Engineering Network Configuration: Transition from Products to Services

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Abstract

Existing approaches to the design and operation of engineering networks are largely product-oriented and pay little attention to the intangible, customer-involving and relationship-based nature of services. With the trend of servitization in manufacturing companies and the emergence of service science, manufacturers, particularly those who are engaged with complex and long-lifecycle products and systems, need to update their engineering networks to support integrated product-service offering. This paper develops a conceptual framework to demonstrate the configuration features of product- and service-oriented engineering networks. It will provide theoretical insight and practical guidance on the design and operation of integrated product and service systems.

Keywords:

Engineering Network Configuration, Service Engineering Networks, the Product Lifecycle, Integrated Product-service Systems

1 BACKGROUND AND INTRODUCTION

The research on international engineering operations is experiencing a stage of cross-discipline integration driven by the increasing complexity of engineering activities and the network of organisations involved in their delivery. Theoretical insights have been proposed to interpret new practices in coordinating internationally dispersed engineering activities. Examples include off-shoring [10], outsourcing [11], and global product development [1]. At the same time, practical guidance has been offered on the collaboration between different functions and organisations in dynamic business environments. Examples include concurrent engineering [12] and collaborative engineering [13]. In addition, increasingly capable information and communication technologies make it possible to bring together traditional computer aided engineering tools and business process management systems effectively. The concept of product lifecycle management has emerged to provide an integrated solution based on efficient communication and collaboration [14]. Most of the changes or transitions are heavily product-oriented with relatively little concern of the intangible and complex nature of services.

Traditional engineering management concepts which were built on a simple assumption of stable business environments are challenged by the increasing complexity and uncertainty of engineering operations. New organisational forms have emerged to better coordinate dispersed engineering activities in dynamic business environments, e.g. matrix structures [15], centre(s) of excellence [16] and the virtual enterprise [17]. Emerging concepts and practices are converging on global engineering networks (GEN) for their efficient, flexible and innovative natures. Zhang, Gregory and Shi (2007) developed an integrating framework for GEN to guide the design and operation of internationally dispersed engineering systems [4]. However, the framework was based on case studies of new product development oriented engineering operations, and paid relatively little attention to service and support issues or through-life integration.

The decline of manufacturing and the rise of services is an important global development [18]. There is a trend for manufacturers to integrate services in their core product offerings [19]. The reason for having an integrated product-service system is multi-fold. For example, significant revenue can be generated from services [20]; customers are demanding more services [21]; or services can be a source of sustainable competitive advantage because they are less transparent and hence more sustainable [21]. However, operational issues are relatively neglected in service research largely due to the difficulty in defining services and service processes [22-27]. There is little theoretical insight or practical guidance on how industries can effectively organise engineering resources or coordinate engineering activities to support integrated product and service offering.

Existing research on engineering networks is largely product oriented and pays relatively little attention to the intangible, customer-involving and relationship-based nature of services. With the trend of servitization in manufacturing companies [6] [19] and the emergence of service science [7], manufacturers, particularly those who are engaged with complex and long-lifecycle products and systems, require a better understanding of the nature of services and its impact on the design and operation of engineering networks. Booz, Allen and Hamilton (2006) estimated that the worldwide spend on engineering services will exceed $1.0 trillion by 2020, and about one quarter of the activities will be off-shored or out-sourced to emerging economies [28]. This will lead to a radical change to engineering network design and operation, not least in order to address the issues of geography dispersion, international inter-firm collaboration, customer relationship management and through-life integration.

The reported research aims to understand how to design and operate engineering networks to effectively support integrated product and service offering. This paper develops a conceptual framework to demonstrate the different sets of organisational requirements for new product development oriented engineering operations and service and support oriented engineering operations.

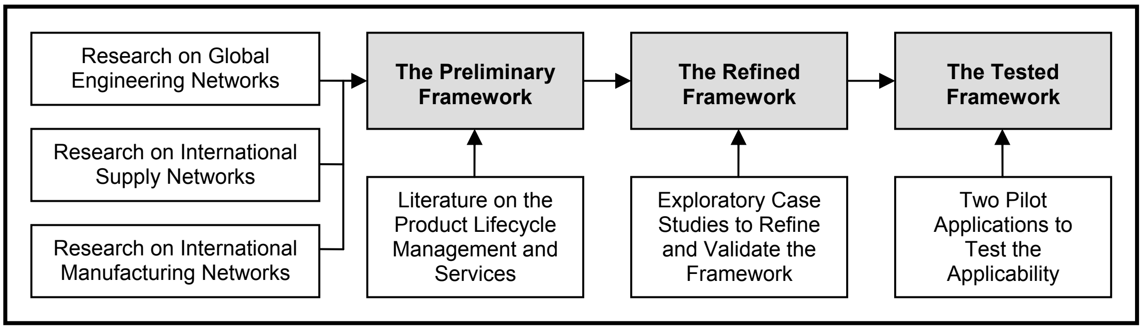

Figure 1. An overview of the research design.

Integrated product-service systems (IPS2) should meet the requirements from both product-orientation and service-orientation. The framework integrates the existing theoretical and empirical knowledge on engineering management, services and network organisations. Key elements of engineering network configuration are defined based on the research of engineering networks [4], supply networks [8] and manufacturing networks [9]. The elements are refined and adjusted to reflect the intangible, customer-involving and relationship-based nature of service and support oriented engineering operations. The framework was improved and validated through exploratory case studies and tested by pilot applications. Main directions for future research and fundamental propositions are discussed based on this framework.

2. RESEARCH APPROACH

The reported research in this area has developed the framework for engineering network configuration largely through case studies. A preliminary framework was proposed through integrating the outputs of the research programmes for global engineering networks (GEN), international supply networks (ISN) and international manufacturing networks (IMN). The preliminary framework was further developed to reflect the influence of inter-firm relationships, product lifecycle management and service orientation; and then refined and validated with exploratory case studies in different industry sectors. The applicability of the framework was tested with two pilot applications. Figure 1 presents an overview of this research.

The configuration framework was based on a big of number of case studies to understand network configuration from different perspectives, including

- Global engineering networks: 7 in-depth cases in the industry sectors of aerospace, automobile, electrics and electronics, and fast moving and consumer goods (FMCG) [4].
- International supply networks: 10 exploratory cases and 10 in-depth cases in the industry sectors of aerospace, electronics, FMCG, garments and pharmaceuticals [8].
- International manufacturing networks: 15 cases in the industry sectors of aerospace, electronics, heavy engineering and pharmaceuticals [9].

A generalised framework to describe network configurations was developed through integrating the above cases. The configuration framework was later refined and validated with exploratory case studies to capture configuration archetypes for product oriented engineering networks and service oriented engineering networks. Case companies with product oriented engineering networks usually give higher priorities to new product development related engineering activities (see Figure 2). Companies with service oriented engineering networks believe that service and support are critical to their business (a simple indicator is that a significant amount of revenues are from services). Table 1 presents a list of the exploratory cases.

The framework was later tested by two pilot applications: case Y and case Z. The two pilot cases were selected with the criteria being to minimise the influence of contextual factors, and to demonstrate the difference between product orientation and service orientation. To meet the first criteria, both cases were selected from the same industry sector, and common geographic region, and were firms of similar and significant scale. (Both companies are within the top 5 service firms in the selected sector and region). Addressing the second criteria, the two engineering networks focus on different parts of the product lifecycle. One of them leads in design and manufacturing of complex equipment in the defence sector. The other case company is a leading after-sales and maintenance service provider in the same sector. The results of these pilot cases are discussed in Section 4.

Cases	Industry Sector	Revenues (in 2007)	Product / Service Orientation
A	Automobile	$174 billion	product
B	Electrics	$29 billion	product
C	FMCG	€40 billion	product
D	Aerospace	$820 million	product
E	Automobile	£310 million	product
F	Electronics	£160 million	product
G	Aerospace	£7.4 billion	service
H	Aerospace	€25 billion	service
I	IT services	US$22billion	service
J	Petrol Chemical	US$284 billion	service

Table 1. An overview of the cases.

3 LITERATURE ON SERVICE ENGINEERING NETWORK CONFIGURATION

3.1 Engineering activities through the product lifecycle

Engineering operations focus on different activities along the product lifecycle (see Figure 2). Product oriented engineering operations (e.g. new product development) usually set a high priority to the activities from initial concept to manufacture. Service oriented engineering operations (e.g. service and support) usually set a high priority to the activities from manufacture to disposal. In reality, the activities are not isolated but interrelated, sometimes requiring iterative development. The design and operations of integrated product-service systems should be based on an overall understanding of engineering activities along the product lifecycle.

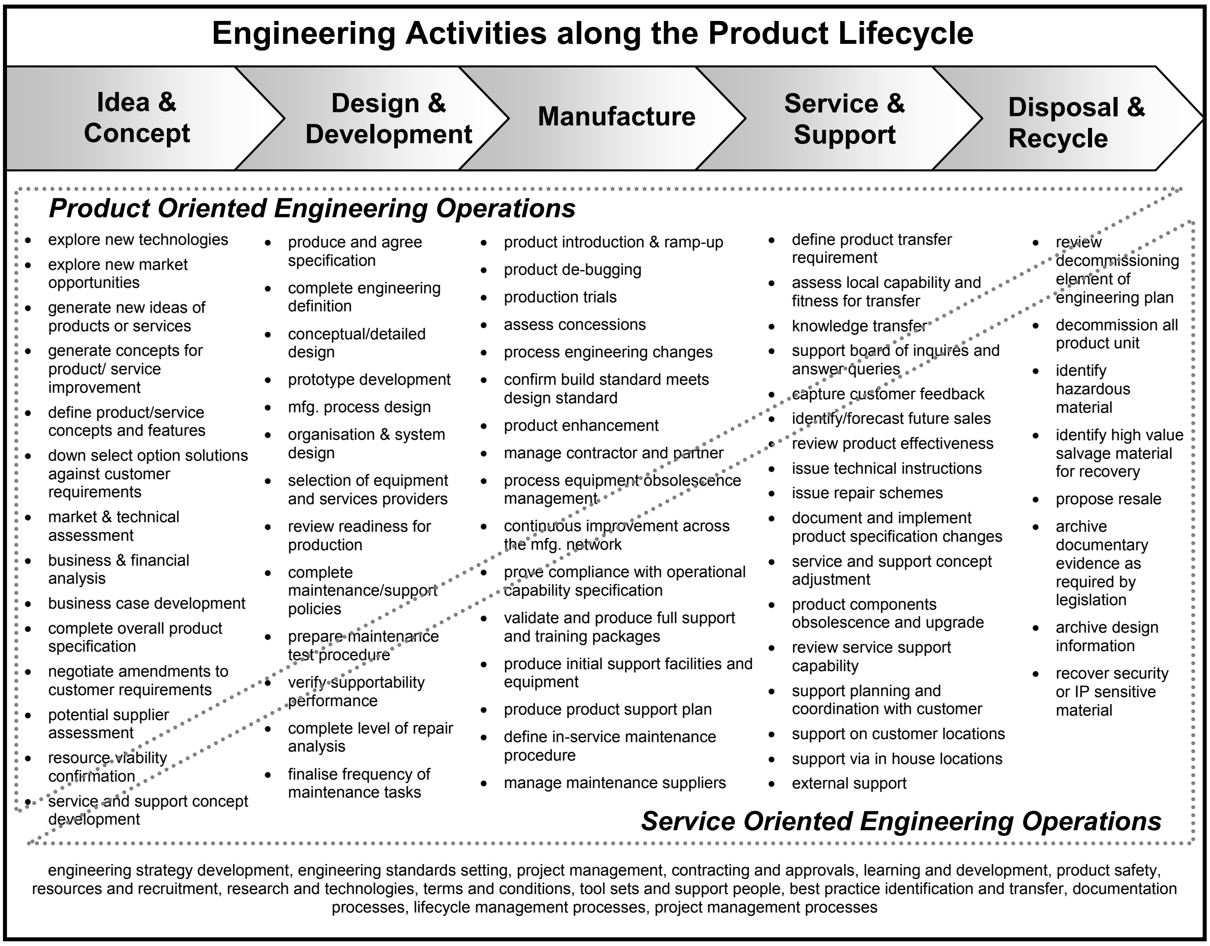

Figure 2. Engineering activities along the product lifecycle [4].

Product lifecycle management (PLM) in an engineering context aims to optimise engineering operations across the product lifecycle. It has been proposed as a strategic approach to creating and managing product related information from the initial concept, through design, development and manufacture, to service and disposal [14]. It provides a common platform for the synergies of technologies, processes, resources and business systems throughout the product lifecycle [29]. PLM systems are usually enabled by IT solutions for product and portfolio management, product design, manufacturing process management, and product data management.

These solutions have been adopted and shown benefits in a wide range of industry sectors, especially the aerospace and automotive industries [30]. A critical issue to the implementation of PLM is to develop business strategies and operational processes across the different stages of a product lifecycle.

3.2 Services and engineering operations

Services have been considered as the application of specialised competencies through deeds, processes and performances for the benefit of another entity or the entity itself [31]. They are fundamentally different from physical products on the basis of intangibility, simultaneity/inseparability, perishability, heterogeneity, human involvement and customer contact [27]. Services can be partly intangible with the process of services being the application of specialised skills and knowledge. Physical products/goods are usually the distribution mechanism for service provision. At the same time, customers may contribute to the production process of services; and the production and consumption of services happens simultaneously. In addition, a customer may experience a service differently each time. This kind of heterogeneity makes it difficult to analyse the process of services or measure the outputs. Furthermore, services are perishable. It is generally not possible to stock a service for future use if it is not consumed when available. Finally, human aspect is a core element for service operations because of the significant people involvement in the process of service production and service provision. To be successful, service providers need to be customer centric- adapting to their often real-time dynamic needs whilst collaborating on both solution design and co-delivery.

Distinguishing Features of Services	Product Oriented Engineering Operation (e.g. new product development)	Service Oriented Engineering Operation (e.g. service and support)
Intangibility (heterogeneity)	• well defined specifications • measurable and pre-specified outcomes • standardised processes and outcomes	• output based 'service level agreements' • subjective and user-dependent outcomes • variable processes and outcomes
Co-creation of Value (simultaneity, inseparability)	• value is determined by the producer/engineering service provider • customers could be separate from the value creation process • it is possible to store outcomes	• value is perceived and partly co-determined by the customer • customers are involved in the value creation process • unable to store outcomes but it is possible to store service capability
Relationship (human/customer centric)	• transition oriented • relatively low impact of human aspect • relatively low customer centric	• relationship oriented • high impact of human aspect • highly customer centric

Table 2. A comparison of product-oriented and service-oriented engineering operations.

In brief, a service-centred view is participatory and dynamic. The value of service provision will be maximised through an iterative learning process on both the service provider and the customer. The logic of service processes is focused on intangible resources and the co-creation of value through mutually benefiting relationships [31]. Physical products oriented methodologies and theories are challenged by the increasing importance of services in the field of operations management. The unique nature of services requires practitioners and researchers to think about their business strategies and operational processes from a new perspective [32]. This radically changes the principles for engineering network design and operation. Table 2 presents the distinguishing features of services and their impact on engineering operations.

3.3 Engineering network configuration

Literature on strategic management and organisational studies implies that organisations function effectively because they put different characteristics together in complementary ways [33-37]. Miller (1986) observed that organisational features are usually interrelated and mutually reinforcing [35]. Organisations might be driven towards common configurations to achieve internal harmony among the elements of structure, environment and strategy. Organisational parameters should be logically configured into internally consistent groupings composed of tight constellations of complementary elements. This concept of cohesive configuration could be predicatively useful for the study of organisational structures and organisational capabilities because the number of possible ways in which constructional elements are combined is reduced. For example, Mintzberg (1979) identified five viable organisation configurations (i.e., simple bureaucracy, machine bureaucracy, professional bureaucracy, divisionalised form, and adhocracy) based on their features of structures (e.g. operating core, strategic apex, middle-line, techno-structure, and support staff) and coordination mechanisms (e.g. direct supervision, mutual adjustment, standardisation of work, outputs, and skills) [34]. Ghoshal & Nohria (1993) articulated four configurations of multinational corporations with the dimensions of differentiation and integration, i.e., ad hoc variation, structural uniformity, differentiated fit, and integrated variety. These configurations would be apt for different environmental conditions, each with different degree of requirement for global integration and local responsiveness [36].

The configuration approach has been increasingly adopted in research on operations management, e.g. engineering operations [4], supply chain management [8] and international manufacturing [9]. By doing so, the researchers are able to simplify and classify network systems, and capture their characteristics and capabilities.

Shi and Gregory (1998) identified eight international manufacturing network configurations according to their degree of geographic dispersion and coordination, i.e. home based manufacturing, home based global manufacturing, regionally uncoordinated manufacturing network, regional exporting manufacturing network, multi-domestic manufacturing network, global integrated manufacturing network, global-local manufacturing network, and global coordinated manufacturing network [9]. A set of structural and infrastructural elements of manufacturing systems were used to describe the configurations, including factory as a node, geography dispersion, horizontal coordination, vertical integration, response, knowledge sharing, operation and evolution. The relationship between network configurations and strategic capabilities was investigated to explain the current transformation towards more globally integrated or coordinated configurations.

Srai and Gregory (2008) considered the configuration of supply networks as the particular arrangement or permutation, of the supply network's key elements including, the network structure of the various operations within the supply network and their integrating mechanisms, the flow of materials and information between and within key unit operations, the role, inter-relationships, and governance between key network partners, and the value structure of the product or service delivered [8]. Each supply network configuration would exhibit different intrinsic capabilities. Exemplar supply network capability and configuration profiles were identified through establishing specific capability-configuration relationship patterns, e.g. distinct approaches to end-to-end network integration, highly responsive risk-pooling supply models, global scale contract manufacture, mass customisation on-demand, product-service integration and alternative types of multi-domestic product supply. This could help determine a supply network's potential for re-configuration, i.e. the ability to rearrange key elements of the supply network to enable improvements in the supply or development of products or services.

Zhang, Gregory and Shi (2007) proposed an overall framework for the design and operation of global engineering networks (GEN) from the perspective of context, capability and configuration [4]. Key organisational elements of GEN include network structure, coordination, governance and support. The configuration of an engineering network could be described with the features of the above elements, e.g. the degree of dispersion and interdependence of network structure, the degree of standardisation of network coordination, the degree of centralisation of network governance, and the degree of unification of network support. An integrated GEN configuration is characterised by concentrated and interdependent engineering centres, formal and structured coordination, detailed and operational governance, and uniform support across the network.

Configuration Elements	International Manufacturing Networks [9]	Global Engineering Networks [4]	International Supply Networks [8]
Structure	Plant's characteristics; geographic dispersion	Structure, including geographic dispersion, resources and roles of engineering centres, and rationales for network structure design	The network structure of the various operations within the supply network and their integrating mechanisms
Operations Flow and Processes	Horizontal/vertical coordination; operational mechanisms; dynamic response mechanisms; product lifecycle and knowledge transfer	Coordination, including operational processes and coordination mechanisms	The flow of materials and information between and within key unit operations
Governance and Coordination	Dynamic capability building and network evolution	Governance, including authority structure and performance measures	The role of and governance mechanisms between key network partners
Support Infrastructure		Support, including tools, IT systems, and people	
Relationships			The role and inter-relationships, between key network partners

Table 3. Key elements of network configuration.

It usually demonstrates strong capability for integration and synergising. An autonomous GEN configuration is characterised by dispersed and independent engineering centres, informal and unstructured coordination, generic and strategic governance, and customised support for customers, technologies or countries. It usually demonstrates strong capability for adaptation and restructuring. There are also engineering networks with strong capabilities for innovation and learning. They are configured between the two extremes between integrated GEN and autonomous GEN.

Table 3 presents the key elements employed by the researchers studying the 'configuration of network organisations'. For an engineering network involving multiple players, taking a multi-organizational perspective, these individual research strand inputs can be usefully integrated as bellows.

- **Structure** refers to the physical footprint of engineering resources, including the size, number and types of Engineering centres, the rationale for location decision, and interrelationship and resource sharing between engineering centres. Network structures are characterised by the degree of dispersion (dispersed vs. concentrated), and the interdependence between engineering centres (independent vs. interdependent).
- **Operational Flow (& Processes)** refers to the flow of material and information between members of the network to create valuable output to customers, e.g. new product development processes, lifecycle management processes, supply chain management processes, service and support processes. Operational flows are characterised by their degree of standardisation (standard vs. tailored /bespoke).
- **Governance (& Coordination)** refers to the mechanisms to direct and control the network, especially authority structures and performance measurement systems. Governance mechanisms are characterised by their degree of centralisation (centralised vs. decentralised) for commercial control, engineering authority and metrics.
- **Support Infrastructure** refers to enablers for network members to collaborate with each other, especially engineering tools, information systems, engineering resource, people, culture and behaviours. Network support are characterised by their degree of unification (uniform vs. customised) and globalisation (global vs. local).
- **Relationships** refer to the interaction with internal/external partners, especially suppliers, customers and users. Network relationships are characterised by their strategic importance (strategic vs. tactical), degree of trust (trust vs. transactional), and scope (global vs. local).

3.4 Deliberate intent for engineering network configuration

Traditional engineering systems were organised for the effectiveness (e.g. the project approach) and efficiency (e.g. the functional approach) of engineering operations. Effectiveness indicates how closely the output of an engineering system meets its goals or customer needs; and efficiency indicates how economically the resources are utilised to produce the output [38]. Zhang, Gregory and Shi (2008) revealed the strategic intent of different forms of engineering networks from an evolutionary perspective [5]. The study demonstrates that an engineering network may seek for greater efficiency through economies of scale/scope, international operation synergies, resource sharing, and reusing existing knowledge and solutions. At the same time, an engineering network may seek for greater effectiveness through quick response to environmental changes, market/technology driven innovation, mobile engineering resources, and flexible operation approaches. Zhang, Gregory and Shi (2007) differentiated two types of effective engineering networks. One focuses on innovative product development and the other focuses on strategic flexibility [4]. Thus, engineering networks could be configured with strategic intent for efficiency, innovation and flexibility (see Table 4).

An efficient engineering network aims to achieve efficient operations on a global scale through minimising waste and maximising value and capability utilisation, e.g. economies of scale/scope, international operations synergies, leveraging expertise or precious resources on a global scale, sharing and reuse existing solutions. It is appropriate for complex products/services in relatively stable business environments. An innovative engineering network aims to satisfy business and customer needs effectively through new product/service/process development, e.g. customer intimacy, technology leadership, and market/technology driven innovation, learning across disciplines or organisations, leaving room for creativity or diversity. It is appropriate for simple products/services in relatively dynamic business environments. A flexible engineering network aims to improve the ability of the network to adapt to uncertain circumstances though flexible working approaches, mobile engineering resources and reconfigurable network structures, e.g. local responsiveness, and quick response. It is appropriate for complex products/services in dynamic business environments.

Efficiency	Innovation	Flexibility
• economies of scale/scope • international operations synergies • leveraging expertise or precious resources • sharing and reusing knowledge or existing solutions	• technology leadership/technology-driven innovation • customer intimacy/market-driven innovation • learning across disciplines, businesses, and organisations • leaving room for diversity and creativity	• reconfigurable network structure • mobile engineering resources • flexible working approaches • quick response to environmental changes

Table 4. The performance preference of global engineering networks [4-5].

4. ENGINEERING NETWORK CONFIGURATION FRAMEWORK AND PILOT TESTING

Figure 3 presents an overall framework for engineering network configuration along the product lifecycle. The exploratory cases of product-oriented engineering networks and service-oriented engineering networks demonstrate different configuration characteristics to support their strategic intents for efficiency, innovation and flexibility. For product oriented engineering operations, an integrated engineering network configuration usually demonstrates strong capability for efficiency; and an autonomous engineering network configuration usually demonstrates strong capability for flexibility.

Engineering Network Configuration	Engineering Operations along the Product Lifecycle					
	Product Orientation			Service Orientation		
	Efficiency	Innovation	Flexibility	Efficiency	Innovation	Flexibility
Structure	concentrated and specialised resources close to manufacturing bases	dispersed resources close to technology bases or customers/users	dispersed and independent resources close to customers or users	dispersed and specialised resources close to customers and manufacturing bases	dispersed resources close to customers and technology bases	dispersed and independent resources close to customers
Operations Flow	common processes	common processes for reference	local processes for customer needs	common processes tailored for customer needs	common processes tailored for customer needs	local processes for customer needs
Governance	centralised control	centralised control on major operations	local authority	centralised control	centralised control on major operations	local authority
Support Infrastructure	uniform support	uniform support on major operations	customised support	uniform support customised for customer needs	uniform support customised for customer needs	uniform support customised for customer needs
Relationships	strategic partnership with suppliers	strategic partnership with suppliers on key programmes	transitional relationship with suppliers	strategic partnership with suppliers and customers	strategic partnership with suppliers and customers on key programmes	strategic relationship with customers and transitional relationship with suppliers
Exploratory Cases	Case A, E	Case B, C, F	Case D	Case H	Case G	Case I, J
Pilot Cases	Case Y				Case Z	

Figure 3. Engineering network configuration framework.

Service and support focused engineering operations have a different set of features due to the nature of services in intangibility, customer-involvement and relationship-based. The network structure tends to be dispersed with customers, the process, governance, and support system are usually tailored for customer needs, and the relationships with customers and users are critical to successful engineering operations.

This framework would enable industries to optimise their current engineering networks or design new engineering networks for integrated product and service offering. The design and operation of integrated product-service systems should consider the requirements from both product orientation and service orientation. Companies can assess the current situation of their engineering networks against the configuration elements and optimise their engineering networks through aligning these elements to their major strategic objectives. They can also use the framework as a template to design new engineering networks according to environmental changes, e.g. the increasing importance of inter-firm collaboration or the demand for through-life engineering capabilities. This is particular helpful for companies in their transition process from traditional manufacturers to services providers, as observed in the pilot application cases.

The definitions and categorisations of the configuration elements and the capture of strategic intents, in this paper have been piloted in two complex equipment service providers: case Y and case Z. Case Y is a complex equipment designer and manufacturer. It is the regional operation of an international defence company. Case Y employs approximately 2,600 people at over 50 sites in the operational areas of global network, marine, air and land. Case Z is a regional scale equipment and maintenance service provider. It employs about 2,500 people in the operational areas of aerospace, land, marine and electronic systems. Case Z's engineering operations are dispersed in a large number of centres across the region. The two companies are currently in the process of post merger integration. The merged business aims to be the leading through-life capability partner of the local government.

For each of the pilot cases, the engineering network configurations were mapped through interviews with groups of front-line managers and in workshops involving senior engineering managers. The configuration framework was used to capture the 'current state' and providing a basis for exploring reconfiguration options for the merged business (see Figure 4).

Both cases give relatively high priority for innovation in concept development. Achieving greater efficiency is the key strategic intent in manufacturing and support, while short/medium term flexibility and innovation is required to respond to well-established platforms and capability inadequacies (especially for case Z). Case Z' engineering operations focus more on service and customer support. Therefore, its engineering resources are relatively dispersed and independent; its operating processes tend to be adaptable and informal; its governance system is relatively decentralised; its support systems are more customised to local needs; and its relationships with suppliers are relatively weak. All the configuration features of the above two cases reasonably comply with the archetype expectations of product-centric and service-centric organisations, and are reflected in the conceptual framework (Figure 3) except for the relationship with customers. In theory, a service oriented engineering network like case Z should have stronger relationship with customers or users. But the mapping result shows that case Y and case Z have a similar level of partnership with customers; and case Y's relationships with customers are perhaps even stronger. The active transition of case Y into progressively more service based operations, and the consequent mindset changes this brings, may influence the mapping outcome.

The pilot cases also demonstrate the need for integrating product- and service- oriented configuration features. The proposed configuration profile for the merged business (see Figure 4) encompasses configuration features from both product orientation and service orientation.

The feedback from the pilot case studies shows that the framework provides a common language which will help dispersed engineering centres and different functions communicate with each other to achieve good consensus or identify common problems. At the same time, the working tools developed from this framework (e.g. tools to identify key success factors, to assess strategic intents, or to generate and evaluate configuration options) help demonstrate a high-level vision of a company's engineering network while breaking the whole issue into manageable elements. This will facilitate companies to form their global engineering strategy and to identify the critical issues in the process of transition.

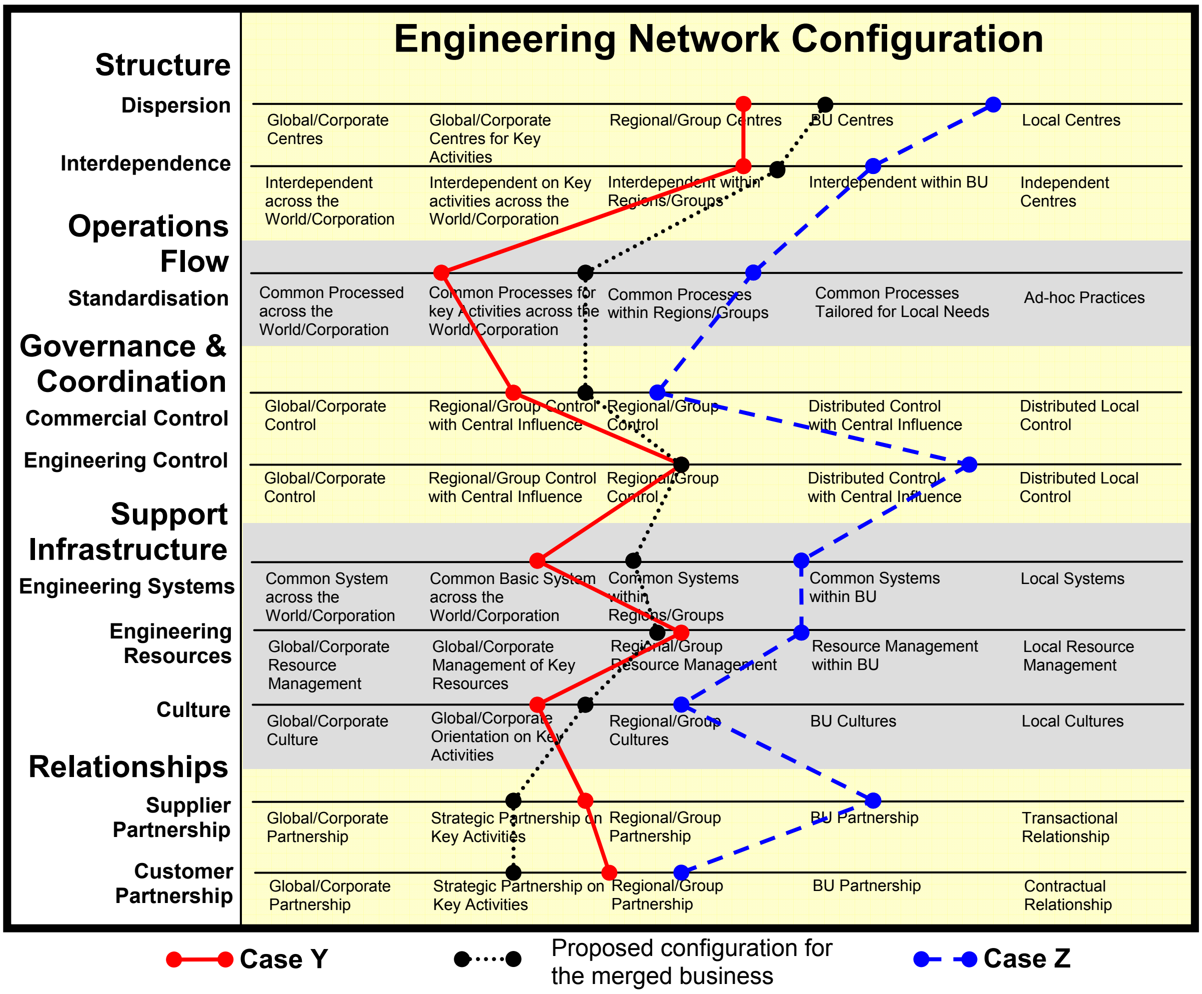

Figure 4. Engineering network configurations of case Y and case Z.

Future research will further develop the framework through in-depth case studies across a variety of industry sectors. The follow-up study will pay particular attention to the comprehensiveness of the configuration elements and their inter-relationships, as well as the potential trade-offs between performance preferences or strategic intents. At the same time, organisational characteristics of engineering networks to achieve specific strategic intents will be captured. Typical combinations of the configuration elements (or configuration archetypes) will be identified in a wider range of business saturations. Configuration features of service oriented engineering networks and product oriented engineering networks will be further investigated.

5. CONCLUSION

This paper demonstrates different organisational requirements for engineering activities along the product lifecycle with a focus on product oriented engineering operations and service oriented engineering operations. It reveals the intangible, customer involving and relationship based nature of services, and assesses its impact on engineering operations. At the same time, this paper identifies the key elements of ‘engineering network configuration’, including network structure, processes, governance, support and relationships. These elements could be configured into consistent constellations with strategic intents for efficiency, innovation and flexibility. This paper concludes by integrating the above insights and proposes a conceptual framework for engineering network configuration along the product lifecycle.

Theoretically, this conceptual framework extends the theory of engineering network configuration from product oriented engineering operations to service oriented engineering operations. It improves the understanding of integrated product and service systems from an organisation perspective. It also contributes new insights to the knowledge domains such as organisational configuration, network organisations, product lifecycle management, and service science. Practically, this research can support industries to effectively design and operate their engineering networks for integrated product and service offering. The transition challenges in moving to a service oriented business are highlighted as the critical engineering dimensions in a service environment have been identified.

However, the framework stems from three strands of research, i.e. global engineering networks, international supply networks and international manufacturing networks. This obviously provides benefits in cross-discipline learning; but at the same time brings challenges in consistency and compatibility. Further integration and more empirical studies would improve the validity and reliability. Future research will refine and test the framework, thus far validated in a number of exploratory cases and piloted in two complex equipment service providers. These follow-up in-depth case studies will aim to identify the configuration features of engineering networks in different service contexts and explore the transition themes in further detail, not least the impact on human resources, people and culture aspects, required capabilities, and performance measures.

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