. Refinements and technical add-ons are introduced. Complementary products and services are developed. Bit by bit, the number of interdependencies between actors and artefacts grows. They crystallise. Technology practices, processes and relations are institutionalised and codified. Standards emerge. Over time, the system becomes socio-technically entrenched [2, p. 47] and little room is left for any significant change. If changes do occur, analogous with the movement of large tanker ships, they are subject to 'technological momentum' [3]. A standstill or change of course is difficult to achieve. An 'inertia of directed motion' ''pushes the system along a path-dependent process of technological change'' [4, p. 1148].

The study by Mulder and Knot [5] on the production of polyvinyl chloride (PVC) illustrates this. PVC production took place from the early 1930s onwards. It posed serious health and environmental risks. These ranged from health risks for workers and those living near the PVC production and processing plants (toxicity and carcinogenity caused by vinyl chlorine; Miamata disease due to mercury emission) to dioxin found in cow milk as a result of incineration of PVC waste in the 1980s.

In response to public fear and recurrent protests, the PVC industry introduced changes to the production process. Ironically these reinforced the entrenchment of PVC because it made the industry's transition to non-chlorinated plastics more unlikely [5, p. 284].

The problem of entrenchment is, in Churchman's words, a 'wicked problem' [6]. It involves complexity, many interdependencies and uncertainty about future demands. It embeds a dilemma earlier formulated by Collingridge [2], that is, that these new demands could easily have been taken aboard at an early stage of system development but often only become manifest when it is 'too late'. While such wicked problems are seemingly impossible to solve [7], several efforts have been made to do so under the headings of, in particular, de-entrenchment strategies [5], alternative path creation [8], niche management [9] and, related to the latter, transition management [10]. The intervention techniques vary, but they are all primarily process-oriented and focus on how to design, instigate and support change processes. For example, Partidario and Vergragt [8] use future visioning techniques together with stakeholder participation, followed by action planning. Studies on the management of transitions, i.e., fundamental changes, [11, p. 238], focus on creating ''niches for setting up experiments and steering the directions of experimenting, learning, innovation and adaptation.'' [10,12,13].

This paper shares with the said studies the central question ''By which mechanisms can obstacles, path dependencies, and adverse interests be overcome?'' [14] But its approach is complementary: it does not focus on how to organize transitions but on which point to focus on to achieve transitions. It explores a novel angle, i.e., the manner in which standards can catalyze infrastructure transitions and, specifically, the standards characteristics that are responsible for doing so.

The structure of the paper is as follows. First, we explain how theoretically standards can be understood to create the room needed to introduce changes (Section 2). The developed framework is then applied to analyze three cases (Section 3), i.e.: the modal shift in container transportation; the transition from barcode to Radio Frequency Identifier (RFID); and the possibility of an energy transition from natural gas to hydrogen in the Netherlands. Finally, we compare the cases (Section 4) and draw conclusions about the catalyzing role of standards in infrastructure transitions (Section 5). An attempt is made to reason under which conditions they typically play this role.

2. Conceptual framework

To better understand the relation between standards and what we call 'infrastructure flexibility', which refers to the available room for introducing changes, we have developed the line of argument and used the key concepts presented below. We start by discussing the seemingly contradictory effects of standards, i.e., system entrenchment versus flexibility. We then introduce the notion of 'gateway technology' [15] as an important auxiliary concept to relate standards to infrastructure flexibility. As the cases will illustrate, we argue that the degree of socio-technical compatibility which these gateway technologies create is pivotal in achieving transitions [1,3,16]. Last, we discuss why certain characteristics of standards are more effective in creating system flexibility than others [17].

2.1. Standards and the scope of gateway solutions

A standard is a technical specification developed in consensus and documented by a committee for common repeated and voluntary use (adapted from [18]). Although standards are held to play a crucial role in the evolution of large technical systems [19, p. 30], few studies clarify this role. Usually, they are seen as catalysts of entrenchment. They fix the parameters of technology development [20]. As points of reference, they coordinate technology development [21]. When implemented in products and services, they reinforce select technological practices. We focus here on compatibility standards, also known as interoperability or interface standards. These standards specify how to develop compatible products and assets, thereby easing market enlargement. All these aspects would seem to increase rather than decrease path dependency.

However, a number of studies call for reconsideration of this standpoint and note that standards can also facilitate system change [20,22,23]. For example, Hanseth et al. see flexibility in the possibility to pick and mix standardized modules into different subsets [20]; while according to Mulgan ‘‘standardization in one part of the productive chain facilitates flexibility at the next’’ [23, p. 202]. But they do not, or not sufficiently, elaborate their point. In our view, a better understanding of how standards work out will highlight that under certain circumstances standards may be used as instruments of change. We argue that insight in the concept of compatibility, the role of gateway technologies, and the degree of compatibility achieved by standards together help clarify in what way standards can facilitate change.

From a system perspective (e.g. [24]), compatibility can be of two types [8]:

- compatible complements, when subsystems A and C can be used together, e.g. plug and socket; and
- compatible substitutes, when subsystems A and B can each be used with a third component C to form a productive system, e.g. the USB interface of a digital camera (A) and of an external hard disk (B) vis a vis the USB interface of a laptop (C).

Technical compatibility is achieved by using gateway technologies, that is, ‘‘a means (a device or convention) for effectuating whatever technical connections between distinct production sub-systems are required in order for them to be utilised in conjunction, within a larger integrated production system.’’ [15, p. 170].

Degree of Standardization	**Scope of Gateway Solution**	**Examples**
Standardized	Generic, wide scope	A4 paper format
Not standardized, 'improvised'	Dedicated, limited scope	AC/DC rotary converter

Table 1: Relationship between the degree of standardization and the scope of the gateway solution (adapted from [26]).

In its role to interconnect and integrate subsystems, arguably, also lies a gateway’s potential to increase system flexibility. For it can integrate them more or less tightly. Thus, if only one type of plug fits a certain socket, the two artefacts are highly interdependent and tightly integrated. In this situation, one then speaks of *dedicated* gateways in the field of ICT. Dedicated gateways link an exclusive and specified number of subsystems. They are a common phenomenon in all areas. For example, the AC/DC rotary converter linked electricity networks based on alternate and direct current. Dedicated gateways may involve more *improvised*, ad hoc solutions. In the case of dedicated gateways, the scope of the gateway solution is limited to the designated subsystems.

Although compatibility can be achieved by different means [25], notably the *standardized* gateways on which we focus play a prominent role because standardization augments the scope of a gateway solution. For example, where the interface between different plugs and sockets is standardized, a looser coupling between the compatible complements arises. The plugs (i.e., compatible substitutes) become exchangeable and the number of compatible complements extendable. Standardized gateway solutions aim to interconnect an unspecified number of subsystems. Because such standards link any subsystem that conforms to the standard we speak of *generic* gateways. That is, whether or not a gateway is standardized determines the scope of the gateway solution. See Table 1.

In sum, standardized gateways introduce a looser coupling between subsystems; they loosen interdependencies between complementary and between substitutive subsystems [17], which is tantamount to increasing system flexibility.

2.2. Socio-technical compatibility

Developing standards can be difficult. Standards committees must take into account – and possibly compromise on – different institutional, organizational and technical contexts in which the standardized technologies will be used, and try to match distinct national policy and regulatory settings. Their socio-technical nature implies that we must include in our study of standardized gateways the social compatibility created between subsystems [15, p. 165]. Thereby the term 'social' may refer to the political, regulatory, operational, institutional, interpersonal, etc. features of subsystems. Depending on the area of study, one or more of these social domains may be more relevant to understand the impact of a gateway and the scope of its solution. See Fig. 1.

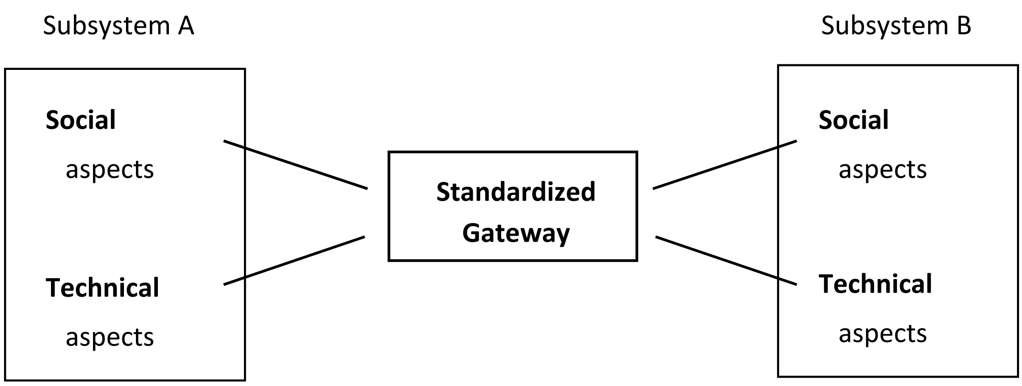

Figure 1: To become a truly generic gateway solution the standard must bridge technical as well as social incompatibilities between two or more subsystems (i.e., regulatory, operational, institutional, interpersonal, etc. incompatibilities).

2.3. Standard's characteristics

In the previous, we treated standards as a black box. However, certain standards characteristics may create more flexibility than others. A remark along those lines was has been made by Duncan [22, p. 54]: ''Standards (…) may be in place to increase flexibility (…). Naturally, how they ensure compatibility will affect flexibility too.'' The possible relevance of differences between standards that she points to has been further explored by Egyedi and Verwater-Lukszo [17]. They identify a set of standards characteristics, two of which are particularly relevant for analyzing the cases in Section 3.

The first characteristic relates to the degree of specificity of a standard. The amount of detail in a standard can vary. Some standards are very detailed and elaborate. They go so far as to specify aspects of product design, and are therefore called *product specifications*. The problem with these standards is that they tend to include requirements that are not strictly necessary. Compliance to such standards will therefore sooner restrict product and technology innovation than stimulate it [18]. An opposite approach is to only specify the required performance of a product or service. Such standards are called *performance standards*. Such standards leave much more room for users to implement them in different ways. Only the required performance is fixed and no restrictions are set on how the performance is to be achieved. As for example standardization of the container dimensions will illustrate, this approach highly increases the system's flexibility to change.

The second characteristic consists of the degree of *simplicity* of the standard. Given the pressure of multiple stakeholders in standards committees to cater to various interests, and given also uncertainties about future markets and technological developments, standards committees may try to ease securing a political compromise and safeguard the standard's wide use by including extra options in their standards. One might initially assume that a standard which incorporates more 'futures' will sooner increase system flexibility than a standard without options. However, in practice the inclusion if different options often leads to interoperability problems. Interoperability problems occur, for example, because the costs of implementing unused options may be too high; or because standards do not always unambiguously indicate how users should deal with options. Parsimonious use of options is therefore highly important [17]. The seamless interoperability achieved by a simple 'inflexible' standard can strongly contribute to system flexibility, as the example of Internet's TCP/IP protocols shows.

3. Cases studies

Having theoretically argued the principle that standards can create system flexibility, we analyze below three cases of infrastructure transition to explore how they may do so. The standards studied are the historic case of the ISO freight container (transport infrastructure); the more recent case of the standardized license plate number used in barcode and RFID technology (information infrastructure); and the case of the Wobbe standard (energy infrastructure). While the first two cases are descriptive, the third case is design-oriented. That is, it is based on a study by Zachariah et al. [56] that examines whether the conceptual framework can be used to support a transition trajectory from a natural gas to hydrogen.

Next to literature study, the empirical data underlying the cases primarily stem from interviews with field experts and standardizers (e.g. RFID and containers), an archive (e.g. the container standardization archive of the Swedish Standards Institute), and project participation and reports (e.g. Greening of Industry project).

3.1. ISO container

From the fifties onwards the world economy experienced a strong growth. International division of labour increased and, in parallel, trade in and transport of (semi-)processed goods. The flow of processed goods exceeded that of raw material (bulk goods). The mean distance in transportation increased. Increasingly, the labour costs on ocean liners and in harbours and the time needed for loading and unloading ships were seen as a bottleneck in cargo handling. For much cargo, unitisation and specifically the use of containers offered a solution [27]. Packing goods in wooden or metal casings eased transport and transhipment. An estimated 75% of the general cargo could be transported in this manner [28].

From the 1960s onwards, container use expanded strongly. Containerisation solved the problem of congestion in harbours. Increased efficiency was achieved. Containers could be handled in a mechanised form (cranes) – a process which was later to be (semi-)automated. The required labour force decreased. Costs dropped and the profit margins for stevedores grew. Liners were able to increase the number of shipments per year. Although higher initial investments were required, containerisation stabilised the costs of liner companies.

The real freight transport revolution was brought about by standardizing container dimensions in the International Standardization Organization (ISO) [29]. The container referred to is the ISO freight container, the dimensions of which have been established in a technical committee of the International Standardization Organization (ISO TC 104). The ISO container highly facilitated the flow of goods between the transport subsystems of sea, rail and road. Between 1968 and 1974 the number of container transhipments steadily rose from 150,000 TEU (Twenty foot Equivalent Unit, i.e., the 20 ft ISO-container) to 1,107,000 TEU in the largest European harbour, the Rotterdam harbour [30]. In 1990, the world fleet comprised 5,102,563 dry cargo containers (in TEUs). Merely 1.6% deviated from the ISO specifications for container height and length [31]. In 1993, 95% of the world container fleet still conformed to the standardized width of 8 ft [32].

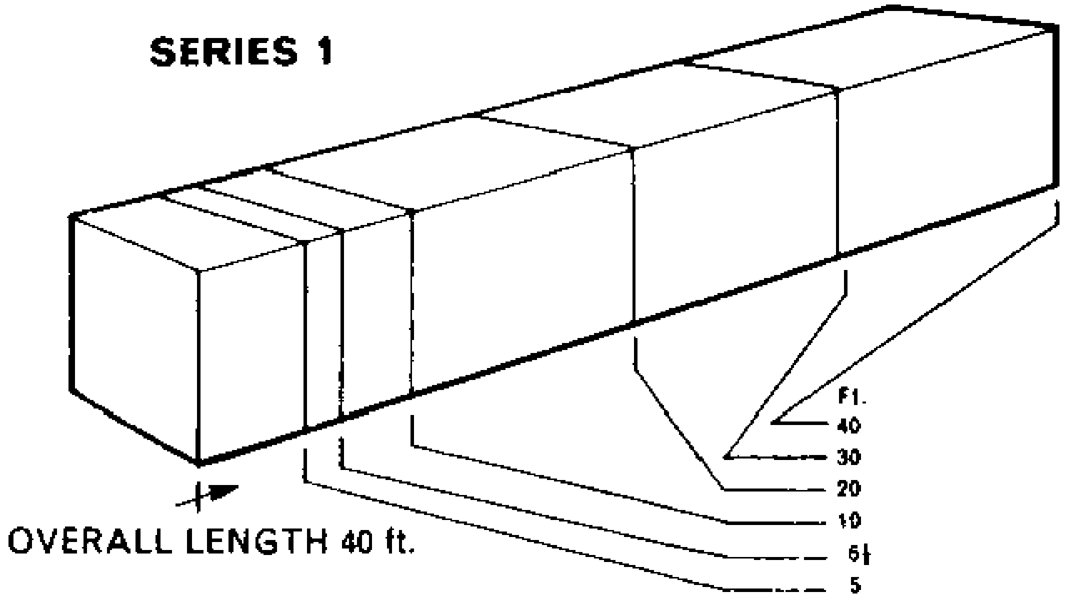

Figure 2: The first ISO Series 1 dimensions [34].

3.1.1. Forging compatibility

The standardized container is a means to organize the flow of goods more effectively between transport modes. In terms of the conceptual framework, the system flexibility at stake is that of choice between transport modes. The standardized container functions as a gateway between different subsystems of transportation. The subsystems of deep-sea transport, on the one hand, and road, rail, short sea or coastal transport, on the other hand, are compatible complements. In respect to the deep-sea subsystem, the subsystems of road and rail are compatible substitutes for land transport. More specifically, with regard to intercontinental transport, the subsystems of road, rail, short sea, and coastal sea are only partly compatible substitutes because short sea, coastal and rail transport generally need the complementary service of road transport to provide a full terminal-to-door service. Only the road transport system can, because of the denser and finer road infrastructure, cover the end-trajectory by itself.

First of all, the intermodal container must interface physically with the vehicles used by the different modes and address the environmental requirements of intercontinental and continental systems (e.g. salt water in sea transport). But apart from technical compatibility, the container standard must forge operational compatibility. It must represent a common solution to the requirements of the different parties involved, such as: shippers, ocean liners, railways, road hauliers, ferries, terminal operators, container industry, producers of container handling equipment, and engineers involved in the design and construction of the modal means. The transport subsystems operate differently and face other problems. They have different interests, priorities and customers, and therefore have different requirements with regard to containers. Because interdependencies between the subsystems will increase, in the process of standardization dilemma's must be addressed such as – for the container safety standard: Are the extra costs of designing a safe container – which might increase its tare weight – for one transport mode acceptable to another transport mode if the latter has an alternative, cheaper or more efficient means of transportation?

Most notable during standardization, the standard specifications must bridge political and regulatory incompatibilities within and between nations and regions. Economic, environmental and transport policies may pose conflicting requirements and address different government levels. Road regulation is primarily a national affair, while also European railway companies are still mainly operating on a national basis [33].

For the purpose of unrestricted intermodal transportation, the container standard must reconcile disparate political and regulatory, operational and technical considerations in order to fulfil its gateway potential. The more effective it is in forging compatibility in these domains, the more choice there is between transport modes and the more influential its role in international cargo transport.

3.1.2. Standardization in ISO TC 104

As a prelude, in the mid-1950s, two pioneer shipping companies in the USA, Matson and Sea-Land, demonstrated the advantage of using containers. Both companies used detachable cargo boxes with special corner fittings for intermodal transport between ship and road. Matson and Sea-Land were captive systems. The containers ''stayed within the confines of the owner's distribution system and his personal control.'' [29, p. 81].

In 1958, the Materials Handling 5 (MH-5) Sectional Committee of the American Standards Association (ASA) started developing standard dimensions for the US domestic container for intermodal transport. The standard width was determined by road regulation. The height of 8 ft was settled on in 1959. The container length provided more difficulties. The lengths of 20/40 ft, 12/24 ft and 17/35 ft were proposed. The 40 ft length derived from railway regulation. Railway companies were at the time permitted to move boxcars that is closed railway wagons, of 40 ft at the most. The lengths of 12/24 ft answered to the needs of West Coast operators (e.g. Matson). The lengths of 17/35 ft were based on the overall trailer length then permissible in all states (e.g. Sea-Land). When in 1959 several states changed their regulation for road vehicles to 40 ft, the 17/35 ft combination was dropped. In 1961, the MH-5 committee settled on a width and height of 8 ft and on the lengths of 10, 20, 30 and 40 ft [35]. The standard was published as MH-5.1 in 1965.

Sea-Land and Matson together handled 70% of the US container transport in 1965. Neither company complied with MH-5's results. In order to be applicable for government orders, they urged the US Department of Commerce to also accept the 35 ft and 24 ft [27], and were successful. The US Congress changed the Merchant Marine Act so no preference was to be given to MH-5 dimensions.

In September 1960, US representatives proposed a programme similar to that of the MH-5 committee to the International Standardization Organization. In 1961, an ISO committee on container dimensions was installed: the ISO Technical Committee 104 (TC104) on Freight Containers. Its first meeting was held in New York. Participants were representatives from ocean shipping companies (e.g. naval architects), railway companies, manufacturers of container handling equipment, etc. TC104 established three working groups: one for terms and definitions, one for dimensions and one for specification, testing and marking.

In the beginning, MH-5 and ISO TC104 worked in parallel. The US was a driving force in TC104. But the issues raised in ISO also affected MH-5 developments [36].

ISO TC104 soon determined that the container standard should be a performance standard. That is, standardization should not entail detailed specifications. For example, the standard was not to make any reference to the material used for an ISO container. TC104's sole aim was to achieve operational exchangeability [37]. This put an end to early discussions on whether containers should be made of aluminium (US) or steel (Europe).

Two proposals on container dimensions were considered. The US put forward the results of its MH-5 committee, while European representatives proposed a container which conformed to the standard of the International Union of Railways (UIC), a smaller container that was much used by Europe's national railways.

An international enquiry was held in 1961 to determine the largest permissible size of transport vehicles. Container dimensions would have to stay within their limits. The US road regulation (40 ft length and 8 ft width) was stricter than the dimensions permitted by European regulation. Therefore, in 1962, TC104 accepted the proposal of the Americans (then 8 ft _ 8 ft _ 10/20/40 ft). The Series 1 dimensions were supplemented with the lengths of 30 ft, 6 ft.8 in. and 5 ft in 1963. (See Figure 2.) These two smaller sizes were chosen to allow containers to be coupled together to form a unit with the overall length of a larger single unit [37]. This required special coupling devices [38].

3.1.3. Scope of the gateway solution

While 'Matson and Sea-Land' started out with a proprietary and thus limited gateway solution for intermodal transport, the ISO container aimed at a generic solution. Vincent Grey, who was chairman of ISO TC104 at the time, remarks

> ''What emerged from the ISO Committee were Standard Container sizes that did not match either Sea-Land's or Matson's boxes. The corner fittings were different from theirs and so were the container ratings, the test methods, the marking system, the chassis securing method, and so forth. This was not a wilful effort to isolate the two pioneering companies but was the result of broadening the scope of operations within which the containers would have to survive. The emergence of an ISO Container depended on an amalgamation of service environments of a world-wide distribution system.'' [29, p. 82]

Grey refers to the difficulty of aligning different political, operational and technical requirements under the 'voluntary consensus' re[1]gime of the ISO. This regime is based on a number of democratic, politically neutral and 'rational' principles [40], e.g.:

- because truly international standards are aimed for, wide acceptance of the standard is crucial and decisions should preferably reflect consensus;
- the national vote on the draft international standard should represent the view of all national stakeholders;
- ISO technical committees should try to arrive at technically optimal solutions, etc.

Several occurrences illustrate that the standards regime strongly influenced the standards process. In order to raise international commitment, the TC104 initially included the European UIC container and the USSR container as a Series 2 and 3 containers in its work programme. In addition, solutions connected to company interests in dimensions (Matson and Sea-Land) and in patented solutions (National Castings Company), were rejected. Lastly, in search for 'technically optimal solutions' the services of research centres were called in. For example, tests were held to determine the safety requirements for container handling and transport (for more details see [38]). In sum, the standards process was conducted in a way that would maximise the scope of the gateway solution.
Moreover, two standards characteristics increased the ISO container's usability and thereby its power as a generic gateway. First, a performance standard was developed. The technical committee did not give in to the pressures for specifications that favoured certain regional economic interests in container production (i.e., aluminium or steel containers). Second, a modular approach was pursued that allowed for different lengths (e.g. 20 ft and 40 ft).

3.2. License plate number: From barcode to RFID

Barcode has traditionally been a technology of choice for identification applications, since it was developed in the middle of the 20th century for the purpose of automated capturing of product data. It found its wide adoption in retail industry when in 1984 Wal-Mart mandated the use of barcodes (and a common standard) to all its suppliers. Since then barcode became the dominant solution for item identification in retail and supply chain, and is increasingly being used in other areas.
The barcode use which we focus on in this article is that for baggage handling at the Amsterdam airport of Schiphol, the Netherlands. The number of passengers using Schiphol airport reached about 47.8 million people in 2007 [41], ranking Schiphol fifth in Europe [42,43]. An airport of this size has to operate extremely efficiently to coordinate the flow of passengers with their baggage with minimal

[1] Regimes are agreements, at once resulting from and facilitating co-operative behaviour, by means of which actors regulate their relations with one another within a particular issue area. (adapted from [39, p. 6]).

disruptions and delays. Inevitably something can go wrong, ranging from missed connections to last-minute stand-by passengers to processing errors. This results in ‘‘irregularities’’, when bags do not end up on the same flight with their owners. Eventually most misplaced bags arrive on the next flight to their destination, but the costs and efforts required to recover them and deliver to the owner are substantial. According to IATA survey [44] lost baggage represents a US$3.8 billion dollar problem for the airline industry – every year. It also affects 42 million passengers annually and is the second greatest concern among first and business class passengers when travelling [45].

3.2.1. Barcode

The use of identification techniques for baggage handling has a long history, which goes back to 1929 Warsaw convention that established common criteria for bag ticket. From that time onward, the carriers were required to issue baggage checks for all checked-in bags. In 1945 the International Air Transport Association (IATA) was formed to represent interest of airline industry and to provide professional support to the industry by among others supporting the development of industry standards and regulations. The industry-wide specifications for baggage tags for airlines have been provided since 1962 by IATA Resolution 740 (Form of Interline Baggage Tag), which was adopted at a IATA conference in Cannes. First bag tags were simple paper tags attached with a string. The resolution 740 continuously evolved since 1962 to meet the changing requirements of airline industry, to finally incorporate the specifications for barcode. The resolution 740 is supported by Airport Services Committee (ASC), which consists of 18 formally elected IATA Members, represented by experts specialising in passenger and baggage service, departure control systems, and ground handling activities.

According to Resolution 740, each baggage tag must contain (1) tag number, which we discuss below (2) information area, including name of passenger, the name of the agent providing the tag, and ‘‘a large barcode which is essential for automated baggage sortation systems’’ [46, clause 5.2.4] (3) routing area, including final destination and transfer points (4) identification/ claim portion, which is affixed to passenger ticket; and (5) removable stubs, which are used for baggage reconciliation procedures [46, clause 5]. The tag number is crucial for the operation of an automated baggage handling system. It is encoded on each tag in the barcode format and as well as in a human readable numeric form. It is also called licence plate number [46, clause 5.1]. It is a 10-digit number consisting of a one-digit prefix identifying tag type, three-digit numeric baggage tag issuer code, and a six-digit serial number [46, clause 5.1.2]. It is issued at baggage check-in.

The licence plate number is essential for the operation of automated baggage handling. It is the linking pin between the baggage tag and passenger details (including routing and flight number data). It is referred to in the Baggage Service Messages (BSMs) that are exchanged between airport systems at subsequent stages of baggage handling. These ‘‘(. . .) messages are sent, received and processed by [airport] systems in order to achieve automated baggage sortation, passenger and baggage reconciliation, and other baggage services. Baggage information included in these messages is linked with the unique 10-digit bag tag number defined as the Licence Plate’’ [47, clause 1.1]. IATA does not prescribe how to transmit BSM messages. It allows the use of different protocols (e.g. airline specific protocols, Edifact, etc.) [47, clause 1.2].

3.2.2. RFID

Baggage handling processes are complex. The reliability and efficiency of the whole baggage handling system relies on the ability to retrieve 10-digit license plate from baggage tags. In order to accommodate the growing number of passengers and increase speed and efficiency of baggage handling, Schiphol initiated a so-called 70 MB project. The project aimed at increasing the throughput of the current system to handle 70 million baggage pieces by 2015. To achieve higher efficiency, the system needed to be more reliable and allow a complete automation, which required new technological solutions.

The legacy system for luggage handling at Schiphol is based on barcode technology, where each bag is identified by a barcode on its tag. While barcode is a very cost efficient solution for automated identification, it has its limitations. First, barcodes require direct line of sight to the reader to be processed. Additionally, successful reading rate goes dramatically down (from 97% to about 75% in Schiphol case) for worn-out barcodes. These limitations translate to the inability to create a highly automated baggage handling system. On the back of these limitations RFID technology emerged as a promising technological solution.

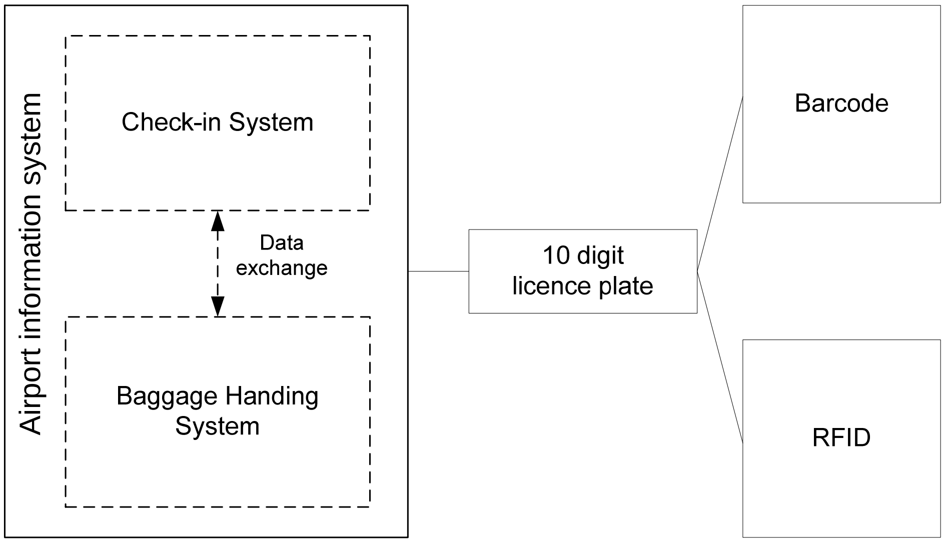

Figure 3. Licence plate number as a gateway.

In order to understand the implications of a possible transition to RFID it is necessary to understand the difference between barcode and RFID. The principles behind working of the barcode and RFID technology are very similar. Barcode consists of a visual representation of binary data on a label in form of a geometrical pattern (e.g. bars, circles or dots) that can be read by a barcode scanner. While barcode technology relies on a visible light spectrum to transmit data from barcode to reader (scanner), RFID stores data on electronic tags and uses airwaves to transmit data from a tag to the reader (interrogator). Both barcode infrastructure and RFID infrastructure consist of readers (scanners) and networks that process data encoded in barcodes or embedded in micro chips.

While the principles behind barcode technology and RFID are similar, these technologies are not interoperable. Barcode equipment cannot process RFID tags and vice versa. Moreover, given the high interdependencies in the airline industry, it is not economically feasible to replace barcode technology with RFID at one particular airport. A complete replacement of all systems based on barcode at all airports is not an option either. Replacing the existing barcode-based system is very costly and not always economically justified, according to an IATA study. However, the benefits from RFID technology are already realized if the technology is implemented at 80 key airports [48]. Because airports must be able to process luggage originating from all airports, the RFID technology needs to operate alongside the barcode technology.

The requirement of integration into the existing barcode-based system lies at the heart of IATA's Recommended Practice 1740c for RFID-based baggage handling. It requires ''compatibility of the technology with airline data systems'' [49, paragraph 1] by means of using the 10-digit license plate number as specified in Resolution 740 [49, clause 1]. The 10-digit licence plate number issued at baggage check-in is to be written on both barcode and RFID tag. Please note that the RFID recommendations (IATA RP 1740c) have been supported by the same Airport Services Committee as the barcode standard (Resolution 740). They represent the interests of the same community.

3.2.3. Baggage handling at Schiphol

RFID technology was initially implemented at Schiphol at departure hall 2, which is operated by KLM. During check-in each bag is provided with a tag that has a barcode and integrated RFID tag based on the same 10-digit license plate number. The license plate number is coupled with additional data and transmitted in a BSM from check-in system to baggage handling system. At baggage handling facility each bag is first scanned by 360 degrees barcode scanner. Because the labels on the bags are just out of the printers (at check-in), the successful reading rate of the barcode label at first attempt is quite high, around 97%. Those bags that are not recognized by barcode scanner are sorted out to be manually processed. The 10-digit license plate number from each bag is used to retrieve the routing details. Based on the routing details the bags are separated in two streams according to the destination (Schengen area countries and non-Schengen area countries). Each stream is processed differently.

The luggage in the first stream with non-Schengen destinations is sorted based only on the initial barcode scan. The second stream of bags going to Schengen countries is mixed with luggage from other transfer flights. All the bags in the second stream are scanned one more time by a 270 degree barcode scanner, which also has an integrated RFID scanner. The 270-degree barcode scanner provides approximately 75% success reading. The lower reading rate can be explained by a narrower scanning angle (270 degrees versus 360 degrees for the first scanner) and by the fact that some bags from transfer flights have worn-out barcode labels. The success reading rate from the RFID scanner remains in the area of 99%, which is considerably better than reading rate of barcode. The results of the barcode and the RFID readings are used. Only when both readings fail, is the bag transferred for manual sorting and can it end up too late on the plane. The redundant check of the data reduces error rates and improves the efficiency of sorting process. At the same time, it requires the integration of data from both barcode and RFID.

3.2.4. Compatibility and flexibility

Applying our theoretical framework, in essence the 10 digit license plate is a standardized gateway that started out by creating compatibility between the barcode and the baggage handling system. It was later integrated in the use of RFID technology. Its generic scope as a gateway solution is partly explained by the common setting in which both standards – the barcode and RFID recommendations based on Resolution 740 and the Recommended Practice 1740c, respectively – were developed. Both standards stem from the ASC, which makes the reconciliation of the interests of stakeholders and the integration of the technologies into stakeholder' organizations easier to achieve. But also, in using the new RFID technology, operational and technical compatibility with existing baggage handling system was sought.

3.2.4.1. Technical and operational compatibility.

The standardized gateway of the '10-digit license plate number' links the compatible complements of the baggage handling system and barcode technology. Together they form what David and Bunn call a 'productive system'.

The '10-digit license plate number' has been reused in RFID tags[2] to create compatibility with the existing baggage handling system. Here, the 10-digit license plate number again functions as a gateway that makes compatible compliments out of the RFID technology and the baggage handling system. At the same time, both RFID and barcode technologies can be seen as compatible substitutes in respect to the baggage handling system and form a productive system with it. This is illustrated in Figure 3.

In this example, the '10-digit license plate number' specified in the IATA 740 resolution functions as a gateway between otherwise incompatible technologies. By creating compatibility, flexibility is introduced in larger system: the gateway facilitates the integration of a new technological solution into an existing system. In term of system flexibility objectives, the standardized gateway facilitates the reusability of existing facilities, and in particular the exchangeability and upgradeability of the two different technologies.

[2] This was required by IATA RP 1740C, e.g. clause 5.15.

In the operational sense, the RFID technology has been used in the same way as the barcode technology has. By integrating RFID tags as part of the baggage tag, no new operational procedures for RFID technology are required. New dual purpose printers, which from the end user perspective are similar to barcode printers, are used to print barcodes on baggage tags and encode RFID tags. Similarly, during the sorting and handling of baggage RFID technology is used in the same way that barcode has been traditionally used. For example, RFID readers are integrated with barcode readers at scanning points. All changes require little adaptation of existing practices, and as such are easy to carry out.

3.2.4.2. Standards characteristics

The main flexibility-enhancing feature of the 10 digit license plate concept is its simplicity and performance nature. By specifying only the key variable, i.e., license plate number and the elements it is composed of rather than prescribing the way the number is to be used, it makes it easier to use for different purposes (e.g. encoding on barcode, RFID tag, and retrieval of additional data). As a result, even though it was originally intended for barcode usage, it could successfully be integrated into RFID technology.

3.3. Wobbe index

In the 1960s a large natural gas field was discovered in the north-eastern part of the Netherlands near the village of Slochteren in the province of Groningen. With it, the Netherlands gained access to a vast, relatively low-cost, reliable source of energy. Since then, natural gas played a very important role in the Dutch economy. The discovery catalysed the change from small local city grids, which had been used to distribute 'city gas' to a nationwide natural gas distribution network [1]. By 1968 all mainland municipalities had been connected to the gas grid [50]. Today the Netherlands has the highest level of natural gas penetration in the world [51]. Natural gas has virtually replaced coal and oil for household usage (gas-fired central heating, cooking and hot water supply). 97% of all Dutch homes are heated with this fuel. Also Dutch industry has benefited enormously.

The composition of natural gas in fields across the globe varies. Groningen gas (G-gas) is composed of 82% methane, 14% nitrogen and minor quantities of higher hydrocarbons along with oxygen and carbon dioxide [52]. Groningen gas contains more nitrogen than gas from most other fields and therefore has a relatively low calorific value (35 MJ/m3). As a result also the Wobbe index, a measure for the combustion velocity of a gas, is low (44 MJ/m3). The Wobbe index is calculated as follows

$$Wobbe\ Index = \frac{Calorific\ Value}{\sqrt{Relative\ Density}}$$

For any given orifice, all gas mixtures that have the same Wobbe index will deliver the same amount of heat. In order to operate properly all appliances using natural gas in the Netherlands are designed for operation within a narrow Wobbe band (43.4–44.5 MJ/m3) of Groningen-gas. Values outside this Wobbe-band may lead to incomplete combustion, will extinguish the flame, or overheat the equipment [53]. Therefore, for safety reasons, all gas distributed in the Netherlands must remain within this Wobbe band.

The Dutch natural gas distribution system has been standardized based on Groningen gas. However, since then, the capacity of this gas field has begun to decline. Thus, the discovery of small fields in subsequent years has become increasingly important. At present, national demand is also supplemented by small offshore fields and by imported natural gas from, primarily, Norway, Russia and Algeria. Long-distance, high-pressure pipelines or trunk mains and smaller regional pipelines transport the gas to the end-consumers at lower pressures. At blending stations – ten in all – different gas streams are mixed in the right proportions. Blending stations have automatic control systems that constantly monitor the Wobbe index of the outgoing gas stream. If the Wobbe index deviates from preset limits, the blending station is automatically shut down. This ensures that different customer groups receive gas of the right quality. The more recently discovered reserves and imported supplies contain more high calorific gas. In order to insure the correct operation of Dutch infrastructure the more calorific gas is 'watered-down' with nitrogen to produce ''pseudo-Groningen'' gas quality. This extraordinary solution of watering down high quality gas illustrates the unusual measures which entrenchment may lead to.

Initially, the stakeholders (producers, network managers, brokers, retail companies, etc. [54]) had been unaware of the speed at which the Groningen gas field would be depleted. Their design decisions did not take into account that in the future there might be a need to cater to different gas quality specifications. Moreover, being one of the first to discover a natural gas field in Europe, they had little experience from other countries to draw on. In retrospect, two opposite ways are identifiable to deal with current differences in gas quality specifications: ''either sufficient flexibility is available at the burner tip and gas quality specifications can be reasonably widened, or flexibility at the burner tip is limited and gas quality specifications will need to be narrowed down. The choice for flexible burners and, where needed, local gas quality monitoring and/or control systems moves the investment costs downstream towards the end users. The choice for narrow range burners however, moves the costs further upstream towards the transporters (blending) or towards the producers (gas treatment). Thus some countries have invested in flexible burners (e.g. Belgium, France) whereas others have opted for blending at the transporters level (e.g. Germany, The Netherlands)'' [55]. The Dutch policy choice may seem somewhat cumbersome given the depletion of the Groningen gas field; however, it also seems to offer unexpected opportunities for a sustainable infrastructure transition.

3.3.1. Transition towards hydrogen

Although natural gas is an attractive fuel in many respects [56], given the rapidly dwindling reserves and the environmental pollution it causes, it is not the ultimate solution to energy problems. In this respect, hydrogen has more potential. When used in combustion engines or more efficiently in fuel cells, hydrogen produces no greenhouse gases or harmful particulates. However, there are several hurdles which must be cleared before hydrogen can be hailed as the energy carrier of the future. Among them is that hydrogen does not exist as a free gas and hence must be produced for use as an energy carrier. This can be done via steam methane reforming; via electrolysis of water using solar, wind or geothermal energy; via coal and biomass gasification, but there are significant costs involved. Despite this and other techno-economic barriers, however, hydrogen is perceived as one of the promising options for future energy systems.

As part of the national research agenda, the Netherlands initiated the Greening of Gas project to investigate the feasibility of adding hydrogen to the Dutch natural gas network. The impetus was two-fold. Firstly, substituting a portion of the natural gas supply with hydrogen would reduce diffuse CO2 emissions. If 10% of the natural gas was to be exchanged for hydrogen, a 3.6% emission reduction would be achieved – this corresponds to 6 Mton CO2 savings, which would already amount to half the Kyoto obligation of the Netherlands [56]. Secondly, it would allow gradual learning of how to deal with hydrogen in the context of an already mature natural gas system. Mixing H2 into the natural gas network, several technical and economic hurdles for using hydrogen could to be cleared (see [56]). The blending, approach promises to ease a shift towards a hydrogen economy.

3.3.2. Wobbe index as a standardized gateway

The Wobbe band can be considered a standardized gateway. It creates compatibility between the compatible compliments of gas and burner. As long as they comply with the Dutch Wobbe band, different mixtures of gases can be used by the same appliance. Thus different gases or mixes of gases become interchangeable and can be considered compatible substitutes. This is particularly relevant given that nitrogen is often added to high-calorific non-Groningen natural gas to reduce the calorific value and bring it within the acceptable Wobbe band. However, precisely because the gas mixture is not specified, it also becomes possible to consider environmentally superior hydrogen as 'just another gas' to be blended into the natural gas streams delivered to end-users.

Adding hydrogen, which has a smaller heating value (3.0 kWh/Nm3) compared to natural gas (8.8–10 kWh/Nm3), reduces the amount of nitrogen needed to meet the strict Wobbe requirements [56]. Thus adding hydrogen to high-calorific natural gas reduces its calorific value and produces a H2/NG blend with a lower Wobbe index. In other words, partial substitution[3] of the nitrogen, which is normally added, with hydrogen (an environmentally benign gas) produces a 'greener' H2/NG blend that still meets the strict Wobbe band. In this manner the Groningen-gas Wobbe band inadvertently creates a back door for innovation.

Indeed, the main flexibility-enhancing feature of the Wobbe band lies in it being a performance standard, i.e., it only indicates a measurement level and not how this level is to be met. For effective operation at the burner any gas – or combination of gases – may be used as long as the Wobbe index falls within the band. We can say, therefore, that the flexibility in the Wobbe index lies in what it does not specify. By facilitating the use of different types of gases for Groningengas burners, it creates a looser coupling between the two complimentary system components. It allows changes in the gas composition without unduly upsetting ongoing operations in the production and distribution of natural gas. That is, the Wobbe band may ease sustainable change within the natural gas industry and beyond by allowing technical change without immediately threatening the existing socio-economic relations.

3.3.3. Flexibility objectives for greener gas

The main objective of the Greening of Gas project is to improve the ecological performance of the system. Adding hydrogen to – or more precisely reducing the carbon content of – natural gas reduces diffuse CO2 emissions at the end-user. Compared to other approaches, such as post-combustion CO2 capture, gradual conversion to hydrogen offers unique benefits. Indeed, the objective of reusability, i.e., to effect system improvements while preserving earlier investments is firmly rooted in the Greening of Gas project. With little or no changes, the majority of existing natural gas lines can be used to transport hydrogen/natural gas blends thereby reducing the capital investment associated with a new hydrogen infrastructure. The capital cost savings achieved by using the already mature natural gas grid for transportation of hydrogen strengthens the economic arguments for encouraging a shift towards a hydrogen economy via this transition path.

Cases	Flexibility objectives	Standardized Gateway	Compatible complements	Compatible substitutes
Freight transport	Transport efficiency	ISO container	Transport modes	Road, Rail, Inland shipping
Automatic baggage identification	Baggage handling efficiency	10-digit license plate number	Barcode / RFID – Baggage handling system	Barcode & RFID
Energy production and provision	Sustainability based on re-use	Dutch Wobbe band	Burner – Gas mixture	Gas mixtures (e.g. methane with hydrogen)

Table 2: The key comparative elements of the three cases.

4. Comparison of the cases

The line of reasoning in this article is that standards are a means to address the problem of system entrenchment and can create room for change. The three cases illustrate this. Therein key standards offer a generic gateway solution, i.e., they interconnect complementary and substitutive subsystems. The subsystems become exchangeable as well as reusable. Thus, the respective standards loosen their system's fabric. See Table 2.

[3] Zachariah-Wolff et al. stress partial substitution of nitrogen. Addition of small percentages of H_2 (say 10%) to H-gas is insufficient for meeting the Wobbe band requirement. Nearly 80% hydrogen must be added to H-gas before the Wobbe index requirement is met. See [56].

The reuse of existing infrastructure provisions is usually high on the agenda of change, irrespective of whether the objective is more efficient cross-border freight transport, handling higher volumes of baggage, or reduced CO2 emissions in energy consumption. Interfaces and compatibility between old and new infrastructure components and subsystems then become of key importance, and this is precisely where standards can play a pre-eminent role in infrastructure change.

In the case of the ISO container dimensions, the standard facilitates the reusability of containers across transport modes in different states and countries, the exchangeability of transport vehicles, and automation of container handling. In the case of automatic baggage identification, for example, the standardized license plate number allows significant reuse of the existing socio-institutional and material infrastructure provisions. The standard fosters operational continuity in the barcode-based subsystem next to the newly installed RFID-based subsystem.

Standardized gateways create room for change at system level, e.g. by facilitating the addition of new subsystems and allowing existing subsystems to evolve in parallel. Depending on the significance of the change, an evolution (A to A0) or an infrastructure transition (A to B) can be said to have taken place. See Figure 4.

Certain standards may more effectively catalyze infrastructure transitions than others. The case studies point, firstly, to the degree of socio-technical compatibility represented by the standard as being crucial. To be widely acceptable, the container dimensions had to meet key requirements of all transport stakeholders. They had to bridge the differences in national road regulation about the size of vehicles internationally; they had to be acceptable for the ship building and container handling industries, etc. The case implies that the better the socio-technical fit achieved for each of the connected subsystems, the more powerful the standard is as a gateway solution, and the less likely it is to change. The standard will be relatively 'future-proof'.

Certain settings of standards development are specifically designed to maximise the 'socio-technical fit' and support an open and democratic the standards process that is more likely to include all relevant stakeholder interests in the standard. They usually support consensus decision making (i.e., no sustained opposition from minorities). The inclusion of this procedure is, for example, typical of the formal international standards bodies (e.g. ISO).

In the cases, the respective standards received additional credibility because they were developed in and/or acknowledged by an officially recognized standards body (ISO container), an industry committee (ASC license plate number) and the Dutch government (Wobbe index). This further increased their acceptance by the stakeholders (e.g. operators, producers, policy makers) and eased their diffusion. The wider the acceptance and use of standards, the stronger and more central their role as a gateway technology.

Given the tension between system entrenchment and change, how can we explain that, for example, the license plate number and the Wobbe index, which are very much entrenched in their respective fields, nevertheless, offer room for change? Like the container standard, they are performance standards. They have been kept as simple as possible (i.e., no over-specification and no options). Because they do not specify in what manner or with which technology they should be implemented, they will sooner remain applicable in – as yet unknown – future technical environments. In other words, their performance-orientedness and simplicity increase standards' usability across time. They also make the standards concerned more 'future-proof'.

A high degree of entrenchment of a key standard need not hamper infrastructure change. The Wobbe case illustrates how the Dutch Wobbe band could have become an agent of undesirable entrenchment – undesirable as it necessitates watering down high calorific gas from non-Groningen gas fields with nitrogen to allow its domestic use. However, simultaneously it has created a back-door for moving towards hydrogen since hydrogen may in part substitute the nitrogen in Groningen gas, thereby reducing diffuse CO2 emissions. Because the Wobbe band is performance-oriented it can exploit parts of the existing infrastructure (i.e., high degree reusability) and can therefore catalyze a smooth(er) transition path.

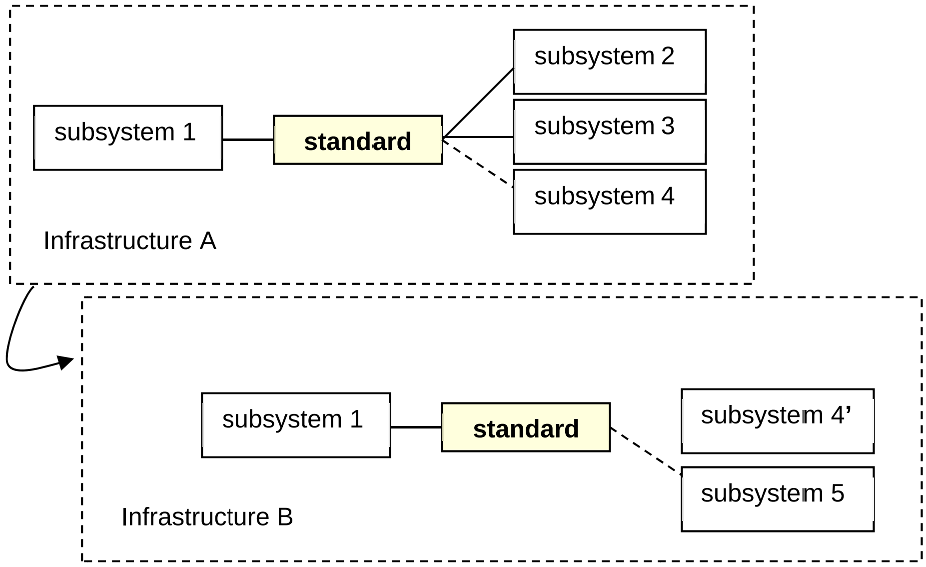

Figure 4. The key infrastructure standard creates room for change, i.e., for new subsystems to be added and for existing subsystems to evolve.

Not all standards will have the same system-flexibility enhancing impact – even if they show the above noted characteristics. Under which conditions are they likely to play a catalyzing role? Extrapolating from the cases, we surmise that, first, as is illustrated by the wide international adoption of the ISO container standard, change need not be overly problematic if the standards process well-represents the existing market, actor constellations and power of interests.
However, if a standard is at the outset biased towards certain interests, by-passing others, its scope as a generic gateway solution will be more limited. The standard will sooner become subsystem-entrenched.
Second, standards are more likely to catalyze change in stable or expanding markets. We surmise that actors will more easily take changes into stride if their own position is not threatened, or if they can even improve their position and reap the benefits of change. The relatively smooth introduction of RFID for baggage handling at airports alongside the barcode confirms a change-supporting role for standards in infrastructure expansion situations. This is less likely where infrastructure replacement is at stake. Resistance is likely to take place if change is expected to upset markets (e.g. radically change value chains, severely increase competition) and turnover dominant technology regimes (i.e., challenging existing technology knowledge, practices, and policies). For example, despite the change potential of the Dutch Wobbe band, introducing hydrogen via the natural gas distribution may in practice be hindered by expected competition between the two fuels. The transition may therefore have little chance to take off. In such situations, the complementary, process-oriented approach is required and insight into de-entrenchment strategies, alternative path creation and transition management becomes crucial.

5. Conclusion

In this article we argue and illustrate that standards can work as catalysts for infrastructure transitions. Although they are usually viewed as part of the problem of entrenchment, they can also be part of the solution. From a system theoretical perspective, they interconnect infrastructure subsystems. They form compatible substitutes and compatible complements, and thus create room for the addition, replacement and reuse of subsystems. They have the potential to create, for example, intermodal container transport (deep sea, inland shipping, road, and rail), intermodal automatic baggage handling (barcode and RFID), and intermodal energy consumption (natural gas and hydrogen). Certain standards characteristics, in particular, enhance this change-catalyzing role. The analyses indicate that

- the better the standards content fits all stakeholder interests (i.e., the higher the degree of socio-technical compatibility) and
- the more performance-oriented and simpler the standard, the better the standard will support system transitions. This seems to hold, in particular, under the condition of
- stable markets, since the encoded balance of interests will then remain topical and the standards content will not be outdated prematurely; and
- system expansion rather than replacement. Expansion implies compliance of the new with existing modes of infrastructure operation and, consequently, the re-usability of existing facilities, which is most often a key reason to aspire for system flexibility. Subsystem replacement would involve a much more competitive transition.

We conclude that, under the right conditions, standards can bring about infrastructure change despite – or rather: by exploiting – forces of entrenchment. This opens up new options for developers of infrastructure transition policy in government and industry. In addition to process-oriented transition instruments that currently being developed, potential impact of a standards-focused transition policy needs to be examined. Theoretically, our standardization oriented framework complements ongoing efforts to theorize and address the difficulty of entrenchment in LTS transitions. Further research is required to determine in what areas and on which transition issues a combined approach could be useful.

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