Complex Built-environment Design: Four Extensions to Ashby

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Abstract

Purpose

To report on development and application of four extensions to Ashby's Law of Requisite Variety that increase its utility in the arena of unplanned changes in hegemonic control of designed complex socio-technical systems/ digital eco-systems in the built environment that are structurally dynamic or emergent.

Design/methodology/approach

Research on which paper is based focused on exploration of classical systems approaches to design of complex socio-technical systems in which ownership, power, control and management of structure and benefit generation and distribution is distributed, dynamic and multi-constituent. Support for development of these four extensions to Ashby’s Law is by observation of 4 decades of socio-technical systems development along with critical thinking that combined systems analysis theories with theories and findings from fields of hegemonic analysis, design research, management, management information systems, behaviour in organisations and sociology. This study of the extended application of Ashby’s Law is a component of a larger research program investigating the application of classical systems analysis tools in pre-design and design processes.

Findings

Outlines application of four new extensions to Ashby’s Law of Requisite Variety in relation to unplanned changes in distributions of power, ownership, control, benefit generation and benefit distribution in complex socio-technical systems/digital eco-systems in the built environment that are emergent or have changing structures. Three of these extensions have been described in an earlier in relation to the design of digital eco-systems; in particular, learning object-based e-learning systems. The fourth extension builds on these via application of Coasian analysis.

Research limitations/implications

The four extensions of Ashby’s Law that underpin the design guidelines in this paper are deduced from observation and critical analysis rather than being ‘proven’ empirically. They are derived from observation of the behaviour of real-world complex systems together with critical analytical thinking that integrated theory and research findings from a range of disciplines that each informs understanding of hegemonic aspects of emergent complex socio-technical systems involving multiple, changing constituencies, and evolving system structures. This means that they are limited to providing the basis for gaining insights into system behaviours, rather than any attempt to provide deterministic modelling of system changes.

Practical implications

A design method is derived comprising five design guidelines for use in pre-design and design of complex socio-technical systems/digital eco-systems in the built environment.

Originality/value

The paper describes the application of four new extensions to Ashby’s Law of Requisite Variety that extend the analytical role of Ashby’s Law in diagnosis of shifts in power relations and unintended design outcomes from changes in the generation and control of variety in complex, multi-layered and hierarchical socio-technical systems that have multiple stakeholders or constituencies. From these four design guidelines are proposed.

Index Terms: Design, built environment, Ashby’s Law of Requisite Variety, digital eco-systems, hegemony, complex socio-technical systems.

Complex built-environment design: Four extensions to Ashby

Introduction

The paper describes four extensions to Ashby’s Law of Requisite Variety (LoRV) developed by the authors. These extend the cybernetic contribution of LoRV in the design of complex socio-technical systems to situations involving design issues of social relations, power, hegemony, politics, the taking control of systems, and the use of changes in designed system structure to gain advantage in the manipulation of system outcomes. These four extensions were derived as provisional findings during ongoing design research exploring the application of classical systems analysis tools in the design of complex socio-technical systems.

The four extensions to Ashby's LoRV described in this paper provide the basis of a new outcomes-based suite of design methods for complex socio-technical systems that support designers to include significant political and economic design considerations not currently adequately addressed by other design approaches. This new suite of design methods is expected to be of broader utility than the built environment and likely to be of value in the design of:

Civil complex socio-technical systems involving multiple competing stakeholders/constituencies (e.g., infrastructures; built environment with complex socio-environmental behaviours; software development; socio-technical electronic systems such as ticketing, payment and information access systems)

Military socio-technical systems that involve multiple players (anti-terrorism, situation control, and war-faring systems)

Politically driven socio-technical systems involving multiple competing interests (e.g., international standards setting and conformance processes; treaty writing such as European Union and similar international agreements; processes for implementing multi-lateral technical, economic and political agreements; and technology-transfer systems).

The design approach described here aligns approximately with the social cybernetic schema outlined by Umpleby (2001). It contrasts with the conventional use of LoRV as an analytical method to model and understand systems with human aspects (see, for example, Heylighen, 1997; Powers, 1992; Stockinger, n.d.) and to identify potential improvements in technology support for design activity (Glanville, 1994).

In design terms, complex digital eco-systems in the built environment are characterized by multiple constituencies. The four extensions of Ashby's Law of Requisite Variety below assume that different constituency groups have different orientations, attributes, power, control and other influences on a system and that different constituencies benefit differently from their involvement depending on structural and dynamic properties of the system. The concept of 'constituency' used in this paper follows its application in Market Orientation and Constituent Orientation Analysis (see, for example, (Tellefsen, 1995; Tellefsen & Love, 2003). 'Constituency' more comprehensively includes all those affected by and affecting a system in contrast, to the concept of 'stakeholder', which refers to those who have an investment, stake in system outcomes. Constituency groups involved in the design of complex socio-technical systems include designers, project sponsors, users, project constructors, those directly and indirectly affected by the system, and those directly and indirectly affecting the design and operation of the system etc. For an example of the breadth of potential constituencies involved in design activity see Tellefsen & Love (2002).

Four extensions to Ashby's Law of Requisite Variety

To date, corollaries and extensions to Ashby's LoRV have primarily been developed from a purely functionalist perspective. This has excluded human subjective considerations central to the design of complex socio-technical systems, e.g., issues of hegemony, management control, constituent orientation, distribution of power, ethical management, evolution of human aspects of systems, struggles for control and ownership.

The four extensions to Ashby's Law of Requisite Variety described below were identified by the authors via observation of four decades of real-world complex socio-technical systems development along with critical thinking that integrated systems analysis theories with theories and research findings from fields of hegemonic analysis, design research, cybernetics, management, management information systems, behaviour in organisations and sociology. Each of these fields contributes understanding, research findings and theory of social and hegemonic aspects of emergent complex socio-technical systems involving multiple, changing constituencies, and evolving system structures. Because these extensions of Ashby's Law are deduced from observation and critical analysis rather than being 'proven' empirically, their utility at this stage is limited to providing the basis for gaining design knowledge about relative changes in size and direction of system behaviours, rather than deterministic quantitative modelling of system changes.

The four extensions to Ashby's LoRV are:

1. For complex, layered and hierarchical systems involving multiple constituencies in which the distribution of variety generation and control is uneven across the system THEN the differing distributions of generated and controlling variety result in a structural basis for differing amounts of power and hegemonic control over the structure, evolution and distribution of benefits and costs of the system by particular constituencies.
2. For complex, layered and hierarchical systems that have a variety of typical stable states of system structure, THEN the structural system state that the system will evolve will depend on the relative locations of subsystems generating variety and the control subsystems able to use variety to control overall system variety.
3. Where differing sub-systems of control are involved in the management of a system and some sources of control are able to increase their variety to accommodate a shortfall of requisite variety in other control systems THEN the overall distribution of control between sub-systems and constituencies will be shaped by the amount and distribution of transfer of control to the accommodating control system.
4. In complex systems in which multiple sources of variety generation and variety control interact, the relative effect of different forms of system variety and control variety on system behaviour and system control are dependent on their relative transaction costs.

The reasoning behind the extensions is straightforward. It presumes a complex socio-technical system with multiple interrelated and interdependent subsystems with a large number of constituencies and stakeholders that 'own', affect and are affected by the functioning of the system in ways that are not simply distributed (i.e., not a simple one-to-one mapping onto sub-system elements).

First, the ownership of controlling variety gives the 'owning' constituencies' at least partial control over the system and subsystems and system outcomes. The relationships are direct though not necessarily linear. Increased ownership over increased levels of control variety provides increased amounts of control over the system. Second, ownership of control variety of the processes of constructing or managing system structure is directly related (again not necessarily linearly) to the power to change the structure of a system and change the balances of control and system variety at different points and times in the system. Third, the location, amount and timing of application of controlling variety within a system influence the relative ability of the 'owner' of that controlling variety to influence system structure and outcomes. For example, the real-world control effect of the use of standards in software development depends on where in the software/hardware spectrum they are applied and at what stage in software evolution (Love & Cooper, 2007). Four, if the amount of controlling variety is insufficient, and if the system remains functioning, it does so by other system elements being able to increase their controlling variety. This implies a shift in the balance of power towards the owners of the system elements that increase their control variety. The constituencies 'owning' system elements that increase their controlling variety increase their power and control over the structure of the whole system and its future. By implication, they also increase their control over system outcomes and the management of future distribution of value created by the system. Finally, the logic of Ronald Coase would be expected to apply to all transactions within a system. Following the implications of the Coase Theorem, the system design and evolution would be likely to tend to minimise overall transaction costs across constituencies in relation to physical considerations (Coase, 1960) and informatic considerations (Agre, 2000).

The following sections explain the conceptual context and implications of these four extensions of Ashby's LoRV for the design of complex socio-technical systems focusing on the design of complex socio-technical systems in the built -environment. Airport infrastructure will be used as an example to demonstrate their practical application in design activity and the types of useful system design knowledge that emerge.

Ashby's Law of Requisite Variety

The cybernetic work of William Ross Ashby has widely influenced researchers involved in systemic analysis and system design to the present through his contributions to systems thinking, cybernetics, control theory and operations research, particularly through his law of requisite variety. Ashby's Law of Requisite Variety is perhaps the only 'Law' that is held true across the diverse disciplines of informatics, system design cybernetics, communications systems and information systems (Heylighen & Joslyn, 2001). This law is stated in short form in many different ways, e.g., 'only variety can destroy variety' (Ashby, 1956, p. 207) and 'every good regulator of a system must be a model of that system' (Conant & Ashby, 1970). More fully, Ashby's Law states that to control any system, the amount of variety (i.e., the number of possible states) of the controlling process has to be at least the amount of variety (number of states) that the system is capable of exhibiting.

Variety in a system comprises anything about that system that can be different or changed. Systems attributes that can have variety include: information; organisational structure; system processes; system activities; inputs; outputs; functions; participants; control mechanisms; ownership and control; opinions, judgments and emotions. In complex socio-technical systems, control and system variety elements are distributed across the system and across constituencies. Different elements of system and controlling variety are 'owned' or controlled by multiple different constituencies. The distribution of variety and the control of variety may change over time. The four extensions to Ashby's LoRV focus on the consequences, in terms of power and value distribution, of the effects of dynamic shifts in the different forms of variety and its ownership in ways that over time change the structure of a designed socio-technical system and its locus of control.

Ashby's LoRV provides a significant reference point for system designers to understand whether the design of a complex system is likely to be manageable, stable and viable. The origin of Ashby's LoRV is in communication theory and cybernetics. To date, Ashby's LoRV has been primarily applied to analysis of systems that can be represented in information terms. Where the LoRV has been applied to human systems, the focus in research to this point has remained on representing the human systems informatically.

The four extensions to Ashby's LoRV paper described above provide a significant change in the application of the LoRV in several dimensions of the design of complex socio-technical systems:

- Multiple constituencies
- Design of variety distribution over time to influence system evolution
- Hegemonic control changing outcomes and the distribution of system generated value
- Hegemonic shifts of control of systems structure
- Designed management of power shifts resulting from failures of system design
- Hegemonic basis for the dynamics of change between alternative stable states
- Potential for quantitative assessment of likely influence of change factors on system evolution via transaction cost

Digital eco-systems in the built environment

In this paper, the roles of these four extensions to Ashby's LoRV as design methods are described in terms of complex partly computerised systems in the built environment. These are increasingly, regarded as digital eco-systems. A typical definition of a digital ecosystem is that of Hussain, Chang, & Boley (Hussain, Chang, & Boley, 2007)

"An open, loosely coupled, domain clustered, demand-driven, self-organizing agent environment, where each agent of each species is proactive and responsive regarding its own benefit/profit but is also responsible to its system".

Some examples of types of digital eco-systems in the built environment are:

- 'Intelligent' buildings including automated security, energy management, environmental management, surveillance, advertising, entertainment, shopping etc.; smart homes.
- Automated access management systems that utilise personal identification and security access management through access to an individual's e-portfolio containing their work and travel histories, permissions, status and certifications. For example, a system to control access to dangerous areas involved in lift maintenance might check to see that the person wishing to have access had valid certification of qualification in lift repair.
- Intelligent systems used in the management of flow of pedestrians, vehicles and goods. These range from traffic control systems and turnstiles to automated road toll collection and logistic systems.
- Automated stored value management systems that charge depending on users' access, e.g., to roads, rooms and other resources.
- Automated management of dynamic building elements e.g., automated room-divider and lighting changes based on timetabled use of a room or building.
- The automated management of business inventory, storage and supply logistics including robotised selection, transport and replacement of inventory and its storage systems
- Automated management of ambient building conditions
- Automated surveillance systems to manage traffic or building use dynamics. Examples include the UK's integration of national public-space, road and petrol station surveillance cameras with a number plate recognition system to map individual driver behaviour and position for crime detection and traffic management purposes; the integration of mobile

phone location information with traffic management systems to intelligently predict traffic behaviour from identifying the behavioural characteristics of individual traffic 'agents'.

In design terms, digital eco-systems may be better regarded as 'digitally-integrated building and infrastructure eco-systems' and as a natural development in the trajectory of increased attention to integrating computer systems and real-world human systems and organisations. By echoing natural systems, these combined real-world and computer systems are intended to gain the benefits perceived to accrue to natural living eco-systems: system stability, system transformation over time, system evolution, improved systemic functioning, improved interaction between digital eco-system members and digital eco-system ecological environment etc. The main criteria of a digital ecosystem include (Love & Cooper, 2007):

- Its elements are networked
- Individual system elements consume resources and provide resources
- Participants vary in their scale, roles, purposes and expertise
- Participants have differences in needs and the resources they can supply
- There is autonomous activity in the system
- The system manages human and technical collaboration and competition in such a way as to preserve system integrity and to encourage growth in positive outcomes system wide.

Cybernetics, systems and design

The role of cybernetic and systems-based design methods is primarily in the pre-design realm; after problem setting and before conventional design processes are commenced. Pre-design methods identify which regions of a solution space of potential designs are likely to be more optimal and worthy of more design effort and why.

The design application of the four extensions to Ashby's LoRV described in this paper was identified as part of a larger research program reviewing the potential of systems and cybernetic approaches in design of complex socio-technical systems. The focus has been on Ashby's LoRV, System Dynamic (SD) modelling and Viable System Modelling (VSM). Each provides design insights in the difficult terrain of complex socio-technical systems (Hutchinson, 1997). SD modelling identifies multiple causal loops and counter intuitive relationships between design elements (see, e.g., Wolstenholme, 1990; Forrester, 1998; Ford, 1997). VSM identifies structural and informatic design characteristics necessary for system viability (see, e.g., Beer, 1972; Beer, 1988; Beer, 1972; Espejo, 1989). Both SD and VSM are based on Ashby's LoRV. Together, they provide the design basis for:

- Assessing whether potential designs for complex socio-technical systems are likely to be viable
- Understanding the design outcomes in terms of hegemonic power effects on systems design, development and evolution
- Optimising designs in terms of managing complexity and longer-term interoperability
- Design of key information pathways between complex socio-technical system elements and their environments
- Identifying factors and configurations that shape the balance and locus of power, control, complexity and standardisation in the design of complex socio-technical systems

- Predicting pathologies inherent in specific designs of complex socio-technical systems and designing changes necessary for restoring or creating viability
- Understanding the power, control, complexity and standardisation issues related to complex socio-technical systems in the built environments.

Five design guidelines

The above four extensions of Ashby's LoRV provide the basis of variety-focused design methods that help designers visualise potential outcomes resulting from the integration of social, environmental and ethical factors in socio-technical system design in the built environment.

The design method consists of five components:

- Identify relative distributions of variety generation and variety management across a design.
- Identify all constituencies and their ownership, power and influence over the design and management of the proposed system.
- Identify the levels and types of benefits that constituencies are likely gain from the system over time and because of different system configurations.
- Identify how system configuration and changes to it are influenced by constituencies, how constituencies can change the distributions of variety, the relative loci of control and the distribution of value to constituencies.
- Assess the relative 'transaction cost' for constituencies to design and change system and control variety. Design the system to take into account that constituencies' actions are likely to tend towards minimising transaction cost in a Coasian manner.

Taken together, these design guidelines offer the basis for designers' increased understanding of the ways that hidden structural factors shape the locus of control of complex socio-technical systems in the built environment. These hidden structural factors in turn change in response to changes in the balance of variety between constituencies such that they redirect benefits between constituencies as these systems evolve and change. The design guidelines, along with the four extensions to Ashby's Law described earlier, provide additional information for those designing complex socio-technical systems/digital eco-systems in the built environment to maximize the likelihood that designed systems will evolve to function as intended.

Airport: Example of Digital Ecosystem in Built Environment

Airports are a typical example of a complex socio-technical digital eco-system in the built environment. They are complex in that they have multiple subsystems, many of which overlap and are capable of fulfilling similar roles. For example, passengers and guests can be directed round the buildings and environs by ticket staff, security, signage, building structures etc. Airport systems have multiple constituencies with differing amounts of power distributed over a variety of subsystems. Distributions of power and constituencies change over time.

Airport systems involve a combination of intelligent, active and passive electronic, physical, human and animal (quarantine and security checking) systems with many processes crossing system and subsystem boundaries. Sub-systems can be outsourced so that control of some sub-systems (and intention to locally sub-optimise) potentially lies outside the system in focus. System characteristics, functions and loci of control are both changing and emergent. This latter can perhaps best be seen in times of civil unrest in which a range of external agencies (e.g., army, police, medical experts, engineering systems designers, information systems designers, security experts) that are relatively independent of each other and of the airport system can strongly shape internal system functioning and structures in ways that can shift the locus and balance of power and the ways benefits are distributed to constituencies.

When designing a new airport or new airport systems, design teams apply what they perceive to be the requisite variety to control the design and construction of an airport with its subsystems. The choices that result in requisite variety are based on design decisions intended to ensure the airport is commercially viable, safe, can be constructed as specified, and will function as intended. Typical variety-controlling activities used by design teams include using well-tested design processes, applying design checking and validation, utilising construction and engineering research and experience, market research, prototyping and user testing to ensure the intended design outcome.

Any outstanding variety, however, relating to the airport and its systems after these activities will be accommodated through alternative variety control mechanisms such as in-construction design modifications, post-completion rework, repairs, building and infrastructure design modifications (often incorporated into a later ‘refurbishment’ schedule), and litigation leading to compensation. These latter methods ‘mop up’ excess variety of possible system states uncontrolled by the requisite variety provided in the design stages in order to result in the intended output of an airport system that functions in the ways expected by all constituencies, particularly the stakeholders. Each time variety is ‘mopped up’ in an unplanned way through sub-systems outside the design process, the intended balance between constituencies in control of the system is changed. Power becomes transferred to other constituencies in different ways than those planned during the design process.

During the design process itself, unmanaged distribution of control of variety across the system can result in primary design decisions being taken outside the official design process and design outcomes being shaped primarily by factors other than those explicitly agreed between sponsors and designers. Changes to the distribution of system, environmental and controlling varieties in a built environment change the distribution of the strength and position of loci of control of among participating sub-systems, constituent individuals and organisations. These include changes involving those constituencies who provide services to manage internal information flows and internal services that directly support the system’s infrastructure.

Extension 1 to Ashby’s Law: *The distribution of variety and controlling variety across constituencies shapes power relationships and distribution of benefits.*

Airports are organisationally complex with a wide range of services being voluntarily and involuntarily available and used on the site. These are usually associated with specific constituencies each with their own internal management. These include: ticketing; passenger, luggage and freight logistics; general security; plane-related (anti-terrorism) security; quarantine services; retail and food services; parking services; customs services; immigration management; building services; engineering services relating to airport and environs; health and safety; medical services provision; religious services; engineering services relating to aircraft; engineering services relating to flying infrastructure; coordinating management groups and air traffic control. As the system evolves or is subject to internal or external changes, the amount and distribution of generated variety changes. Planned or unplanned, controlling variety dynamically changes to match the amount and distribution of generated variety. System regulation always occurs, regardless of the provision of explicit control variety and its locations. The system functions in whatever way it functions unless failure is catastrophic. The necessary implicit unintentional controlling variety results from a variety of sources including relative transaction costs, system constraints, timing and sequencing issues, unplanned aspects of system structure etc. Thus, the provision of control variety does not necessarily occur in a rational way in which there is a matching between new generated variety in an area for which a sub-system is responsible and the provision of new control variety in that subsystem. For example, if there is a security problem and internal security cannot respond sufficiently, then it becomes a matter for other security systems such as police or the military. Other changes in the distribution of variety may be more prosaic. For example, if retail processes began to dominate an airport's commercial activity, then the constituencies associated with retail activity would likely increase their controlling variety and in parallel, there would be a shift in the power balances. If, however, the additional controlling variety were to be supplied by another constituency or group of constituencies, e.g., those charged with expediting passenger movement to planes or those responsible for minimising carryon luggage (both of which impact on retail activity), the outcomes and balance of power relations are likely to be different. In both cases, the benefits to passengers and other constituencies are likely to change.

Extension 2 to Ashby's Law: *In a system that can have multiple stable configurations/structures, the relative location in the system of variety generators and suppliers of control variety will influence the choice of system structure.*

In airports, management of access is a key issue for many constituencies. Access control crucially depends on accurate identification and information. The physical control of access after identification and information gathering is most easily done with physical restrains such as walls and doors. The choice of information gathering technology dominates access design. For some constituencies involved in access management, their primary controlling variety is related to direct inspection of an individual for identification and for gathering information about them. For other constituencies, control variety can be exerted via surrogates such as identity cards, radio frequency identification devices, luggage smell (via dogs) and uniforms. Airports can manage access in several ways. The choice of configuration is dependent on the relational positioning and ability of constituencies controlling variety to use their control variety to influence overall system variety. An example of this is the way that airlines are now managing passenger variety associated with check in processes by moving them earlier in the system processes. In some cases, it is possible to 'check in' for the flight before leaving a hotel or 'check in' 'online' at home or at the airport. This is possible because the airlines' contact with the variety-generating passenger is closer to the start of processes. In turn, these control variety interventions shape overall system configuration in terms of managing luggage and security and the distribution of space and logistics round the site. Contrast, for example, some small European provincial airports in the 1980s with all luggage handling, customs, and security management happening on the tarmac next to the plane. Another contrasting example is the now defunct People's Express airline, which managed ticketing variety issues by selling tickets in flight and dealing with payment defaults using the police and conventional legal processes on landing, rather than controlling access to passengers before take-off.

Extension 3 to Ashby's Law: *Where shortfall in control variety by one constituency group or sub-system is accommodated by increase in controlling variety by another constituency/sub-system then power and control tends to be redistributed to the constituency(ies)/sub-systems(s) providing the necessary additional controlling variety.*

An example already mentioned is when one security constituency is limited in the control variety it can provide to respond to a security problem and the additional generated variety is 'mopped up' by increase in control variety of other security constituencies. Alternatively, the mopping up of excess variety can occur through actions of other constituencies, e.g., engineering services' increasing controlling variety through the design of secure cockpit doors. In these cases, there is an increased access to power and control of the distribution of benefits and to shaping the system structure by the constituencies providing the additional control variety. Another example is airport design processes. The more variety is controlled in the earlier stages of airport system design, the more the outcome is likely to be similar to what was conceived and intended. If the system variety exceeds the variety provided by the control sub-systems in the design processes, and if the outcome is to be controlled, it must be done so by the application of additional variety later. Experience from many large-scale infrastructure design contexts indicates later unplanned application of control of variety tends to be ad-hoc, inefficient, have knock-on adverse outcomes, and may offer unexpected opportunities for stakeholders and constituencies outside the system to take whole-of-system control.

Extension 4 to Ashby's Law: *Relative effects of elements of controlling variety are dependent in a Coasian sense on their relative transaction cost.*

Recently, it was proposed that security personnel who have national security clearances (e.g., FBI, CIA staff) should have expedited passage through airport security systems because their provenance has already been checked by a higher-level security agency (Schneier, 2006). In this case, the variety of individuals arriving and needing security clearance can be matched by several modes of controlling variety. There are several possibilities. For example, personnel with national security clearances could be security checked the same as anyone else. They could be given free passage. They could have a special process that took into account that their clearance must be especially well checked because it is of more value to falsify. Alternatively, they could be given additional privileges and authority over and above existing airport security staff in respect of their national security clearances. In terms of systems outcomes, all of these appear to make good sense. Viewing the choices in terms of 'transaction costs', however, factors in the 'costs' of establishing and running the alternative systems along with the potentially significant additional costs associated with failure of the security system (e.g., if a terrorist obtained airport security privileges by obtaining or falsifying national security identification). In real life, the outcome was that all personnel have to pass through the standard system of airport security and undertake normal passenger security assessment regardless of their other security clearances. The reason is the relative transaction costs: the current system minimises transaction costs overall. This situation contrasts with an alternative in which passengers can elect to be security checked by an approved external private security organisation and given an individual security threat assessment and a 'registered traveller' ID that enables them to bypass the initial airport security assessment processes (New York Times News Service, 2006). This reduces a passenger's time spent in security assessment processes at the airport by about 90%, with a cost to the traveller of around $80 per year. The alternative security assessment processes remote and within airports are expected to be undertaken by approved external organisations. In this case, the balance of transaction costs has shifted with the changes in the variety mix. Participating passenger's shoulder some of the costs. There is a redistribution of benefits in reduced costs for the existing security providers at the airport. 'Registered Travellers' benefit by jumping the security queue, there are slightly reduced queue lines for regular passengers; and there is a new revenue stream for the constituencies providing the new security services. There are also likely variety changes in relation to management of airport space and passenger logistics. Again, in terms of the variety underpinning system design, all of these changes are likely to affect the relative balances of power and control in an airport in ways described by the three earlier extensions to Ashby's Law.

Conclusions

This paper has reported the application of four extensions to Ashby's Law of Requisite Variety and five design guidelines to improve pre-design and design of complex socio-technical systems/digital eco-systems in the built environment. The paper demonstrated the use of the four extensions in exploring the shifts in the balance of power, control, use-value and benefits via an example: airport design.

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