Chapter 8

MODELS OF CYBERINFRASTRUCTURE-BASED ENTERPRISES AND THEIR ENGINEERING

An Evolutionary Journey

Cheng Hsu

Rensselaer Polytechnic Institute, 110 8th Street, Troy, NY 121809-3590, USA

Abstract: The object of the analysis here is to understand how to simultaneously maximize the value to customer and the economy of scale, for enterprises that rely on knowledge workers and digital production factors. Cyber-infrastructure, in this study, is defined to be the fusion of information technology and information resources, including the elements that integrate persons and the environment with the enterprises. Computerized manufacturing, e-commerce/e-business, and on-demand business/services all represent the evolution of cyber-infrastructure-based/assisted enterprises. The evolution is analyzed to be driven by a new mode of micro-economical production function: the Output-Input Fusing paradigm. In this context, the value to client/customer is acquired with on-demand co-production, and the economy of scale is achieved through concurrent co-productions with the assistance of the cyber-infrastructure. Basic principles for planning such enterprises are derived from previous results. A "thought model" for the design, administration, and processing of the new cyber-infrastructure is presented. Particular new results, including a specific design for person-environment-enterprise interaction, are proposed.

Key words: Cyber-infrastructure, Enterprise Engineering, Service Productivity, On-Demand Business/Service, Person-Centered paradigm.

1. CO-PRODUCTION IS THE SOLUTION, NOT THE PROBLEM

- **The Micro-Economical Production Function.**

The journey of natural sciences is marked by discoveries of the basic laws, elements, and structures of our universe. In a similar albeit far less definitive way, the journey of economic sciences also manifests certain basic principles that have withstood the test of time. One such principle is the pursuit of economical efficiency embodied in this micro-economical model: efficiency (E) is achieved by the quotient of output (O) over input (I); or:

$$E = O/I$$

From a person-centered perspective, E is measured in utility, or the value to the person. For firms, however, E is ultimately evaluated in terms of profit. More telling is, perhaps, the principles revealed for I and O. They define the models of enterprises and their engineering at a macro (societal) level – i.e., their implementation determines the production function of an economy. Clearly, there can be three basic paradigms for improving the production function and creating better E: O-pulling (user/demand-dominate), I-pushing (provider/supply-dominate), and O-I fusing (user-provider co-production).

The O-pulling paradigm is the historical norm [8]. That is, human economical activities are always motivated by demand and delivered on demand. We do not have much reason to believe that the force of demand today is weaker or stronger than it was in the past, or it will be in the future. However, I-pushing has become a norm, too, especially for manufactured goods since the Industrial Revolution. This mode of production thrived on its promises of affordability and availability to the customers, achieved through the ever-lowering of production costs made possible by electricity and other technological breakthroughs at the time. The innovations opened up a historical possibility to alter the micro-economical production function and pursue the economy of scale on the provider side. The then new paradigm pursued and achieved standardization of parts (e.g., bills of materials) and rationalization of processes (e.g., flow shops and job shops), and resulted in attendant enterprise engineering models. They perfected mass production and the organizations that implemented this paradigm of production [4, 15].

I-pushing can reconcile with O-pulling as long as user demands are substitutable. That is, users could trade less preferable products for more affordable ones and still satisfy their basic needs. This premise fits well with most physical products, but it is dubious when the utility is concerned with services – be it personal services such as medical care or business consulting such as enterprise processes. Consequently, the I-pushing paradigm has never really succeeded on services, thus failed the need of service economy.

- **The O-I Fusing Paradigm**

The third paradigm, O-I fusing, stems from yet another wave of technological breakthroughs: the advent of digital chips, computers and telecommunications/networks. This mode of production places the user (persons and enterprises) alongside the provider throughout the product cycle as in a pre-Industrial Revolution O-pulling ideal, but this time with the affordability and availability of the I-pushing promises. If we employ the notion of co-production from services, then this mode is precisely co-production with economy of scale.

The paradigm first emerged in the form of computerization as a fix or extension to the I-pushing mode, i.e., a pursuit of automation with flexibility, so as to further lower the cost and better accommodate the demand [6]. The notions of agile manufacturing and mass-customization reflect this initial understanding of O-I fusing; both of which seek to make standardization flexible by using informatics. Then, the pursuit became a fundamental shifting of paradigms prompted by the New Economy of e-commerce/e-business [3, 5, 11] and on-demand business/services. The new vision, riding on the new waves of technological innovations, calls for bringing the illusive productivity gains into the service sector, or even reconcile the models of service enterprises with those of manufacturing.

To fully realize the vision, the field needs more specifics to substantiate the new paradigm. For instance, automation implies embedded intelligence, and flexibility the ability to reconfigure. When they are put together, the implication is automatic reconfiguration using the intelligence embedded in the "system", the "environment", or the "infrastructure" (in the sense of ubiquitous, pervasive, and mobile computing). These required results need to be developed using new technology. If electricity has enabled the I-pushing paradigm, do we have sufficient technological innovations to fully enable an O-I fusing paradigm? Many would agree that the answer is affirmative, and is found in the notion of Cyber-Infrastructure. Many would even assert that the O-I fusing paradigm is becoming a reality in certain segments of the economy since 1980's.

- **The Cyber-Infrastructure.**

Intuitively, for the purpose of this study, we consider cyber-infrastructure to be the fusion of information technology and information resources at a societal level. It connects enterprises with their external constituencies, along their respective demand chains and supply chains. The field does not offer a definitive, scientific model of cyber-infrastructure, but many would describe it as a digital nervous system of the society, consisting of wired and wireless networks, computing hardware and devices, digital data and knowledge resources, computing software, and digital user interface mechanism (the phrase “digital nervous system” was first coined by Mr. Bill Gates). The societal cyber-infrastructure connects all persons and all organizations, and adds a digital dimension to all traditional infrastructures (e.g., a layer of wireless sensor networks on highways and terrains as well as shop floors; a transponder-transceiver chip on every vehicle, cargo, and workstation; and a network of (wireless) chips carried by all persons to go about their daily lives). It may include embedded analytics and databases at all nodes, as well as afford two-way communication capabilities among all nodes and between physical elements and human users. A lot of this definition is still a vision, but a lot else have already been realized since the 1960’s when computers were first widely employed in industry and commerce.

The above description could be organized into a “totem pole” of cyber-infrastructure elements. At the bottom is the layer of networks and telecommunications elements. Above it is a layer of computers and other digital devices, including transponder-transceiver systems, person-carried chips, and environmental sensor networks. The third layer from below signifies digital information resources, ranging from data to knowledge and basic algorithms. The layer above the information resources is process resources made of application software programs and workflow controls. The fifth and highest layer is users and user interfaces. The totem pole describes a comprehensive environment of enterprising.

We also consider three classes of deployment of cyber-infrastructure: enterprise, environment, and person. Enterprise cyber-infrastructure refers primarily to the enterprise information technology and systems that have been widely employed by firms. This class continues to evolve, develop, and perfect. The notion of environmental cyber-infrastructure goes beyond the Internet and telecommunications satellites to include a possible digital dimension added to the physical environment. In a similar way, the personal cyber-infrastructure includes possible new technology that provides embedded or automated digital devices to persons and mobile objects.

- **Service Enterprises.**

Service products typically require co-production – i.e., on-the-spot participation of the user in the production of the service by the provider, such as consultation and the transactions of enterprise processes. By definition, the provision of this type of service must be individual, on-demand, and real-time; and hence the production processes involved must be personalized or customized. These characteristics, among other things, make standardization difficult – e.g., how to define the standard parts and the bills-of-materials for knowledge-based, perishable products? The only success of mass production in the realm of personal services is arguably the school model of education. Even here, the mode of production still differs fundamentally from that of manufacturing (e.g., the real-time, individual counseling to students). In general, the field needs to figure out what is, and how to achieve, the economy of scale of services to boost productivity.

The new technology, i.e., cyber-infrastructure, may have an answer to the problem. With the assistance of cyber-infrastructure, the user-provider co-production nature and the reliance on knowledge may become a solution for achieving the economy of scale, rather than a root cause of the failure of the I-pushing paradigm. When the products are characterized by digital production factors – which are re-usable (not consumed); and engineered by knowledge workers, who can collaborate with the users; the cyber-infrastructure that connects and organizes them all becomes the rendition of the enterprise's co-production function. The enterprise succeeds or fails on its ability to share these re-usable factors. Therefore, the cyber-infrastructure promises to be the object on which an enterprise achieves economy of scale. Cyber-infrastructure-based service enterprises in the O-I fusing paradigm could, and perhaps should, focus on pursuing co-production and achieving the economy of scale through sharing the cyber-infrastructure for all co-productions. This mode does not require standard bills-of-materials, but virtual configurations of the cyber-infrastructure on demand.

If co-production is not the problem, but the solution, then the question is how to enable it. Since large scale co-production is enabled by cyber-infrastructure, the proper way to achieve economy of scale has to be through large scale sharing of the cyber-infrastructure among co-productions, not through more I-pushing standardization. Recent results in the field, ranging from computerized manufacturing (e.g., flexible manufacturing systems) to e-commerce/e-business (e.g., the ISP and ASP models), have illustrated this point. We discuss these results in Sections 3 and 4, respectively.

We submit that co-production is the ideal of the O-I fusing paradigm. It could achieve economy of scale for enterprises using cyber-infrastructure (beyond computerization). Cyber-infrastructure-based/assisted enterprises implement the O-I fusing paradigm and, if e-commerce/e-business is any indication, up-lift the micro-economical production function for our society.

We discuss below how cyber-infrastructure-based/assisted enterprises can achieve economy of scale with co-production. Section 2 derives some principles of cyber-infrastructure-based/assisted enterprises from the lessons of computerized manufacturing and e-commerce/e-business. Section 3, then, summarizes how these principles are working for manufacturing, in a transition from I-pushing to O-I fusion. Section 4 discusses some new results required to consummate the transition for services. First, a "thought model" for achieving economy of scale using cyber-infrastructure is presented. The model features a "three-schema cyber-infrastructure" concept to support virtual configurations. Some of the best practices of e-commerce/e-business are summarized in this context, along with a suggested research agenda to develop the new model. Section 5 proposes a particular Subject-Environment Interaction Model to make the cyber-infrastructure itself an active partner of enterprise engineering, and thereby achieve automatic re-configuration of co-productions. A discussion, in Section 6, of possible future directions of the evolution concludes the chapter.

2. PRINCIPLES OF CYBER-INFRASTRUCTURE-BASED/ASSISTED ENTERPRISES

Concepts such as "computer-based", "IT-enabled", and "Internet-based" are harbingers of the notion of "cyber-infrastructure-based/assisted". As stated in Section 1, cyber-infrastructure is defined as the fusion of the common information technology and information resources for the society as well as for individual enterprises. Therefore, although the concept of cyber-infrastructure-based/assisted enterprises is newly formulated in this chapter, it is not a discrete change but rather represents an extension of the previous concepts, and embodies the lessons of their practices in the field.

2.1 The Principle of Transaction Cost and Cycle Time Reduction

The value of investment on Information Technology is not always clear. For example, the so-called "productivity paradox" of late 1990's and early 2000's shows the difficulty of properly accounting for the contributions of IT to firms – or, more broadly, the micro-economical production function for the society. Firms tend to rely on such measures as Return on Investment (ROI) to evaluate their IT projects, although it is well known that ROI does not account well for intangible benefits, which happen to be crucial contributions of IT and Information Systems.

A broader and more appropriate view is found in the concept of organizational transaction cost [27], which examines the whole enterprise and accounts for both tangible (e.g., savings on labor) and intangible (e.g., effectiveness) returns. This concept corroborates with the well-established premise that an organization is brought into being to process information (transactions) for making the right decisions and taking the right actions to accomplish the organization's goals [9]. The interesting point is, while the notion of organizational information processing could be abstract and measurable only in theoretical terms, it becomes concrete for cyber-infrastructure-based enterprises. That is, if the cyber-infrastructure is brought into being to implement the organization, its processing is the organizational information processing. Therefore, from the productivity perspective, the value of cyber-infrastructure is manifested in its contributions to the organizational transaction cost for the enterprise. Furthermore, we submit that the contributions are measurable in terms of the reduction to the individual process transaction costs and the reduction to the total cycle time.

Cycle time is evidently measurable, such as the time to market for new product development and the throughput (service or physical) of a process. It is related to transaction cost but is not necessarily reducible to it. In particular, if a cycle consists only of sequential processes, then the cycle time is determined by the sum of the process transaction costs. However, if it is not, then the total cycle time could be more a function of the sequences of processes, than the individual transaction costs. Naturally, engineering the arrangements of component processes determines the total cycle time in the general case. In addition, automation, simplification and consolidation of processes could also reduce total cycle time. They, especially automation, are commonly associated with cost reduction – the tangible benefits.

However, transaction cost appears to be intangible in the general case since organizational tasks and processes outside shop floors tend to be non-definitive. This non-definitiveness includes service co-production. Albeit not as concrete as time and money, transaction cost is still measurable in this case, at least in terms of utility functions and overall performance. Often, it may even be measured directly through the evaluation of workload and workflow involved in these tasks and processes.

For example, how much transaction cost has paper currency saved the society over bartering? One could answer this question by asking how much it costs one to return the bottles and collect the refund at a supermarket, or how much they would be discounted if one barters them for groceries at a corner store. The transaction cost of a particular job to the person performing it could be assessed by how much the person is willing to pay others to do it for her/him – such as hiring an agent or a broker. The value of the Internet can be substantiated case by case; for instance, how much time (effort) it takes us to collect information about colleges without using the Internet? In this case, the total sales of all college data books prior to the Internet indicates an upper bound of the fungible value of the Internet on the reduction of the transaction cost for doing the job. In general, the so-called "red tapes" are precisely transaction costs, which could be so high as to become an inhibitor for undertaking an enterprise. As an illustration, if certain tax breaks are required to attract a direct foreign investment, then the value of the breaks could reflect the cost of the red tapes perceived. Finally, to show one more example, an organization could quantify the minimum value of a global database query system by compiling the time its employees spend on the phone and meetings that could have been saved by the system. In one word, "convenience" succinctly describes the nature of transaction cost. Transaction cost and cycle time together spell productivity.

We submit that the value of cyber-infrastructure investment should be measured in terms of reduction of transaction cost and cycle time. The traditional ROI could be incorporated in this new, extended measure. More fundamentally, we submit that the economy of cyber-infrastructure-based enterprises on productivity is the reduction of transaction cost and cycle time. The challenge is, therefore, how to achieve the scale factor in a cyber-infrastructure-based enterprise. The following principles explore this question. In particular, the next two achieve the digital scale advantage.

2.2 The Principle of Digital Connection and Sharing

Digitization is a premise of cyber-infrastructure-based enterprises. That is, these enterprises turn their information resources into digital, their processing digital, and their communication channels digital. However, the unique power of digitization is not just tapping into the computing power of IT – i.e., digitization is not just computerization. The really unprecedented promise of digitization is the ability to connect and share: the potential that all digital elements in the world could be connected – fused, indeed – through cyber-infrastructure and be shared as a whole by any, with infinitely many possible ways of utilization. Adam Smith's "invisible hand" promises to be visible in the cyber-dimension of the economy.

Digital camera and e-mail provide two ready examples of the power of connection. Camera for camera, the traditional optical pictures still enjoy clear advantages over their digital competitors. However, digital cameras win over the market because their pictures are digital resources that can be connected with the users' other digital resources. Users can email, edit, and publish them as they do their ordinary files on the computer; and they can integrate them with these files, as well. The fax machines lost to email as a favored means of written communication for the same reason. They are an isolated tool that cannot fuse with others, while email is open and scalable in its connection and coupling with other digital resources. More broadly, the history of Information Systems is one of integration of digital resources for their users. Needless to say, the Internet offers the most conspicuous exhibit of the power of this principle.

One might mention informally the "small world phenomenon" (due to Stanley Milgram [2]). This interesting postulate suggests that two random persons in the society are connected with no more than six intermediary acquaintances (called six degrees of separation – which could be conversely called six degrees of connection). For example, if one knows someone who knows President Bill Clinton, then s/he has one-degree connection with Mr. Clinton; and anyone who knows her/him has two degree connection with the President. With the Internet, along with search engines and email, one could argue that the small world is crashing into one where everyone is poised to connect with everyone else in zero degree through the societal cyber-infrastructure. The saving of the intermediaries spells reduction in societal transaction cost. Therefore, connection represents reduction of transaction cost (vis-à-vis the costs of connection).

We submit that an enterprise should integrate itself through digital connection for all its internal and external constituencies. All enterprise resources, especially databases, should be connected and made sharable; and ultimately, all that the cyber-infrastructure can reach should connect, including the persons in the extended enterprise. This principle reduces transaction cost. It is especially important for co-production, where the users need to share the production resources and facility with the providers, in a manner of enterprise collaboration.

2.3 The Principle of Concurrent Processes and Co-Productions

If connection is reduction of transaction cost, then concurrent processes are reduction of cycle time. With the cyber-infrastructure connecting the whole (extended) enterprise, enterprise processes become the particular uses of the cyber-infrastructure to accomplish particular tasks. The use, and hence the process, manifests a particular virtual configuration (path of usage) of certain elements of the cyber-infrastructure. The economy of scale principle suggests that the cyber-infrastructure should be shared by as many users, processes, and products as possible. Therefore, the moral here is to make all processes from all products – be it on-demand, custom, or pro forma – concurrent users of the cyber-infrastructure, for as much as they can be conducted concurrently and as long as the cyber-infrastructure can support all the virtual configurations required. A reference point is the enterprise databases. The same database infrastructure drives all virtual configurations of the data resources (e.g., views) to allow all users running their processes (e.g., global queries and applications) against it, concurrently.

This principle has a humble but intuitive illustration of its cycle time reduction nature. If, for example, a job requires 1000 man-hours to complete, then it takes only one hour to finish if 1000 men work on it simultaneously. The sophistication comes when one considers the reality of how to make all 1000 men working at the same time on the same job. Resources availability could be a bottleneck and sequencing of work could be another. Also, there is the need for coordination and synchronization. Computer science offers some basic answer at the algorithmic level, and human ingenuity provides many intriguing ideas in various domains (such as the distributed data processing in the SETI project [21]). However, the most rigorous results at the enterprise engineering level come from manufacturing.

Since 1980's, the field has established substantive models, technology, and systems under such visions as Computer-Integrated Manufacturing, Concurrent Engineering, and Agile Manufacturing. They revealed particular ways to allow for parallel manufacturing control, distributed engineering design, and simultaneous execution of product life cycle tasks. Most of all, they developed a basic concept, that of virtual team, for concurrent undertaking of enterprise processes using cyber-infrastructure. For example, the simultaneous engineering models, referred to as Design-for-X, with X being anything ranging from manufacturability to serviceability, connect tasks and processes at the later stages of a product development life cycle with the earlier ones, and executes them through virtual teams. These teams configure persons and resources from different stages without having to physically co-locate them. The team method turns sequential processes into concurrent by interweaving the detailed steps and tasks of each process with those of others, with the support of a common cyber-infrastructure.

For enterprises that rely on knowledge workers and digital resources, cyber-infrastructure could generalize the concept of virtual teams into one that includes the users and other external constituencies, along the supply chain and the demand chain, with unlimited possibilities. Teams could readily implement co-production for any cyber-infrastructure-based enterprises without changing fundamentally their internal production systems every time this mode is attempted. Therefore, an application service provider or on-demand enterprising provider could run millions of co-productions against its cyber-infrastructure. All processes of the co-productions could use different, virtual configurations of the cyber-infrastructure. Therefore, the economy of scale is achieved in this mode.

We submit that concurrent processes achieve the scale advantage made possible by digital connection and sharing. They should be designed with the concept of virtual teams for, possibly, co-production; and be implemented with concurrent virtual configurations of the enterprise cyber-infrastructure.

2.4 The Principle of Openness, Scalability, and Re-Configurability

Cyber-infrastructure is societal in nature. An enterprise cannot confine itself to proprietary technologies when using cyber-infrastructure. Instead, it has to leverage what is available in the society in order to, at least, work with its external constituencies. Furthermore, one physical cyber-infrastructure can support many different uses and could appear differently to different users if necessary. The concept of virtual teams and virtual configurations describe this virtual nature of cyber-infrastructure. Therefore, an enterprise cyber-infrastructure is inherently dynamic in almost every aspect.

It follows that the enterprise cyber-infrastructure has to be open to different technologies and proprietary controls. This call leads to the open source ideal; but could also use common standards as an open connectivity solution for proprietary technologies. Next, the cyber-infrastructure has to be able to expand continuously, without requiring reconstruction or causing major disruption. Such a requirement could arise easily from innovations in a firm's business vision. Finally, the cyber-infrastructure has to support smooth re-configuration and restructuring of its physical elements, in order to adapt to their changing usage patterns by the virtual configurations. This adjustment optimizes the overall performance of the cyber-infrastructure.

We submit that cyber-infrastructure-based enterprises need to be prepared to connect with any part of the society and deal with perpetuating transient states of their business. The IT revolution since the 1990's shows that the ever-evolving societal cyber-infrastructure brings about ever-deepening changes to all corners of the economy.

2.5 The Principle of Cyber-Infrastructure Assistance

Cyber-infrastructure possesses information resources (see Section 1); thus it is capable of being intelligent to assist the user in a responsive or even proactive way. This capacity should be exploited. In a broader sense, the history of the man-machine system evolution is one of “downloading” the burden of mundane operations and analytics, along with their attendant data tasks (gathering, storage, and processing), from the man to the machine. Examples include CATSCAN, Computer-Aided Engineering, Computer-Aided Manufacturing, Computer-Based Information System, and other models of the application of computers to human jobs. This down-loading defines fundamentally the profitable relationship between the enterprise and the cyber-infrastructure, too. (Otherwise, why bother?)

However, as the notion of machine scales up from computer to cyber-infrastructure and the man to (extended) enterprise, the man seems to humble himself into being lost in his reliance on the cyber-infrastructure; and forget that the latter is meant to be an active servant to the users in cyber-infrastructure-based enterprises. For this purpose, we might stress that the definition of cyber-infrastructure allows it to work in the background to assist the users, either automatically by itself or on the users’ command. A successful cyber-infrastructure-based enterprise is poised to do better by exploiting these promises and developing embedded intelligence to support the users. For example, the cyber-infrastructure could provide automatic sensing, monitoring, and adaptive control to the enterprise processes, real-time and online. Therefore, this principle could also be called the proactive digital nervous system principle, in the spirit of self-organization [17].

We submit that a cyber-infrastructure-based enterprise should strive to become cyber-infrastructure-ASSISTED, with the ability of automatic re-configuration. That is, the cyber-infrastructure should be conceived and constructed in an end user-oriented manner. In a co-production context, the user (person or enterprise process) assumes the role of the man of the man-machine system, with the cyber-infrastructure the role of the machine. The assistance automates certain enterprise processes and virtual configurations.

2.6 The Principle of Person-Centered Service

The co-production concept is further extended into person-centered service. This notion is self-evident for personal service products. However, it is equally fundamental to all service enterprises, including the services provided to manufacturing and other physical product firms. That is, when the co-production is concerned about client enterprise processes, the users of the processes immediate fit the persons' position. Moreover, the consulting in this case will also consider the demand chain of the client when planning and designing the client processes. Therefore, ultimately, the entire chain of production is a service to the persons at the center. The distinct value of this principle is to place the client/customer of a co-production mode in a position of control: the user can pull some control levers and command the cyber-infrastructure to make the enterprise produce the product demanded. The principle further indicates that new societal value chains may emerge to provide services for effecting "enterprise of enterprises"; such as the case when cyber-infrastructure-assisted enterprises recursively expand up along the demand chain to service the ultimate users: the persons.

Conceptually, this principle leads to a man-meta-enterprise thought model where the societal cyber-infrastructure connects the economy into a virtual meta-enterprise (with many renditions) for the persons to command. The virtual meta-enterprise serves as the one-stop provider of a person-centered economy, providing everything that the person requires in going about his/her live. The service here will be the provision of the virtual meta-enterprise demanded and the (virtual) configuration of the societal cyber-infrastructure required. The notion of a person-commanded, cyber-infrastructure-assisted meta-enterprise could arguably describe an ultimate service of the O-I fusing paradigm.

In retrospect, e-commerce has revived the notion of person-centered services for the first time since Industrial Revolution. Personalization is now an iron rule for destination Web sites and personal communications – e.g., the practice of "My Yahoo!" and the like. The personalized services not only prove, once again, the power of O-pulling, they also show that cyber-infrastructure is indeed an ideal tool for personalization. One could expect that personalization of products on-demand is inevitable for cyber-infrastructure-based/assisted enterprises. This is true for any personal service, the service of physical products, the service of providing other enterprises' products to the persons, and the service of enterprising enterprises.

We submit that personalization of the product, on-demand, will become the norm for cyber-infrastructure-based (better yet, assisted) enterprises. The competition will be the continuing push of the envelope to bring about more and better cyber-infrastructures and more and better assistance through the cyber-infrastructure to enable on-demand enterprising. Clearly, protection of privacy and societal integrity and security must accompany personalization.

3. MODELS OF ENTERPRISE INTEGRATION AND COLLABORATION

The O-I fusing paradigm (see Section 1) is taking shape by virtue of the evolution of cyber-infrastructure and cyber-infrastructure-based enterprises (see Section 2). The evolution has thus far revealed some general approaches to implementing the paradigm for, especially, manufacturing. We summarize these general approaches into the conceptual models of enterprise integration and enterprise collaboration. These models are made possible by certain particular technologies for manufacturing; which we refer to as the manufacturing informatics. These results are briefly discussed below.

3.1 The Model of Enterprise Integration

This model develops an enterprise digital nervous system using cyber-infrastructure, and thereby transforms the enterprise from operating in an I-pushing paradigm towards one pursuing an O-I fusing model. Because the focus of many applications in the field is digital connection, we refer to this focus as enterprise integration (through cyber-infrastructure).

- **The Objective:** Reduce the Transaction Cost and the Cycle Time of the Enterprise (while satisfying the users' demands – the O-I fusing ideal).
- **The Means/Decision Variables:** The Design of the Cyber-Infrastructure, including its elements, configuration, and application.
- **Enterprise Engineering Principles:**

– Digitize information resources (data and knowledge), communication channels (persons and machines), and process resources (control and workflow).
– Connect digital resources to users and tasks, and thereby construct a digital nervous system.
– Develop embedded or automated capabilities in real-time analytics and data processing to enhance the performance of persons and machines in the enterprise, using cyber-infrastructure.
– Develop either global or peer-to-peer administration capability to enable the cyber-infrastructure to support sharing of digital resources among distributed persons and machines.
– Simplify enterprise processes by using the new cyber-infrastructure (through consolidating sub-tasks and/or sharing results).
– Convert sequential enterprise processes into concurrent by using the new cyber-infrastructure (through interweaving sub-tasks and/or sharing resources).

– Employ the concepts of teams and virtual organizations, the flexible machinery, and the automated control systems to make the enterprise and its facility agile.
- **Constraints:** The availability of the open, scalable, and re-configurable technologies; an industrial standard for inter-operation; and the costs.

The next model, collaboration, applies the above to extended enterprises along its supply/demand chain. These two models share common logic.

3.2 The Model of Enterprise Collaboration

For the purpose of enterprise engineering, one could argue that the fundamental difference between integration and collaboration is proprietary control. Collaboration, without the control, not only is always applied to extended enterprises, but it is especially applied to virtual organizations. Thus, for instance, if a prime manufacturer actually controls its suppliers, through stock-holding or some other long-term bonding arrangements, then the extended enterprise could actually integrate rather than just collaborate.

- **The Objective:** Reduce the Transaction Cost and the Cycle Time of the Community of the Collaborating Enterprises.
- **The Means/Decision Variables:** The Mechanism and Boundaries of Collaboration; Methods of the Connection of the Cyber-Infrastructures; and Design of the Connection, including the elements, configuration, and application, and the resultant federation of the cyber-infrastructures.
- **Enterprise Engineering Principles:**

– Make digitize information resources (data and knowledge), communication channels (persons and machines), and process resources (control and workflow) compatible, either directly or through some intermediary design (e.g., middle-ware).
– Create an inter-operable proxy for each enterprise cyber-infrastructure, for connection with other enterprise proxies, and thereby construct a community cyber-structure for the collaborating extended enterprise.
– Connect digital resources in the connection (of proxies) to users and tasks, and thereby construct a virtual digital nervous system for the community.
– Develop either global or peer-to-peer administration capability to enable the virtual cyber-infra-structure to support sharing of digital resources among distributed persons and machines of the community.
– Simplify extended enterprise processes by using the new extended cyber-infrastructure (through consolidating sub-tasks and/or sharing results, along, e.g., the supply chain).

- Convert sequential extended enterprise processes into concurrent by using the new extended cyber-infrastructure (through interweaving sub-tasks and/or sharing resources).
- Employ the concepts of teams and virtual organizations, the flexible machinery, and the automated control systems along demand chain and supply chain, to make the community and its facilities agile.

• **Constraints:** The availability of the open, scalable, and re-configurable technologies; an industrial standard for inter-operation; and the costs.

The enterprise value chain could serve as guidance for identifying the candidates for process-level collaboration for the extended enterprise. At the level of strategic vision, the Person-Centered Service Principle of Section 2 could promote identification of possible opportunities of collaboration.

3.3 Manufacturing Informatics

The above models describe some of the past and emerging practices in computerized manufacturing, including supply chain management. Much of the manufacturing cyber-infrastructure required has already been proven in the field. We summarize some of the representative results below.

• **Standardization**
- Computer-Aided Design/Engineering (parts)
- Bill-of-Materials (product)
- Product Data Management (parts database)
- Computer-Aided Process Planning (generic machining control process)
- Computer-Aided Manufacturing (workstation)

• **Rationalization -** Industrial Engineering
- Work and Workflow Design
- Facility and Factory Layout Design
- Scheduling and Production/Inventory Control
- Quality Control/Statistical Process Control
- MRP/MRP II/ERP: manufacturing enterprise resources planning

• **Flexibility**
- SCADA: automated factory data collection (monitoring)
- AGV-MHS: flexible material handling and layout (facility)
- Flexible Manufacturing Systems (cells)
- Manufacturing Execution Systems (shop floor control)
- Computer-Integrated Manufacturing (factory)

• **Extended Enterprise**
- Concurrent Engineering (distributed design)
- Simultaneous Engineering/Design for X (design-production collaboration)

– Agile Manufacturing (team)
– Product Lifecycle Management (design-production-service collaboration)
– Supply Chain Integration/Management (prime-supplier collaboration)
- **Standards**
– STEP (and PDES, etc.) (international/US, for CAD-CAM-CAPP)
– ESPRIT/CIMOSA (European, for CIM)
– Society of Manufacturing Engineers models (US, for flexibility)
– IEEE (international/US, for hardware and others)
– ISO/OSI (international, for networking and software)

The above list is by no means complete. They represent the technological innovations that transition from the I-pushing paradigm into the O-I fusing domain. It is the co-production dimension that they miss, that requires new fundamental results. The O-I fusing paradigm is evidenced in certain emerging technologies that continue the previous progress in the directions of, e.g., mass-customization and enterprise collaboration. They include the core product models and other standards to enhance STEP (ISO 10303) [22] and other industrial specifications; the reference models and ontology for supply chains [16, 20]; and process description languages and process libraries to automate process planning [7]. An obvious direction for future development is to make the previous deterministic results adaptive to changes, such as making the manufacturing process specifications stochastic. An approach envisioned herein is to incorporate the concept of "tolerance" into process design. In this sense, automated data sensing, monitoring, and analytics can be embedded into machines that execute the processes, and thereby adjust the processes. Such a concept is referred to as the Manufacturing Process Informatics (by Dr. Mark Dausch and the author).

We submit that cyber-infrastructure-based service enterprises should consider the proven practices in manufacturing, including the above models of integration and collaboration and the manufacturing informatics, to the extent applicable. The best example of cyber-infrastructure-based enterprises thus far is e-commerce/e-business, which shows the extent to which manufacturing informatics may apply to service.

4. SERVICE INFORMATICS: ACHIVING THE ECONOMY OF SCALE FOR SERVICE

The premise here is that the economy of scale is a relevant ideal to service enterprises. However, this ideal is not achieved by standardization, such as figuring out the bills-of-materials, for service products that are inherently personal, custom, and on-demand. Rather, it is achieved through concurrent co-productions of service using concurrent virtual configurations of the cyber-infrastructure, in a model of cyber-infrastructure-assisted enterprises. In other words, the previous notion of concurrent processes is extended to include concurrent co-productions using on-demand processes executed through virtual configurations of resources, with the embedded assistance of the cyber-infrastructure itself. Such a conceptual model is discussed first, followed by a summary of previous and emerging technologies that support this vision, and concluded in a general analysis of the requirements for new results.

4.1 The Thought Model of Concurrent Co-Productions

Again, we invoke the model of databases as a reference point [25]. Formally speaking, the enterprise database model defines a three-schema logic consisting of the internal schema (defining the access methods of the physical data storage), the conceptual schema (defining the logical data objects and their semantics for the enterprise as a whole), and the external schemas (defining the virtual data objects and semantics that individual classes of users and/or applications use). The external schemas are derived from the conceptual schema and do not determine the underlying physical data structures; therefore, they can be added, dropped, or modified online without affecting the underlying database. The conceptual schema, on the other hand, determines the internal schema and hence the physical data structures used. It represents the real database. This three-schema model can and has been extended to administer distributed databases, where the conceptual schema is generalized into some (federated) global or common schema, with the external schemas accommodating the conceptual schemas of local databases. Depending on the design and requirements, the global or common schema could be explicit – i.e., actually serving as the schema for a central synchronization mechanism. But, it could also be implicit, taking the form of some ontology and/or middleware to facilitate peer-to-peer interchange of data. The latter is particularly popular for Internet databases.

The enterprise database model sheds light on a possible conceptual model of the new cyber-infrastructure at an enterprise level. A key concept to this thought model is the formulation of the co-production of service – be it a consulting, a process, or an enterprising – to be a concurrent use of the cyber-infrastructure (e.g., running a client company's payroll processes). This use is then compared to the use of a database, such as a particular query job for an end user or a data processing job for an application program.

Therefore, the co-production 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 co-production 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 co-production do not have to be repetitive, nor standardized. The economy of scale comes from the concurrent co-productions 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 (see Section 2).

The technology required will center first on the acquisition of an open, scalable, and re-configurable cyber-infrastructure for the enterprise. Next, person-centered “control levers” must be afforded to the users, including both the client/customer and the producer of the co-production, to enable virtual configurations of the cyber-infrastructure for individual co-production sessions, ideally with the assistance of the cyber-infrastructure itself. That is, the cyber-infrastructure should be able to customize 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 realized in the on-demand employment of the cyber-infrastructure, or, the virtual configurations commanded. If a co-production process is compared to a database query/application, then the virtual configurations are compared to database views. This model of cyber-infrastructure affords both large scale construction and on-demand flexibility for individual service products.

Albeit in an initial state of development, the above thought model actually describes many e-commerce/e-business enterprises. A prime case is the ISP (Internet Service Provider) and ICP (Internet Content Provider) models. They, along with Portals and Search Engines, have thrived on sharing their digital resources among customized (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, as we envisioned above for cyber-infrastructure-based/assisted enterprises, they are still telling precedents.

We submit that the above three-schema cyber-infrastructure model will reduce the challenge of service productivity to cyber-infrastructure design, rather than to standardization of co-productions and their production factors (e.g., the processes and the knowledge workers). The former can stand on the shoulder of the giant of the science, engineering, and management results; while the latter may be intractable, and inappropriate, too.

4.2 Service Informatics for Co-Production

As discussed in Section 3, although service enterprises can and have employed a lot of the cyber-infrastructure results developed in the field of manufacturing, they also need to develop new results that handle the co-production aspects of service products. That is, when a service product is user dependent and time dependent, and the user is a participant of the production using knowledge workers, then the enterprise needs to develop cyber-infrastructure-based/assisted concurrent co-production to achieve economy of scale. This concept is supported in some proven practices of e-commerce/e-business, with some proven results of the service informatics required, as discussed below.

- **Application Service Provider**

One can argue that the ASP (application service provider) model is a harbinger of On-Demand Business/Services (see below). Although the ASP model is practiced primarily on the basis of leasing some common application software to different clients and/or running some pro forma operations (e.g., payrolls processing) for them based on the software, it nevertheless features co-production. Often, the application requires running the software at the client sites, involves client-side computing, or entails some co-production enterprise processes. Well-known examples include online ticketing services for airlines and many other B2C (business-to-customer) e-commerce services. The ASP model is also widely found in B2B (business-to-business) services where firms outsource certain administrative operations to some online specialist businesses, such as payrolls. The ASP firms are cyber-infrastructure-based enterprises that achieve economy of scale by running (massive) concurrent co-productions on their common, sharable, but non-consumed digital resources.

The ASP cyber-infrastructure features strong server-side computing. When client-side computing is also significantly involved, additional results for coordinating the service side and the client side computing also become important. In many ways [24], the ASP model shares the same technical characteristics with those of the ISP/ICP models. The co-production features are typically built in the user interface, application maintenance, and software support aspects of the cyber-infrastructure.

- **Exchange and Marketplace**

Another signature e-commerce/e-business practice is the Exchange model; of which Marketplace is another name. An exchange either connects person-to-person or business-to-business, or both. In a broad sense, the practices of blogs, MSN zones, and many other peer-to-peer sites can be considered P2P exchanges. In the business world, all supply chains, B2B sites, and B2C sites have the potential to consolidate and turn into exchanges. The Exchange model – beyond the stock and commodity exchanges – was touted widely as the future of the New Economy, only to find itself rapidly fell out of favor afterwards. However, this concept and its technical results are basic to the economy, regardless of whether it is in vogue at the time.

The economical promises of the Exchange model are pretty much every thing that we have discussed: consolidation of processes, removal of duplicates, sharing of resources, concurrent co-productions, and so on, to reduce the transaction cost and cycle time. With sufficient participation, a successful exchange archives the economy of scale not only for the exchange provider, but more importantly also for the sellers and buyers in the market. Both of them gain through the access to the market at large and the availability of near perfect information on the market for their decision making. In the ideal case, an exchange mimics the economy itself and reveals Adam Smith's invisible hand for that particular space. Stock and commodity exchanges have demonstrated this promise.

The exchange cyber-infrastructure features user side computing and middleware [19]. The server side could be relatively moderate compared to the ISP, ICP, and ASP. A typical design for exchanges is to develop proxies to represent the market at the user sites [10]. These proxies use a global design (including data models and languages) neutral to the local sites to facilitate both the inter-operation between the user sites and the exchange site, and the interaction among user sites in a peer-to-peer mode.

- **On-Demand Business/Service and Emerging Results**

The phrase "on-demand business" is credited to IBM. However, for the purpose of this research, On-Demand Business and On-Demand Service are considered generally to be a concept of providing services and enterprise processes to firms, on-demand, using cyber-infrastructure. The providers will practice this model on themselves, as well – i.e., providing on-demand enterprise processes to their own need. If the previous e-commerce/e-business practices illustrate cyber-infrastructure-based enterprises, then on-demand business/service providers are expected to exemplify cyber-infrastructure-assisted enterprises; since the capability of automatic re-configuration is implied in the notion of on-demand.

The required cyber-infrastructure will combine three categories of results: manufacturing informatics for the enterprise processes amenable to the I-pushing paradigm; service informatics for the ASP and Exchange level co-production; and emerging new results for more complicated co-production. The third category represents an evolving effort; however, some of the current results are listed below, which contribute to user side computing, the middleware, and the inter-operation in a peer-to-peer mode.

- Open Source Technology (community-sanctioned software such as Web Services, ebXML, JAVA, PostgreSQL, RubyRails, and the like)
- Industry Standards and consortia (e.g., UN/Oasis)
- Internet databases: ontology, Semantic Web, XQuery, and the like.
- Agent-based approaches to software design.
- Results under the labels of Ubiquitous, Pervasive, and Mobile Computing
- High performance computing (including collaborative/grid computing)

We submit that significant results are already available to enable some significant cyber-infrastructure-assisted service enterprises. The enterprise engineering effort required is primarily the vision and design of the cyber-infrastructure. We postulate that the requirements for future research and development in the field may be identified from the three-schema thought model of cyber-infrastructure discussed in Section 4.1.

4.3 New Research: an agenda

In general, new results required will fall into three basic categories: basic elements of the cyber-infrastructure (the totem pole), design and administration of the cyber-infrastructure (the three-schema model), and application of the cyber-infrastructure (engineering of on-demand enterprise processes). All research will promote the O-I fusing paradigm.

- **Development and Integration of Enterprise, Personal, and Environmental Cyber-Infrastructures**

The first category will cover all three classes of deployment: the enterprise, the person (and other moving objects concerned), and the environment – see Section 1. Practically, all previous results of cyber-infrastructure available in the field, including the manufacturing informatics and the service informatics discussed above, belong to the enterprise class and promise to continue progressing along the current lines. Therefore, the other two classes will be a focus of new development. These new results will be fully integrated with the enterprise cyber-infrastructure results to enable extended enterprises and connect the economy in unprecedented ways. A possible scenario will envision a supply chain to be an extended enterprise that controls its freight on the public transportation infrastructure (e.g., trucks on highways), as it does the parts on the material handling systems within their factories. An integrated, cyber-infrastructure-assisted supply chain can therefore display the status of its overall production at any components of the chain in a manner of a global control panel, and command re-configuration of the processes anywhere - either at will, based on the real-time online intelligence of the cyber-infrastructure, or conducted automatically by the cyber-infrastructure itself.

The field is full of endeavors for developing personal and environmental cyber-infrastructures. Examples include the wireless sensor networks deployed in the environment to monitor animal migration as well as seismic conditions. Person-carried bio-chips are popular in many popular scientific writings. In some specific applications, such as intelligent transportation systems and inventory control, person-carried and mobile object-carried RFID chips are connected to enterprise cyber-infrastructures. However, we submit that much more will emerge, bringing both new elements and their comprehensive integration for the whole economy.

- **The Cyber-Infrastructure Model: integrated design, administration, and processing**

The second categories will formalize the three-schema cyber-infrastructure model discussed in Section 4.1. The key driver here will be the recognition of the cyber-infrastructure as the digital equivalent of the (physical) organization itself. This recognition will open up the field and develop the models and techniques required. An analogy here is, again, the development of the data models, database designs, database management systems, and database applications. One would expect design-focused investigations to develop particular architectures and guide the construction of the cyber-infrastructure. For the administration tasks, the field needs three classes of results: that enable openness, scalability, and re-configurability for the cyber-infrastructure; that enable the cyber-infrastructure to provide assistance; and that provide virtual configurations and support user interface/interaction with the cyber-infrastructure. Together, they may constitute a formal model and the attendant management system for the envisioned cyber-infrastructure. The processing of the cyber-infrastructure, including the provision of virtual configurations, will be carried out through the (distributed) cyber-infrastructure management system. Person-centered control levers (user-cyber-infrastructure interaction) will be required.

- **Enterprise Engineering Using the Cyber-Infrastructure**

A new field of enterprise system engineering will rise from on-demand co-productions if they are achieved through using custom enterprise processes running on virtual configurations of the cyber-infrastructure. The analogy here is system analysis and software engineering for developing information systems. Since the cyber-infrastructure is by definition distributed, the enterprise systems and their engineering will be, too. Therefore, a central theme of the engineering will be the employment and deployment of the built-in assistance provided by the cyber-infrastructure, throughout the enterprise. The products and their enterprise processes will be developed on a basis of automatic re-configuration. This principle means that the service products themselves may become automatically re-configurable by using built-in support of the cyber-infrastructure, along with their enterprise processes of co-production. In a way, one could envision certain classes of physical products be designed and produced in a re-configurable way using the built-in assistance of the cyber-infrastructure that they employ. In general, the more cyber-infrastructure elements the physical products include in their design and use, the more likely they can become automatically re-configurable by the assistance of the cyber-infrastructure.

We submit that the above new results will help enable the concept of cyber-infrastructure-assisted enterprises and implement the O-I fusing paradigm. Conversely, if the concept describes the direction of evolution of the micro-economical production function for our society, and captures the essence of the new economy of scale for, especially, the service sector, then the above new results should be brought into being.

5. SUBJECT-ENVIRONMENT INTERACTION: MAKING THE ENVIRONMENT A PARTNER

To help reduce the research agenda in Section 4.3 to practice, we propose some particular solution approaches using current technology. These results help integrate the personal and environmental cyber-infrastructures into enterprises, and thereby develop the environment into an active partner of the digital nervous system that possesses intelligence. This intelligence, downloaded from the users (the subjects), represents a key ingredient of the vision of cyber-infrastructure assistance. At the center of these new results is a new model of user-environment interaction, on the basis of a digital dimension added to the environment.

5.1 A Digital Layer onto the Physical Infrastructure

This goal is not out of ordinary. A recent study (2003-2006) at the State of New York under the auspices of the U.S. Federal Highway Administration includes a vision of turning the I-87 corridor (from the border of Montreal, Canada to New York City, New York) into a "Smart Highway" that supports regional economical growth as well as improves highway maintenance and transportation. Among the possibilities considered, massive wireless sensor networks could be deployed along the highway and exchange data with the vehicles and freight cargos that carry next generation RFID (capable of light data processing). When the real-time feed of data from the sensors are also connected to enterprise databases at the freight companies, government agencies, and all other concerned parties, the Smart Highway would become an integral part of a Homeland Security monitoring system for the U.S.; or a supply chain management system for any cargo owners or users; or an extended Just-in-Time system for any trucking companies; or a control mechanism for any intelligent transportation systems…; or, simply, it would become a digital nervous system for many possible extended enterprises.

With this possibility of a digital dimension added on top of traditional infrastructure and space, we consider below a new model of subject-environment interaction. The notion of subject here refers to persons and mobile objects concerned that need interaction with the environment.

5.2 The Subject-Environment Interaction Model

The key concept here is to make the environment "intelligent" – or, downloading some basic analytics from the subjects to the environment to perform for the subject. This is also a "co-production" partnership between the subject and the environment. This partnership is new to the field. For instance, mobile robots may use pre-placed physical marks on their environs to help them navigate. However, these marks are "dumb" in the sense that they do not possess adaptive knowledge and decision-making analytics.

Cruise missiles and Unmanned Aerial Vehicles also use similarly "dumb" sensors on the ground to augment their topographical databases during navigation. These practices, nonetheless, show the value of involving the environment into the guidance regime. A logical next phase in this direction is to make these sensors "intelligent" - capable of decision-making, and thereby make the environment an intelligent partner of the navigation.

In this vision, intelligent sensors and wireless sensor networks are optimally deployed to the environment and connected remotely with enterprise databases to form a (massively) distributed information and decision system. The sensors and wireless sensor networks serve as the local information units that interact directly with the on-board control models of the subjects. The databases - the global information units - provide contextual knowledge to the local units and facilitate data fusion and adaptation of control knowledge at these devices. Together, the sensors and databases form a local-global decision model that makes the environment intelligent. The real-time interaction constitutes a collective decision process that continuously adapts itself during the entire journey of the subjects.

As such, sensors and wireless sensor networks are also decision-makers in the process; sometimes they just assist the subjects in the navigation but sometimes they also direct. We refer to this new design the Subject-Environment Interaction (SEI) model, so as to contrast to the traditional model that we call Subject Self-Reliance. A major property of this new model is that the interaction may draw from enterprise information – such as the global patterns and requirements of the subjects, and use the information to better integrate the subjects with enterprise operations.

For example, under the new SEI regime, the factory control systems could route its Automated Guided Vehicles (AGV) according to the real-time conditions on the shop floor, and integrate the AGV into the Manufacturing Execution System for Just-in-Time production control. The subject-environment interaction in this example would be comparable to an intelligent transportation system in a city that uses multimedia sensors and computerized signs to remotely control the traffic of vehicles and pedestrians on streets, while taking into consideration the control information from other government agencies (databases). The difference would be automated control (AGV-SEI) vs. human-decision-making (transportation). The former exhibits an automatic re-configurability capability.

The same idea could be employed in different contexts for a wide range of applications. For example, a homeland security system could remotely adapt its wireless sensor networks' monitoring rules based on the real-time instructions or decision information provided by its enterprise databases, which fuse data for the entire system. Similarly, exploration projects could drop wireless sensor networks that possess the necessary environment-sensing capabilities to remote regions. These intelligent sensor networks would constitute a "live" map of the region and work with the exploring robots to jointly negotiate the alien terrains.

The SEI approach requires new results to perform the following tasks: making real-time decisions at the local level, inter-operating between sensors and enterprise databases, and globally configuring the logical and information capabilities on sensors and wireless sensor networks in an open, scalable, and adaptive way. Some aspects of the problem are physical, such as the limited computing power, energy supply, and sensing capabilities on which the above tasks rely. These issues are expected to vanish soon as the technology and materials continue to progress rapidly. However, other aspects of the problem are simply not satisfied in a few areas.

From local to global, the first requirement encountered is Efficient Computing for the new sensors and wireless sensor networks. The need is to afford the sensor nodes an operating system, with sufficient on-board metadata, that supports re-programmable embedded analytics and light database processing, to make them capable of gathering decision data from other sources and process them. Next, new Data Fusion and Information Integration results are required to make a cohesive digital nervous system out of the massive collection of sensors and wireless sensor networks and enterprise databases. Finally, the design and optimization of the digital nervous system need new System Modeling and Placement results to determine the location of local units, and the configuration of the different classes of capabilities at local and global nodes. These requirements and their solution approaches are discussed below.

5.3 The Basic Components of the Model

Environment: networked (multimedia) sensors and wireless sensor networks, including the gateways and other infrastructure; they are responsible for sensing the environment, monitoring the moving objects concerned, and directing the subjects as required.

Subject: chip-based RFID (radio frequency identification) and (personal) computer-based control systems on-board the automated guided mobile objects; they are responsible for performing primary navigation (the subject of movement).

Context of Interaction: enterprise databases, including SEI-specific systems and related application systems; they are responsible for facilitating data fusion among sensors and sensor networks, information integration between the environment and the subjects, and bi-directional management of the local metadata on-board environment and subjects.

The information processing capabilities for each class include the following:

Sensor Nodes and RFID chips: implementing on-board processors with at least a few mega-bytes of memory sufficient for creating and processing a (light) main memory database.

Central Nodes and Subject Databases: PC-class machines with full range of analytical programming and database management capabilities.

Enterprise Databases: multiple-user and multiple-application environment, with full-fledged middleware to support common schema and system integration.

Given these capabilities, the concept of Subject-Environment Interaction is reduced to an automated guidance model that joins the subjects with the environment through the above distributed information units in making real-time navigation decisions. Therefore, the analytic nature of the SEI concept is the optimal distribution of the information units (including the location and connection of the sensors and sensor networks, the allocation of metadata and other decision capabilities to them, and the development of these capabilities) and their real-time processing (local execution with certain global synergism).

We define a global model of collaboration for the distributed real-time decision-making under the SEI regime:

Autonomous local nodes: any nodes of sensors, wireless sensors, chip-based RFIDs, and subject databases could be structured and controlled by different authorities, and processed under indigenous systems without constant support from the enterprise databases.

Global nodes: any application databases could be connected to any SEI nodes through at least one global node, which is a dedicated SEI enterprise database providing and maintaining global metadata (e.g., common schema and contextual knowledge) and administering global database queries.

The above components constitute the cyber-infrastructure of the SEI model. The cyber-infrastructure, to which individual information units subscribe, embodies the wholeness and achieves the global cohesiveness of the distributed local executions. The embedded metadata at local nodes that the global model maintains achieve common purpose for the SEI nodes community. At the real-time behavior level, global optimality is replaced by local feasibility, compensated by continuous adaptation.

5.4 Efficient Computing Design for Sensors, Sensor Networks, and Chip-Based RFID

Sensors, wireless sensor networks, and (chip-based) RFID belong to the same class of mobile data processing technology. Sensors and wireless sensor networks perform both transponder and transceiver roles, while RFID is conventionally considered mainly from the perspective of transponders and lacks computing capacity. However, both technologies can be considered together from the perspective of chip-based data processing, and benefit from the same design of Efficient Computing.

A wireless sensor network is a multi-hop self-configuring wireless network consisting of many sensor nodes, each of which performs sensing, computation and communication. The sensing component can be Seismic, Magnetic, Thermal, Visual Spectrum, Infrared, Acoustic or Radar. The computation component can include data analysis such as beam forming or aggregation of related data. It can also include routing computation overhead. The communication component involves radio frequency transmission and reception between multiple nodes within the transmission vicinity. A sensor network could have a central node (and/or gateway sensors) to provide necessary computing and communicating capacity to supplement the distributed processing taking place at sensor nodes. These nodes have more permanent power supply. For the purpose of this research, they are considered as belonging to the PC-class of information units.

The proposed SEI model envisions a two-way inter-operation between these "leaf nodes" of the digital nervous system and the enterprise databases. That is, the system will feature direct feeding of real time sensor data into enterprise databases on the one hand, and adaptive control of sensor networks based on new information from enterprise databases, on the other. This two-way inter-operation promises to make sensors a system of distributed information units capable of real-time decision-making. However, it also means that new efficient computing results need to be applied to support the heightened on-board computing and to limit the burden on communication. Also included in the new capabilities will be filtering and signal processing to handle noise at the sources of raw data, with the assistance of the global data and knowledge at the central nodes and the enterprise databases. The proposed research will draw from previous results [1] to design new thin operating systems that also embed metadata (knowledge) and analytics, manage databases, and execute decision tasks.

5.5 Data Fusion and Information Integration

This task realizes the synergism of the cyber-infrastructure-assisted enterprises. Therefore, its analytic nature is the development of a global regime to integrate the data from sensors, wireless sensor networks, and subject databases (on-board RFID-control systems) with the enterprise databases. The suggested approach is to focus on metadata technology, including developing an open and scalable common schema/ontology for the interaction, coupled with distributed metadata at local nodes.

The most pertinent metadata results come from the field of global database query and multiple databases inter-operation. Although these results assume certain conditions that do not exist in the SEI model, they could be modified and extended to achieve the required data fusion and information integration. The modifications and extensions are concerned with two fundamental conditions of the distributed model: collaboration of all information units and light database processing capabilities at sensors.

The field of multiple, heterogeneous, and autonomous databases have provided many metadata methods to help reconcile different data models when no one authority can practically impose a single, comprehensive data semantic standard. However, these results do not offer sufficient simplicity to work effectively in large-scale environments such as the SEI model of cyber-infrastructure-assisted enterprises. In fact, industrial experiences (e.g., the E-Engineering effort at GE and the ebXML Registry Information Model at Oasis [26]) show that an open and scalable common schema would not be feasible unless it is based on some sound ontology. Sound ontology, however, is evasive. Common practices in the field tend to base ontology on domain knowledge; that is, the ontology would enumerate all possibilities and/or requirements of the “concepts” of the application domain. Domain knowledge is a moving target at best.

In academia, a popular approach is to base database ontology on some class of linguistics [16, 23]. An alternative is to base ontology on the information modeling concepts and constructs that systems use, and employ directly these generic elements to structure a repository of enterprise metadata. The Metadatabase model, due to this author, is an example. We submit that the Metadatabase results could form a basis for developing the open and scalable common schema required. The previous Metadatabase-supported global query processing methods also provide a starting point for the execution of data fusion and information integration. The major new effort required will be the development of the new distributed metadata methods to empower local nodes at the efficient computing level [12-14].

5.6 System Modeling and Placement of the Information Units in the Cyber-Infrastructure

Any sensors and wireless sensor networks face a location-connection problem: how many gateway sensors (and/or central nodes) to use, and where to place them in order to optimize the communication of the sensors subject to fixed power supply and other constraints of the network? This problem would have to be solved continuously, in an automatic re-configuration manner if possible. Similar system-optimization problems exist. For the SEI model, the optimal assignment of decision capabilities to the information units for particular applications is also required. For instance, embedded analytics and metadata could be added or removed to activate, de-activate, or modify the functions of particular sensors, either on command or by self-adaptation – i.e., automatic re-configuration. These issues call for new engineering methods and techniques to perform the design and evaluation of SEI systems.

The analytical nature of the (automatically re-configurable) distributed SEI systems may be described by the Artificial Neural Networks (ANN). However, the traditional ANN approach faces difficulties when applied to large-scale systems – i.e., neural network models not only entail voluminous computing in their simulation, but also require considerable training data (prior history) to operate. Neither condition is favorable to cyber-infrastructure-assisted enterprises. To facilitate these problems, we propose to aggregate the basic neurons of the ANN into some prototypical modules representing the fundamental functions germane to the SEI model. An analogy is the aggregation of basic electronic elements such as gates for Integrated Circuit design. The ANN literature includes such efforts, too [18]. For the SEI model, these aggregate constructs will be the basic modeling blocks to represent the cyber-infrastructure. The development needs to determine a complete set of the functions as well as to develop the aggregate constructs; both of which will be conducted in the future research.

We submit that new aggregate ANN constructs could be developed from previous results in the field. On this basis, a modeling methodology could also be formulated to guide the general application of the new constructs and evaluate their inherent benefits. Intuitively, this approach promises to reduce the complexity of modeling and simulation (training), in proportion to the sophistication of the aggregation itself. In fact, as the aggregate constructs increase the order of their standard representation, one could expect them to decrease the size of the ANN models (as measured by the number of these modules), and hence the attendant modeling effort, by more orders of magnitude. This situation is comparable to chip design, where aggregate constructs of “pre-fabricated” gates and other IC elements are commonly used to make the design tasks attainable as the logical size of the chips continue to grow exponentially.

In conclusion, the above SEI model represents a concrete approach to develop some new results to enable cyber-infrastructure-assisted enterprises. These results extend enterprise cyber-infrastructures with personal and environmental components and capabilities. The extension, in turn, makes it possible to design person-centered, cyber-infrastructure-assisted, and even automatically reconfigurable co-productions for enterprises.

6. FUTURE OUTLOOK

The above vision is centered on a cyber-infrastructure that fuses information technology with information resources to connect persons, enterprises, and even the environment for our society. It further uplifts the micro-economical production function through the O-I fusing paradigm of production. Enterprises use it to achieve economy of scale for service, as well as for personalization of physical products. In this vision, persons are propositioned to be at the center of the economy through co-productions with various enterprises; as enabled by the cyber-infrastructure. If this vision makes sense, then it could be extended to describe the possible next steps of the evolutionary journey of cyber-infrastructure-based/assisted enterprises.

The outlook may start with Figure 8.1, (adopted from [11]) which shows a person-meta-enterprise interaction through the societal cyber-infrastructure referred to as the “Personal Wizard Architecture”. The notion of “person” here could be replaced by “family”, “team”, or even “enterprise” as the subject of concern.

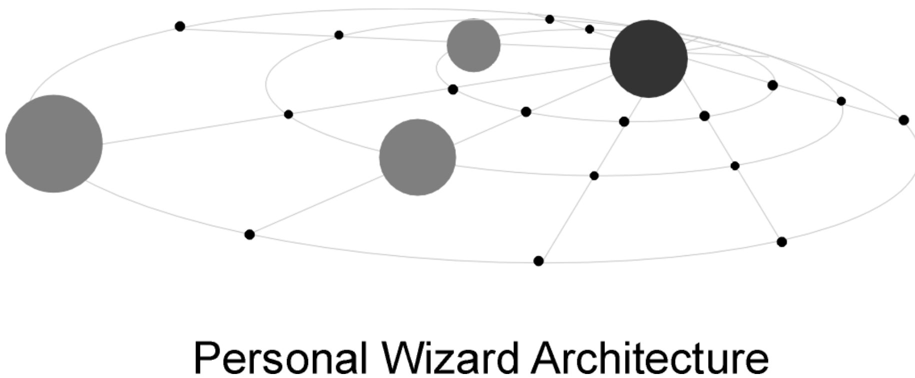

Figure 8.1 A Virtual Configuration of the Societal Cyber-Infrastructure for a Particular Person.

The central node of the Personal Wizard Architecture is the person in command, and all other nodes are enterprises. Some of the enterprises provide the cyber-infrastructure (such as those depicted in the inner-most concentric orbits). Some provide products (the outer-most orbits). The others provide services that enable the Personal Wizard Architecture and/or the meta-enterprises (the middle orbits) – such as On-demand business/service.

From the perspective of supply chain, an enterprise could be conceived at the central node and command through its own virtual "Enterprise Wizard Architecture". However, all enterprise wizard architectures ultimately lead to persons if following the demand chain. Thus, the person-centered rendition of the virtual configuration of societal cyber-infrastructure fits the O-I fusing paradigm best. In theory, the economy has as many such personal wizard architectures as it has persons; and each is a virtual configuration of the societal cyber-infrastructure. Needless to say, these virtual configurations run concurrently on the same cyber-infrastructure and tap (use, not consume) into the same digital resources.

We submit that enterprises should explore the opportunities that the societal cyber-infrastructure presents, along these orbits or across them. Consolidation will occur along societal value chains. The principles discussed in Section 2, and the models of integration and collaboration in Section 3, could be applicable to the economy as a whole – i.e., the economy could be considered as a societal virtual enterprise. To the extent that this notion is relevant, a top-down recursive application of the principles and the models from the whole economy down to industries and enterprises could shed light on future evolution of cyber-infrastructure-based/assisted enterprises. Conversely, a bottom up pursuit to apply them to extended enterprises could reveal possible business strategies. In any case, an O-I fusing paradigm using cyber-infrastructure is a reality in our economy now.

ACKNOWLEDGEMENT

The author wishes to express his gratitude to Dr. Thomas R. Willemain, for his review of the manuscript. His comments made the chapter better.

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