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How Can System Engineering Improve Supplier Management In Megaprojects?

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Abstract

Megaprojects are frequently delivered with very poor project management performance. Poor performance consists of cost and time escalation, poor outcome quality and shortfall benefits. This is due to several reasons such as intrinsic complexity, biased forecasts, conscious misinformation about costs and benefits, poor stakeholder management. Concerning project stakeholders there are three main criticalities: (1) opportunistic behaviour; (2) lack of skills and know-how; and (3) poor communication and coordination.
Systems Engineering (SE) is both a technical and managerial approach to manage complex projects, in particular megaprojects. SE can enable project managers to properly manage stakeholders optimizing the trade-off between a short project planning and a detailed holistic stakeholder analysis. The purpose of this paper is to present a framework enabling managers: (1) to select and manage suppliers in order to enforce supplier coordination and to prevent opportunistic behaviour; and (2) to decide how to involve suppliers in different projects, present or future, considering past projects performance.

Key Words: Systems Engineering; stakeholders; megaprojects performance; suppliers; portfolio.

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1 Introduction

Megaprojects have frequently very poor project management performance: cost and time escalations, poor outcome quality, shortfall benefits. (Flyvbjerg, 2007) focuses on cost escalation, identifying three main types of explanations: (1) Technical; (2) Psychological and (3) Political. Other scholars (Marrewijk, Clegg, Pitsis, & Veenswijk, 2008) suggest that megaprojects poor performance are due their intrinsic characteristics (uncertainty, high complexity, high risk, huge project size, large variety and number of people involved, political influence, etc). In addition decision makers operate with limited rationality and decisions are based on incomplete information or wrong data.

Some examples of megaprojects delivered with poor performance are:

(1) The Hong Kong international airport (Davies, Gann, & Douglas, 2009). The ambition of authorities to inaugurate the Hong Kong international airport on time makes them to open the airport although it was not ready. This caused the cargo chaos and flight displays disasters. To overcome such problems it was necessary to find additional funds, which caused globally the national deficit of GDP of 0.22 %.

(2) The Big Dig project in Boston (Attorney General of Massachusetts, 2008). The objective was to restructure highways and tunnels in Boston. The project finished in litigation due to very poor performance because of the very high cost escalation (from the initial US $ 2.8 to final US $ 14.8), delay (total of 9 years - mostly because of the many leaks found) and the fatal accident in the William Ted Tunnel. The Massachusetts prosecutor ordered a judicial investigations and discovered that intentional fraud, lack of technical knowledge and know-how, poor stakeholders coordination were the main causes of poor performance.

(3) The Shoreham Nuclear Power Plant (Ross & Staw, 1993). This project registered continuous cost escalation, mainly because biased optimism. The final cost was US $ 5.5 billion, instead of initial cost of US $ 75million. The power plant has never been operated.

System Engineering (SE) is a both managerial and technical approach to manage big, complex and risky projects. This paper fits in this research stream presenting a framework (integrated within SE project management approach) to strengthen collaboration among stakeholders and in particular between main contractors and suppliers. The benefits of adopting this model are: (1) to reduce technology and supply risks; (2) to reduce the opportunistic behaviour of suppliers; (3) to improve supplier commitment and performance.

The paper is organized as follow. Section 2 deals with literature review: (i) megaproject, (ii) Systems Engineering approach; and (iii) project stakeholder management with a particular attention to suppliers. Section 3 presents a SE framework for supplier management within a megaproject. Section 4 discusses and summarises the main findings and contributions of this paper.

2 Literature Review

2.1 Megaproject

(Marrewijk, Clegg, Pitsis, & Veenswijk, 2008) define “mega” those projects characterised by: (1) initial investments over $ 1B; (2) significant complexity (i.e. technology used, project size) and (3) high inherent risk. Cost escalation due to poor performance of megaprojects could be very high bringing to company bankruptcy (Brealey, Cooper, & Habib, 2000) or significant deficit on the national Balance of Payment (Steinberg, 1987).

Summarising the contributions of different authors discussed in the introduction, it is possible to conclude that megaprojects have poor performance mainly because: (1) inherent higher risk and uncertainty; (2) high project complexity; (3) misinformation; (4) political influence. Empirical studies show that both public and private megaprojects register poor performance (Flyvbjerg, 2007), (Locatelli & Mancini, 2012a). Megaprojects are usually commissioned by governments and delivered by private organizations into a Public Private Partnerships (Brealey, Cooper, & Habib, 2000) (Locatelli & Mancini, 2010). These private organizations, commonly known as Engineering, Procurement and Constructions (EPC) companies are huge projects-based companies ((Locatelli & Mancini, 2012b). These companies collect and manage projects at different levels namely portfolio, programme and project levels. At the portfolio level the main objective is to optimise the allocation of scarce resources (i.e. budgets, skills) to different projects, while at the project level the main objective is to make an efficient use those resources (Hobday, 2000).

2.2 Systems Engineering

There are available many approaches and standards to run megaprojects:

- PMI Body Of Knowledge (PMI, 2008). It focuses mostly on managerial processes. It is mainly developed for “standard” project (better if managed by companies with strong process oriented culture like the north-American). It is suitable for projects such as Olympic Game organization, new product development, organizational process engineering, but it is less efficient with big and complex projects (i.e. nuclear power plants, large dams, large bridge, highways, etc.)
- IPMA Competence Baseline. It focuses mostly on overall social and managerial aspects of competences needed to manage projects. It covers a wider range of potential users (no matter on their culture) but it is not specific for megaprojects.
- Waterfall model (Royce, 1970). It is a sequential approach, where an activity must be completed before the next is started. The best application is on small and not complex projects. It presents many limits on project risk management. It has more managerial prospective than technical.
- Spiral model (Boehm, 1988). It is dynamic approach, more efficient than the waterfall model to cope with complex project and high inherent risk. It is common for IT projects.
- Systems Engineering (SE) (INCOSE, 2006). SE is both a managerial and a technical approach to manage complex systems such as engineering and construction megaprojects. It has been developed to manage large and complex projects (Locatelli, et al., 2013). Therefore SE is the starting point for the analysis presented in this paper.

The cornerstone of SE is the careful identification and analysis of stakeholder requirements. It is based on continuous system integration, verification and validation processes in order to anticipate constraints and integration problems. To understand the reasons of this latter success the key question is: how the SE approach defined by the standard ISO/IEC 15288 differs from traditional one? The success factor is the shift from a single project prospective to a portfolio perspective, as it is shown in Fig. 1. In fact, in order to deal with project-based organizations context, this standard provides additional processes: *Enterprise and Agreement Processes,* and *Organizational Project-Enabling Processes*.
The International Council on Systems Engineering (INCOSE) is a non-profit organization aimed to promote the SE application into industry, academia and government (INCOSE, 2006). Nowadays one of INCOSE most important driver is to move from a single project view to a portfolio prospective. Under this perspective the standards still miss a formal stakeholder management framework. This paper aims to fill that gap.

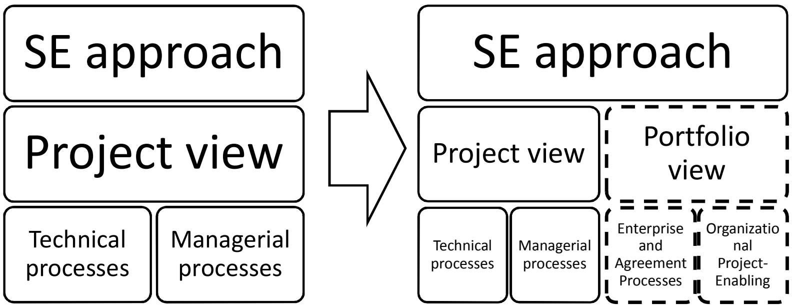

Fig. 1: SE approach shift on prospective level, from (INCOSE, 2006).

2.3 Project Stakeholders

In recent years there has been a great interest in stakeholder theory with a proliferation of scientific papers as analysed in (Littau.P, Jujagiri, & Adlbrecht, 2010). Stakeholder theory was formally established in 1984 with the publication of “Strategic Management: A stakeholder Approach” by Freeman (Freeman, 1984). A good synthesis of the major stakeholder models is on (Mitchell, Agle, & Wood, 1997). A specific research on project stakeholders is presented in (Aaltonen, 2010).
Agent-principal theory is a good reference to analyse stakeholder interdependence and prevent conflicts. Agency

theory is defined as a relationship on which a one person (the principal) engages another person (the agent) to perform some services on his behalf. The key point of agency theory is the assumption that the interests of principles and agents diverge. Differently to traditional agent-principal theory, stakeholder-agency theory, defined by (Hill & Jones, 1992), admits *market disequilibrium* in the short and medium run. As a consequence there is a *power differentiation* or unequal distribution of power between the "principal" and the "agent". For example, a given stakeholder could accept the contract under certain conditions, aware that after the agreement he will ask for changes (Brouthers & Bamossy, 1997). In fact, once the contract is signed and the project is started, the counterpart is obliged to come to a compromise in order to get the project finished. The key point is that the stakeholder controls one or more key resources (i.e. licence authorization, funds) the counterpart has few or no alternative in the short-medium run to acquire such resource from an alternative font. Such situations are common in the EPC industry (Ruuska, Ahola, Artto, Locatelli, & Mancini, 2011).

Given the huge variety and number of stakeholders involved in megaprojects, this paper focuses on suppliers because are often one of the most salient and critical stakeholders.

In general terms, supplier selection process consists of four main steps (Boer de, Labro, & Morlacchi, 2001): (1) problem definition, make or buy decision; (2) formulation of criteria and techniques to select suppliers; (3) qualification, to sort potential suppliers who respect given preconditions; and (4) choice, selection of the best alternative. Among supplier selection techniques, the most common are: linear weighting models (i.e. simulation-based techniques, AHP, conjoint analysis – (Locatelli, G; Mancini, M., 2012c)); total cost of ownership models; mathematical programming models. (Micheli, Cagno, & DiGiulio, 2009) define a risk-based supplier selection method specific for EPC industry. Supplier selection process includes also analysis of items criticality (strategic versus no critical) and market condition (legal or de facto monopoly or competitive market) (Kraljic, 1983). It is important to pinpoint that in the EPC industry not all suppliers are selected by the EPC. Project managers could be obliged to use particular supplier because of: (1) by contractual constrains, for example only local suppliers; (2) on the marketplace there few skilled suppliers (new technology); (3) supplier to be used must be certified (e.g. N-STAMP for Nuclear sectors), etc. Another important aspect while dealing with suppliers in engineering and construction megaprojects is the supplier performance evaluation. Supplier performance is measured with different criteria. Besides the traditional performance criteria managed by the procurement office (cost, delivery, quality), other criteria must be included in supplier evaluation to ensure safety for people and assets, limited environmental impact, reliability and maintenance facilities, etc.

The literature shows as SE is an efficient methodology to reduce the risk in very complex megaprojects. However the state of the art of SE approach still misses a formal process to manage stakeholders. This paper fills this gap proposing a SE management process to: (1) reduce suppliers' opportunistic behaviour; (2) overcome lack of skills and know-how through close collaboration with key suppliers; and (3) to improve communication and coordination throughout the different organizational level and improve suppliers' performance.

This new process could be added to the enterprise process defined by (INCOSE, 2006). The inputs of the process are: strategic guidelines for supplier management; analysis of items criticality; analysis of marketplace context; stakeholder network. The outputs are: selected suppliers; evaluation of commitment to deserve to each supplier; supplier and stakeholder network analysis; supplier satisfaction measurement (tools, methodologies, etc.); suppliers ranking (from excellent to inadequate ones); updated vendor list; evaluation of supplier partnership opportunity (cost and benefits analysis).

2.4 Supplier Selection

In literature supplier selection processes are usually generic for all types of industries. During the supplier selection process, decision makers need to identify all suppliers' requirements. Requirements are distinct in: (1) technical, (2) expectation and (3) opportunistic interests or personal goals. SE is suitable to identify technical requirements and we propose to adopt different types of variables for different types of requirement in order to check completeness of supplier requirements. In particular we propose fuzzy variables (Zadeh, 1975), which are efficient to deal with not well defined requirements such as expectations and opportunistic interests. The variables are: (1) numerical variable for explicit requirements, which must be clear as much as possible; (2) numerical fuzzy variables for implicit stakeholders requirements and needs; and (3) linguistic fuzzy variables to identify supplier opportunistic interests. While identifying supplier opportunistic interests (i.e. opportunity to acquire new competence and know-how or to have an international experience) project managers could refer to the Maslow's needs hierarchy (Maslow, 1943) for supplier as individual or the Organization Lifecycle Theory (Littau.P, Jujagiri, & Adlbrecht, 2010) for supplier as a company.

The output of this process is a matrix (see Fig. 2), based on requirement typology (horizontal axis) and variable typology (vertical axis). In this matrix, dark grey cells might be empty. Requirements inside these cells belong to other cells and must be formalised. Light grey cells need more information to be completed; and in the white cells there are well defined requirement, to be confirmed and validated. This matrix enables project managers to control the completeness of supplier requirements, identifying which requirements are clear and well defined and which need additional information. This matrix could be used whenever it is necessary to identify or update suppliers' requirements, for example at the beginning of the project or when there are new suppliers or there is change in the supplier network.

Numerical variables	**To be confirmed**	**(It is a technical requirements)**	**Is it a technical requirement to be formalised?**
Numerical fuzzy variables	**More information needed to complete the requirements**	**Redefine these requirements in numerical variables**	**Is it an expectation formalised?**
Linguistic fuzzy variables	**Redefine the requirements at the beginning**	**More information needed to be more clear**	**Define how to quantify them**
	Technical requirements	**Expectations**	**Opportunistic interests**

Fig. 2: Requirement typology and variable typology matrix.

Once identified all supplier requirements it is necessary to understand to what extent such requirements are consistent with the project goals. For this purpose, we distinguish requirements into: (1) consistent requirements, satisfaction of these requirements enables to meet project goals; (2) inconsistent but compatible requirements, satisfaction of these requirements does not compromise the objective to meet project goals, even if it could potentially occur; and (3) inconsistent and incompatible requirements, satisfaction of these requirements automatically compromise the purpose to meet project goals.

To conclude, managers might combine the requirement analysis with the supplier criticality analysis. Supplier criticality analysis is based on items' criticality and market conditions, using for example the (Kraljic, 1983) framework.

From this analysis, the decision maker could understand:

- which suppliers are important;
- how much attention must be devoted to different suppliers;
- the mutual dependence with critical suppliers;
- the consistence of supplier interests with the megaproject goals;
- the level of completeness of supplier requirements.

2.5 Supplier Performance Evaluation

Ability to select suppliers as in the standard supplier selection process is not enough while dealing with megaprojects. Given the huge impact of megaprojects on the society and environment, suppliers must ensure (besides the usual performance on cost, time and quality) safety for people and assets, limited environmental impact, maintenance facilities, etc. Therefore, suppliers performance evaluation is not limited to the suppliers selection process, but it an on-going process throughout the project lifecycle and in particular during the construction and installation stage and the release stage.

In the EPC companies, managers generally suffer poor communication among different organizational levels, for example between project level and portfolio level. To overcome this criticality, this paper proposes the use of the PDCA *(Plan-Do-Check-Act) cycle* (Deming, 1986). This well proven managerial tool enables a constant, systematic and rigorous evaluation of supplier performance and, at the same time, improves communication between different organizational levels (see Figure 3). In this prospective, information from the project level (operational level) could support decisions at the portfolio level (strategic level) to define a more efficient purchasing strategy, coherent with supplier performance and market conditions. The targets are:

1. to involve suppliers with good performance in other projects of the portfolio;
2. to eliminate from the vendor list suppliers with poor performance (when possible).

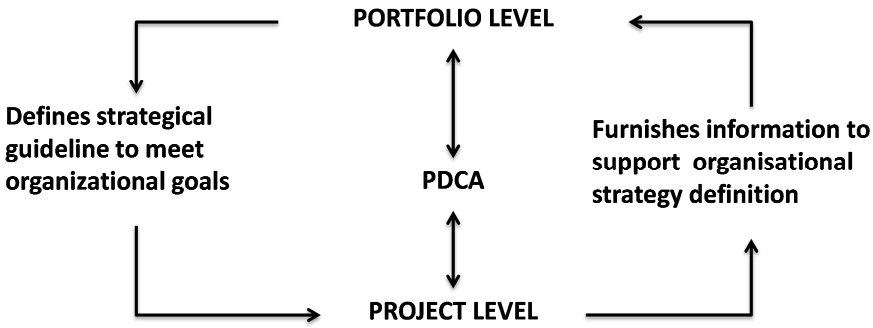

Figure 3 : The PDCA cycle, a bridge between project level and portfolio level.

Projects are often managed by "decision gates". In decision gates (defined in the SE processes "Organizational Project-Enabling" (INCOSE, 2006)) project managers take go/non go decision. They analyse project performance to control if the work done is consistent with the project scope and schedule or if the project needs correction.

Supported by the decision gates managerial approach, the PDCA cycle can be implemented as follow:

i. To start, at the *Plan phase*, project managers decide the activities to do. Then project team pursues the implementation of such activities in the *Do phase.* Now, the suggestion is to make the *Check phase* of the PDCA cycle corresponding to decision gates. So at each decision gate, project managers, cooperating with the purchasing office (agreement processes) and project team members, evaluate the single supplier performance considering contextual factors of the megaproject. They evaluate the necessity for corrective action in the *Act phase*.
ii. Later on, the project manager sends his analysis to the program manager. This must combine analysis of all projects program.
iii. Finally all program managers send their analysis to the portfolio manager to support purchasing strategic decisions.

The first goal, at project level, is to evaluate suppliers' performance. For suppliers with poor performance, project manager makes a cost-benefit analysis to substitute them. For obliged suppliers, in case of poor performance, the strategy is based on damages limitation. At least, partnership collaboration could be considered in the prospective to support the supplier in improving his performance.

The second goal, at portfolio level, is to define if best suppliers could become business partners. In this case, it is crucial to create the conditions for partnership collaboration. For suppliers with poor performance, portfolio manager progressively reduces their involvement in the business company, till arriving to their elimination from the vendor list (when possible).

2.6 Supplier Satisfaction

To undertake a successful, efficient and long term partnership satisfaction of both partners is essential (Essig & Amann, 2009). Historically academics and managers mattered on buyer satisfaction ignoring supplier satisfaction (Meena & Sarmah, 2012). The framework addresses this gap in the EPC industry. For this purpose, firstly, we identify which factors influence supplier satisfaction, then, we identify a tool to measure such satisfaction.
Supplier satisfaction is defined as "*the feeling of equity with the relationship no matter what power imbalance exists*" (Benton & Maloni, 2005). In the long term, suppliers are mostly interested in three main objectives: (1) financial; (2) technology knowledge; and (3) business reputation. We identify three factors which influence supplier satisfaction:

- Economic (E). It measures economic and financial opportunities the supplier perceives from the suppliers, now and in the future.
- Communication (C). It measures how much the two organizations are integrated (organizational culture, IT systems, quality standards, etc). It measures also the buyers and engineers' competence (numbers of modification, ri-negotiation of orders conditions, and modification of technical requirements). It includes analysis of how much buyers are rapid to furnish communication and answer to suppliers and the completeness of such communication.
- Innovation and knowledge Opportunity (O). It measures opportunity for knowledge creation and sharing, technical know-how acquisition, product innovation, ability for better risk management and complexity management, ability of customer to manage contingencies.

To measure supplier satisfaction, this paper proposes a Supplier-Satisfaction-Index (SSI) based on the three factors. For each factor, we identify 10 indicators, summarised in Appendix A. Each indicator has value on the range 0-10, where 0 stands for very unsatisfied and 10 for very satisfied

The index is: $SSI= \alpha E + \beta C + \gamma O$, (with $\alpha+\beta+\gamma=1$).

Since suppliers are not all equal, the definition of the index includes three parameters, alpha, beta and gamma, which reflect the importance of the single supplier to the buyer. For example, using the (Kraljic, 1983) terminology, for a strategic-supplier the parameter gamma is the most important for the buyer. Co-design collaboration is essential to meet buyer objectives. The buyer might ensure the supplier satisfaction and commitment to his job. In a relationship with a bottleneck-supplier, the bargaining power is on the supplier side and at the same time the item supplied is not technically critical to the buyer. So the buyer might ensure a good communication (parameter beta) with the supplier to avoid tension with the supplier, who has less interest in the relation. For a non-critical-supplier or leverage-supplier, parameter alpha will have major weigh. This kind of supplier cares mostly on economic issues rather than communication and innovation and knowledge opportunities. The overall framework allows manager to understand the weak points in their relationship with suppliers. Through statistical analysis managers can understand if poor performance on some indicators is specific for a certain supplier only or if it is common to many suppliers. This index enables an indirect employees' performance measurement. The index can be used in two ways: (1) the buyer defines the weight of the parameters while the supplier defines the indicators; or (2) both the parameters and the indicators are made by the supplier.

3 Conclusion

The contribution of this paper is the formal introduction of supplier management process, with a portfolio perspective, in the SE approach (INCOSE views). This process consists of: (1) Supplier selection; (2) Supplier performance evaluation and (3) Supplier satisfaction analysis. In particular for supplier performance evaluation we tailored the PDCA cycle to capture information about operational performance at project level and transfer such information to portfolio level. Here, this information contributes to make decision on purchasing strategy, coherent with supplier performance, item criticality and market condition. In order to reduce project risk and opportunistic behaviour, opportunities for business partnership are assessed. We defined a supplier satisfaction index, to improve supplier commitment and performance.

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APPENDIX A

Factors	Indicators	Indicators Description
Economic	Business experiences	Many years of business experience offers opportunities of technical know-how and managerial skills acquisition
	Customer business reputation	Good reputation of buyers increases supplier reputation, facilities access to new market and to financials funds
	Customer size	A big customer has more business opportunities in terms of volume purchased, offers major business opportunities in the future
	Customer social reputation	Customer social reputation could potentially improve supplier social status. For example customers with good relationships with politicians or banks, could be a positive reference to the suppliers
	Grade of internationalization	International customer could enable access to foreign market at a minor cost. He could be a guarantee to new customer or business relationship
	Payment condition	Equity on the definition of payment condition
	Perceived business opportunities	It measure present business opportunities the supplier think he could take advantage from his customer. While strategic value is projected on the future, perceived business opportunities focus on present or on short run opportunities
	Strategic value	It measure business opportunities related to the partnership (access to new market, technology know-how acquisition) in the long run
	Time delivery	Buyers makes orders with sufficient time to supplier to organize him self
	Willingness to invest in partnership	It measures how much a supplier is inclined or, symmetrically, he is reluctant to partnership with customer
Communication	Ability to solve conflict	Ability of buyer to solve conflict in an equity way, without abusing of his position and power within a win-win approach.
	Commercial clarity in order	Ability of buyer to define clearly all aspects of a commercial order (time delivery, payment condition, quality control responsibility, supply risk reasonability, etc)
	Cost of integration with the customer	It analyses all cost related to the partnership. For example, employees 'training, IT system integration, commitment for organizational culture change
	Customer faithful	Supplier trusts the buyer honesty, during and after the negotiation process
	Customer Personnel courtesy and reliability	It measure politeness through customer's employees relate with supplier 'employees
	Number of strategic contacts	Not all contacts between buyer and supplier are value creation. For a raw materials supplier, few contacts are sufficient. A lot of contact could be just irksome. While for high-tech supplier, need more interactions for a good co-design outcome. Buyers must optimize the number of contact with supplier, not too much to be irksome and too few to be insufficient.
	Quality of Communication	It measure clarity of communication (i.e. the need, quantification, quality, etc)
	Response Time	It measures the time customer uses top respond to supplier
	Technical clarity in order	Ability of buyer to define clearly all aspects of a technical order (technical specifications, quality standard, etc)
	Willingness for product design or process improvement suggestion	It measures the degree on which customer take seriously into consideration supplier's suggestion to improve product design or production process.
Technology	Equal technology risk sharing	It measures how much the technology risk is distributed between supplier and buyer, for example if the buyer tends to transfer completely such risk to the supplier
	Frequency of design modification	How mush buyer' engineers ask for design modification due to insufficient technical requirements definition, poor technical communication, not completely understood technical requirements
	Intensity of integration with R&D	It measures the degree of integration between buyer and suppliers in terms of IT systems, competence and formation, availability general tools and resources to enable such integration
	New knowledge creation	Ability to create, capture and share knowledge
	Proactive approach to collaboration	It measure preparations and commitment of customer employees to collaborate with suppliers
	Solve-problem technical ability	Ability and experience to solve technical problem (time, quality of solution)
	Technical competence	It measures technical competence and skill of buyer' engineers; technology competence of the buyer; access to new technology
	Technical competence of purchasing personnel	Ability of the purchasing personnel to understand the technical criticality of what they are purchasing
	Technical requirement definitions	Ability to define technical requirement in exhaustive way, clear and complete
	Technology compatibility and complementary	It measures how much the two organization are technologically compatible (i.e. IT systems integration) and complementary (i.e. customer is software skills and the supplier hardware.