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Engineering Network Operations for International Manufacturing: Strategic Orientations, Influencing Factors and Improvement Paths

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Abstract: Engineering operations support international manufacturing networks (IMN) by improving IMN capabilities. The literature has recognised engineering networks (EN) with different strategic orientations (e.g. efficiency, innovation and flexibility); explored IMN capabilities in four key areas (i.e. accessibility, thriftiness ability, manufacturing mobility and learning ability); but provided diverse views on their possible connections. Especially, the received wisdom offers little guidance on how EN may enhance IMN capabilities. At the same time, the challenges of making effective decisions at the EN-IMN interface are compounded by a large number of influencing factors that are interrelated in complex ways. To cope with these challenges, the paper reveals four ways that EN may contribute to IMN capabilities, identifies 15 key influencing factors, and suggests optimal paths to enhance IMN capabilities based on the interpretive structure model (ISM) method.

Keywords: International Manufacturing Network (IMN), Engineering Networks (EN), Network Capabilities, Influencing Factors, Interpretive Structure Model (ISM)

1. Introduction

With increasing competition and emerging opportunities in the global economy, international manufacturing networks (IMN) have been developed to create greater value for companies by taking advantage of lower cost resources, better information and knowledge bases, and closer access to new markets (Ferdows, 1997; Shi and Gregory, 1998; Koren, 2010). At the same time, the process of internationalisation has introduced new challenges in dealing with increasingly dispersed production and innovation activities at different geographic locations (Zhang and Gregory, 2013, de Treville et al., 2017). It is critical to understand how to really achieve these benefits and to effectively cope with the challenges of IMN through improved network operations (Vereecke et al., 2006; Jonathan et al., 2014; Zhang et al., 2016).

There is a consensus in literature on a close link between engineering networks (EN) and IMN in general (Shi and Gregory, 1998; Hayes et al., 2005; Zhang and Gregory, 2011; Zhang et al., 2013). But existing studies provide diverse views on possible EN-IMN interactions. In addition to a logical assumption that the progress of IMN will enhance engineering performance as the result of cross-border learning and sharing of good practice, some scholars believe that optimising EN as a precursor improvement will enhance IMN capabilities thanks to a better degree of manufacturability and production stability (Tani and Cimatti, 2008). Recent empirical evidences have been identified to support the significant contribution of EN to the output of machinery manufacturing operations (Houssein et al., 2015). There are also studies suggesting a concurrent improvement of EN and IMN as required by the overwhelming complexity and dynamics in international operations (Giret et al., 2016). An important line of development is to adopt concurrent engineering for manufacturing (Kristianto et al., 2017) and especially in digital manufacturing operations (Tchoffa et al., 2016). Furthermore, there are recommendations to integrating these two areas of operations through adopting an engineer-to-order business model for manufacturing (Azevedo et al., 2016) or an overall engineering framework for service-oriented intelligent manufacturing systems (Giret et al., 2016). Nevertheless, these studies are mainly focused on the technical aspects of network operations and hardly address the broader range of operations management matters which are critical to international production and innovation in the contemporary business environment (de Treville et al., 2017). In this research setting centred at the EN-IMN interface, we think it is rightly necessary to investigate how exactly these two areas of operations are interrelated in a view to exploring effective ways that EN may enhance IMN capabilities.

Be specific, existing studies recognised three primary value creation approaches of EN (Zhang and Gregory, 2011; Zhang et al., 2016). The first is the efficiency oriented approach to helping manufacturers gaining cost advantages. The second is the innovation oriented approach to establishing technology leadership and creating high value added products and services. The third is the flexibility oriented approach to providing adaptive solutions (even proactively) for changing customer needs. Albeit that EN with these strategic orientations may have significant implications for IMN, the existing literature provides diverse and often conflicting views on how to make effective EN decisions to support manufacturing operations in an international context. Some researchers consider a high degree of centrality as an effective approach (Fershtman and Gandal, 2011), whilst others believe in a lower degree of centrality to address diverse operational needs (Smith and Shalley, 2003). Some researchers promote a well-defined network structure (Canonico et al., 2010), but others argue that a rigid boundary may become a barrier (Chakravorti, 2004). More examples include conflicting views on the need for professional trust vs. explicit contracting arrangements in network operations (Chinowsky et al., 2010); on the effect of having more or less participants in a network (Cantwell, 2011), etc. These confusing viewpoints in literature provide little help for researchers to possibly understand EN-IMN interactions or for practitioners to manage their network operations effectively.

The paper sets out to investigate the EN-IMN relationship through addressing these knowledge gaps, aiming to find out how to effectively manage EN to enhance IMN capabilities. In the rest of the paper, the relevant literature will be reviewed to form theoretical foundations; the connections between EN and IMN will be analysed; and the influencing factors will be identified. After reporting EN configuration characters and the results of path analysis with the interpretive structure model (ISM) method, their implications for IMN will be discussed, and directions for the future research will be suggested.

2. Literature Background

2.1 The IMN

The traditional research on international manufacturing was mainly focused on the production of physical products (Spring et al., 2017). Nowadays, an increasing research interest has been given to intangible resources and services, with an aim to cultivate competitive advantage through effectively integrating knowledge, information and resources (Omid and Mahmoud, 2014). The focus of IMN research is also expanding to include activities along the whole value chain (Spring et al., 2017). From an organisational perspective, various strategic roles can be assigned to individual factories focusing on various value creation activities in IMN beyond production, e.g. design, packaging, delivering, or servicing (Ferdows, 1997; Verrecke et al., 2006; Pekkola, 2013). Besides the role of an individual factory, IMN literature has also studied the whole network which requires factories to be coordinated and managed in line with its strategic objectives. Some IMN scholars consider their research scopes involving both the network level and the factory level issues by analysing how the change of a factory's role may affect the network and the other factories in the network (Cheng et al., 2011; Feldmann et al., 2013). In brief, existing IMN studies largely remain with intra-network issues by focusing on the role of individual node (site) or the relationship between one node and the whole network.

Obviously, there is a dearth of studies to understanding the relationship (and interactions) between IMN and network operations focusing on other closely related functions such as EN (Cheng et al., 2012; Zhang et al., 2013). The manufacturing capability approach provides a promising direction to study issues at the IMN-EN interface because it can help researchers to cope with the increasing complexity and dynamics in the contemporary operations contexts and in doing so to address the limitation of the traditional process choice approach in operations management (Prahalad and Hamel, 1990; Hayes and Pisano, 1994; Hayes et al. 2005; Shi and Zhang, 2017). In this paper, we focus on the four strategic capabilities of IMN as initially recognised by Shi and Gregory (1998) - strategic resource accessibility, thriftiness ability, manufacturing mobility and learning ability.

2.2 EN Strategy Orientations and their Contribution to IMN

Engineering can be broadly considered as the discipline, art, skill and profession of acquiring and applying scientific, mathematical, economic, social, and practical knowledge, in order to design and build structures, machines, devices, systems, materials, and processes (Zhang et al., 2014). With the trend of internalisation, engineering activities form a network of complex interactions among dispersed resources (Koendjbiharie et al., 2010). Zhang and Gregory (2011) suggested three strategic orientations in a wide range of engineering activities (focusing on specific tasks, e.g. R&D, new product development, services, etc.) along the whole value chain from idea generation, design and development, production and delivery, to service and support, recycling and disposal. The wider implications of these strategic orientations have been discussed by Zhang et al. (2013) with the context-capability-configuration framework. Zhang and Gregory (2016) extend the discussion by identifying essential network capabilities for global engineering services which may possibly enhance IMN capabilities in various areas.

2.2.1. Efficiency orientated EN

The goal of this kind of EN is to meet IMN objectives by using available resources more efficiently and improving performance through more efficient operations to guarantee profitability and reliability (Heikkilä, 2002; McGuire and Dilts, 2008). In doing so material and information flows can be well controlled; cost reduction can be achieved (e.g. total cost, product cost, or process cost); and inventory capacity (Danese and Romano, 2011) can be better managed. In general, efficient EN can help IMN achieving better financial performance as well as meeting budget, time and quality requirements through obtaining, transferring, controlling and integrating resources in an efficient way, and thus improving IMN thriftiness ability and resource accessibility.

2.2.2. Innovation orientated EN

Innovation orientated EN will support IMN in three aspects- products, processes and systems (organization or administrative) innovation (Kim et al., 2012).

- Product innovation. This kind of EN has a high level of research and development (R&D) inputs, and a high rate of new product/service introduction (Hagedoorn and Cloodt, 2003). Their key feature is novelty that can hardly be imitated by competitors (Alegre and Chiva, 2007). This allows IMN to create new products and services for international markets, attracting new customers and keeping a high degree of customer loyalty. IMN's accessibility to new markets will thus be improved.
- Process innovation. This kind of EN creates new working processes and introduces new initiatives to improve manufacturing and servicing operations through continuous improvement and knowledge sharing. This contributes to network learning especially when the learning of intangible knowledge is critical. IMN accessibility to new knowledge and learning ability will thus be improved.
- System innovation. This kind of EN explores new business models and new concepts of operations (Liao et al., 2008) leading to substantial benefits to IMN. Through system innovation, IMN can not only change its organizational structures and routines (and thus having better manufacturing mobility); but also make a better use of strategic resources.

In summary, innovation orientated EN can enhance IMN learning ability, mobility as well as accessibility to new markets and new knowledge.

2.2.3. Flexibility orientated EN

This kind of EN responds to changes quickly (Gong and Janssen, 2012), and thus continually meeting the changing needs of customers (Gunasekaran et al., 2001) as well as offering customised services or products for different customers (Cheng et al., 2015). Flexibility can also be reflected in many other aspects, e.g. shorter lead time to introduce new products/services, quicker response to a product or service request (Schütz and Tomasgard, 2011), faster to restructure a collaborative business network, shorter time to reconfigure organizational processes, shorter time to meet unexpected order changes (Das and Abdel-Malek, 2003), etc. This kind of EN allows IMN to be more adaptive to external changes through effective collaboration among network participants, and thus enhancing IMN mobility. Quick response allows IMN to enter new markets faster, and short reconfiguration time can help IMN meeting customer requirement changes more effectively. These in general will contribute to IMN mobility and accessibility to market.

By summarising key points from the above discussions, Figure 1 presents EN-IMN linkages focusing on the four IMN capabilities areas (Shi and Gregory 1998). Specifically, EN efficiency contributes to IMN thriftiness ability; EN innovation contributes to IMN learning ability and accessibility to new knowledge; and EN flexibility contributes to IMN mobility and accessibility to markets. These strategic orientations often co-exist in a particular EN.

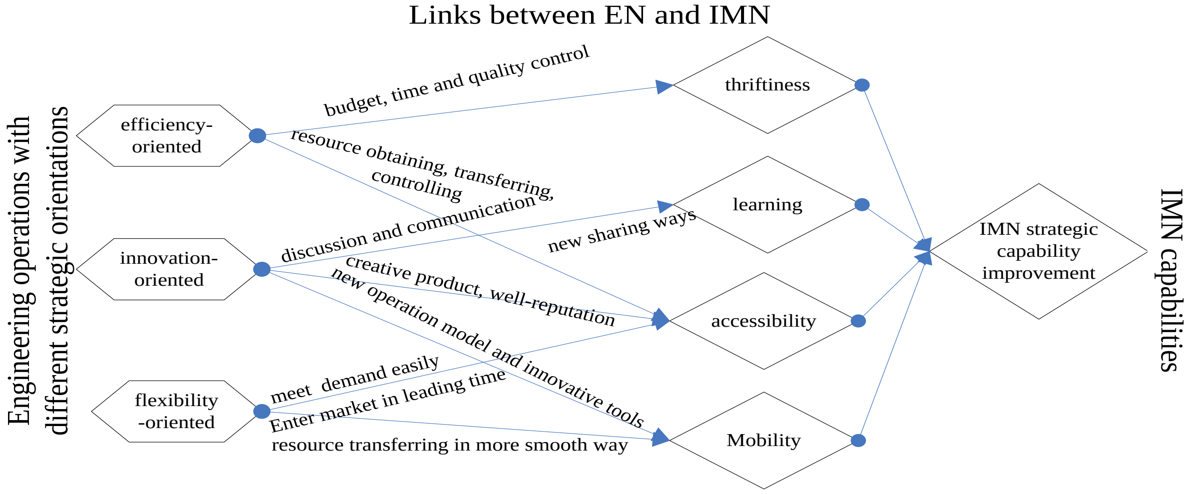


Figure 1. IMN capabilities and EN-IMN connections

2.3 Four Ways of EN contributing to IMN capabilities

An engineering network (EN) in this context stands for the network of dispersed engineering resources to achieve some common strategic objective of a focal organisation. EN contributes to manufacturing innovation as well as optimising manufacturing processes (Zhang et al., 2013) through the application of engineering knowledge (including engineering technologies, skills and expertise) in effective problem-solving (Zhang et al. 2016). It allows manufacturers to access a wide range of resources, knowledge and market opportunities (Koendjbiharie et al., 2010), which can enhance their learning capabilities and create successful products and services (Kuei et al., 2011; Cheng and Johansen, 2014). EN's contribution to IMN capabilities can be analysed from the following four perspectives as illustrated in Figure 2.

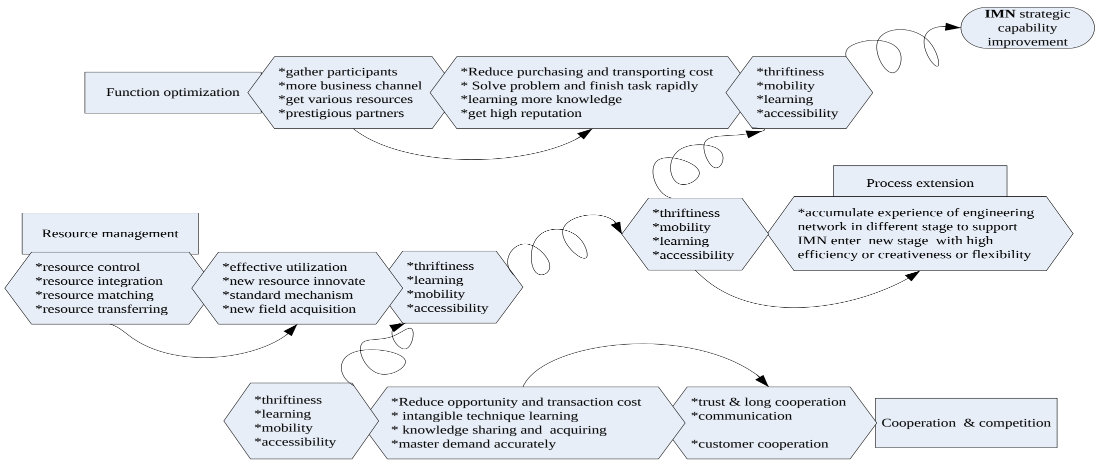


Figure 2. Four ways of EN contributing to IMN capabilities

The first is from a functional perspective (Sanchez et al., 2010). The relevant studies (e.g. Walter et al., 2001) consider that network value can be added from volume function (preventing fragmented purchases), safeguard function (guarantees a certain level of supply), innovation function (cooperation among agents), and market function (exchanges with prestigious partners), etc. EN can bring various participants together to improve the volume function and reduce purchasing and logistics costs, and thus enhancing IMN thriftiness. It can access more business channels to improve its safeguard function and can complete a task more rapidly, and thus enhancing IMN mobility. At the same time, EN can assemble various resources to improve its innovation function, which will improve learning and accessibility to new knowledge. Finally, the involvement of prestigious EN partners is helpful to improving IMN reputation, and thus enhancing market accessibility.

The second is from a relationship perspective. It has been pointed out that collaborative relationships are beneficial to manufacturers by introducing new opportunities to achieve superior results (Ulaga, 2003; Lee et al., 2012). The social network formed in global engineering operations among manufactures, customers, suppliers and strategic partners can help IMN improve production capacity. EN collaboration can increase the sharing of good practice and improve communication among participants, which provides an good access to intangible knowledge. At the same time, close collaboration with customers allows IMN to meet customers' requirements more accurately. In summary, EN improves IMN strategic capabilities through interactions of network participants with complementary and mutually beneficial relationships (He et al., 2012).

The third is from a resources-based perspective to create value by combining various resources.

It has been widely believed that value is created in the process of resources transformation and integration (Cristina et al., 2010); and that value creation through integrating intangible resources can hardly be imitated by competitors (Michel et al., 2008). EN not only helps IMN improve resources allocation and utilisation with effective routines, but also helps IMN improve resources transformation and integration with high value-adding initiatives (Zhang et al. 2016).

The fourth is from a process perspective. Value can be created at different stages of the manufacturing process. For example, research techniques that have concentrated on capturing customers' previous experiences with a product or service can be used for ideas generation (Witell et al., 2010). Service operations are also becoming increasingly intertwined with production activities, and the value delivered to customer is not only through products but also through services (Hallikas et al., 2014). In this context, EN can help IMN integrate critical value creation activities beyond production. Zhang and Gregory (2011) point out that an engineering value chain consisting of interrelated activities at various stages (idea generation, design and development, production and delivery, service and support and recycling and disposal) will help IMN create value from the perspective of process integration.

Figure 3 presents an overview of connections at the EN-IMN interface as discussed so far. It is clear that through these connections, EN with three strategic orientations can contribute to IMN capabilities in four possible ways. The next research task is then to find out how to make effective decisions around these connections.

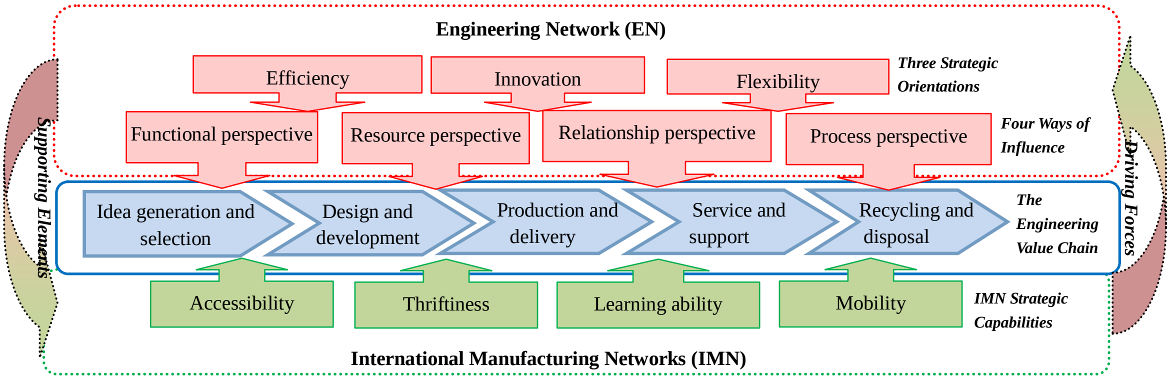


Figure 3. Connections at the EN-IMN interface

3. Research Approach

3.1 Influencing factors and strategic orientation confirmation

The optimal path for an EN to support IMN capabilities may change when its strategic orientation alters. Therefore, the first research task is to confirm EN's strategic orientation based on a configuration framework. This includes two steps. The first is to develop a configuration framework supported by influencing factors analysis. The influencing factors have been selected based on literature review and experts consultation. Experts are from academic and industrial fields (who hold senior roles in areas closely related to EN and have a proper degree of familiarity with IMN). We first identified 52 factors based on literature review, and the list was reduced to 44 factors after an internal peer review to remove the ones with little relevance to EN and IMN. An initial categorization was developed, and the 44 factors were grouped into five main categories and 16 sub-categories. We finally confirmed the framework with 5 main categories and 15 sub-categories with a number of factors merged or regrouped. We can then progress to the second step to assess the configuration characteristics of an EN with a 0-1 judging method and thus confirming its strategic orientation.

3.2. Influencing paths analysis

Two issues should be considered in order to make effective EN decisions to enhance IMN capabilities. One is to identify the most important influencing factors, and the other is to understand the interacting mechanisms among these factors.

Two rounds of surveys were conducted to identify the importance of influencing factors. These two surveys were the same but with the latter one serving as a robustness test. In each survey we selected twenty participants. We selected academics who are working in the related areas, such as international production, manufacturing networks, international engineering operations, and engineering network design, to ensure a comprehensive profile of inputs; and at the same time we selected industry experts across sectors, such as aerospace, automotive, electronics and engineering services, to make sure that our conceptual developments are well grounded in practice. For each survey we asked the participants to choose the three most important factors for network efficiency, innovation and flexibility respectively after explaining to them the characteristics of these three types of EN. We then calculated the results to confirm the most important factors. Considering that academics and industry experts might have different views on the importance of these factors, we completed a comparative analysis of the results between the academics and industry experts. Results from the second and the first surveys consistently matched each other. We therefore concluded that the results were stable and no need for any further survey input.

After confirming the importance of these factors, the relationships among them can be further studied. The available methods to do that are mainly from two categories. One is the quantitative analysis method such as the structural equation modelling method (SEM) and the system dynamics (SD) method. They confirm factor relationships based on data of large scale samples. SEM focuses on the current static structure among factors, while SD focuses on the dynamics and future predication based on the discovered factor influencing rules. These two methods may get accurate influencing coefficient among factors, but the results are heavily data driven and may not closely reflect actual practices in industry. In addition, we have identified a large number of influencing factors, which would demand huge efforts in data collection to possibly reach some meaningful result. This made this quantitative category an infeasible choice in our studies.

The other is based on expert experience. Some method can only offer a structural concept (e.g. the connectance model) to develop possible options (Tan and Platts, 2004). In a research setting like our studies where a large number of influencing factors are identified, computer tools are expected for action plan selection, which is beyond our existing expertise. We finally adopted the Interpretive Structure Modelling (ISM) method because it only requires experts to judge the interacting relationship of the factors; and at the same time it is capable of suggesting exact directions of improvement which is a key objective of our research.

Based on the initial development of Warfield (1974), ISM transforms unclear, poorly articulated models of the system into clearly visible, well-defined models that can be used for various purposes (Sage and Smith, 1977). The analysis process can deal with complex relations among the large number of influencing factors involved in our studies (Talib, 2011), which allows us to develop several types of structures, including influence structures, priority and categorisations, etc. The method has been widely used in a wide range of operations settings to identify factors interacting mechanisms. This paper therefore analyses factors interacting mechanisms of different kinds of EN based on ISM, since a distinct interacting mechanism among underlying, transforming and surfacing factors allows a company to focus on on the most important EN-IMN connections. As suggested by similar studies that adopt the ISM method, the findings can help managers to gain an overall understanding of the influencing factors and their interacting mechanisms, in a view to taking actions to enhance IMN capabilities.

4. Confirming the Strategic Orientation of EN

4.1 Influencing factors of EN

Operations management researchers have dedicated consistent efforts to understand network configuration characters by studying their influencing factors. For example, Srai and Gregory (2008) study supply networks from four types of factors: tier structure, shape and location; unit operations and their internal manufacturing processes; roles and relationships; and product structure, complexity and composition. Thorgren et al. (2009) identify network size, bottom-up formation and size of administrative function to analyse its influence on project network innovation performance. Zhang et al. (2011) put forward five aspects of global engineering networks- network structure, operations processes, governance systems, support infrastructure and external relationships. These studies suggest key categories of factors including network character, network relationship, network support, network governance and network environment, which will be further developed through a more comprehensive literature review and case study validation.

4.1.1 Network Character

*N*etwork structure, participants, and resources are three important aspects of network character.

(1) Network Structure (S_1). Network centrality (Fershtman and Gandal, 2011) is highly associated with network efficiency thanks to centralised decision making and standards. However, the downside of network centrality is that it can assimilate diverse views and ideas needed for innovation (Smith and Shalley, 2003). It has also been believed that a clear structure boundary enhances network efficiency (Koendjbiharie et al., 2010) for its obvious benefit of resources allocation, and every participant pays full attention on its tasks in the well-defined network structure (Canonico et al., 2010). But a rigid boundary and a high degree of hierarchy may become a barrier for information and experiences sharing which will restrain creativity and flexibility in the network (Chakravorti, 2004).

Furthermore, networks with a highly complementary and reciprocal structure have a greater tendency for integration and collaboration (Pullen et al., 2012). Network members in the reciprocal structure know each other well, and have more common and mutual knowledge. While some researchers believe that it is better for network participants not to know each other too well, for example Kratzer et al. (2010) suggest that newcomers, who may offer more complementary information and new knowledge, can effectively support innovation in a network. In general, the long established reciprocal structure is preferred in an efficiency oriented EN, and the diverse complementary structure may work better for an innovation oriented EN.

(2) Network Participants (S_2). It has been observed that the requirement to access new competences correlates positively with the number of network participants involved. Thorgren et al. (2009) examined the influence of the number of participants (network size) on network performance. The results reveal that larger networks achieve greater innovation performance. A larger scale will also improve network efficiency for abundant supply of resources, whilst the large scale of operations may reduce network flexibility.

Participant types also influence network operations. Networks with multiple participant portfolios and constellations have better opportunities to access diverse resources, which have a positive influence on network innovation. Possible combinations of various participants along the engineering value chain may improve network flexibility. While participants with diverse objectives may possibly cause conflicts within a network, faulty project conceptualisation, and aggressive competition among participants, which will adversely affect network efficiency (Jha et al., 2006).

(3) Network Resources (S_3). Intangible resources, especially knowledge, skills and experiences, are the most important resources of EN (Zhang et al., 2014; Zhang et al., 2016). Broad diverse knowledge can enrich the resource pool of EN while in-depth specialised knowledge will lead to high quality ideas for innovation (Laursen and Salter, 2006). The importance of tangible resources such as equipment and facilities still remains since they are fundamental to engineering project delivery. In addition, resources abundancy is critical for EN in an uncertain context, which will directly influence network flexibility.

4.1.2 Network Relationship

Knowledge sharing, communication and relationships are important for effective network collaborations, and thus influencing network performance.

(4) Sharing among Network Participants (S_4). Knowledge sharing is critical in an innovation oriented EN. Information sharing (especially targeted information sharing) enhances the efficiency of engineering project delivery, which can ensure that each participant knows the progress of other participants, and adjusts its operations for the benefit of the whole network (Alderman et al., 2005).

(5) Communication among Network Participants (S_5). Proper information exchange will

improve network innovation. However, excessive information exchanges may jeopardise the efficiency of an engineering project (Chinowsky et al., 2012). Jayaram et al. (2011) suggests that communication between customer channels is negatively related to network flexibility (the small size effect); and not so cohesive communication with customers and suppliers will improve flexibility. Network participants are expected to communicate directly, and work together with a common goal to improve innovation (Gronum et al., 2012, Kratzer et al., 2010).

(6) Relationship Types (S_6). Besides formal contractual agreements, professional trust within a network (Chinowsky et al., 2010) is needed for communication and coordination. Cantwell (2011) shows that having redundant relationships will increase network complexity, and thus harming its performance. The structural-hole theory sees cohesive ties as a source of rigidity that hinders the coordination of complex tasks; and managers within cohesive communication networks are less likely to adapt to changes (Gargiulo and Benassi, 2000).

4.1.3. Network Governance

(7) Conflicts and Emergency Resolving Procedures (S_7). Foreseeing network evolution can improve mutual understanding within a complex network (Kim et al., 2011), and thus making network configurations less error-prone. EN with different strategic orientations will face different conflicts and problems, so different governance priorities are required (Maylor et al., 2006). For example, resources/tasks conflicts control should have the highest priority in efficiency oriented EN; and the control of an innovation oriented EN should focus more on ideas or concepts conflicts.

(8) Monitoring, Controlling and Performance Management (S_8). Monitoring/controlling cost, schedule and quality (Vaithiyalingam et al., 2010) can lead to continuous improvement for network efficiency. Reflection on previous experiences can enhance managerial skills, which should be prioritised in an efficiency oriented EN (Thakurta and Ahlemann, 2010). For a flexibility oriented EN, it is hard to set standards in every aspect for all the participants due to a high degree of diversity among local standards. Therefore, it is important to allow a certain degree of risk taking and uncertainty in a flexibility oriented EN.

(9) Scheduling and Resources Allocation Mechanisms (S_9). Scheduling and resources allocation are necessary for the efficient use of scarce resources (Elonen and Artto, 2003). Safeguarding necessary resources for R&D activities are critical for an innovation oriented EN (Katsuhiko et al., 2010). Keeping slack resources and adopting soft scheduling are often emphasised in a flexibility

oriented EN.

4.1.4. Network Support

(10) Learning and Training Approaches (S_{10}). Effective knowledge management among network participants is a catalyst for co-creating innovative ideas. However, as network participants come from different disciplinary and organisational backgrounds, it is a major challenge to keep everyone focused on the same target (Cormican et al., 2007). An innovation oriented EN should avoid using conflicting methods since they can result in obstacles to effective learning (Lee et al., 2009). For an efficiency oriented EN, maintaining common standards is necessary to keep different participants at the same pace. Effective learning from changing customer needs are important for a flexibility oriented EN.

(11) Information Management and IT Infrastructure (S_{11}). Poor information quality leads to poor decision making (Blichfeldt and Eskerod, 2008). Having sufficient information about the overall progress of a network as well as about specific tasks is essential to improve network efficiency (Formentini and Romano, 2011). Having diverse and dynamic information is emphasised for network innovation; and it is critical to handle information exposure properly for network flexibility (Sverre et al., 2010).

(12) Engineering Tools (S_{12}). Engineering tools support a wide range of operations tasks from conceptualisation to production and delivery. Tools for resources allocation and activities coordination are essential for network efficiency. IT compatible tools are crucial for network flexibility (Srivastava et al., 2001). Tools to facilitate the generation and development of creative ideas are required for network innovation.

4.1.5. Network Environment

(13) External Environment (S_{13}). EN flexibility is not only influenced by regulations and institutional structures, but also by employment laws, environmental policies and economic cycles (Akinci and Fischer, 1998). These factors should be closely examined in different types of network operations, for example EN in a relatively stable environment can improve its efficiency, in a dynamic environment should explore innovative options and improve flexibility (Zhang and Gregory, 2013).

(14) Internal Environment (S_{14}). Having an open working environment (Nakagaki et al., 2012) will improve knowledge co-creation, and thus contributing to idea generation and innovation. A

flexibility oriented EN will promote an adaptive working environment (Spohrer and Maglio, 2008). An efficiency oriented EN will require an abiding working culture to maintain standards within a common structure.

(15) Engineering Environment (S_{15}). Interdependence (between engineering tasks and participants) of an engineering project will affect network efficiency and flexibility (Chinowsky et al., 2011). For example, the interdependency between sub-tasks will lead to difficulties in project scheduling, and thus reducing efficiency. Meanwhile, the interdependency between network participants will affect network integration, and thus influencing flexibility. Engineering task changes will negatively affect network efficiency (Cha et al., 2012); and tasks within a tight timeline require participants to pay attention to completing these tasks on time, which has a negative effect on innovation.

The above analysis suggests fifteen factors that have a significant influence on EN and its contribution to IMN capabilities. They are aggregated from studies in different operations contexts, e.g. project networks, R&D networks, manufacturing networks, supply networks or business networks in general. Case studies have therefore been conducted to validate and refine these factors for our studies (see Appendix 1 for a brief outline of the relevant case analysis). The process started with Internet search to get generic information about possible cases with a potential to help us assess varying network configurations with strategic orientations suggested by the literature review and the research framework (see Table 1). We then approached them for participation through available contacts. For the sample cases presented in Appendix 1, informants (i.e. managers with relevant responsibilities) were suggested by the companies and interviews were conducted by following the suggested schedules. Over 30 interviews were conducted, and each took about 1 hour. After that we produced the interview transcripts and validated them through emails or phone calls with the informants. The transcripts were then analysed by following the coding and pattern-matching methods suggested by Yin (2009) around the key categories presented in Table 1.

4.2 Strategy Orientation Confirmation

Table 1 lists the 15 influencing factors relevant to EN and IMN capabilities. They will help us to confirm EN with different strategic orientations and to identify their optimal paths to enhance IMN capabilities.

Table 1. Network influencing factors and configurations with three strategic orientations

Influencing factors		Influencing ways	Network configurations with three strategy orientations		
			Efficiency oriented	Innovation oriented	Flexibility oriented
Network Character	S_1	Network Structure	stable, reciprocal structure	complementary, diverse structure	open boundary, low-hierarchical structure
	S_2	Network Participants	a large number of participants	diverse participants	compatible participants
	S_3	Network Resources	broad, diverse resources	in-depth, specialised resources	abundant resources
Network Relationship	S_4	Sharing among Network Participants	systematic, regular sharing	in-depth, multi-channel sharing	pro-active, task-focused sharing
	S_5	Communication among Network Participants	formal, sufficient communication	informal, not so excessive communication	not so cohesive communication
	S_6	Relationship Types	contractual relations, low redundancy	strong ties, professional trust	weak ties, low cohesion
Network Governance	S_7	Conflicts and Emergency Resolving Procedures	resources/tasks conflicts	idea/concept conflicts	network evolution
	S_8	Monitoring, Controlling and Performance Management	continuous review and improvement	generic performance	risk and uncertainty
	S_9	Scheduling and Resources Allocation Mechanisms	fully utilising key resources	ensuring R&D resources	managing slack resources
Network Support	S_{10}	Learning and Training Approaches	focusing on operating processes and standards	focusing on working methods	focusing on project and change management
	S_{11}	Information Management and IT Infrastructure	task specific information	diverse and dynamic information	information exposure of changes and risks
	S_{12}	Engineering Tools	tools for control and resources arrangement	tools to facilitate creativity	tools for managing changes and interfaces
Network Environment	S_{13}	External Environment	complex and relatively stable environments	dynamic and relatively simple environments	dynamic and complex environments
	S_{14}	Internal Environment	abiding working culture	open working culture	adaptive working culture
	S_{15}	Engineering Environment	interdependence of engineering tasks	interdependency of technology areas	interdependence of participants

The current literature is mainly focused on some of these influencing factors under certain strategic orientation without considering interactions among multiple orientations together, i.e. existing studies rarely analyse the influencing factors systematically within an overall framework. However, it is critical to understand how these factors interact across different strategic orientations to possibly enhance IMN capabilities in practice. The influencing factors that managers are familiar with are often limited to some specific area. As the result, the relative importance of influencing factors can hardly be confirmed due to the lack of a systematic view on these factors. Critical interactions among influencing factors might be neglected or misunderstood, which are especially dangerous in complex network operations. The paper has developed the following method to addressing this knowledge gap. First, characteristics of the fifteen influencing factors are identified with different strategic orientations. Second, the suitable strategic orientation for a single factor is confirmed. Third, the relevance of these fifteen factors is provided to possibly confirm a particular strategic orientation. The method will also evaluate the factor’s importance for strategy selection, and confirm each factor’s weight and then calculate the total score of each strategic orientation. The strategic orientation with the highest matching score will be the one at which the network should target for future improvement.

With reference to the 15 influencing factors (see Table 1), we have developed a judging matrix, i.e. if the i^{th} (i=1, … , 15) factor reflects the j^{th} (j=1,2,3) strategic orientation, then X_{ij} is 1, if it does not reflect the j^{th} strategic orientation, then X_{ij} is 0. When one factor character is suitable for two strategic orientations, the both scores are 1. This will then give us the 15 * 3 matrix. Accordingly, based on the weight of each character the total score of each strategic orientation can be obtained. The strategic orientation with the highest score is then identified as the most appropriate one for that network.

5. The Importance of Influencing Factors

A systematic survey was used to confirm the importance of influencing factors for different kinds of networks. In the first survey we choose twenty experts who work in different areas of EN and with a broader view of IMN, including nine academics and eleven managers. In order to test the robustness of the survey results, we did a second round of data collection with eight academics and twelve managers. In total, there were twenty three managers involved in the surveys, including six from the aerospace & defence industry, seven from the electronic device industry, four from industrial equipment, four from automotive and parts, and two from oil equipment and services, and energy distribution. The seventeen academics’ research fields included engineering design and R&D, manufacturing and engineering, servitization and international operations, etc. We calculated the accumulated scores of each factor in the first and second surveys. The comparisons between academics and industrial are presented in Table 2.

According to the survey results, the most important factors for engineering efficiency are network governance and network support. For network innovation they are network character and network relationship. The results are consistent in the first and second surveys, and in both academic and industrial aspects. However, the first survey showed that the most important factors for network flexibility are the network relationship and network character; and in the second survey it turned out to be network environment and network relationship. The interpretation of this difference could be that academics generally consider the network relationship and network character to be the most important factors influencing network flexibility, while industrial experts consider the network environment and relationship to be more important. In the second survey we had more industrial experts than the first time, so the results changed. Nevertheless, in both the first and second surveys, academics and managers considered the network environment, and relationship and network character were the three most important factors influencing network flexibility. The difference existed only in how to sequence them. Therefore, we conclude that the results from these two surveys can sufficiently confirm relations between these influencing factors and the strategic orientations.

Table 2. Results from the first and second surveys

factors		Accumulated times of factors selected as the most important three factors for network performance																							
		The first survey						The second survey						From academics						From managers					
		①	*	②	*	③	*	①	*	②	*	③	*	①	*	②	*	③	*	①	*	②	*	③	*
Network Character	(1)	4		7		1		3		3		6		2		5		4		5		5		3	
	(2)	2	9	8	**23**	7	**16**	4	9	10	**21**	5	14	2	6	6	**17**	5	**16**	4	12	12	**27**	7	15
	(3)	3		8		8		2		8		3		2		6		7		3		10		5	
Network Relationship	(4)	4		12		2		2		7		5		3		9		4		3		10		3	
	(5)	3	7	6	**19**	9	**17**	0	6	5	**13**	9	**17**	1	4	4	**13**	8	**16**	2	9	8	**20**	10	**18**
	(6)	0		1		6		4		1		3		0		0		4		4		2		5	
Network Governance	(7)	3		0		1		3		3		5		1		1		1		5		2		5	
	(8)	10	**25**	3	6	3	4	13	**32**	3	11	0	5	12	**26**	1	7	1	2	11	**31**	5	10	2	7
	(9)	12		3		0		16		5		0		13		5		0		15		3		0	
Network Support	(10)	3		9		5		2		8		1		3		9		1		2		7		5	
	(11)	6	**15**	1	10	2	10	3	**11**	4	12	5	7	4	**12**	3	12	3	7	5	**14**	2	9	4	10
	(12)	6		0		3		6		0		1		5		0		3		7		0		1	
Network Environment	(13)	0		2		8		0		1		11		0		0		6		0		3		12	
	(14)	2	4	0	2	2	13	1	2	1	3	6	**17**	2	3	1	2	3	10	1	3	0	3	5	**19**
	(15)	2		0		3		1		1		0		1		1		1		2		0		2	
Total		60	60	60	60	60	60	60	60	60	60	60	60	51	51	51	51	51	51	69	69	69	69	69	69

Note: ①stands for efficiency; ②stands for innovation; ③stands for flexibility; *stands for the subtotal of five main influencing factors.

6. Interacting Mechanisms of Influencing Factors

Interactions exist among these influencing factors, i.e. some factors are the cause or result of other factors. Discovering their interacting mechanisms is necessary to possibly identify optimal paths of improvement, which can in turn help managers to recognise the most critical factors to support IMN capabilities. Three interacting mechanisms are obtained based on the method of Interpretive Structure Modelling (ISM) in the following two steps.

Step 1: Based on the viewpoints of experts, the relation among these influencing factors is shown in Table 3. If two factors have an interacting relation then the score is 1, otherwise the score is 0.

Table 3. Relation index table

Efficiency-oriented network	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
S_0	1															
S_1	1	1				1										
S_2	1		1	1												
S_3	1			1				1								
S_4	1				1	1						1				
S_5	1					1	1	1								
S_6	1						1									
S_7	1							1								
S_8	1							1	1		1					
S_9	1								1	1						
S_{10}	1										1					
S_{11}	1								1			1				
S_{12}	1									1	1		1			
S_{13}	1								1					1		
S_{14}	1								1						1	1
S_{15}	1								1							1

Innovation-oriented network	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
S_0	1															
S_1	1	1			1											
S_2	1		1	1			1				1	1				
S_3	1			1				1								
S_4	1				1		1	1			1	1				
S_5	1					1	1	1			1	1				
S_6	1						1									
S_7	1							1								
S_8	1				1	1			1		1	1				
S_9	1							1		1						
S_{10}	1										1	1				
S_{11}	1											1				
S_{12}	1				1						1	1	1			
S_{13}	1						1							1		
S_{14}	1										1				1	1
S_{15}	1						1									1

Flexibility-oriented network	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
S_0	1															
S_1	1	1	1	1	1	1	1	1				1				
S_2	1		1								1	1				
S_3	1		1	1				1								
S_4	1				1		1	1	1		1	1				
S_5	1					1	1	1	1		1	1				
S_6	1						1	1	1		1	1				
S_7	1							1								
S_8	1				1	1	1	1	1		1	1				
S_9	1								1	1						
S_{10}	1										1					
S_{11}	1											1				
S_{12}	1								1				1			
S_{13}	1							1						1		
S_{14}	1				1	1									1	1
S_{15}	1						1									1

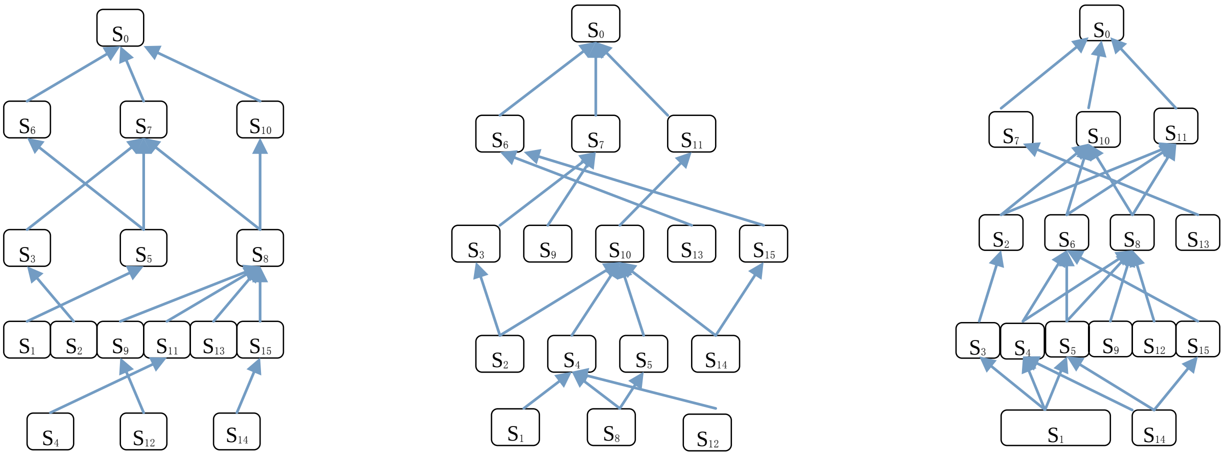
Step 2: S_i are the influencing factors, and S_0 stands for targeting strategic orientation. According to the relation index table, a reachable set of influencing factors R can be developed. $R(S_i)$ is the reachable set, and $A(S_i)$ is the antecedent set, and the common set is $R(S) \cap A(S)$. If $R(S_i) \cap A(S_i) = R(S_i)$, we delete the related rows and columns with S_i in matrix R, and then repeat the same procedure until no row remains. The first layer factor is the first time S_i meeting the requirement that $R(S_i) \cap A(S_i) = R(S_i)$. The other layers remain same.

Take network with efficiency oriented networks as an example, according to the relation index table, the reachable matrix R can be obtained. The first layer division is shown in Table 4; and the detailed procedures are presented in Appendix 2 (Tables a-e).

S_i (i=1…… 15, referring to the 15 factors) in black bold is the factor chosen for the related layer, accordingly we can get the influencing factor ISM for efficiency oriented networks. In the same way, the models for innovation and flexibility oriented networks can be found, see Figure 4.

The results show that with different strategic orientations, influencing factors interacting mechanisms are different. Among the three models, the ISM for flexibility oriented networks is the most complex one; and the ISM for efficiency oriented networks looks rather straight forward.

Factors in the ground layer for different networks are not the same. For efficiency oriented networks, sharing, engineering tools and internal environment are the most fundamental factors to optimise network operations. Sharing can help participants understand project schedules and standards. Engineering tools are important for controlling and scheduling. An abiding working environment can ensure action coherence and target cohesion, all of which are needed for network efficiency. By improving these three aspects the other factors can also more effectively support IMN capabilities. The detailed interacting mechanisms can be seen in Figure 4-(a).



(4-a) efficiency-oriented network (4-b) innovation-oriented network (4-c) flexibility-oriented network

Figure 4. Influencing factor ISM and interacting paths

For innovation oriented networks, the ground layer factors are network structure, performance management, and engineering tools. An open and low-hierarchical network structure improves sharing and communication, which can help create novel ideas. Effective performance management can motivate capability building for innovation, as well as improving enthusiasm of participants. Advanced engineering tools for design, simulation, testing and documentation are important for product design and development, which are also the essential requirement for network innovation. The interacting mechanisms among these factors to enhance IMN capabilities are presented in Figure 4-(b).

The ground layer factors of flexibility oriented networks are network structure and internal environment. An flexible network structure contributes to greater responsiveness. An adaptive working culture allows the network restructure itself with less resistance. Figure 4-(c) illustrates the detailed interacting mechanisms.

7. Implications

The above findings provide a systematic view of influencing factors of network operations and their interacting mechanisms. The result suggests that network governance is critical for network efficiency, which is in coincidence with Marjolein's (2012) view that contractual incentives and control systems (authority) are essential to guarantee network efficiency. Network character has a significant impact on innovation and flexibility as explored by Gosling et al. (2010), for example network coordinators can group partners under different categories to maintain a suitable level of flexibility by maintaining a pool of suppliers in each category. Gemiinden (1996) claimed that only a high intensity of interweavement secures process innovation success, which is in compliance with our results in the aspect that network relationship has a great impact on network innovation.

In general, this paper offers guidance for managers to enhance IMN capabilities through engineering operations in the following aspects-

(1) Strategy confirmation. Figures 1 to 3 illustrates connections between three EN strategic orientations and four IMN capabilities. Table 1 can help managers to assess and then optimise their network operations for some particular strategic orientation in line with expected IMN capabilities.

(2) Important factors confirmation. After confirming a network's strategic orientation, an analytical method is offered to help managers to identify the most important factors for different kinds of network operations (as shown in Table 2). This will allow them to more effectively to develop and deploy strategic resources to enhance IMN capabilities.

(3) Factors interacting paths. The importance of factors can not only help managers to identify the factors that need attention by horizontal comparison, but also can help managers to identify the succession and orders of factors. Influencing factors interacting mechanisms and optimal paths for different types of networks are suggested based on our studies (see Figure 4). It can help managers to understand the sequence of improvement and transformation paths among the complex improvement processes of IMN. The generic sequences are highlighted as below (an illustrative example is presented in Appendix 3):

- Efficiency oriented networks: since the ground factors are network governance and network support, the optimal path for network improvement is $S_{12} \Rightarrow S_9 \Rightarrow S_8 \Rightarrow S_7/S_{10} \Rightarrow S_0$. That means managers should update engineering tools, then improve resource allocation, refine performance management system, specify conflict resolving procedures, and finally encourage sharing of good practice.
- Innovation oriented networks: in the ground layer the most important factors are network character and relationship. Thus the optimal paths are $S_1 \Rightarrow S_4 \Rightarrow S_{10} \Rightarrow S_{11} \Rightarrow S_0$ and $S_5 \Rightarrow S_{10} \Rightarrow S_{11} \Rightarrow S_0$. The first path begins with optimising network structure, followed by improving sharing among network participants, developing an effective knowledge

management system, and upgrading IT systems. The second path begins with improving communication among network participants, followed by developing an effective knowledge management system, and upgrading IT systems.

- Flexibility oriented networks: the most important factors in the ground layer are network relationship, character and environment. The optimal path is $S_1/S_{14} \Rightarrow S_4/S_5 \Rightarrow S_6 \Rightarrow S_{10}/S_{11} \Rightarrow S_0$. It suggests improving network structure and internal environment at the beginning. Managers can then improve network relationship by encouraging sharing and communication among network participants as well as promoting trust in the network. The next is to improve knowledge management in the network and upgrade IT systems.

8 Conclusions

This paper reveals complex connections at the EN-IMN interface. The interrelations between EN and IMN operations are brought forward by analysing EN's contribution to IMN capabilities with three strategic orientations. In brief, EN by cultivating efficiency, innovation and flexibility can help IMN to develop strategic capabilities for mobility, thriftiness, learning ability and accessibility in a systematic way. In doing so, we developed a comprehensive network influencing factors framework with fifteen specific elements in five aspects-network character, relationship, governance, support and environment. A systematic network strategy confirmation method was developed to align engineering operations with IMN capabilities.

The relative importance of the influencing factors was also analysed in this paper, which suggests that an efficiency oriented network should pay more attention to governance and support; an innovation oriented network should pay more attention to network character and relationship; and network environment, character and relationship are critical for a flexibility oriented network. Finally, the influencing factors' interacting mechanisms were presented in Figure 4, which suggest optimal paths for network improvement with these three strategic orientations.

There is some limitation of the findings. Specifically, we selected industrial managers and academics from ten companies and five universities. Although the data were consistent and sufficient to support our findings, it might be helpful to extend the survey scope by including a broader range of views from policymakers and other sectors in future research.

Direction for further research is suggested based on the above discussion. The first one is to conduct larger scale empirical research to further confirm the influencing mechanisms of network characters and network performance. The second is to develop practical guides for network transformation from the current condition to its favourable type. The third is to suggest conflicts solving methods in international network operations by better understanding trade-offs among these influencing factors, e.g. knowledge sharing and protection, participants diversity and consistency, the breadth and depth of learning, standardisation and customisation, centralisation and localisation, etc.

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Appendix 1: Sample cases to validate and refine the influencing factors

Cases	Network character	Network relationship	Network governance	Network support	Network environment
A	(1-1) the dispersed subsidiaries are under central coordination of parent company; (1-2) Participant are required to undergo audits from EICC certified auditors. They clear know what they should finish, and have uniformed tactics in both strategic and operating level. While the strategic contribution is a little fuzzy. (2) The network includes over 300 suppliers and over 5000 customer channels. (3) It is in large scale; it has more than 33,000 employees in more than 60 countries serving customers in more than 160 countries.	(4) They share advanced technology and their resources, they together make product and R&D scheme. The subsidiaries in different districts will share schedule and procedures together. (5) The communication is usually dyadic between core enterprise and participants, and communication usually happen when conflicts or emergency occur. Network participants will communicate with each other together periodically or on specific theme, such as environment affairs and standards. (6) Network participants have close relationship; the network operates as a company; participants always sign long period cooperating contracts. Now it establishes mechanism of the survival of the fittest, suppliers would be updated; some new suppliers may enter into network.	(7) It construct purchasing platform to deal with the emergency and keep its strategic position in purchasing market. (8-1) For the network should meet target efficiently, the supervision is made every day. The feedback is immediately sent to related parties and countermeasures will be taken in time to guarantee the final target; (8-2) It implements a supplier self-Assessment questionnaire (SAQ) for production supplier, to grantee their activities is compliance with the whole network; (8-3) Establish performance oriented evaluation system, and everything is based on final result. (9) According to the target, network divide its strategic targets into small pieces for every participant and employee, it's very detailed.	(10) It actively makes training for employee and other participants to realize further development. (11) E-learning platform is established to assist learning and training. ERP/APS, E-commerce and information system are very advanced in network. (12-1)Network participants together create tools and processes to proactively pave the way for a standards-based approach for monitoring suppliers' performance across several areas. (12-2) Network adopts lots of standards, its manufacturing locations are ISO 9001 (Quality), ISO 14001 (Environmental) and OHSAS 18001 (Health and Safety) certified.	(13-1)Network usually has good relationship with government; (13-2) Network consistently contributes to the development of society and environment; (13-3) It has lots of competitors. The whole PC market is shrinking, network will meet great challenge. (14) In network, people share a common aspiration to be the very best. The strength of network lies in its diversity. They create a new language for respect for others. (15) Network is related with diverse engineering stages and products, it's a complex network.
	Orientation: A Chinese multinational technology company, the world's largest personal computer vendor. Its mission is to become one of the world's great personal technology companies by the advantages of cost-effectiveness and innovation. It has large scale acquisition capability. Performance: The fastest growing major personal computer company for more than 4 years. In the second quarter of 2013, the revenue research 8.8 billion dollar and net profit is 174 million dollar. Important factors: Governance- the supervision and in time adjustment should be good to guarantee every department, every participant and every employee to finish their task precisely; Environment -the materials shortage or delay, or the changing of customer requirement or the competitor innovation in some areas will affect network performance.				

B	(1) Participants exchange information freely, doesn't need to transfer through RR; the boundary is clear for participant, they can learn from each other. (2) Cooperate with specialist agencies, universities and national government. (3) employ over 42,000 people in more than 50 countries; take Defence Aerospace for example, it's related with 18,000 engines, 24 engine programmes, 103 countries and 160 armed forces.	(4) Provide well-established communication channels for employees and their representatives to share issues and concerns. (5-1) Place the customer at the heart of the organization, focus on responsiveness and connect innovation to customers; (5-2) different department take in charge of communications with shareholders regarding business strategy and financial performance, etc.; (5-3) Conduct a dedicated investor relations programme with institutional investors. (6-1) participants have long cooperation experience, and wish further cooperation; (6-2) membership meets monthly; (6-3) At every stage work closely with suppliers.	(7) Manage the risks associated with supply continuity, both in the short and long term, by using requirements set out in Supplier Advanced Business Relationship quality system. (8-1) Suppliers are expected to fully comply with all policies including the Rolls-Royce Supplier Code of Conduct. This sets out the standard expected of suppliers at all times; (8-2) welcome feedback; (8-3) recognise high performance through a range of pay, share and incentive programmes and inspire young people to pursue rewarding STEM careers; (8-4) set definite goals on deliver mutual business benefit. (9) participants in six steps communicate to make good arrangement of schedule	(10-1) Provide an educational framework; (10-2) invest significantly in research and technology; (10-3) builds the best management team by investing in training, education and development; (10-4) offer open training for all participants to meet standard requirement. (11) Constantly develop methodologies for information analysing, such as assessing the impact of procurement decisions working with customers. (12-1) a wide range of engineering tools are adopted in network; (12-2) Form regular way, such as participant selection.	(13-1) National governments are often strategic partner; (13-2) Act in a socially responsible manner, within the laws, customs and traditions of the countries in which they are based; (13-3) OEM competition is not as fierce as it in MRO; (13-4) customer demand changes not frequently. (14) Has high reputation as a leading power systems company. (15) Membership covers operations, manufacturing, engineering, quality, supply chain and purchasing, etc.
	Orientation: A global company, providing integrated power solutions for customers in civil and defence aerospace, marine and energy markets. Invest significantly in research and technology to develop increasingly efficient power systems. Performance: High profit, leading companies in the Carbon Disclosure Project (CDP) index, innovate operating method and mode. Important factors: Network character-technology level, resources and engineering ability participants have; Environment- material market or policy or customer requirement changes.				
C	(1) Decentralised structure is considered a key part of network ability to deliver services to its clients. There is special person to coordinate disperse divisions in same areas. (2) Cooperated with central and local government, major financial and retail companies, utilities, manufacturers, developers, and other blue chip companies; (3) It employs over 17,000 staff across 29 countries and has undertaken projects in over 150 countries. Over 1500 planners, urban designers and architects.	(4) Their vendor independence and proficiency in a wide range of technologies enables them to produce solutions ranging from configured off-the-shelf systems through to bespoke mobile and web applications; (5-1) they ensure a wide range of groups and individuals are involved, from the client and consultant teams, to the wider community. (5-2) Their team of professional communication and engagement consultants and graphic designers work hand-in-hand with their technical professionals to ensure that they combine the highest standards of verbal and visual communication. (6) The network endeavours to operate cohesively, and the combination of their technical excellence and outstanding regional and segmental capabilities enables them to continue to deliver good results.	(7) There are consistent controls in place to ensure the network is able to assess and manage overall business risk. The internal audit function supports this aim by providing the directors, through the Audit Committee; (8-1) Their business conduct policy sets out the standards of behaviour they expect from their staff in dealings with clients, suppliers, colleagues and other parties; (8-2) Within each business a framework of controls exists that forms a robust business management system. (8-3) There is common management structure governs quality, safety and environment. Activity and performance are tracked through monthly and quarterly reports; (8-4) They manage the entire engagement process, including strategies and plans for all stages of project. (9) There is early identification of constraints and opportunities in network.	(10-1) It is working in the R&D of aircraft, and undertaking own research into the latest advanced composite materials; (10-2) Commitment to training and developing staff and providing fulfilling & diverse careers. (10-3) They provide consultancy services and even entire programme management teams to assist clients deliver controlled change to transform their business. (11-1) Their "Angles" is the platform independent publication, accessible on desktops & mobile devices. (11-2) They develop communication material, visual and non-verbal, to reach the widest possible audience. (12) They use a wide range of both tried-and-tested and innovative qualitative and quantitative techniques.	(13-1) The social and environmental framework of work is crucial, and they view all projects in the context of the communities in which they are delivered; (13-2) It provides ecological assessment, and combines the highest technical standards with a pragmatic approach to help meet the balance between wildlife conservation and progress. (14) It has high passion and reputation for low carbon design and sustainable development solutions. (15) Their experts including planners, architects and engineers, related fields are many.

	Orientation: It is one of the largest designs and engineering consultancies in the world, it has breath and depth of expertise to respond to the most technically challenging and time critical infrastructure projects. Performance: Revenue is £1.7 billion (Full year ended 31 March 2013). It has many years servicing experience which help it get more customers. It has lots of notable projects and it will offer planning and infrastructure support for the London 2012 Olympics Park. Important factors: Network relationship- different experts and participants (including customers) opinion and knowledge exchange & integration, and plenty communication & understanding are important for network servicing quality, such as understanding of local government, investor, developer and operator operating methods, business flow and standard regulations. Network character- experts in different areas, and creative design ideas as well as their systematic and comprehensive service based on all participants.				
D	(1) Subsidiaries clearly know their task and definition. (2-1) SAIC participates in cooperative efforts with foreign automakers and operates a large research and development centre in German, UK and USA; (2-2) SAIC has numerous production facilities in China It also has an assembly plant in UK; it has overseas company in Europe, Korea, Japan and so on. (3) SAIC Motor has nearly 3000 engineers in passenger vehicles;	(4) SAIC integrated distributed information, by integrating and analysis it offers the information for its subsidiaries, and the share three layer of information, macro information includes policy and economy situation, and medium layer information includes competitor situation etc. micro information includes related data and survey. (5) Participants usually establish joint ventures together, they communicate together to make decisions. (6) By acquisition and merging it establishes jointed ventures or wholly owned subsidiaries of auto parts companies, and for other auto parts companies which don't have close-relation with network, it plan to let them become listed companies as a whole.	(7) Always control the risk in controllable scope and make comprehensive risk management by strictly internal control mechanism. (8) Set over four hundred key points and KPI evaluation. Set stimulating system, including material reward and career opportunity and value/sprit inspiration three modes.	(10) Establish training centre to undertake training task including technique & knowledge training as well as cooperating and culture training, and trainee offer valuable advices for training centre to improve their work. (11) With the support of IT technology, SAIC Motor realize its information management in purchasing, producing and distribution and service; and based on IT company of SAIC, it establishes its own platform of purchasing, design, producing and sales service, which are under unified control , resources allocation and share unified equipment, to make sure efficient operation.	(13-1) China government support the development of SAIC Motor and there is still vast auto market in China ; (13-2) there is competition among "Big Four" Chinese automakers (the other three are Chang'an Motors, FAW Group, and Dongfeng Motor). (15) SAIC Motor cover the R&D, manufacturing, and sales of whole-vehicles (passenger and commercial vehicles), spare parts as well as auto financing, logistics, vehicle information, second-hand cars, and other car service and trading business.
	Orientation: It is the largest automotive corporation listed on the A-Shares market in China. To create a brand of excellence with a globalizations insight, it enhances its capability for international business operation. It makes effort to integrate resources of the whole world, such as designer, engineer and manufacturer etc. Performance: In 2012, it grew fast, and continued to play a leading role in domestic market and sold 4.49 million Vehicles, which is an increase of 12% over 2011. The network has initially established a global self-owned brand R&D framework; local R&D capability of major joint ventures is getting stronger. Important factors: network character-resources that network can get from participants, they stick to quickly occupy market through M&A, and in every M&A the patents/technique/markets other resources that can be obtained are important for further operation and final performance. Network governance-They want to develop and establish their own brands based on M&A, therefore how integrated these resources and by incentive form their own advantage is important				
E	(1) The participants communicate together to offer the whole solution, and sometimes they will arranged by core enterprise to discuss some issues. (2-1) Network participants come from industries, academics and research institute as well as government	(4) The whole network create harmony environment for the whole participants, they create value together and share the value and benefits; It realizes IT integration and linkage of key customers and strategic suppliers, can share and exchange information in time. (5-1) By discussion and communication and letting participant take part in project in early stage, offer a set of solutions together. (5-2)	(7) Risk manage department is established to identify and control the technique risk, culture/team conflicts and emergency, they predict environment changes' potential influence on network, and offer countermeasure to decision makers of network. (8-1) Inter control is based on network structure and operating mode, the framework and mechanism of inter control are adopted in all business flow and	(10) It trains all employees and participants to mast their regulation; (11) Establish global supply chain management system, the main is ERP/APS. (12) By the end of 2012, it had joined 150 domestic and international industry standards bodies, occupying 180 leadership positions, including chairpersons of the ETSI, ATIS, IEEE,	(13-1) Merge into local community and culture; develop local talents and participants to offer best products and services for the local customer. (13-2)They assess the impact of product designs, product recycling, resource and energy consumption, greenhouse gas emission, waste

	department. (2-2) It has more than 200 tier-1 channel partners and over 2,000 tier-2 channel partners. (3) It has high effective managing team. It has 150,000 employees, Their products and solutions have been deployed in over 140 countries, serving more than one third of the world's population.	Multi-information & communication channels are established to obtain external information from customer, supplier etc. (6) They make deep cooperation, and actively make integration of market, customer. They firmly implement a transparent and stable channel policy and strive to share more benefits with partners and work hard to build a harmonious ecosystem for win-win partnerships.	financial flow and subsidiaries business unit. (8-2) Key managing points of the global flow are set. Checking and testing results will be published monthly. Optimal countermeasures will be offer in feedback; Every half a year the assessment will be done on whole flow design and business unit implementing effectiveness, and offer results to audit committee. (8-3) Large sum of profits is used to incentive engineers.	OMA, CCSA, WFA, WiGig and OASIS. In 2012, it submitted more than 5,000 international standard proposals.	disposal, and other activities, and adopt innovative solutions to continuously reduce negative impacts on the environment, thus driving low-carbon and circular economic growth. (15) Business covers lots of areas, engineering activities covers several stages.
	Orientation: A leading global information and communications technology (ICT) solutions provider, make sustainable innovation according to customer requirement, create customer value by advanced products and service, till the end of 2012, international PCT applied are 12453, R&D input take up 13.7% of its revenue. Performance: In 2012, it submitted more than 5,000 international standard proposals; Create new business areas and new working ways; make green ideology is adopted. Important factors: network character - resources, especially human resources, are important factor for network, technological bottleneck and innovation depends on talents. Environment-government restriction in some place seriously influences business operation. Market & customer requirement changing will greatly affect network performance.				
F	(1) The divisions in different geographic is basically independent, structure is decentralized; (2) Network collaboration does not end with clients. They willingly team with local and global firms and with their supply chain to ensure the very best outcomes; Participants mainly focus on banks, enterprises and research institute. (3) It spans 140 countries, including a strong presence in North America, Europe, Africa and the Middle East, as well as across Asia. It has over 14,000 staff.	(4) Network encourages the exchange of ideas and information, which is supported by a portfolio of publications, a Group-wide intranet, websites, videos, forums, seminars, meetings, staff councils, online discussions and regular email updates from the chairman to all staff. (5-1)It brings total energy and commitment to the participants. (5-2) The communication of dispersed divisions usually focus on projects, the same areas or experts related with the same project may have chance to communicate with each other. (6) Make efforts to establish long term and close relationship with participants.	(7) To minimise their customers' and own exposure to risk they have developed a risk management approach encompassing the company's strategy, processes and procedures, and the attitudes and behaviours of their staff. (8-1) The Group Board close engagement with network responsibility enables it respond quickly and appropriately (top manager support). (8-2) It's an employee owned company, performance directly influence employee benefits, therefore employee are encouraged to involve in decision making. (9) For operation and manufacturing activities, usually resources are gathering step by step, after the first stage, financials and other resources will be later prepared for the second stage	(10) Employee will receive a comprehensive, choice-driven learning and development package: from award-winning 'upGRADe', to hundreds of online, classroom-based courses and business-school-led management training. (12-1) Lots of advanced tools for design or manufacture can be used in network, and these tools are shared by divisions. (12-2) they have standard flow and mode, when meet customer requirement, this approaches and methods can help them to design satisfied scheme rapidly.	(13-1) They support customers, nurture staff, protect the environment and caring for their communities. They aim to contribute to the long-term wellbeing. (13-2) Competitors in UK are not many, but in other foreign countries, lots of other foreign consultant companies are their competitors. (14) Accumulated experience and reputation help them get more customers and participants. (15) Related sectors are from transport, energy, buildings, water and the environment to health & education, industry and communications.
	Orientation: It is a UK based $1.6 billion global consultancy company; it creates satisfied customers through professional excellence, embraces change and continuous improvement. Performance: It won the Engineering Consultant of the Year Award at the Building Awards, overcoming opposition posed by competitors such as AECOM, Arup, Cundall and WSP. Throughout the recession its income has grown year on year, and the growth in their international work, customer satisfaction levels and low staff churn rate are also praiseworthy. Important factors: network relationship- participants coordination is important to guarantee project schedule and quality; network environment-customer requirement changing, some problems left by others, shortage of qualified personnel and some other emergencies will lead deviation from original targets, and once one deviation occur the following would meet great challenge.				

Appendix 2: Path analysis details

Table-a. Reachable and antecedent set of the first class

S_i	$\mathbf{S_0}$	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
$R(S_i)$	**0**	0,1,5	0,2,3	0,3,7	0,4,5,11	0,5,6,7	0,6	0,7	0,7,8,10	0,8,9	0,10	0,8,11	0,9,10,12	0,8,13	0,8,14,15	0,8,15
$A(S_i)$	**0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15**	1	2	2,3	4	1,4,5	5,6	3,5,7,8	8,9,11,13,14,15	9,12	8,10,12	4,11	12	13	14	14,15
$R \cap A$	**0**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Table-b. Reachable and antecedent set of the second class

S_i	S_1	S_2	S_3	S_4	S_5	$\mathbf{S_6}$	$\mathbf{S_7}$	S_8	S_9	$\mathbf{S_{10}}$	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
$R(S_i)$	1,5	2,3	3,7	4,5,11	5,6,7	**6**	**7**	7,8,10	8,9	**10**	8,11	9,10,12	8,13	8,14,15	8,15
$A(S_i)$	1	2	2,3	4	1,4,5	**5,6**	**3,5,7,8**	8,9,11,13,14,15	9,12	**8,10,12**	4,11	12	13	14	14,15
$R \cap A$	1	2	3	4	5	**6**	**7**	8	9	**10**	11	12	13	14	15

Table-c. Reachable and antecedent set of the third class

S_i	S_1	S_2	$\mathbf{S_3}$	S_4	$\mathbf{S_5}$	$\mathbf{S_8}$	S_9	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
$R(S_i)$	1,5	2,3	**3**	4,5,11	**5**	**8**	8,9	8,11	9,12	8,13	8,14,15	8,15
$A(S_i)$	1	2	**2,3**	4	**1,4,5**	**8,9,11,13,14,15**	9,12	4,11	12	13	14	14,15
$R \cap A$	1	2	**3**	4	**5**	**8**	9	11	12	13	14	15

Table-d. Reachable and antecedent set of the forth class

S_i	$\mathbf{S_1}$	$\mathbf{S_2}$	S_4	$\mathbf{S_9}$	$\mathbf{S_{11}}$	S_{12}	$\mathbf{S_{13}}$	S_{14}	$\mathbf{S_{15}}$
$R(S_i)$	**1**	**2**	4,11	**9**	**11**	9,12	**13**	14,15	**15**
$A(S_i)$	**1**	**2**	4	**9,12**	**4,11**	12	**13**	14	**14,15**
$R \cap A$	**1**	**2**	4	**9**	**11**	12	**13**	14	**15**

Table-e. Reachable and antecedent set of the fifth class

S_i	$\mathbf{S_4}$	$\mathbf{S_{12}}$	$\mathbf{S_{14}}$
$R(S_i)$	**4**	**12**	**14**
$A(S_i)$	**4**	**12**	**14**
$R \cap A$	**4**	**12**	**14**

Appendix 3: An illustrative example

Table-f: Influencing factors of Case A

Factors	Characteristics	Matching condition (if match the score is 1, if not the score is 0)		
		Efficiency oriented	Innovation oriented	Flexibility oriented
S_1	The dispersed subsidiaries are centrally managed with definitive goals	1	0	0
S_2	Network includes over 300 suppliers and over 5000 customer channels	0	1	0
S_3	Large scale and diverse knowledge bases	1	1	0
S_4	Sharing of advanced technologies and processes across subsidiaries	1	1	0
S_5	Dyadic communication between the focal company and participants regularly	1	0	1
S_6	Close relations and long-term collaborative contracts among participants	1	1	0
S_7	A dedicated platform to deal with emergency and guarantee scheduled deliveries	1	0	0
S_8	Daily close monitoring. Well-developed performance measurement system. Timely feedback.	1	1	0
S_9	Overall strategic target is divided into smaller tasks specific to each participant	1	0	0
S_{10}	Dedicated training for further development and adaption for future changes	0	1	1
S_{11}	E-learning platform is established to assist information management and learning	0	1	0
S_{12}	Tools to proactively pave the way for a standards-based working approach	1	0	0
S_{13}	Mature industry, heavy competition	1	0	0
S_{14}	People share a common aspiration to be the very best. The strength of network lies in its diversity.	0	1	0
S_{15}	Diverse engineering technologies and products. Innovation is needed to survive.	1	1	0
Total scores		11	9	2

Table-f demonstrates the influencing factors judging method for Case A with reference to Table 1. In practice a company should confirm the weight of each factor (from 0 to 1) at the beginning of the assessment. We assume that they have the same weight (i.e. 1) in this example. The overall score for an efficiency-oriented strategy is 0.733(11/15), an innovation-oriented strategy is 0.6 (9/15), and a flexibility-oriented strategy is 0.133 (2/15). Case A can therefore confirm its strategic orientation for network efficiency.

As suggested by Table 2, Case A should focus on governance and support to effectively support IMN capabilities. The company should follow Figure 4-a and get the optimal EN-IMN interacting path: $S_{12} \Rightarrow S_9 \Rightarrow S_8 \Rightarrow S_7/S_{10} \Rightarrow S_0$. That means the company should above all examine whether its tools for task scheduling and resource allocation are appropriate for IMN. If not, these tools should be upgraded to improve IMN mobility. The next step is to examine its monitoring, controlling and performance management system, and when necessary improve them to enhance IMN thriftiness and accessibility. The next step is to review its network coordination and conflict resolving procedures to encourage sharing of good practice among network participants and thus enhancing IMN learning ability. In this way, IMN capabilities can be effectively enhanced by EN efficiency.