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Services and Support Supply Chain Design for Complex Engineering Systems

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1. Introduction

The design and operation of complex engineering systems such as an aircraft or a refinery require substantial planning and flexibility in delivery of services and logistics support. Classical services and maintenance plans are designed on the principle that mean time between failure is a constant and hence the focus is to replace components before it is expected to fail (Armstrong, 1997). Service activities including inspection, adjustment and replacement are scheduled in fixed intervals (Chan *et al*, 2005). These intervals, which are prescribed by the Original Equipment Manufacturer (OEM), are often suboptimal because of deviations in the multifaceted relationship between the operating context and expectations on the complex system's performance from the intended circumstances (Tam *et al*, 2006). The rigid maintenance plans are unable to unveil inherent issues in complex systems. To improve this situation, Reliability Centred Maintenance (RCM) regime has been developed to focus on reliability and safety issues (Moubray, 1997; Abdul-Nour *et al*, 2002). However, the process tended to ignore some secondary issues and rendered the system in sub-optimal operating conditions (Sherwin, 2005). Modern machine systems are of increasing complexity and sophistication. Focussing only on system reliability does not meet the demand on the performance of complex engineering systems due to business requirements and competitions. From the point of view of the engineering system's owner, the system is an expensive asset that is required to fulfil certain business functions. For the purpose of discussions in this chapter, the term asset is used as synonym of a complex engineering system rather than the common understanding of a static investment.

In maintenance oriented service regime, many factors are governing the operations of the asset (Colombo and Demichela, 2008). The consequences of system failures can cause losses in opportunity costs. Unfortunately, these losses are often difficult to quantify and measure. Many service decisions on assets are therefore made on rules of thumbs rather than using analysed system performance data. Replacement of assets should be made at the time when the asset is about to fail so that the value of the asset over its usable life can be utilised (Huang, 1997). The strategy is to minimise expenditure that should be spent on the asset. Many complex systems are therefore left vulnerable with high risks of failure. The performance of the asset will degrade over time as the asset gets old and technologically out-of-date. However, an expensive engineering system is expected to be in service for years. In addition, due to technology improvement, capability of the system should keep increasing in order to meet functional demand by end users (Fig. 1).

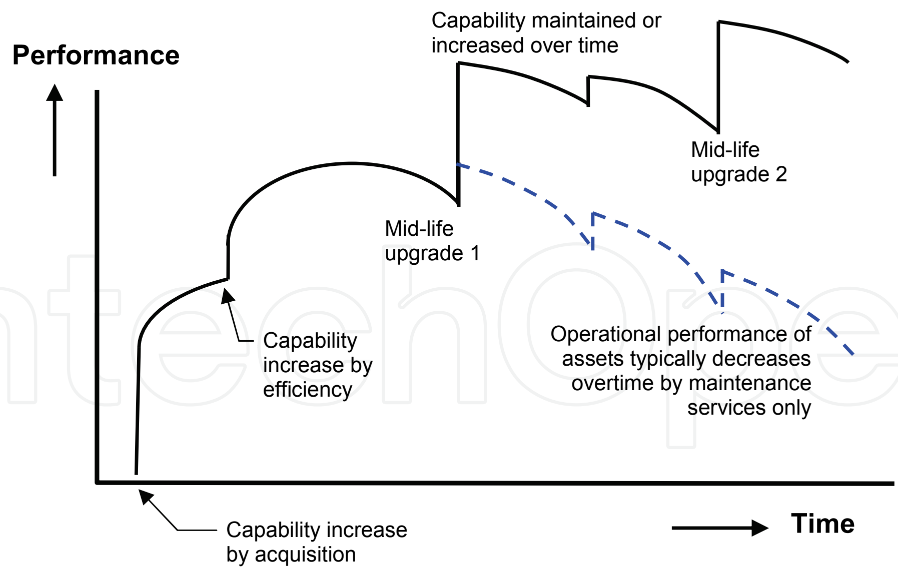


Fig. 1. Performance improvements due to mid-life upgrade

If the operating performance of an engineering system diminishes over time, the asset owner has to take the risk of either continue operating the equipment at unsatisfactory level or initiate a major investment project replacing the aging asset. This is not a desirable situation for the asset owner because there are significant risks in operating the asset after what is normally known as the service life of the asset. From the owner's point of view, it is necessary that the performance of the asset should increase over time to meet changing demands of the customers. To achieve this goal, many assets undergo significant mid-life upgrade (solid line in Fig. 1) but due to limitations in the original system design, this route is often not practicable.

In recent years, there is an increasing trend for complex engineering systems' operators to outsource their services and support activities. Instead of an effort based maintenance contract, customers demand performance and reliability on the asset that they operate. Performance based contracting has emerged in recent years as one of the favourable choices of contracting mechanisms for the public sector and asset intensive industries such as water, transport, defence and chemicals (Mo *et al*, 2008). Performance based contracting is a service agreement based on satisfaction of operating outcomes of the asset. Hence, how the asset is serviced or supported over time is irrelevant to the customer. The responsibility of maintaining an agreed service level is shifted from the asset operator to the service provider, under the constraint of a set price. The performance based contractor is expected to take all risks in the provision of services, including operations support, emergency and planned stoppages, upgrades, supplies and other asset services while fulfilling the contractual requirements of providing a satisfactory level of asset performance over a long period of time. Provision of these services will be strongly influenced by the business environment including customer's operational schedule, logistics support, spare parts inventory, customer relations, knowledge management, finance, etc.

Decisions such as asset replacement, upgrade or system overhaul are in many respects equivalent to a major investment, which is risk sensitive. This chapter examines past experiences of services and support of complex engineering systems and discusses the need for integrating with services research and business process management in order to keep these complex systems to perform at a satisfactory level. The rest of the chapter is organised as follows. In the next three sections, the key aspects of a services and support system are examined with cases reported in literature. Understanding of these characteristics and issues is essential for designing services and support supply chains for complex engineering systems because they form irreplaceable ingredients in these supply chains. This chapter concludes with a conceptual model of services and support systems and identities the body of knowledge that can be used to design a customer focused services and support solution.

2. Performance monitoring and reliability prediction

First, we examine the technological requirement of services to complex engineering systems. System health condition monitoring plays a critical role in preventative maintenance and product quality control of modern industrial manufacturing operations and therefore directly impacts their efficiency and cost-effectiveness. Uusitalo (1998) describes an operations support system for a paper pulp processing plant. The system is a process prediction and monitoring system that has a direct connection between the plant (in Australia) and the manufacturer (in Finland) so that operating data can be transmitted back to the engineering department in intervals of one set of parameters per minute. The operating data are compared to simulated process model of the plant so that discrepancies can be diagnosed.

In the power industry, the electricity market is highly volatile by design due to the need to balance regulation, competition, public and private investment risks, power network coordination. Hence, services to this industry require thorough understanding of the market operating conditions. Hu *et al* (2005) has developed a simulation system that integrated historical market data with weather conditions, market behaviour and individual's preference, in order to predict electricity prices. When this information is integrated with real market data, companies can explore the impact of different sustainable maintenance plans and the effect of outage due to all types of breakdowns.

The use of predictive and condition monitoring systems greatly enhances the ability of system owners to predict failure. Reliability centred maintenance relies on the availability and accuracy of facts acquired through such monitoring systems (Pujades and Chen, 1996). Maintenance decisions are then made according to the prediction. The problem is that it depends on data accuracy which is not always collectable at the required level of precision (Apeland and Aven, 2000). To extract more efficiency from the large amount of operating data and reduce waste of resources in standby components, more sophisticated methodologies have been developed for maintaining performance of processes that are sensitive to variations (Marmo *et al*, 2009). The key to these studies is the recognition of continuously monitored performance metrics that provide the basis for modern day reliability decisions.

Advancement of IT networks has enabled more sophisticated, distributed health condition monitoring of complex systems to be commissioned and integrated with operation controls in real time (Leger *et al*, 1999). Essentially, a condition monitoring system acquires time-varying signal generated by the system. The signal data are processed using various classical methods of signal analysis such as spectrum or regression analyses. After initial signal data transformation, abnormal signal patterns are detected indicating problems in the machine.

Yang *et al* (2003a) has applied chaotic theory to analyse axes movement signals from a computer controlled multiple axes grinding machine and developed a 2-tier diagnostics system. This type of grinding machines has very stringent accuracy requirements. If the axis accuracy drops by a few microns, the surface finish of manufactured parts can become unacceptable. Successful and timely identification of faults that cause surface finish problems on machines can reduce the time-to-fix as well as downtime and materials wastage.

Similar signal analysis techniques have been used for monitoring of consumable conditions for plasma metal plate cutting process (Fig. 2). In this case, the voltage between the torch and the grounded plate is used as the monitoring signal data stream (Yang *et al*, 2003b). This voltage is characteristics of the process and is used to generate an arc. Unavoidably, any electric arc contains noise, including thermal, digital, high frequency, etc. Hence, the monitored voltage data consists of two components: the signal component (relates to the conditions of the system), and the noise component. The difference between the two is that the signal component is correlated whereas the noise component is un-correlated and eliminated by a polynomial filter (Schreiber and Grassberger, 1991; Gong *et al*., 1999).

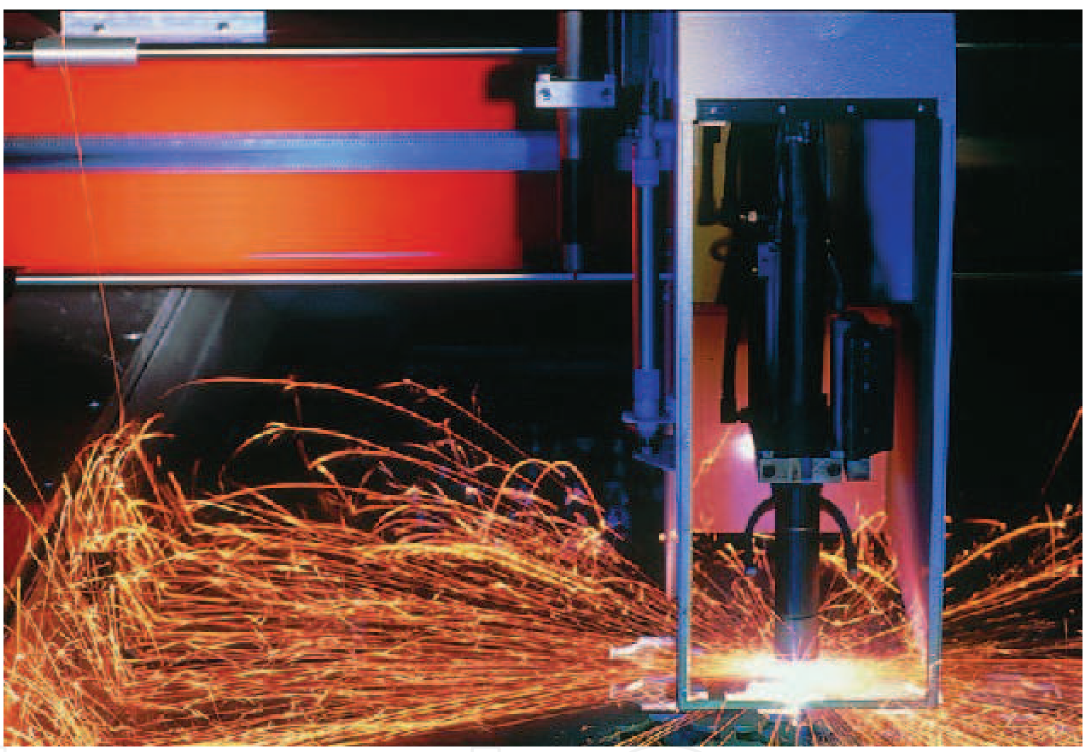
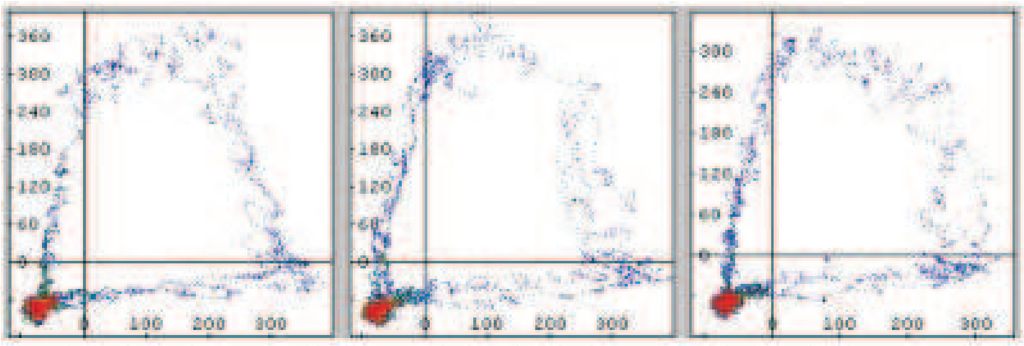


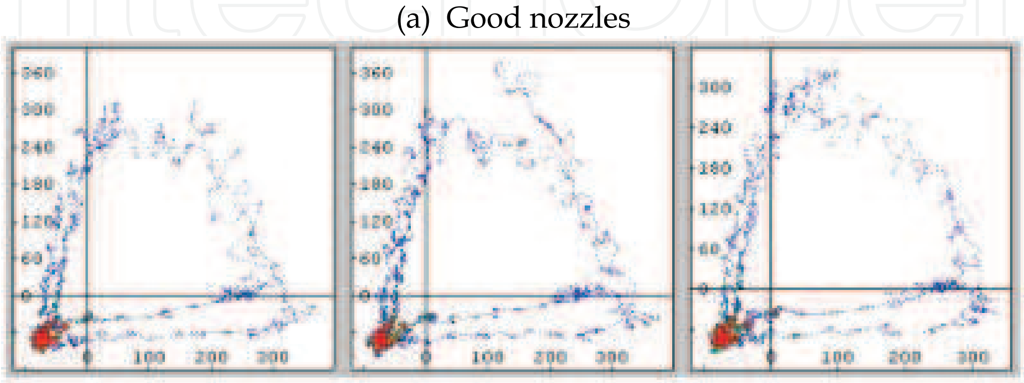
Fig. 2. Plasma cutting process for metal plates

The voltage data is a time series that can be processed to generate the attractors using a phase-space reconstruction technique (Fig. 3). The experiment has been planned such that it captures data from three consumable conditions: good, fair and bad. For each consumable condition, three tests are performed. It can be seen from Fig. 3 that, for the same condition, the graphical pattern of the attractors are similar. For different conditions, the lower parts of the attractors show significant difference. Where the condition of the consumables is deteriorating, the lower parts of the attractors show a distinctive split. With a suitable image recognition algorithm, the graphical difference can be recognized and used as an indicator for consumable condition.

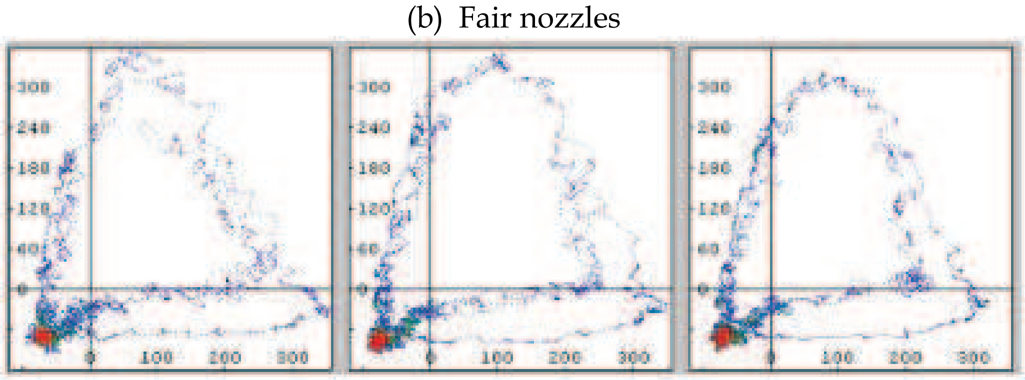
These researches show that most engineering intensive service providers are focussing on data driven technologies that assist them to predict performance of the system when it is operating under different conditions. There is no doubt that this is an important part of service system research but the question is, is it sufficient?



(a) Good nozzles



(b) Fair nozzles



(c) Bad nozzles

Fig. 3. Reconstructed Poincaré section graphs using time-lagged embedding of the total arc voltage time-series data for plasma metal plate cutting process.

3. Service virtual enterprise

A complex engineering system is built from a large number of components by many engineers and contractors. In the past, customers as system owners usually maintain their own service department. However, the increasing complexity of the system and operating conditions such as environmental considerations require service personnel to have a higher level of analysis and judgment capability. The concept of designing support services to these assets as a system is not new. Rathwell and Williams (1996) has studied Flour Daniel and used enterprise engineering methodology to analyse the company. They concluded that companies providing services to complex engineering products need a management and engineering technology which can 'minimize the apparent complexity' of these systems. Mo and Menzel (1998) have developed a methodology to capture process operation knowledge and deployed operations support services as a dynamic web based customer support system. The system is linked to a global services model repository where service engineers of the vendor and operations engineers of the customer can help to build a knowledge base for continuous support of the complex asset.

A service system comprises people and technologies that adaptively compute and adjust a system's changing value of knowledge (Spohrer *et al*, 2007). Abe (2005) describes a service-oriented solution framework designed for Internet banking. In the enterprise model, common business functionalities are built as shared services to be reused across lines of business as well as delivery channels, and the Internet channel-specific SOA is defined by applying the hybrid methodology. The Institute of Manufacturing at University of Cambridge summarises the nature of services systems as "dynamic configurations of people, technologies, organisations and shared information that create and deliver value to customers, providers and other stakeholders" (IfM and IBM, 2007). It is generally accepted that an important element in the design of service systems is the architecture of the system itself. Research is required to develop a general theory of service with well-defined questions, tools, methods and practical implications for society.

Johannson and Olhager (2006) have examined the linkage between goods manufacturing and service operations and developed a framework for process choice in joint manufacturing and after-sales service operations. Services in this case are closely related to the supply chain that supports the product. In a performance oriented service system, decisions for optimization can be quite different from maintenance oriented service concepts. For example, in order to reduce time to service to customers, Shen and Daskin (2005) propose that a relatively small incremental inventory cost will be necessary to achieve significant service improvements.

In managing the design and manufacture of a chemical plant for their customer, Kamio *et al* (2002) have established a service virtual enterprise (SVE) with several partner companies around the world providing after-sales services to a customer (Fig. 4). A "virtual enterprise" is a consortium of companies working together in a non-legal binding environment towards a common goal. It is the equivalence of a supply chain in which the "products" are services or similar intangible business entities. Each partner in the virtual enterprise is an independent entity that is equipped with its own unique capabilities and competencies, assuming responsibility to perform the allocated work.

In Fig. 4, the system provider of the complex engineering system is located in Europe. The system is owned by a customer in South Asia. The ability of providing support services by the European system provider is restricted by time zone difference. By partnering with a component supplier in Australia and a service company in North Asia, the SVE is designed as a "hosting service" which has a broad range of services including plant monitoring, preventive maintenance, trouble-shooting, performance simulation and evaluation, operator training, knowledge management and risk assessment. It is clear from the structure of SVE that all participants have well-defined roles and responsibilities. Services and support to the customer are much more responsive through the SVE which has both the supplier and the service company in more or less the same time zone as the customer.

In another large scale complex engineering systems development project, Hall (2000) has developed a highly integrated documentation and configuration management system that serves the on-going need of ten ANZAC class frigates. Over the life time of the asset (30 years), changes due to new technologies, people and defence requirements are inevitable. Mo *et al* (2005) describes the project to develop the ANZAC Ship Alliance (ASA) as a SVE with three partners for continuous support and improvement of the capabilities of the frigates after completion of the design and build phase. The ASA has been charged with the

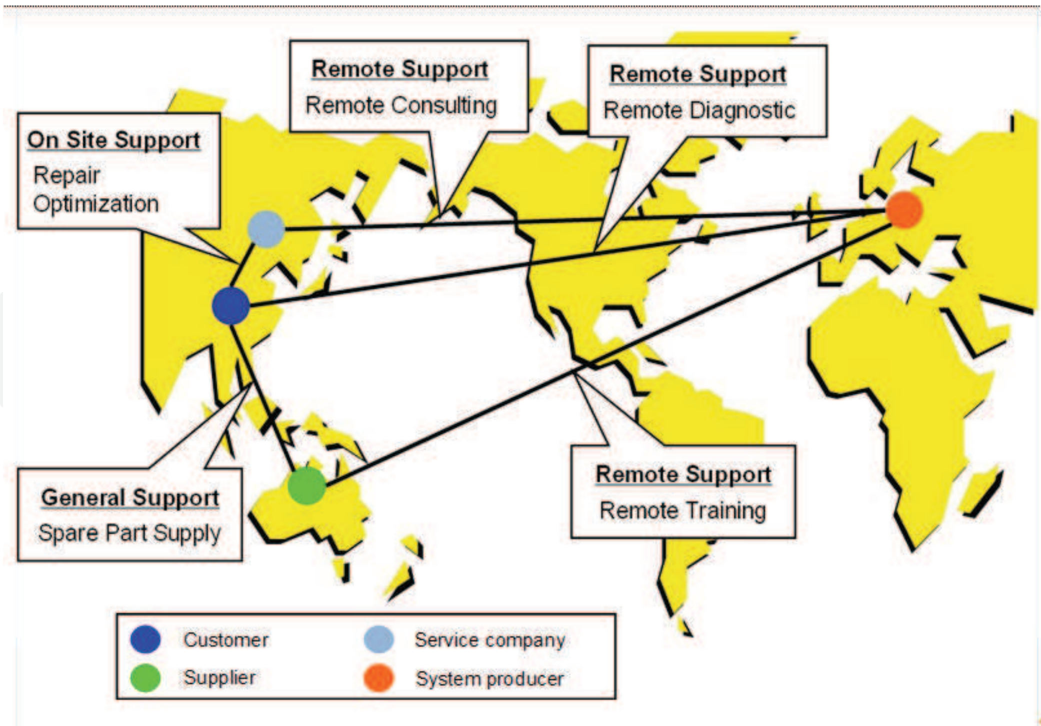


Fig. 4. A globally distributed service virtual enterprise

responsibility to upgrade the ships while they are in-service. To design the SVE, the system requirements are analysed by process modelling techniques to identify responsibilities and work flow in system upgrade projects (Fig. 5).

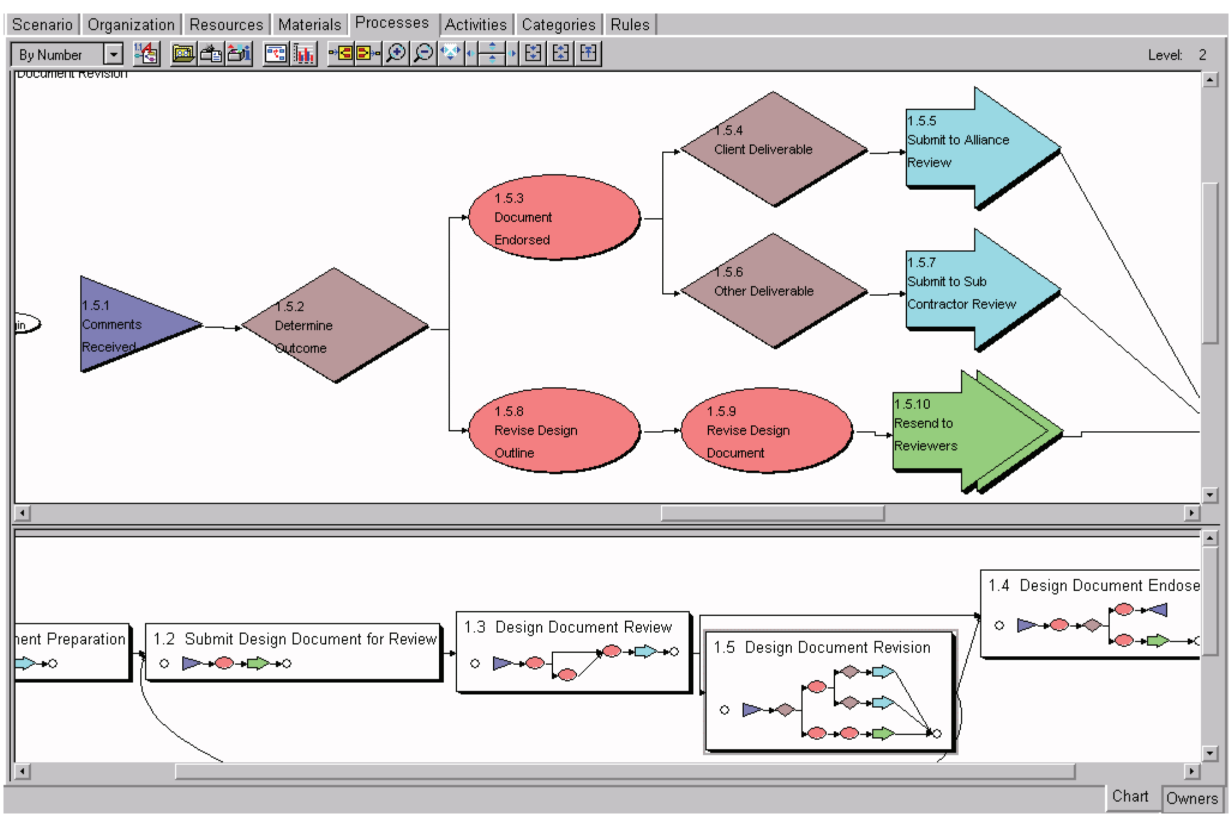


Fig. 5. Work flow of design change of the complex engineering product

A critical design development step of the SVE is to define the mission of the virtual enterprise. The SVE design team conducts a series of interviews with engineering and managerial personnel from all levels in the ASA and develops the mission fulfilment cycle of the ASA in Fig. 6. Within the ASA, the term "shareholders" are partners in the ASA charged with the mission of servicing and supporting the ANZAC frigates for the life of the assets. The activities of the "shareholders" are solution focussed, that is, developing solutions that can be implemented on the ANZAC assets for continual or improved capabilities. The ASA has the role of managing the change program, which can be done by one or two of the ASA partners, or by subcontracting outside of ASA.

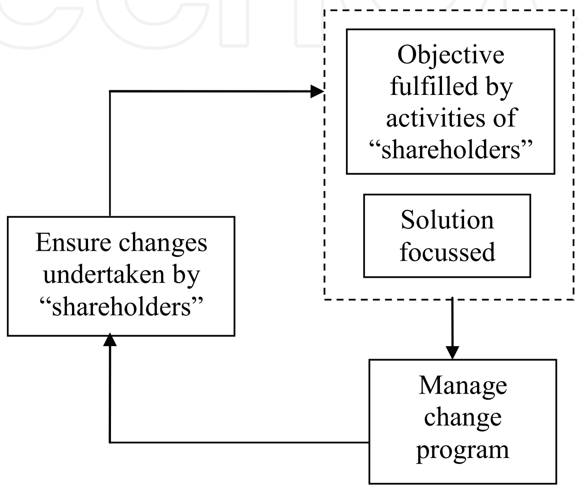


Fig. 6. Mission fulfilment cycle of the ASA

To fulfil this mission, the SVE design team has analysed the system requirements of the ASA using a thorough enterprise modelling methodology (Bernus & Nemes, 1996). The outcome of the enterprise design process that involves experts in enterprise analysts and designers and develops an enterprise structure that is consistent to a "Consultant VE" (Fig. 7).

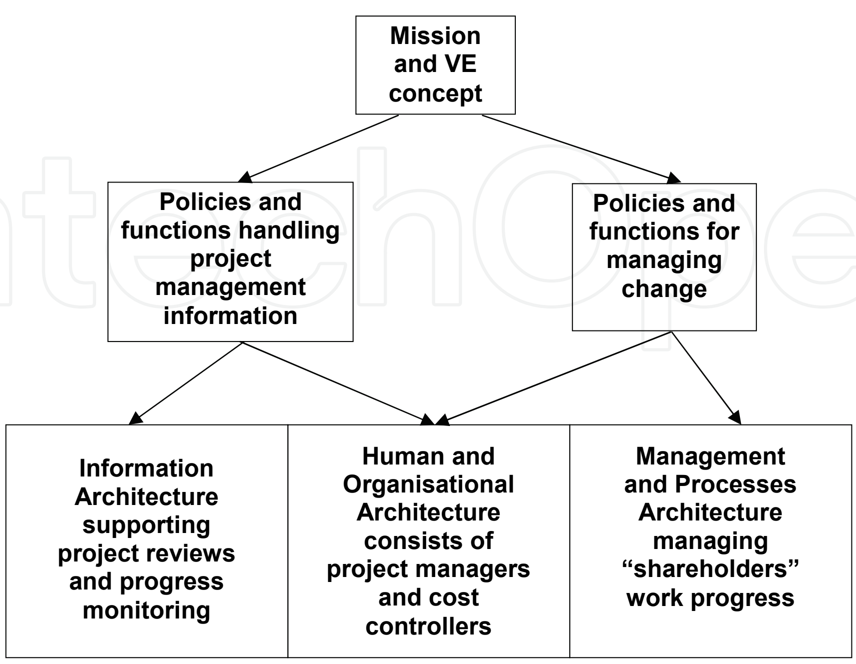


Fig. 7. ASA enterprise architecture evolved as a "Consultant VE"

A SVE is essentially a supply chain set up for providing service "products" for complex engineering systems. These cases show that a clearly defined enterprise infrastructure linking different parts of the service supply chain has to be created and managed for supporting large scale assets. An essential element in the design of a service enterprise is to develop efficient system architecture and provide the right resources to the right service tasks. By synchronising organisational activities, sharing information and reciprocating one another's the technologies and tools, each partner in the service enterprise will be able to provide services that would have been impossible by individual effort. The support solution therefore requires properly designed systems to support the use of technology in the provision of support services to customers. This illustrates that services system design is an integral part of a support system solution.

4. Whole of contract risk assessment

Due to the extremely long term commitment, a services and support contract presents a high risk to the service provider's business. If the risks are not well understood, small hiccups in the life of the services and support contract will result in a sizeable financial loss. Likewise, large mishaps in the operations under the contractual arrangement will impose significant liability to the service provider that may be driven out of business. Hence, apart from setting up the SVE and the corresponding condition monitoring system, the system designer should also ensure continuity of business. It is necessary to estimate the level of risk that the service virtual enterprise has to face over the life of the contract providing the service at the agreed price. This concept and the technique are illustrated with a simple worked example.

In a typical services and support scenario, a service provider (supported by partners in his/her own supply chain) wishes to bid for a 30 year long term contract for the services and support of a waste oil treatment plant. Due to continuous research and development of the oil treatment process, it is envisaged that the plant will undergo several major upgrades within this 30 years. The SVE is fully responsible for continual operational availability of the plant to the plant owner.

In order to achieve a a profitable contract, a thorough understanding of the nature of services is critical to the design of a successful system support solution. Given the aforementioned scenario, the question is how should the service provider assess viability of the service solutions? How much the contract should be? To analyse this scenario, some essential data are solicited, either from historical or comparable cases. It is assumed the following data are collected (all costs are in million dollars $M).

a. There are upgrades required in the 30 years. The year of upgrades t depends on many factors. Table 1 shows the probability of timing of such upgrades.

Year t	Upgrade occurring in the year after first install or last upgrade
5	0.4
10	0.3
15	0.2
20	0.1

Table 1. Probabilities of upgrade timing

b. The cost of upgrade u depends on many factors and can be expressed as probabilities in Table 2.

Cost u (in \$M)	Probability
20.0	0.1
40.0	0.2
60.0	0.2
80.0	0.2
100.0	0.3

Table 2. Probabilities of upgrade costs

c. The services and maintenance (S&M) costs x in \$M vary over the years based on a probability function in Table 3. The average S&M costs will increase by \$0.5M every year, i.e. if the figures in Table 3 are used for determining the S&M costs in Year 1, then the cost figures in x will be increased to 2.5, 3.5 and 4.5 respectively in Year 2.

Cost x (in \$M)	Probability
20.0	0.4
30.0	0.5
40.0	0.1

Table 3. Probabilities of services and maintenance costs

d. After an upgrade, the average S&M costs x in \$M will be reduced by \$1M from the year immediately before the upgrade.

The key to risk assessment is to determine a "reasonable" cost of the contract. This is often computed using expected value method.

Expected year of upgrade: $\mu_t = E(t) = \sum_{i=1} t_i p_i = 10$ (1)

Expected upgrade cost (\$M): $\mu_u = E(u) = \sum_{i=1} u_i p_i = 68.0$ (2)

Expected S&M costs depend on the time after first operation or the years of upgrade t. Since the expected year of upgrade is 10, there are two upgrades in 30 years. The expected S&M costs at different year y up to the year before an upgrade occurs is given by eq.(3).

$$\mu_{x,10} = E(x,y) = \sum_{i=1} (x_i + 0.5y) p_i \qquad \text{where } y < 10 \tag{3}$$

$$\mu_{x,20} = E(x,y) = \sum_{i=1} (x_i + 0.5y - 1.0) p_i \qquad \text{where } 10 \le y < 20 \tag{4}$$

$$\mu_{x,30} = E(x,y) = \sum_{i=1} (x_i + 0.5y - 2.0) p_i \qquad \text{where } 20 \le y < 30 \tag{5}$$

If the marginal rate of return r is 10%, the net present value of total costs of the service contract in \$M is:

$$S = \sum_{i=0}^{9} \frac{\mu_{x,10}(y)}{(1+r)^y} + \frac{\mu_{u,10}}{(1+r)^{10}} + \sum_{i=10}^{19} \frac{\mu_{x,20}(y)}{(1+r)^y} + \frac{\mu_{u,20}}{(1+r)^{20}} + \sum_{i=20}^{30} \frac{\mu_{x,30}(y)}{(1+r)^y} = 319.047 \quad (6)$$

Note that the SVE is still servicing in Year 30 but there is no further upgrade agreement requirement in the last year of the contract.

However, eq.(6) only provides an estimate of a "likely" total cost S of the contract. Is it a good deal for the asset owner? Is it a risky endeavour for the contractor? To answer these questions, we need a way to compute the distribution of the total cost.

A simulation model is set up to calculate an instantaneous total cost for each simulated scenario. We use the notation $|j$ to denote a scenario generated by a random number generator that determines the corresponding stochastic values in Tables 1 to 3. Note that j is generated separately for all variables so that their values are independent. The model can be represented by the following equations:

An instant of years of upgrade due to random number $j = t_k|_j$ (5)

where k = 0, 1, 2, 3, … (max. 5), subject to constraint $\sum_{k=0}^{5} t_k|_j \le 30$ (6)

An instant of cost of upgrade due to random number $j = u_k|_j$ (7)

An instant of S&M cost due to random number $j = x|_j$ (8)

For upgrade period $k \in m$, the S&M cost of the plant is given by:

$$x|_{j,y} = x|_j + 0.5y - 1.0k \quad (9)$$

where y is the year at which the S&M cost is evaluated.

Hence, the net present value of the instant of total cost is given by:

$$S = \sum_{k=0}^{5} \sum_{y=0}^{t_k|_j - 1} \frac{x|_{j,y}}{(1+r)^y} + \sum_{k=0}^{5} \frac{u_k|_j}{(1+r)^y} r^i \quad (10)$$

The simulation is run 200 times and the result is shown in Fig. 8.

It is important to analyse the risk of setting a quotation figure. If we assume a normal distribution, the mean and standard deviation of Fig. 8 are \$398.72M and \$47.74M respectively. If the contract cost is set at say \$450M (in order to compete), the risk of incurring a loss is 14.1%. This is a high risk contract and is not acceptable in normal business practice. On the other hand, if the SVE wants to have 99% certainty of a profit, the contract sum should be increased to \$509.79M.

This case study shows that a system support engineer will need to develop a mathematical model that represents behaviour of the system over a period to analyse sustainability of the support solution according to prevailing business conditions. The business requirements of service contracts drive a fundamental change in the way services to complex systems are designed. Minimising cost of replacement part will not be the objective. The main focus is to maintain or improve the performance with changes that is sustainable. Hence, it may mean change of parts at a higher rate but the savings in better performance from the system will pay for the increased component cost. The analytical techniques vary from case to case. A thorough research in the fundamental of support system sustainability is required to establish a standard methodology.

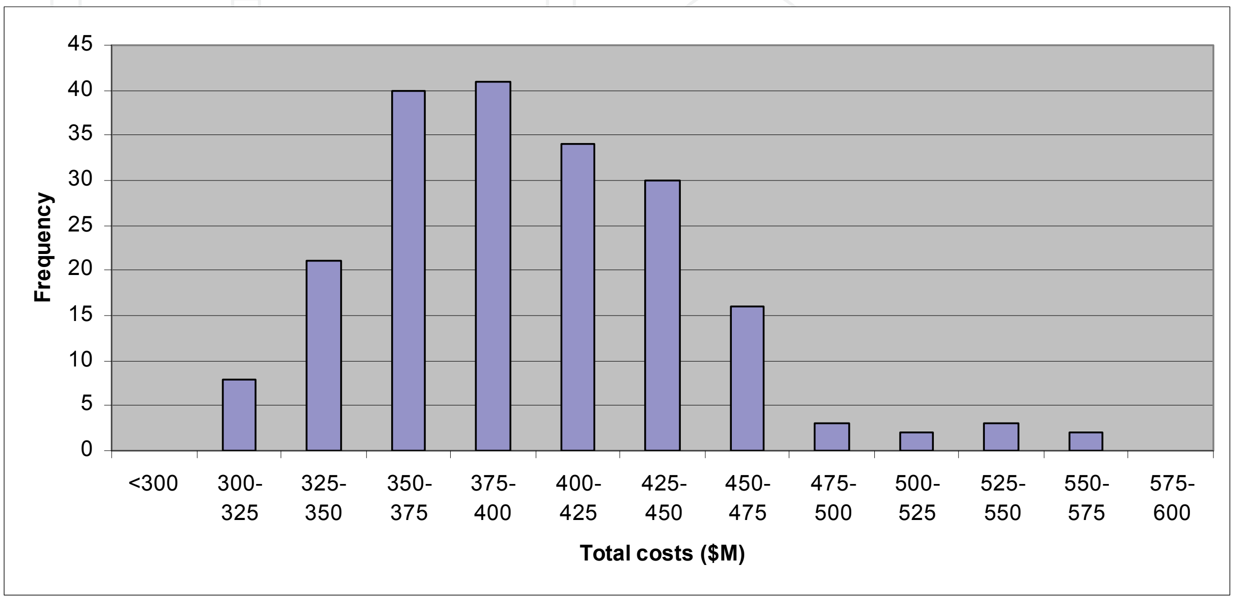


Fig. 8. Frequency of possible total costs for the service contract

5. Design of services and support virtual enterprise

A services and support contract will include incentives and penalties against agreed service levels. Hence, the service contract requires a thorough understanding of how the engineering system works and how the supporting systems around the asset should operate to achieve the desirable performance. Due to the highly complex nature of services provision, services and support contracts are all different. It is an extremely knowledge intensive, labour rich business. The support solution then becomes a one-off development which imposes significant system design issues to both asset owners and contractors. They will need to work through the contract which incorporates unfamiliar contractual metrics and risks. The shift in business environment and model has driven the research need for new methods and processes to design service solutions for complex systems, for example, intangible elements for achieving successful service delivery should be incorporated. The objective is to “get the best value for money” on supporting asset capabilities for the asset owner.

Hence, in designing support solutions, due to the interacting relationships between the customer and the service provider, the characteristics of both service elements and hard system components must be integrated into the service system with a critical reasoning process that aims to produce a solution design in unison with all parties involved in the performance based contract. Irrespective of industry sectors or types of customers, services are co-produced with and truly involving consumers. To illustrate this concept, Fig. 9 shows a generic model of a services and support system that has 4 interacting ingredients.

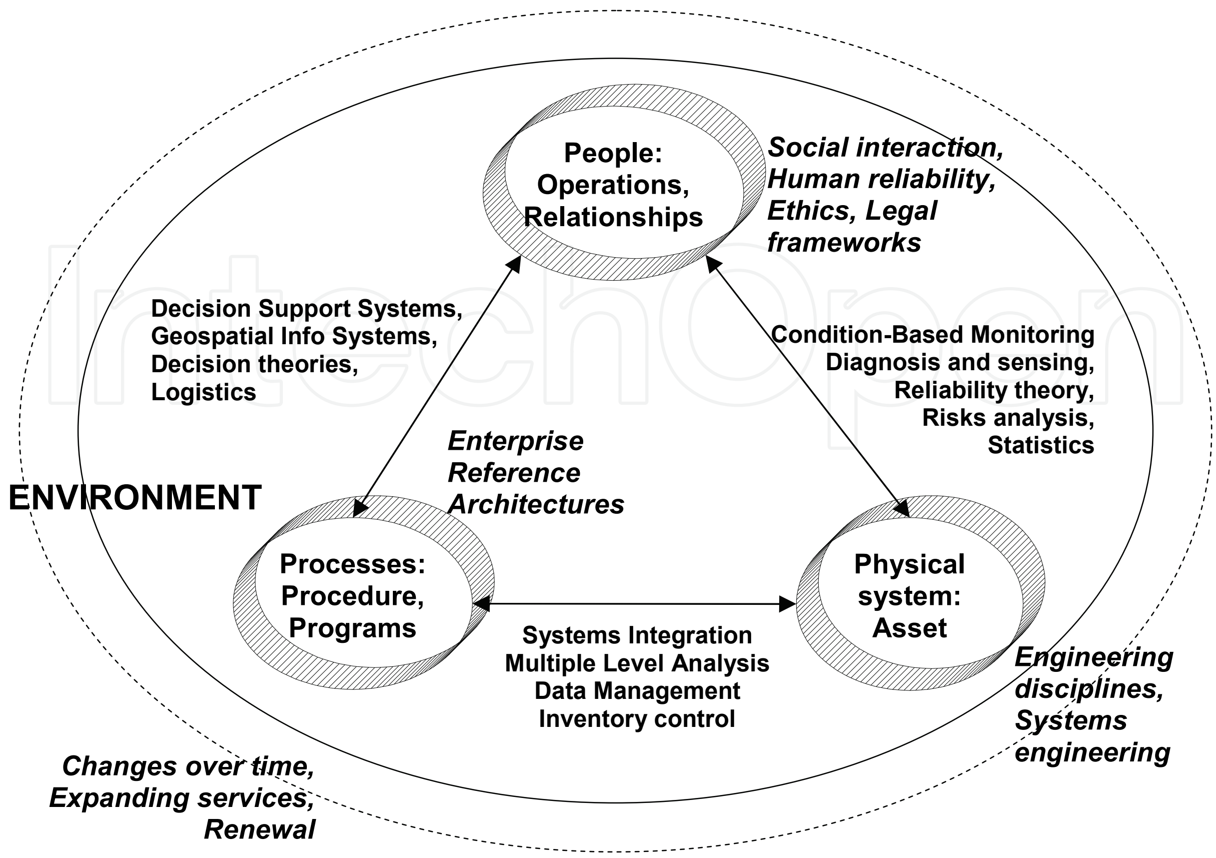


Fig. 9. Services and support systems have four interacting ingredients that need to be well understood for the formation of a SVE

5.1 Physical asset

A services and support solution must have a physical system on which the services and support requirements are defined. A complex engineering system is often either specially designed from conceptual requirements specified by the customer, or customized from an existing engineering system to the need of the customer. In this context, the knowledge of discipline based engineering domain coupled with systems engineering is necessary to design and build the engineering system. The structured, systematic approach in this design process is a risk minimized way of producing a workable physical asset.

Complex engineering systems are created through an intensive life cycle of data accumulation and information re-structuring. Usually the life cycle of such an engineering system can be divided into 6 phases as shown in Fig. 10 (Jannson et al, 2002).

It is obvious that the information in the complete product life cycle are particularly important to support both asset owners and service contractors. Knowledge from domain engineering (such as mechanical engineering) should be amalgamated with feedback from business aspects of system-in-service, within the life cycle of the system in order to design a workable SVE and develop a viable service solution. What is important in this case is therefore to make sure that information available at different stages should be archived in compatible formats so that future staff and systems can use the same data set for services and support.

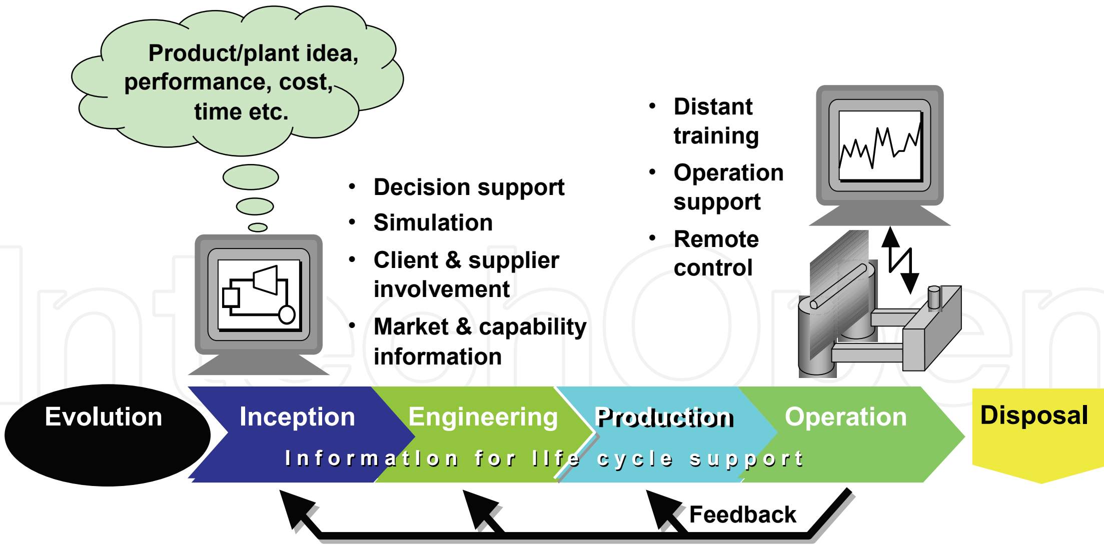


Fig. 10. Complete life cycle management of complex system

5.2 Processes

The hardware system design should be supported by corresponding processes that are required to operate, service and support the performance of the physical asset. Operations are related to the measurement of performance. Systems integration and data management regimes are required to support designing and structuring a system support solution. The provision of service is different to product-based business model. Service is a negotiated exchange with the asset owner (and operator) to provide intangible outputs together with the asset owner. A service is usually consumed at the time of production and cannot be stocked. Hence, the development of appropriate processes and performance metrics that help the people involved to synchronise their activities is essential. These processes are constrained by the environment in which the complex system and the business are operating. Most of these are supported by advanced information and computational technologies that integrate with on-asset systems such as sensors or signal processing capabilities.

In the design of the processes around the physical asset, the services solution designer draws upon principles derived from experience that are obtained in previous projects or recorded literature elsewhere. The use of enterprise reference architectures that forms the initial base for adopting to a wide range of scenarios is crucial to the success of the newly designed SVE and its support solutions. The enterprise model helps the system support engineer to take into account as many constraints as possible during the system design phase.

5.3 People

What is normally ignored in the design of systems are the people who are either involved (e.g. operators, beneficiary of use, etc), or not involved but are affected by the operation of the engineering system (e.g. by noise, pollution, etc.) People working on the physical asset will require data for them to judge the status of the asset and act accordingly. New developments in diagnostics and sensing technologies are important data capturing components that enable people to close the information loop. However, the need of human interaction in providing the required services and support imposes a different challenge, that is, the issue of human reliability. Many researches have been found in the area of human safety but the integration of human error in an engineering system scenario has never produced reliable risk assessment due to the variability of data (Kirwan, 1996). Hence, when assessing the risk of a services and support contract, it is necessary to allow for a higher level of uncertainty in the final decision.

Another issue with human involvement is the necessity for providing meanings to the people in the process. Participation of human should be on voluntary or incentive basis. The support solution design should contain adequate information that explains the meaning of the solution to anyone working in the SVE. The services solution must be characterised by the need to create value for both asset owner and the service provider. As such both sides are treated as co-innovators in the design of the service support solution. Many decisions are made based on incomplete data rather than fully analysed data set. There are a lot of risks, both from the point of view of data availability, as well as subjective human judgement and communication. In this context, decision theories that can draw upon information that are critical to the people around the asset are particularly useful to assist the group or society to a logical, win-win outcome.

5.4 Environment

All three elements physical asset, processes and people work within some kind of environment. The term environment does not limit to the natural system of mother nature. It also means artificial circumstances in which the three elements are made to work in. For example, a business environment created by the defence requirements of a country often defines its own rules and objectives that are totally different from the general civilian community. Companies in the defence environment will need a different set of data and process it in mission critical projects.

Sustainability issues are related to the continuity of business and viability of the support contract. A characteristics of the environment is change over time. Changes can be in the form of technological change, aging of people, loss of memory, renewal requirements due to regulatory or sociological changes. Unfortunately, the complexity of the changes in environment is difficult to predict.

6. Conclusion

In this chapter, we discussed the difference between a maintenance oriented regime and a services and support contract in the context of complex engineering systems. A complex engineering system is an expensive asset that the owner-operator is keen to keep and continues to use as long as possible. From the owner's point of view, it is important that capability should increase over time to meet changing demands. To achieve this goal, the business environment now favours the use of services and support contracting mechanism that puts responsibility to the services and support providers.

In the past decade, researches in the development of support systems have been fragmented. Due to the highly individualised nature of a service contract, it is an extremely knowledge intensive, labour rich business. These services are substantially more complex than routine, reliability based maintenance. In order to create a viable support solution, three essential elements are required:

- A condition prediction and monitoring system that provides feedback to the services provider assisting continuity of operations;
- A service virtual enterprise (SVE), which is a supply chain offering service "products" to customers with complex engineering systems;

- The knowledge that can be used to analyse the risks in committing to service levels agreed upon between the asset owner and the SVE.

In conjunction with these elements, a conceptual model that describes the interacting nature of four ingredients in a services and support system is also presented. Understanding how the ingredients work together and how they change over time is critical to the successful design of the SVE and its system support solution.

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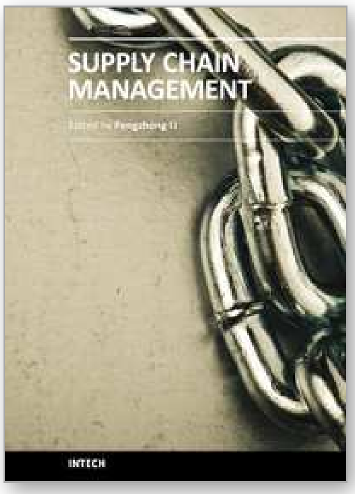

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The purpose of supply chain management is to make production system manage production process, improve customer satisfaction and reduce total work cost. With indubitable significance, supply chain management attracts extensive attention from businesses and academic scholars. Many important research findings and results had been achieved. Research work of supply chain management involves all activities and processes including planning, coordination, operation, control and optimization of the whole supply chain system. This book presents a collection of recent contributions of new methods and innovative ideas from the worldwide researchers. It is aimed at providing a helpful reference of new ideas, original results and practical experiences regarding this highly up-to-date field for researchers, scientists, engineers and students interested in supply chain management.