Improving service quality and productivity: exploring the digital connections scaling model

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Abstract: The basic model argues that Digital Connections Scaling (DCS) of customers, providers and/or resources is a fundamental way to reduce service cycle time and transaction cost, and thereby to improve service quality and productivity. Digitisation makes entities connectable, and scaling decreases the marginal cost for the customer and the provider to cocreate new values. Three types of economies of DCS are postulated: the accumulation effect, the networking effect and the ecosystem effect on facilitating value propositions and cocreation. The paper also presents enterprise engineering principles, new micro-economic production functions, and an extended cyber-infrastructure model to substantriate DCS.

Keywords: service science; service quality and productivity; digital connections; enterprise engineering; cyber-infrastructure; production function for extended enterprises.

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1 The problem of scaling in service and service-led economy

Service is a well-defined concept in economics; however, service science is not. The paper is an attempt towards service science. Thus, to facilitate our discussion, we first delineate the title. Service is co-creation of value between the customer and the provider. Quality is a measure of value from a customer stakeholder perspective, and productivity is a measure of value from a provider stakeholder perspective. We define the problem of improving service quality and productivity, for the purpose of our analysis, as equivalent to the problem of increasing value co-creation outcomes over the complete life-cycle of populations of customer and provider interactions. Therefore, Digital Connections Scaling (DCS) studies how the connection of the stakeholder populations and resource populations by digital means may prove to be the new foundations of the increase in value outcomes. The basic proposition of the model is that digitisation reduces the cycle time and the transaction cost of connection for service systems and service co-creation, and scaling these connections decreases the marginal cost for new value propositions and new value co-creations, as well as the average cost for individual services. It follows that DCS increases value outcomes, improves service quality and productivity, and ultimately enhances the utility of service to the customer and the profit of service to the provider. On this basis, the scientific studies of DCS, such as the digitisation (for resources), the connection (for co-creation and systems), and the scaling (for value propositions and outcomes), provides a substantiation for a service science. In particular, *the understanding of digital connections makes service scaling a concrete subject of scientific study*.

At present, many practitioners are calling for a new science to guide their efforts to systematically innovate and improve service quality and productivity. These practitioners see existing academic disciplines as knowledge silos, each with something important to contribute, but nonetheless with only a piece of the puzzle. The most successful sciences (physics, chemistry, and biology) all provide models at the appropriate level of abstraction to deal with the phenomena (entities, interactions, and outcomes) relevant to their emergent layer of the complex systems that exist in the world. Economics and anthropology come closest. However, judgement of value from a customer perspective involves psychology and marketing. Measurement of value from a provider perspective involves computer science, management of information systems, industrial and systems engineering, operations disciplines, and more. The new service science is envisioned to integrate these knowledge silos and fill in gaps with new basic results. The DCS model sheds light on the nature of the service science, concerning especially scaling.

Scaling was first made a science by Industrial Revolution. The story of the Industrial Revolution is the story of establishing an investment roadmap for solving the scaling problem for manufactured products, factory supply, and wholesale and retail distribution. Improving quality and productivity through standardisation, specialisation, and scale economics has continued to this day, and resulted in increased material wealth in a growing number of regions of the world. This product-dominant mode of production continues to this date, and manifests in such modern manufacturing techniques as Computer-Aided Design, Computer-Aided Manufacturing, Computer-Aided Process Planning, Computer-Integrated Manufacturing, Concurrent Engineering, Product Data Management, and Product Life Cycle Management. While craft production still continues, there is little doubt that scaling the production of any physical product is largely a solved problem.

Service, on the other hand, presents some more fundamental challenges when it comes to scaling. On the customer side, each customer is complex and unique, and service activities that aim to transform the customer (education, healthcare, business outsourcing) each start with a unique 'as is' state of the world. On the provider side, each employee is complex and unique, and service activities that require an on-going transformation of the knowledge and expertise state of an employee (professor keeping up with advances in the field, doctors keeping up with latest techniques, business consultants keeping up with the latest technology advances) each start with a unique 'as is' state of the world. In spite of the complexity and uniqueness challenge, many service operations (geographically distributed franchises in retail, banking, travel, entertainment, etc.; online services, etc.) have used standardisation, specialisation, and scale economies to their advantage. Nevertheless, the more complex and the more innovative the service offering, the more challenging co-creation of value becomes between the provider and customer, and for providers the challenge of scaling profits along with revenues is largely an unsolved problem when compared to manufacturing.

An illustration of the above observation is the company IBM, which is converting from primarily a manufacturer of computers and Information Technology (IT) to a provider of IT and business service offerings, in the context of becoming a model Globally Integrated Enterprise (Palmisano, 2006). One could ask that what advantages a company of 100,000 knowledge workers has over a collection of 10,000 companies having ten knowledge workers each? In fact, service industry for IT and business consulting is highly fragmented with a large number of small players. However, this situation could rapidly change as deeper understanding of the advantages of scale in service is achieved. We first analyse the general situation below and then focus on the problem of improving service quality and productivity.

The industry, led by IBM, is calling for a new service science (e.g., the IBM Conference on Service Science, Management, and Engineering, 2006 – see Murphy et al., 2006), and a number of scholarly conferences have responded (e.g., the Cambridge SSME Symposium, 2007) to address the gaps in scientific knowledge about service research and innovation (Anderson et al., 2006; Bitner and Brown, 2006; Cherbakov et al., 2005; Davenport, 2005; Dietrich and Harrison, 2006; Gautschi and Ravichandran, 2006; Hsu, 2007a; Lovelock and WIRTZ, 2007; Lusch and Vargo, 2006; Maglio et al., 2006; Tien and Berg, 2006). The works by the second author and others (Spohrer and Riecken, 2006; Chesbrough and Spohrer, 2006; Spohrer and Maglio, 2007, 2008) seek to provide a common reference point for the emerging field, which defines service to be the co-creation of value between service systems (customers, providers, etc.), and service systems as dynamic configurations of resources (people, technology, organisations, and shared information) connected internally and externally by value propositions. As such, service innovation is realised in the design of service systems to implement new value propositions. A fundamental question remains: What is the intellectual nature of service science? Has our society already entered a new era which can no longer be explained sufficiently by the results obtained since the Industrial Revolution? It may be that a service science is mainly an integration, synthesis, and formalisation of the accumulated results in the service-related fields to date. Or, it may also be that the new science is a distinct new discipline that requires a new fundamental scientific field characterised by new research and education programs to advance its knowledge.

To shed some light on these questions, we review the popular notion of New Economy (referring loosely to all new economical designs in our society due to the internet) using the general concept of connection (e.g., Kauffman, 1993; Carley, 1999; Blass, 2004) and value proposition (Normann, 2001): Perhaps the changes of New Economy are reflections of a constant expansion of personal reach to ever new contacts and sources of information, and the expansion of new genres of services and designs of business that utilise the reach? Also, perhaps the reach is a direct result of digitisation, which makes heterogeneous objects compatible and thereby opens up all the unprecedented, large scale connection of resources, organisations, and persons, both within and across them, at affordable cost and cycle time? Perhaps, finally, the digital connection of individual production factors, processes, organisations, and systems explain the density of value propositions in different industries and economical activities? Therefore, we recognise DCS *as the defining mode of the New Economy* and formulate a model using it to analyse improving service quality and productivity.

Compared to the general notion of IT being the enabler of the New Economy, DCS is a more precise and explanatory concept that leads to particular possibilities of investigation around value co-creation interactions. It's being the common denominator is not coincidental: *digitisation makes objects connectable and hence connections scalable* (Hsu, 2007b). A prime example is the integration of previously separated industries, such as computing and entertainment (e.g., iPod with iTune). One not only can expect the eventual convergence of network television, telecommunications, internet business, news media, and entertainment; but also can expect their alliance with utility and other industries, on the basis of DCS. In this vision, the household computer and TV are but two different devices connected to the same monitor-set-up-box system receiving contents from different providers on the common cyber-infrastructure such as the internet. Other devices and equipment, ranging from phone and camera to appliances and utility, could plug in, too. For example, with a digital electricity meter that can detect the use of particular light fixtures and appliances, and a digital system that controls house electricity usage, the house owner could remotely turn on and off these appliances and lighting via the internet. More immediately, when customers can see the current hourly electricity costs on their appliances, this may shape their behaviours to economise and do certain chores and activities in off peak demand periods. The concept of DCS makes this vision natural, and perhaps, inevitable.

The practice of DCS is tangible (e.g., interactions with devices), and hence provides a tangible focus for the new science of service, which is constrained only by the extent to which economical activities can employ it. The concept of DCS engages the philosophical studies of connection, and analyses the economies of scaling from this basis. However, it further reduces the philosophy to the physical disciplines that implement the connection, such as computer science, industrial and systems engineering, and management and micro-economics. This focus also provides a measure with which one could calibrate the New Economy and debate about a Service-Led Revolution, such as to what extent DCS has brought about new paradigms of economic taxonomy, transformation functions, and production functions to the economy.

In this context, the paper develops a model of using DCS to innovate certain types of service to improve quality and productivity. The scope of study is the types that use digital means to represent, store, and process micro-economic production factors (including the service system resources), and to configure and inter-operate them to achieve common value propositions for a service domain – i.e., the digitally connected services. The basic idea is to analyse service systems at the level of the physical elements of digital connections, since they yield quality and productivity scaling. As such, the challenge of improving quality and productivity is accordingly focused on the scaling of digital connections and the gaining of the economies of such scaling. This is the '*DCS*' approach. It is postulated to achieve three types of *economies of scale: accumulation effects* (the linear joining of customers, resources, and/or providers, that can be shared and re-used among service systems to reduce the cycle time and transaction cost for value propositions and co-creation), *networking effect* (the peer-to-peer expansion among stakeholders to grow the accumulation effect), and *ecosystem effect* (the total expansion of system-wide interactions to grow the accumulation effect) due to the DCS.

The service systems worldview has three important stakeholder perspectives: customer (creation of value for the customer), provider (improvement of productivity for the provider), and authority or societal (renovation of inter-personal interaction for the society, where the person is both the user and the provider and value is calculated as an aggregate for the whole population). The combined customer and provider side (industry models) has received a great deal of attention (such as the Component Business Modeling (CBM) and Key Performance Indicator (KPI) works due to IBM – see Nayak et al., 2007; Sanz et al., 2007), but it still shows gaps and does not provide detailed roadmaps for improving service quality and productivity. The scientific understanding of service systems that can guide detailed roadmap approaches to improving service quality and productivity remains complex and underdeveloped. This paper studies service quality and productivity at the level of micro-economical and managerial models and contributes the DCS concept. The new concept has synthesised certain previous results, as well as proposing new analyses and postulations. In addition to the works by the second author and others, as cited above, it has also employed the first author's work (e.g., Hsu and Pant, 2000; Levermore and Hsu, 2006; Hsu et al., 2006, 2007; Hsu and Wallace, 2007; Hsu, 2007b). A preliminary version was presented in a conference (Hsu, 2007c). The DCS model represents a new framework of understanding for service scaling and the new service science.

We complete the new DCS model in Section 2, including its scope and conceptual framework, the challenges and requirements of digital connections, and its propositions on the improvement of service quality and productivity. Some particular scaling design frameworks, foundations, and micro-economical principles are developed in Sections 3–5 to substantiate how the DCS model may be applied to reduce cycle time and transaction cost for service systems. Section 3 presents the enterprise engineering models for intra-enterprise scaling and inter-enterprise scaling, and Section 4 presents the model of extended cyber-infrastructure as a common foundation for scaling. In addition, in Section 5, we also present the basic production function of a new paradigm of micro-economics to define the intellectual nature of extended firms that the DCS model predicts. Section 6 concludes the paper with a remark on the research and education requirements of the new service science.

2 The digital connections scaling model

2.1 Scope: digitally connected services

The way the customer, provider and supplier resources become digitally connected to realise value co-creation can help classify and characterise the types of service systems that co-create and deliver the service. The customer of a service could be person or enterprise (service system), and different customers could join forces with each other on demand if the utility that they gain from the service allows this gain. The provider of a service could also be person or enterprise (service system), and different providers could collaborate on demand as well. Moreover, the service offerings of the providers could be inherently associated or even integrated with manufacturing goods at many levels (e.g., leasing a car, the operation/maintenance of a physical plant, and the provision of computing services on a platform). Examples of traditional service offerings include person-to-person, location-based service such as hair cut and gardening; warrantee and after sale service for automobiles and machinery; and service and operation contracts in heavy industry. More recent service industries include consulting, telecommunications, finance, transportation, etc.

In practice, DCS is transforming many of these services from relying exclusively on personal contact to also being performed remotely. Even personal contact based service systems such as health care and education are proven to be amenable to digital connection. The transformation has even made some service offerings difficult to distinguish from manufacturing; examples include designer medicine and IC design foundry which are catered to individual clients, as well as leasing and operation of generators, aircraft, and other major industrial equipment by the maker for the user (Dausch and Hsu, 2006). DCS has also created whole new genres of economical activities that characterised the New Economy, ranging from Industrial Exchange (e.g., Glushko et al., 1999) and Application Service Provider (ASP – see Tao, 2001) to business designs for globally integrated enterprises.

Clearly, the transformation has been giving rise to new types of (extended) firms, production functions, and mode of production for our economy. The connection of customers (and users) has resulted in peer-to-peer social networking and information portals; that of providers led to B2B (procurement), consortia, private exchanges, ASP, and supply chain integration; and that of users and providers opened up B2C (retailing), transaction portals, on-demand business (demand chain integration), public exchanges, and digital government. These are just some well known cases.

To bring our focus into light, we refer to the service offerings that use DCS as the *Digitally Connected Service*. Digitally Connected Service can scale more cost effectively, while traditional services can not. For example, a physical therapist performs exercise service in isolation and a fixed grain-size of interaction, but connected knowledge workers could draw information resources of multiple grain-sizes from all over the world to assist the jobs on hand. In a similar way, hair stylising is not yet scalable, but distance learning is; personal one-to-one counseling most often has to be synchronous, but an ASP of enterprise processes can perform asynchronous processing; and newspapers are not personalised, but in car information services such as On-Star provide person-centred assistance. Therefore, Digitally Connected Services are further characterised with digital sharing of resources, service scalability, asynchronous co-production, and personalised assistance. The basic platform on which the scaling of digital connection is enabled is societal cyber-infrastructure.

Digitally Connected Service continues to describe many new business designs in the New Economy, as well as many service innovation models that seek to create new value propositions and transform previous service systems. Consequently, a design science for Digitally Connected Service promises to play a central role for the new Service Science that the field needs. As stated above, Digitally Connected Service possesses a significant promise on its scientific design; viz., it is integrated with physical systems which implement the digital connection. Therefore, its productivity is based on the efficiency and effectiveness of the digital connection systems; which in turn are amenable to the mature science of scaling proven in manufacturing.

Nonetheless, scaling service systems with digital connections poses significant challenges. The basic problem is a combination of the lack of understanding of the characteristics of Digitally Connected Service as it is still evolving, and the large-scale nature of digital connections, which has scale emergent properties that are difficult to predict.

2.2 Requirements: the large-scale challenge

The internet, in particular, challenged Computer Science since its start, and represents a core set of computing requirements of Digitally Connected Service. The traditional scientific foundations of computer science are based on models of single machines, especially the von Neuman machine and Turing machine. They now need to scale for massively multiplex environments required by Internet enterprises (Hsu and Pant, 2000; Dhar and Dundararajan, 2007). Emerging results such as collaborative computing, web services, and data and application ontology represent attempts to respond to these large-scale challenges, but their scientific proofs remain scarce (Erl, 2005; Kalfoglou and Schorlemmer, 2003; Stonebraker et al., 1996; UN/CEFACT, 2003). Similar observations also arose from other disciplines that enable digital connections, ranging from Industrial and Systems Engineering to Management and Economics.

Industrial and System Engineering are disciplines that standardise, rationalise and optimise the design and operation of products, processes, and facilities. Previous studies tend to focus on the off-line analysis and modeling that feature steady state solutions and derive inference based on small samples (Krishnamurthy, 2007). Digitally connected service systems, in contrast, require real-time regimes that perpetuate transient state and population-based planning and control (Tien, 2007). Their complexity, uncertainty and dynamic nature defy many classical results. Examples include global network flows (of data streams as well as physical goods) in supply chain integration and co-production of e-business services (Swaminathan et al., 1998). The knowledge worker riddle mentioned above well illustrates the challenges facing the field.

Management and Micro-Economics also have their traditional premises challenged by digital connection. As discussed above, many emerging economic activities feature collaboration due to digital connection. These new business designs have made extended enterprise collaboration a significant if not primary mode of production.

However, raditional micro-economics uses the concept of 'firm', single firms and not extended firms, as its theoretical corner stone; and the field of management always observed (or even promoted) the boundaries of a firm (Bradley et al., 1993; Williamson, 1985). The situation has already caused issues in collaborative manufacturing (Agile Manufacturing, Virtual Engineering, e-engineering, etc.) and service (e.g., e-commerce/business), and even clashed with many P2P social networking enterprises.

These large-scale challenges will become even more pronounced as the explosion of digital connections reaches the level of individual production factors, beyond the traditional reliance on firms to control them as their intermediaries. We do not address any particular large-scale challenges in the paper, but we submit that a design science can be developed by using available results in the field for service systems in the domain of Digitally Connected Service.

2.3 Postulations: economies of scaling

We propose to focus a design science on the development of value propositions and service systems. To guide the development, we need an understanding of the basic 'gravitational pull' of scaling using digital connections. That is, we need to understand the economies of scaling. A few basic postulations describing the economies of DCS are proposed here. On this basis, the design can focus on methods that develop either or both of intra-enterprise scaling and inter-enterprise scaling; and methods that prescribe common, extended cyber-infrastructure for scaling.

The Digital Connections Scaling (DCS) model: Employ digital connections to build a networked population of customers (users) and providers (resources and suppliers), and thereby transform service enterprises to scale up value propositions, service co-creation, and service systems to gain service quality and productivity.

Service: The co-creation of value by the customer and the provider.

Service system: The dynamic configuration of resources (people, technology, organisations, and shared information) for the co-creation of value as required by internal and external value propositions (relationships).

Digital connections: The use of digital computing, information, and communication technologies to represent and inter-operate customers, providers, and resources/production factors, within or across types (customer-customer (user-user), provider-provider, resource-resource, and/or customer-provider-resources).

Digitally connected service: The service that uses digital connection.

Extended cyber-infrastructure: The extended capabilities to the common public and privately developed cyber-infrastructure for digital connection, including the open technology; embedded knowledge/analytics; and cyber-infrastructure administration that facilitate the connection and on-demand disconnection of resources, sharing, and security control of the cyber-infrastructure, at the levels of person, process, database, computer, and networking infrastructure.

Digital connections scaling: The pooling of digitally connected services, including the expansion of digital connections; the joining of customers in a demand chain and/or for a common purpose; the collaboration of providers in a supply chain and/or for a common purpose; and the sharing of resources across sources, using extended cyber-infrastructure.

Service quality: A measure of value to customer, related to the utility function of the customer and the customer's life cycle requirements.

Service productivity: A measure of value to the provider, related to the profit (the gap between the price function and the cost function) and the life cycle requirements of the provider.

Economies of scale of digital connection: The increase of service quality and/or service productivity, in a way that the marginal cost of such increase decreases, due to DCS.

Proposition: Improving service quality and productivity

Improving service quality and productivity is equivalent to increasing value co-creation outcomes over the complete life-cycle of populations of customer and provider interactions. Digitisation reduces the cycle time and the transaction cost of connection for service systems and service co-creation, and scaling these connections decreases the marginal cost for developing new value propositions and new value co-creations, as well as the average cost for individual services. The DCS model increases value outcomes, hence improves service quality and productivity, and ultimately enhances the utility of service to the customer and the profit of service to the provider. Both quality and productivity are improved when the cycle time and/or the transaction cost of the co-creation of value are reduced, since the reduction increases both the utility of service for the customer and the profit of service for the provider.

Postulate 1: The accumulation effect of DCS (maximum growth: linear, O(n))

The basic economies of scaling for service are found in the accumulation of knowledge and other resources, the accumulation of providers, and the accumulation of customers, that the stakeholders can share and/or re-use for the co-creation of value and/or the development of new value propositions. For example, from the provider perspective, the accumulation of customers using the same or similar resources base decreases marginal cost and builds marketing advantages. In a similar way, the accumulation of knowledge and other resources decreases the marginal cost of co-creation for new but similar value propositions. The accumulation of providers decreases the marginal cost for collaboration, as well as for dissimilating knowledge and joint marketing for customers (i.e., the accumulation of customers and resources). From the customer perspective, however, the accumulation of providers reduces the cycle time and the transaction cost for the customer to locate the right provider, conduct co-creation, and develop new value proposition. The accumulation of knowledge (customer's experience and sophistication) and customers (peer support and collaboration) have the same reduction effect on cycle time and transaction cost for co-creation and value proposition. Many digitally connected services such as e-commerce have proven this type of economies, and their practices include incorporating social networking into their business design. The strategic service contracts sector of heavy equipment industry, such as GE's operating and/or maintaining generators for their clients, also compete on the basis of fleet information, which is a combination of knowledge and customer. The resulting customer base and knowledge base from the accumulation often become a barrier to entry as well as competitive advantages for the businesses.

Postulate 2: The networking effect of DCS (maximum growth: polynomial, $O(n(n-1)/2)$)

Peer-to-peer interactions are beyond linear accumulation and promise to scale with an order of magnitude more possibilities. For example, social networking often results in massive parallel circles formed by massively fluid value propositions. The joining of two customers for a provider means not only the possibility of accumulating these two individual value propositions, but also the possibility of developing a value proposition for both customers. The same argument applies to everything covered in the accumulation effect and promises to expand the effect by an order of magnitude. We can also consider this effect a bi-dimensional accumulation.

Postulate 3: The ecosystem effect of DCS (maximum growth: factorial, $O(n!)$)

A service system is actually an ecosystem where all stakeholders co-exist, interact, and collaborate in many different roles. In the two customer example mentioned above, these two customers could generate many value-proposition-based pairs in the ecosystem, where the sequence of pairing matters (e.g., prime and contractor), too. Therefore, the possibilities of accumulation for increasing value propositions and decreasing marginal cost are much more than networking. The lessons of massive online games, such as the Second Life, provide ample evidence for this observation. We consider the ecosystem effect an exponential accumulation.

Theorem: Economies on knowledge, resources, and values and value propositions

The above effects of DCS apply to the knowledge and resources of the co-creation of service, as well as to the values and value propositions that drive the co-creation. The knowledge of co-creation comes from both the customer and the provider (e.g., the knowledge workers); and hence the scaling will take the form of accumulating, integrating, and cross-referencing the pertinent experiences, skills, and other classes of knowledge to satisfy and facilitate the co-creation. An example of the economies on knowledge is the understanding of the entire space of particular business applications (i.e., a domain of service), or the population model. With the understanding, the co-creation (e.g., the design and development of the service systems required) can re-use some of the past results and thereby reduce the learning curve and minimise the marginal cost. Resources are concerned mainly with the provider, but their particular nature may extend to including the customer as well, such as a virtual organisation for an extended enterprise between the customer and the provider. Examples of the economies on resources include the ASP model of e-business and the 'lease' model of heavy industrial equipment. In these cases, the providers (e.g., Symantec for internet security and GE for utility power stations) operate and maintain the applications and/or the products for the whole population of customers. They therefore can leverage the fleet resources – and knowledge – to optimise the operation and maintenance of individual applications/products for customers. This is another class of population model. The economies on values and value propositions build directly on the DCS effects as discussed above. However, an important form of the scaling is the integration of different, previously separate industries such as the case of digitally connected household (the integration of entertainment, network TV, computing, utilities, appliances, etc.).

Finally, we wish to stress that the DCS model intersects Engineering (for digitisation), Science (for connection), and Management (for scaling), with an integrated purpose. As such, it represents a cohesive perspective for the research responding to the large-scale challenges and the development of a new service science. The notion of population modeling provides a particular objective for collaboration among, especially, service providers, since no one company can be large enough to own the whole space and every space. It also shows a need for collaborative research between industry and academia as well as among researchers.

3 Enterprise engineering models of scaling: the DCS guideline for systems

We now analyse some design principles to achieve DCS for service systems from the perspective of enterprise engineering. A set of models is proposed to build digital connection for enterprises in the road of innovation, to pool users and share resources on demand.

3.1 The model of digitisation: building digital connections

Digital connection starts with digitisation of resources, including both the representation of resources (persons and physical production factors) and the resources themselves (e.g., shared information, knowledge assets, and institutions), and extends to the digital requirements of service systems in their configuration of user, provider, and resources in accordance with particular value propositions. From the perspective of system development, we define five basic types of elements of digital connection as categorised below.

The digital connection elements

Person: User and provider, including knowledge workers of organisations at either end of service, completed with security, interface, and embedded tools for interaction.

Process: Software resources for the digital representation, storage, and processing of production factors, production processes, and their interaction with the user; with security control.

Data/knowledge: Digital representation of persons and production factors, including the ontology and embedded intelligence that define them, and business component models.

Computing: Computer, collaborating computation platforms, and shared facilities that constitute the computational capacity of the space of digital connection (i.e., the cyberspace).

Infrastructure: Networks, telecommunications, protocols, and the management systems that connect computing elements and administer the infrastructure.

The roadmap of enterprise engineering for service innovation

Basic value proposition/objective: Create value propositions of Digitally Connected Service for users, and pool their service systems to gain economies of scale by digitally connecting users, providers, and resources, both within each type (i.e., user-user, provider-provider, resource-resource) and across types (user-provider-resource), and sharing them for the co-creation of value required.

Digitisation: Build/expand digital connection elements – i.e., convert paper-based data resources and manual processes into (stand-alone) digital enterprise systems, using application-level (dedicated and proprietary) models, designs, and technology.

Intra-enterprise scaling (Transformation): Integrate digital connection elements – i.e., connect and configure enterprise digital resources into performance-enhancing systems for the whole enterprise, using (proprietary) models, designs, and technology of enterprise informatics.

Inter-enterprise scaling (Collaboration): Configure digital connection elements across enterprises – i.e., inter-operate the corresponding digital resources throughout the extended enterprise value chains (e.g., supply chain and demand chain), using open and scalable models, designs, and technology.

We present two models below from the provider perspective. Since they are based on our previous work, we refer in particular to Hsu (2007b) for more discussion on them.

3.2 The model of intra-enterprise scaling (Enterprise transformation)

Objective: Reduce intra-enterprise transaction cost and cycle time; pooling resources for shared use; align business processes/resources with value propositions.

Means: Use (open and scalable) enterprise cyber-infrastructure to integrate (on-demand) digital connection elements; i.e.,

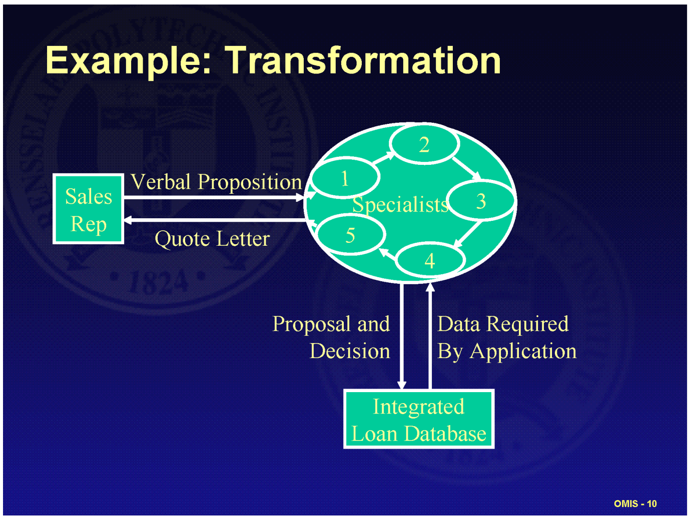
- connect (on demand) users and tasks with data and knowledge, and process resources (‘Subject’ orientation)
- provide (on demand) enterprise informatics to users and enable sharing of resources across tasks (‘Subject’ model)
- simplify business processes toward a user- and task-centred (on-demand) architecture (‘Subject’ paradigm)
- convert sequential processes into concurrent (teams).

Scope: The enterprise and the clients (on demand); i.e., pursue the opportunities of (on-demand) co-production.

The concept of ‘subject’ in the model is a capsulation of business components and the resources that they require. It represents some basic, common, and presumably reusable building blocks for service systems. Therefore, subject is a neutral conceptual reference to service orientation and such representative practices in the field as the Business Component Modeling due to IBM (Nayak et al., 2007; Sanz et al., 2007). An example of intra-enterprise scaling is shown in a commercial loan approval process in Figure 1.

The original workflow was sequential (processes 1–5 in the figure), but an integrated database that supports all five processes converts them to concurrent. The key concept here is to integrate system resources into enterprise resources, and connect them to the enterprise users on demand in the users’ own management regimes (i.e., the subject orientation).

Figure 1 Intra-enterprise scaling: enterprise transformation (see online version for colours)



3.3 *The model of inter-enterprise scaling (Enterprise collaboration)*

Objective: Reduce inter-enterprise/societal transaction cost and cycle time along the demand and supply chains; join resources from enterprises; and align processes with value propositions.

Means: Use societal cyber-infrastructure to globally configure the related digital connection elements across collaborating enterprises to facilitate each partner's respective life cycle tasks and requirements (extended co-production); i.e.,

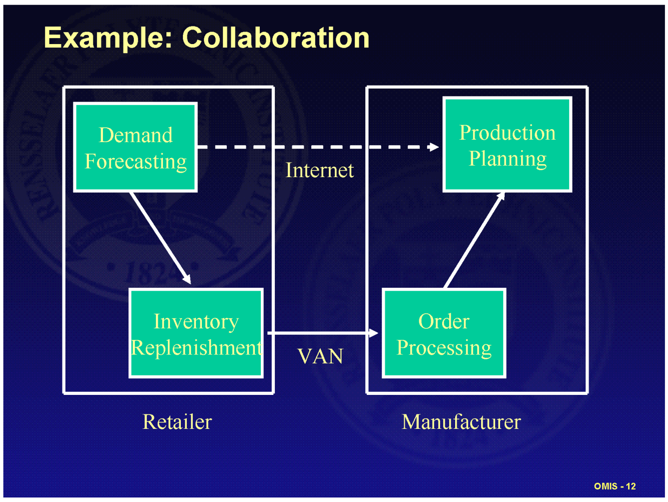
- follow the value chain to form (on-demand) extended enterprises and pursue opportunities of co-production
- apply the enterprise transformation model to extended enterprises, recursively if possible. ('Subject' paradigm)
- put the 'Person/Client' at the centre; i.e., renovate the industrial value chain to connect (on-demand) enterprises along the life cycle requirements of a person/client
- employ innovative virtual organisations (e-business).

Scope: Drill through the demand chain and/or supply chain.

Figure 2 shows an example of enterprise collaboration, where a retailer and a supplier join their enterprise processes to reduce the cycle time and transaction cost of their procurement process.

The collaboration connects directly the retailer's demand to the supplier's production, as depicted in the dashed line, rather than the previous sequential processing (the solid lines in the figure). The key concept illustrated is considering the extended enterprise as a whole and apply the enterprise transformation model to the virtual whole.

Figure 2 Inter-enterprise scaling: enterprise collaboration (see online version for colours)



4 The DCS foundations: scaling by sharing extended cyber-infrastructure

The DCS model calls for implementing concurrent service systems on a common extended cyber-infrastructure, so as to damp the resources required as the number of concurrent co-creations of value increases. The basic idea is to make service systems the concurrent users of some common digital connection resources – i.e., the enterprise and societal cyber-infrastructure extended with core elements that support inter-operation of resources. The premise here is that such common basis is emerging, beyond the current internet. For this purpose, we define the extended cyber-infrastructure elements below, which integrate embedded data and metadata, knowledge, and analytics with the usual computing and communications infrastructure. This extended cyber-infrastructure is envisioned to possess a signature property in its ability to allow for massive concurrent virtual configurations of its elements, and thereby support massive concurrent implementation of digital connection on it. In this sense, the problem of how to engineer and manage DCS is reduced to that of the extended cyber-infrastructure.

The extension is focused on the common resources that user service systems can employ and deploy to share embedded knowledge accumulated in the cyberspace, virtually administer the cyber-infrastructure, and regulate the secure use of the connection. Unlike the above section, the technology required of the extended cyber-infrastructure is not entirely available at present. However, the gaps tend to be areas of active research, except perhaps the administration system.

The extended cyber-infrastructure elements

User: Personal, system, and organisational information, access security, user interface, and embedded tools for interaction.

Process: Public business process libraries, open standards and open technology, and embedded analytics for connection, on-demand disconnection, and security control.

Data/Knowledge: Meta-models to inter-operate business components, ontology and embedded intelligence to inter-operate service resources, protocols for pooling of digital connection, and population models to regulate the operation of the cyberspace.

Computing: Public common platforms, shared facilities, and other open source technology required to join the computational systems for the cyberspace.

Infrastructure: Common networks, telecommunications, protocols, and cyber-infrastructure application generators required for shared use and administration of the cyber-infrastructure.

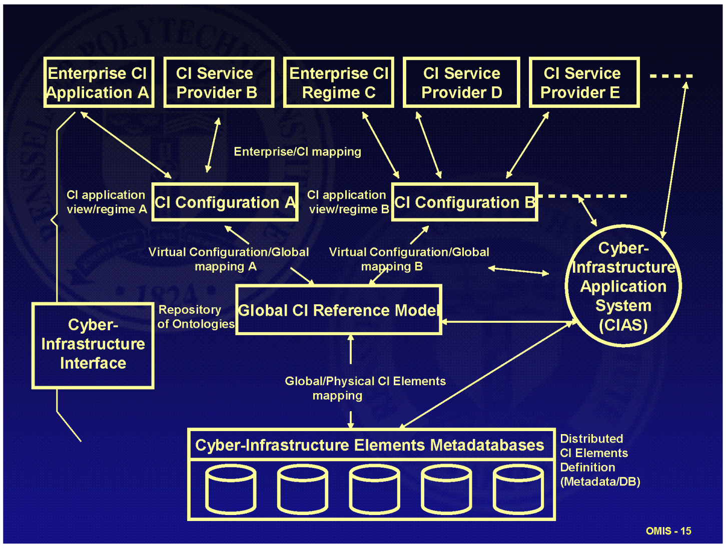
The sharing of extended cyber-infrastructure for Digitally Connected Service requires additional basic results (Hsu, 2007b). We proposed below a three-schema conceptual model, or a thought model, to technically define the requirements of a management system for the extended cyber-infrastructure in the spirit of a database management system. A key concept here is the formulation of a service systems – be it a consulting, a process, or an enterprising – as a concurrent user of the cyber-infrastructure (e.g., running a client company's payroll processes). Therefore, the service system (or, the digital connection involved) is a session (e.g., payrolls) of the running of the cyber-infrastructure, rather than being a structure of it (e.g., a dedicated payroll EDI/network). Each service system can be unique, in terms of the processes involved and the (virtual) configuration of resources required; but they will be supported by the cyber-infrastructure as sessions. The processes involved and production factors used in the service system do not have to be repetitive, nor standardised. The economy of scale comes from the concurrent service systems performed on the same cyber-infrastructure – or, simply, the sharing of digital resources. The economy will come primarily in the form of transaction cost and cycle time reduction to the entire scope of the Digitally Connected Service concerned.

The technology required will centre first on the acquisition of an open, scalable, and re-configurable cyber-infrastructure for the service enterprise. Next, person-centred 'control levers' must be afforded to the users, including both the user and the provider of the service system, to enable virtual configurations of the cyber-infrastructure for individual service system sessions, ideally with the assistance of the cyber-infrastructure itself. That is, the cyber-infrastructure should be able to customise its jobs (e.g., helpdesk processes, customer relations processes, and payrolls) for the particular sessions on the users' command, in a manner in which the cyber-infrastructure appears to be custom designed just for the particular co-production at hand. The processes can be one-of-a-kind since they are realised in the on-demand employment of the cyber-infrastructure, or, the virtual configurations commanded.

This thought model actually describes many e-commerce enterprises. A prime case is the Internet Service Provider (ISP) and Internet Content Provider (ICP) models. They, along with Portals and Search Engines, have thrived on sharing their digital resources among customised (virtual/non-consuming) uses – or, concurrent co-productions using the same cyber-infrastructure. Although their service products are not nearly as complicated as enterprise processes and professional consulting, they are still telling precedents.

The conceptual model is illustrated in Figure 3. As shown, the notion of a "cyber-infrastructure application system" envisions that the common resources of societal/enterprise cyber-infrastructure are manageable for creating virtual configurations and supporting application sessions. Common reference models, open standards, and embedded intelligence including ontology and analytics are incorporated.

Figure 3 Cyber-infrastructure application system (see online version for colours)



Again, the above concept helps to reduce the challenge of service productivity to that of cyber-infrastructure design, rather than to the standardisation of service systems (i.e., the service resources, especially the processes and the knowledge workers involved). The former can draw from the vast results in the fields of science, engineering, and management; while the latter may be both intractable and inappropriate.

5 A new mode of production using DCS: scaling by extended firms

The big picture of Digitally Connected Service is considered in this section from the perspective of economics (Becker, 1971; Friedman, 1976; Solow, 2000). Specifically, we take a review of the significance of DCS to the institutions of New/Knowledge Economy. The utility theory of economics provides a good starting point for a conceptual development. Before Industrial Revolution, utility (demand) was the driving force behind all economical activities that focused on persons, and service and product were not separated. That is, a product was custom made according to the utility that it was supposed to deliver to the customer; and hence production was but a genre of service that happened to involve the making of products. The craft production possessed many of the same characteristics that we now attribute to service, such as co-production and one-of-a-kind. We refer to this mode of production the *Output Pulling Paradigm (O)*. In this *O*-Paradigm, the economical connection was characterised by pair-wise relationships, or direct pairing between the service provider and the customer. Each pair is a system of co-creation of value. The science is the co-production and the performance is the utility. Each co-production has an individual *Ratio of Output to Input (O/I)*, and the performance of the economy under the *O*-Paradigm is basically the average of all such individual ratios. It was difficult to scale either input or output, separately, in a co-production, while the pooling of pairs did not change the performance – i.e., did not yield economies of scale.

Then, machinery made the pooling of the input possible and Industrial Revolution ensued. Both the product and the production became so significant that they dominated the customer-provider pairs. The domination rewarded pooling of resources and products on the supply side, and promoted the pooling of usage patterns – the standardisation of utility – on the demand side. What resulted was a new mode of production that focused on products, and thereby alienated utility (e.g., the 1/4–inch holes) from the means of providing utility (e.g., the 1/4–inch drills) – we refer to this mode the *Input Pushing Paradigm (I)*. Service was separated from product in this *I*-Paradigm since co-production was abandoned and product aggregated. Business designs and institutions followed. The provision of utility became a major genre of service, such as the economical activities that provide or support the utility of aircraft, vessel, and vehicle to travelers (e.g., transportation and routes), owners (e.g., financing and insurance), and operators (e.g., gasoline, and training and maintenance). This *I*-Paradigm features connection of production factors into a hierarchy of economical entities: such as workshop, factory, firm, industry, supply chain, demand and distribution chain, and national and international trade organisation. The institution Firm, which minimises transaction costs, has become a corner stone of the economy. In this paradigm, the science is the science of product and the performance is the scaling of production (from design to manufacturing to distribution). In the paradigm, the end users of products are connected neither with the production, nor with other users. The scaling is limited to the Input, or to product. Service continues to be dominated by the *O*-Paradigm even in the post Industrial Revolution economies.

Connections in these two previous paradigms were based on physical means, such as buildings, roads, and telecommunications. The advent of digital means opens a completely new world of connection, the cyberspace. In this connection, and through this connection, all production factors, including knowledge workers, are connected, all end users are connected, and the entirety of both sides are connected, too – or, at least, these connections *can* be made when so determined. The value co-creation pair can now be scaled up in any configuration of *O*, *I*, and *O-I* aggregation to change the O/I ratio favourably. Therefore, we are afforded a new mode of production which promises to fuse both the *O*-Paradigm and *I*-Paradigm and reap their benefits – the *Output-Input Fusion Paradigm (O-I)*. This *O-I* paradigm is characterised by digital connections and the science is digitally connected co-creation, with the economies stemming from the scaling of co-creation systems and values; and the performance measure is the utility, once again. Utility unifies quality and productivity to reflect value to both the customer and the provider. The *O-I* Paradigm connects individual customer-provider pairs of the *O*-Paradigm in dynamic service systems: connection of customers for the same input, connection of production factors and providers for the same customer, and connection of any input and output for any value propositions. The e-business/e-commerce models and the Globally Integrated Enterprise model all serve as examples of the connections. We consider the *O-I* Paradigm a signature property of the New Economy.

A mode of production can be defined by micro-economic production functions, transformation functions, and taxonomy of economic activities (Betancourt and Gautschi, 1998). The previous *O*-Paradigm and *I*-Paradigm can be substantiated with the numerous results in the field of economics (Solow, 2000). Similar results for the

New Economy are still emerging. We propose below a thought model for a new class of production functions that characterise the collaboration between demand chain (customer) and supply chain (provider) based on DCS.

The model of production by extended firms for demand chain and supply chain

Objective: Maximisation of utility and/or minimisation of cost (C) across the demand chain and/or supply chain.

Decision maker: Users and providers of the output – service or product (collaboration through digital connection).

$C = h\,(I, D, F, K, Z)$ where I: the institution; D: the digital connection/ cyber-infrastructure; F: the non-digital production factors; K: the digital, knowledge production factors; and

$Z = f\,(A, R, P)$ where A: the consumption activities or enterprise processes; R: the restrictions on the selection of A; and P: the market price for A. (The nature of constraints R defines goods vs. services)

$$C^n = h^n\,(I, D, F, K \mid Z) \text{ if } n = p \text{ (provider) or}$$

$$C^n = h^n\,(I, D, Z \mid F, K) \text{ if } n = u \text{ (customer)}$$

(C^n is recursively expandable along the demand chain and the supply chain.)

The above model serves as a starting point to the formulation of some formal analysis of the productivity of Digitally Connected Services. On this basis, the design of service systems and the improvement of service quality and productivity will also gain some formal grounding for their analysis and design. Therefore, these results promise to contribute to the new service science.

6 Remark: requirements for research and education

The paper provides a case for a new service science, in support of the on-going industrial calls for SSME. The DCS model is proposed as a mechanism to explain the evolution of populations of service systems, via digitisation, communication, and collaboration scaling phases. DCS can improve service quality and productivity via ongoing value proposition changes (standardisation and innovation). These changes result from more appropriate information about resources being put into a digital form, and more value co-creating connections between appropriate service systems.

The DCS model is a synthesis of previous results in the field and emerging industrial evidence. It contributes an analysis (Section 1) that leads to a theory of service scaling (Section 2) and a set of implementation methods at the level of enterprise engineering, cyber-infrastructure, and micro-economical principles (Sections 3–5). These results need further studies, both empirical and theoretical, to verify, modify, or expand its propositions, such as the accumulation effect, networking effect, and ecosystem effect of scaling. The model may open particular possibilities for the study of the new service science, since it recognises the pivotal roles of digital connections and their scaling for the improvement of service quality and productivity.

In this context, the large-scale challenges of Computer Science, Industrial and System Engineering, and Management and Economics constitute some core, disciplinary research requirements for the new science. The DCS model also creates a need for more research to specify the mechanism by which value propositions standardise and are innovated. We submit that the new service science is needed to study the New Economy characterised by a new mode of production using technology-based cyberspace, hence it is both synthetic across traditional disciplines and unique in its own right, with its own definitive characteristics. The large-scale nature and population orientation of service system design illustrate this point. Therefore, the emerging service science discipline should be considered an interdisciplinary field with its own identity. That is, it should embody a collection of core results from a number of disciplines, *plus* its own unique results, all unified under a cohesive framework, adherent to scientific principles that apply to new layers of emergent complexity as complex systems evolve.

Ultimately, new doctoral programs will be required to anchor the new field, as the sustaining force of research and education for the emerging science. The doctoral research will likely feature new requirements and new structure, such as a problem-centric, industry-pull approach that actively involves industry in the educational process. Therefore, new paradigms of academia – industry collaboration seem to be necessary, too. Exploratory and forward looking research problems resulted from the industry-academia collaboration will help define the new doctoral programs. The doctoral programs can then cascade into masters programs and undergraduate programs both in the new discipline and in traditional disciplines as required.

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