Chapter 2
Through-Life Engineering Services: Definition and Scope: A Perspective from the Literature

Louis Redding

Abstract Through-life Engineering Services (TES) provide product support throughout each stage of the product-lifecycle; from conception, through design, manufacture and operational life, to end of life disposal. They are seen as a natural stage in the evolution of product support and maintenance, repair and overhaul strategy. They are the sum of many diverse product support strategies which use emerging and traditional technologies, processes, and applications. Whilst there are increasing numbers of contributions to be found within the literature defining the content, scope, purpose and application of the supporting technologies one sees no definition for TES emerging. This chapter offers a definition for Through-life Engineering Services which states what the concept **is**. It gives dimension, application, and purpose for TES in its role as a facilitator of Technology Enabled Service Delivery Systems which support manufacturing organisations wishing to compete through the adoption of Product Service Systems. An initial taxonomy is also presented.

2.1 Introduction to, and Definition of, Through-Life Engineering Services (TES)

As manufacturing organisations seek '*whole-life*' revenue streams the role of service in support of their products becomes ever more important. Driven by the requirement to offer sustainable solutions due to the realisation that material resource is limited, and the need to be ever more competitive in the face of increasing competition from both the emerging industrial (BRIC) economies and the global market, one sees Product-Service Systems (PSS) [1–3] and *servitization* [4, 5] emerge. The traditional contract of design, manufacture, sell, and maybe offer

L. Redding (✉)
EPSRC Centre for Through-Life Engineering Services, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK
e-mail: l.e.redding@cranfield.ac.uk; louis.redding@btinternet.com

L. Redding and R. Roy (eds.), *Through-life Engineering Services*,
Decision Engineering, DOI 10.1007/978-3-319-12111-6_2

a limited service by way of spares and repair, is no longer seen as the sole order qualifiers for those manufacturers who provide complex engineering products (typically aeroplanes, ships, trains, machine tools, etc.) [6]. Organisations who operate/use such products are choosing to only pay for the use (or the availability to use) these products resulting in manufacturing organisations offering whole-life service support for their offerings. One such often quoted and leading initiative is Rolls Royce's 'Power by the Hour' [7]. Here the operators of Rolls Royce engines pay for the '*availability for use*' of the asset to the manufacturer with the engine typically being owned by the leasing company or bank. This structure is also observed with other transport systems such as railway rolling stock. In the UK Rail Sector trains are designed and produced by the manufacturer who then sells them to Rolling Stock Operating Companies (ROSCO's) who are fundamentally leasing companies. These in turn offer franchises to the Train Operating Companies (TOC's) under fixed term franchise agreements. The revenue stream back to the manufacturer is therefore heavily reliant upon the train (or other such product) being available for use.

Underpinning all of these initiatives is the role of the engineering service support function. Such support can manifest itself as either/or a hybrid solution of dynamic 'real time' support (the monitoring and resulting decision systems) and maintenance, repair, and overhaul function. Through-life Engineering Services as discussed in this chapter (and in the following chapters) will be seen as the sum of both these dimensions which, when applied within the service delivery system, not only increases the product's availability for use, but offers the potential to 'engineer out' inherent degradation mechanisms (or at least minimise their occurrence) by using whole life product related knowledge to inform design. This thus has the potential to greatly reduce whole life cost for the stakeholders who obtain revenue through manufacture, service support, and operation of the products function.

2.1.1 Evolution of Maintenance in Support of Manufactured Products

Pinjala et al. [8] and Waeyenburgh et al. [9] suggest that there are few management disciplines that have undergone so many changes as those observed in the field of maintenance and product support. Initially the maintenance repair and overhaul function (MRO) was nothing more than an essential activity which was called upon to remedy a failed or degraded component, system, or product. It was seen as a function which was secondary to manufacturing, a necessary 'evil' and, if no more than an irritant, a constant drain upon the organisations balance sheet that was to be minimised at all cost. Typically service support and maintenance at this level consisted of the provision of spares, repair call outs which were treated as a separate standalone contract, routine inspection of equipment covered by statutory requirement (i.e. insurance driven), and in some cases engineering upgrades of

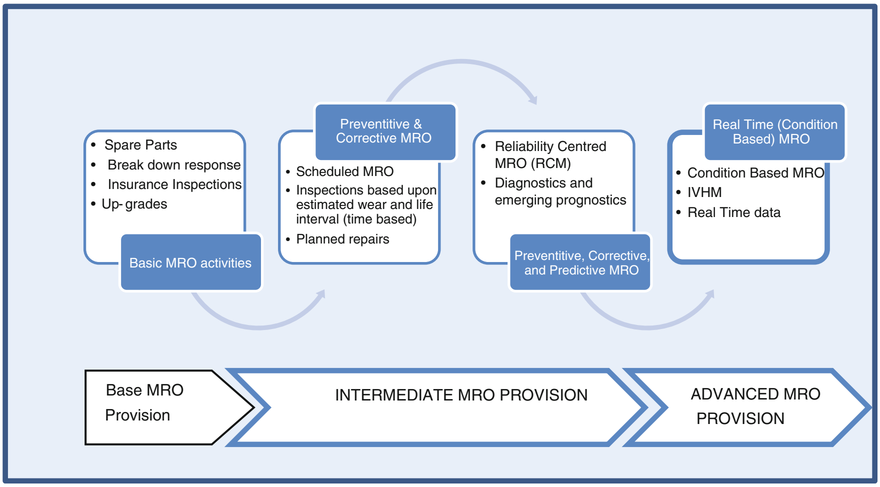

Fig. 2.1 The Evolution of maintenance repair and overhaul (MRO) strategies

controlled products. In categorising service levels the author takes guidance from Baines et al. [3] who suggest that services fall into three categories, they being '*base*', '*intermediate*', and '*advanced*'.

Base level services were sufficient in a period where assets and products were simple stand-alone items offering little by way of revenue to the manufacturer post of point of sale. However as products become more complex their reliability and availability become more important to the user and the commercial performance of the manufacturing organisation. The drivers of technological advancement, the emergence of modular design, reduction of redundancy within a given design, and more bespoke designs based upon aligned customer requirements and specifications, call for products that are ever more reliable and available for use. This sees a move into the 'intermediate' service provision. Here scheduled service activities which are time based evolve with estimates for service intervals based upon wear and service (as used) life emerging. This evolution is illustrated in Fig. 2.1.

2.2 Through-Life Engineering Services—a Definition

Whilst the literature offers both explicit and implicit insights [10–14] into the role of services in support of servitization and PSS it offers little by way of a definition for Through-life Engineering Services (TES). The concept finds its introduction based in the literature and associated research relating to Condition Based Maintenance (CBM) [15–17], Integrated Vehicle Health Management (IVHM) [18–20], Technical Product Service Systems [10, 21] and Design for Service [22–24] which address service support from a 'whole-life' perspective driven by the changes in business paradigms. It is not until the emergence of the 1st and 2nd International

Conferences on Through-life Engineering Services in 2012 [25] and 2013 [26] respectively does TES start to gain an identity which is distinct from the plethora of other product service support initiatives.

Roy [25, 27] suggests that TES are "*technical services that are necessary to guarantee the required and predictable performance of an engineering system throughout its expected operational life with the optimum whole life cost*". Whilst this is the first attempt at defining the concept it says more about the purpose of TES rather than offering a definition relating to its identity, content, context, and rationale which helps to distinguish the concept from other product service support initiatives. Whilst these conference proceedings offer 53 papers (2012 Conference) and 79 papers (2013 Conference) respectively relative to aspects and applications of TES, none define TES directly.

In seeking to understand TES and the concept of service support within the life-cycle Aurich et al. [11] propose looking at the product life-cycle through three differing lenses (Fig. 2.2). They suggest that for the Product Life Cycle (PLC) lens the stages of evolution are '*engineering*', '*production*', '*usage*', and '*re-cycling/disposal*'. Whilst these are intuitive and well documented these stages are not simply sequential in all industrial sectors in the world of concurrent engineering of complex products. In the automotive sector, for example, significant overlap can be witnessed as OEM's launch advanced pilot build vehicles into the market to harvest usage performance prior to main volume build. During this process product processes are analysed, pilot vehicle performance harvested, degradation mechanisms identified, and service response defined, all of which are fed back into the design '*engineering*' activity before the final design stage gate is completed.

Aurich et al. [11] continue to propose that from the manufacturer's lens the 'product' consists of two attributes, the 'physical' (the physical product) and 'non-physical' (service support) elements of the product offering. From the manufacturing of the physical product perspective within the organisation the PLC is defined as 'product design', 'product manufacturing', 'spare parts manufacturing', and 'product re-manufacturing'. However, within manufacturing organisations producing complex engineering products there is also a service offering (the non-physical product) supplied by the company. From the manufacturer's service support department the life-cycle is different and is as illustrated in Fig. 2.2. It is seen that

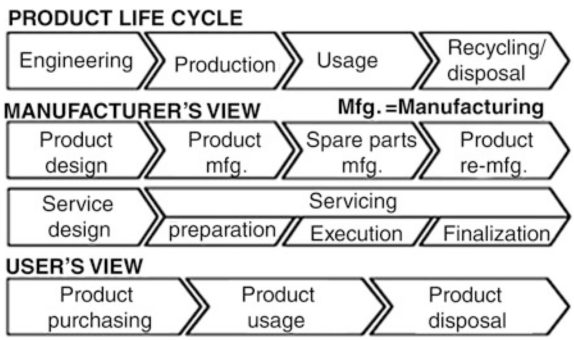

Fig. 2.2 Service in the product life-cycle (PLC) [11]

service design leads to the delivery of service through preparation, execution, and finalisation. The final lens defined by Aurich et al. [11] is that of the user and it is proposed that there are three elements within the lens as illustrated in Fig. 2.2.

Whilst Aurich et al's. [11] illustration (Fig. 2.2) serves to offer the reader a perspective of the PLC through the different lenses specified it does not offer insight as to the position and duration of each element against a time scale within the PLC. Traditionally, organisations designed and manufactured products to suit a specification relative to a defined function, with service activities being an afterthought based upon explicit (or tacit) knowledge gained by previous experience of the performance of generic parts. As maintenance, repair, and overhaul activities evolved (Fig. 2.1) so did the awareness of the benefits of putting service experience and knowledge into the design activity. In the world of increasing *servitization* the users of complex engineering products "expect the…(product)…suppliers to provide more efficient and reliable products and services, with lower and more predictable operating costs" [22].

As organisations evolve through the PSS continuum [28], from that of pure product provider to that of pure service provider through the process of *servitization* this, and the evolution in service delivery systems (maintenance, repair and overhaul), converge as both concepts become interdependent. This is no better illustrated than the initiatives being pursued within the aerospace sector (i.e. Rolls Royce—Total Care™) and its 'Power by the Hour' availability contracting solutions [7]. Harrison [22] identifies this convergence of evolution and interdependency when stating that "the real potential for quantum reductions …(in whole life cost)… comes when the product and service are designed in harmony. This requires a…shift… from '*offering a service around an existing product*' to '*designing a service and the product that supports it*'" [22].

Implicit in the discussion thus far is the role of service data and information from which knowledge and hopefully wisdom can be acquired relative to the product [29]. That is data which is relevant to the design and use of the product; the degradation and failure mechanisms experienced by the product; the means of detection of such degradation and failure; and the technologies and methodologies by which original design function can be restored and prolonged. Jagtap and Johnson [24] illustrate this in their study which proposes how 'in-service' information may be used by engineers when seeking to design the next generation of aero-engine [30]. In their paper they state that "in-service information related to … degradation mechanisms of similar aero-engines is utilised to avoid the same issues in future aero-engines …(and the)… flow of information from the service domain to designers is thus crucial for minimising in-service issues and can also reduce the cost of both planned and unplanned maintenance" [30].

In seeking to offer a definition which is grounded in the aforementioned literature the following questions are posed:

i. What do we mean by service knowledge in relation to engineering services?
ii. How do we define Through-life Engineering Services (TES) and how do they differ from other product service support systems?

Much is written within the literature relative to the distinctions between data, information and knowledge, and the *content*, *context*, and *structure* of each of these dimensions ranging from definitions for each dimension [31, 32], its structure and management [33–35], the comparison between semantic and syntactic knowledge structures relative to storage and retrieval systems [36], and studies as to how service knowledge can be used to benefit design [14, 37–39]. After review of all of these works cited the following definition for service knowledge is offered which is relevant to the focus of this work.

> Service knowledge is the ability to initiate a change of state in a product or asset facilitated by the awareness of the current condition of that product or asset, its historical usage, and means of restoring the 'as designed' functionality supported by explicit (codified) and tacit knowledge of the degradation and failure mechanisms of that component (Paper forthcoming by the author 2014)

Having provided a definition for service knowledge which is seen as the foundation from which TES operates and which is grounded in the literature, this definition becomes an essential component of any definition proposed for TES. In order to offer such a definition for TES the literature is reviewed to find similar service support concepts which can be applied to complex engineering products and their use in facilitating PSS through a process of servitization. Whilst not exhaustive, several concepts and definitions are presented in Table 2.1.

The literature relative to the definitions of engineering service support is very limited and of those offered they are all generic. Most definitions state purpose of the concept with few (if any) stating content. Of those service support concepts cited in Table 2.2 which support PSS several common factors emerge. These refer to through-life considerations and state that the service provision is the sum of element parts;

- Aurich et al. [11], physical and non-physical components and the need for stakeholder integration; (*Dimension*)
- Houschild et al. [40], application of scientific principle throughout life-cycle with consideration to sustainability (*Application*)
- Meir et al. [41], delivers value, integrated planning, development, provision, use; dynamic provision, enable availability (*Purpose*)
- Roy et al. [27], guarantee design performance and reduce whole-life cost (*Purpose*)

Whilst all of the definitions cited give value and insight into the identity of the concepts to which they refer (*Dimension, Application, Purpose*), none actually state what the concepts **are**. In consideration of these elements extracted from the definitions cited and the author's proposal that the underlying premise for such initiatives is that they are based upon the acquisition, storage, retrieval and application of service knowledge, the following definition of TES is offered.

> Through-life Engineering Services are a result of the application of explicit and tacit 'service knowledge' supported by the use of monitoring, diagnostic, prognostic technologies and decision support systems whilst the product is in use, and maintenance and repair

Table 2.1 Definitions and characterisation of differing service support concepts found in the literature (not exhaustive)

Author (ref)	Concept	Definition
Aurich et al. [10]	Technical product service systems (t-PSS)	"With respect to the understanding of technical product-service systems and their non-physical components… three constitutive characteristics can be identified, which distinguish technical services from physical products: • Technical services are mainly non-physical. Their realization can therefore often be performed at minimum consumption of resources, which is one of the decisive reasons for services being considered in the context of dematerialization. Furthermore, due to their non-physical character, services can neither be produced to stock nor distributed like physical products. Hence, the service provider must build up corresponding resources for 'on demand servicing' • Unlike physical products that are first manufactured and later consumed over a period of time, technical services are realized and consumed simultaneously. This principle is referred to as the 'uno acto principle' • The realization of technical services requires the integration of the customers in terms of providing the products, respectively, staff, to which a service (e.g. maintenance and user training) refers"
Hauschild et al. [40]	Life cycle engineering (LCE)	Engineering activities which include: "the application of technological and scientific principles to the design and manufacture of products, with the goal of protecting the environment and conserving resources, whilst encouraging economic progress, keeping in mind the need for sustainability, and at the same time optimizing the product life-cycle and minimising pollution and waste"

and overhaul (MRO) functions to mitigate degradation, restore 'as design' functionality, maximise product availability, thus reducing whole life operating cost.

This definition defines TES by stating its **content** and acknowledging that the underlying principle from which the concept is based is the acquisition, storage, retrieval, and application of **service knowledge** for the purpose of extending the life of the design function throughout the whole life-cycle. This increases the availability for use of the product by the owner/operator thus reducing the whole life cost of operation and/or ownership whilst mitigating risks to the revenue stream by component degradation and failure.

Table 2.2 Definitions and characterisation of differing service support concepts found in the literature (not exhaustive)

Author (ref)	Concept	Definition
Meir et al. [41]	Industrial product service systems (IPS^2)	"…is characterised by the integrated and mutually determined planning, development, provision, and use of product and service shares including its immanent software components in business to business applications and represents knowledge-intensive socio-technical system. This means in detail… • An IPS^2 is an integrated product and service offering that delivers value in industrial applications • IPS^2 is a new product understanding consisting of integrated product and service shares • IPS^2 comprises the integrated and mutually determined planning, development, provision and use • IPS^2 includes the dynamic adoption of changing customer demands and provider abilities • The partial substitution of product and service shares over the lifecycle is possible • This integrated understanding leads to new, customer-adjusted solutions • IPS^2 enable innovative function-, availability- or result-oriented business models"
Roy et al. [27]	Through-life engineering services (TES)	"Technical services that are necessary to guarantee the required and predictable performance of an engineering system throughout its expected operational life with optimum whole life cost"

2.3 The Scope of Through-Life Engineering Services

Having offered a definition for TES the next question which naturally follows relates to the scope of the concept. There are many product support initiatives discussed within the literature which cover many aspects of through-life product support. These include (i) knowledge of degradation mechanisms (their root causes and means of manifestation) which exist within a given product/system; (ii) knowledge of the means of restoring design functionality; (iii) knowledge of degradation/fault diagnostic methods and the means of assessing remaining useful life, (iv) knowledge of the mode of use which can be either in 'real time' and/or historic in nature; and (v) knowledge of the design function and manufacturing methods used to produce the product. These inputs either collectively or individually facilitate TES enabled solutions which in turn offer numerous benefits to the organisation when seeking to compete through PSS generic solutions (Fig. 2.3).

When reviewing the inputs to a TES system one sees that several supporting technology applications are implied that enable such services to deliver the benefits above. In seeking to understand the scope of TES it is helpful to have a taxonomy

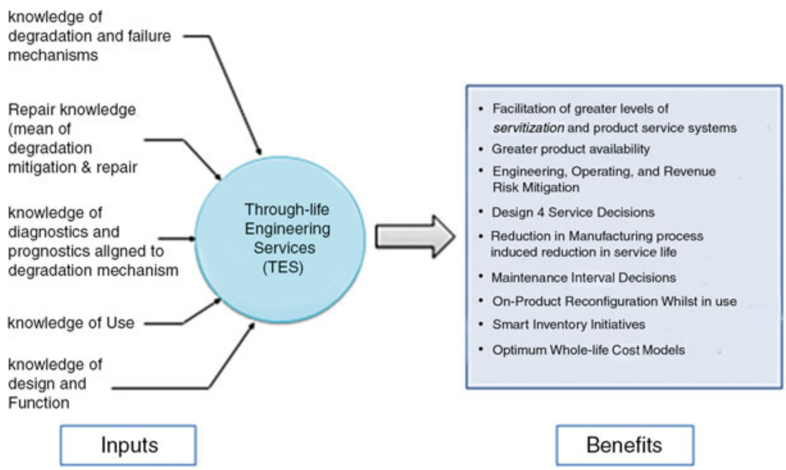

Fig. 2.3 Inputs to, and benefits of, through-life engineering services

for the concept. The literature offers no such single holistic insight however to the breadth or depth of TES and its component applications by way of service delivery systems. In order to illustrate the scope and content of TES the following illustration is offered (Fig. 2.4).

The diagram illustrates that TES enabled product support systems are the sum of many technical applications. Whilst all these elements have significant bodies of

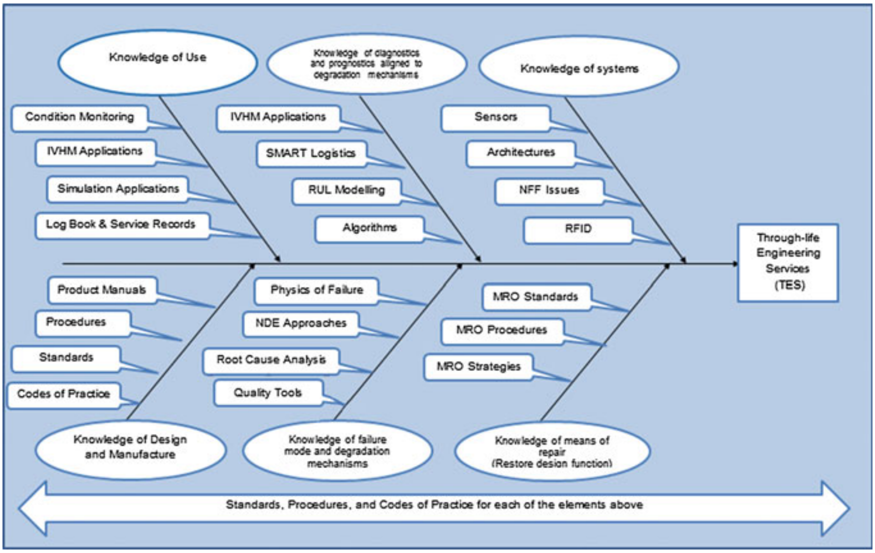

Fig. 2.4 Initial taxonomy for through-life engineering services

literature relating to each of them, with the exception of Integrated Vehicle Health Management (IVHM), and Condition Based Management approaches which could be described as philosophies, they each appear in silos with few approaches seeking to look at holistic whole life solutions resulting from the cumulative sum of the bodies of knowledge. The foundation for each of these concepts is the acquisition of data from which information, knowledge and hopefully wisdom is derived and then applied.

2.3.1 Knowledge of Use

An understanding of the product code of use and performance against pre-defined parameters is important when organisations seek to offer extended support. This understanding was traditionally achieved by reviewing historical usage and performance records supported by maintenance, repair, and overhaul data. This is increasingly being delivered today by Condition Based Monitoring (CBM_1) and Condition Based Management (CBM_2) techniques which see the use of sensors being fitted to the product, with data being harvested intermittently by either download from on-product data storage systems, or via transmission using telecommunication and satellite technologies. IVHM generic solutions are the pinnacle of this type of application. The concept is far more than just condition monitoring but has the potential to offer a paradigm shift in business operations and support strategies. An often cited example of such a solution is the aerospace sector and particularly the OEM's supplying gas turbines. Here the engines are fitted with on-board sensors which transmit engine data at pre-determined times and positions within the flight curve (take-off, mid-cruise, and landing). These packets of data are then cleansed and trended by third party support organisations before arriving in control rooms where engineering and operating teams monitor the engines and take mitigating actions to engine operating configurations during flight as required. Decisions relating to existing operating life, maintenance intervals, strategies, and logistics are also informed by the data, information and knowledge acquired. With aircraft the operating profiles are also recorded and the loads on an engine are significantly different between short haul and long haul operators (i.e. cycle times throughout life).

Similar product support is also observed within the UK Rail Sector with suppliers of rolling stock. Typically the manufacturer produces the train which is then subsequently owned by the Rolling Stock Operating Companies (ROSCO'S) who in turn lease the train to the Train Operating Companies (TOC's) through complex leasing agreements and operating franchises. The revenue is achieved increasingly by the provision of availability contracting and risk to the revenue is mitigated by on-board monitoring, one such solution being Bombardier Transportation PLc's *Orbita*™ solution.

This approach also facilitates the use of simulation techniques using real time acquired data. This can be used in scenario assessments thereby facilitating better understanding of the products operating performance, degradation mechanisms and reaction to defined operating parameters. Knowledge of remaining useful life, better strategic decisions relating to product support solutions and business models are also facilitated.

2.3.2 *Knowledge of Diagnostics and Prognostics Aligned to Degradation Mechanisms*

For any product support system to operate effectively, knowledge of how to detect, diagnose and predict when a product should be maintained or overhauled is essential. Whilst IVHM generic systems monitor the *dynamic* as used situation and *real or near real time* condition, under pinning this is the ability to understand the data obtained and through the use of modelling and bespoke algorithms, decisions relative to diagnostics and prognostics are made. Implicit in this is the requirement to have in-depth understanding of the degradation mechanisms that can occur given a set of operating parameters and the rate at which such degradation would develop, evolve and propagate. This understanding and knowledge is the sum of the inputs acquired whilst the product is in use, and also from the MRO function who see the product in the maintenance facility when a requirement for repair or replacement after failure is needed. Such knowledge and the ability to effectively predict critical thresholds of degradation which trigger mitigation events are is also analogous to a KANBAN signal which in turn can trigger smart logistics and component replacement throughout the supply chain. However knowledge of the means of conducting diagnostics and prognostics relative to understanding degradation is far more than just evaluating condition based data from IVHM generic systems. The ability to undertake effective diagnosis and offer a prognosis relative to RUL requires in-depth understanding of the degradation mechanism observed.

2.3.3 *Knowledge of Failure Modes and Degradation Mechanisms*

The knowledge of failure modes and degradation mechanisms comes from the application of many tools and techniques which relate to the body of knowledge found within the literature and the acquisition, analysis, and synthesis of MRO data acquired from practitioners in the field which is both explicit and tacit in nature. There are many techniques that can be applied to aid diagnostic and prognostic decisions. These include such 'quality tools' [42, 43] as *ISHIKAWA* approaches, *root cause analysis* [44], understanding the '*physics of failure*' [45], and the application of product testing and non-destructive testing approaches (X-ray, CT Scan, Thermography etc).

When considering the degradation of mechanical components knowledge is required not only of the in-service operating parameters, but also the inherent degradation and failure mechanisms at component feature level if design is to be able to mitigate product failure. Typically an understanding of the high levels of degradation taxonomy is a pre-requisite to delivering an effective service delivery system in support of the physical product which includes fatigue, creep, fracture mechanics, corrosion, stress, strain etc., which can be caused by such parameters as mechanical and/or thermal stress, environment, temperature, pressure, impact, wear/abrasion, and other operating parameters.

2.3.4 Knowledge of Means of Repair (Restore Design Function)

Whilst the understanding of diagnostics, prognostics, and the degradation mechanisms which may occur are essential foundation elements to the service delivery system facilitated by MRO and CBM initiatives, they add little value unless they are aligned to the means of repair in order to restore the 'as designed' function of the product. The explicit and tacit knowledge of the MRO processes used is also required if rectification of degradation or failure is to be done in a timely and cost effective way.

2.3.5 Knowledge of Design and Manufacturing

The role of MRO is directly linked to both the design and manufacturing functions. Design for function is the foundation of product development. Traditionally requirements are identified from which a specification is defined and agreed. The resultant design is deemed to be successful if it meets the attributes defined in the specification which are primarily function and performance based. The outputs of the design process normally include approved General Arrangements, Detail Designs, Service Layouts (Pneumatic, Hydraulic, and Electrical), Bills of Materials, Bills of Process, Gauge and Inspection Plans, Reporting Schedules and Instructions, and Service Instructions. These outputs are generally in both hard and soft copy formats supported by Product Manuals and Procedures which in turn are guided by standards and guidance notes etc. These outputs inform both the manufacturing and service functions.

A TES approach has the potential to close the loop and use service knowledge to drive design. This is seen as being important when considering whole life approaches where the design life of the product could be 20–30 years. When this lens is applied the cost of service throughout the product's life becomes significant for complex products and can be many times the cost of manufacture. With greater levels of servitization and the emergence of availability contracting the risk to the revenue stream for the manufacturer makes the efficient acquisition and assimilation of service knowledge ever more important. The effective use of TES and its elements becomes a game changer for organisations competing using these business models with a major aerospace manufacturing OEM stating that over 50 % of its revenue is now achieved from its service activities. The ability to fully understand the design, manufacturing, and through-life service interaction and alignments are seen therefore as essential in order to increase product availability and reduce whole life costs.

2.3.6 Knowledge of Systems

Supporting these dimensions of TES is the role of systems and system engineering. The dynamic monitoring and transmission of performance data is based upon sensor applications, data handling systems, data transmission systems, and decision algorithms. Within the TES related references to date the majority of *technical* contributions to the literature focus on these aspects of the application with system architectures featuring prominently although the majority base these on moderated systems based upon the open-system architecture for condition based maintenance (OSA-CBM). The literature also discusses at length the issues relating to the interface of new systems to federated and legacy systems to be found in products which are significantly through their design life. All too often system failure occurs at the interfaces in the system rather than within the subsystem itself.

Significantly, issues relating to false error codes with a given system are also worthy of significant study and this research and practitioner supplied solutions are essential facilitators of efficient and effective service delivery systems. The ability to understand and identify the presence of 'false positive' error codes in such solutions is very important when seeking to effectively mitigate or reconfigure remote and/or autonomous operating systems in support of product performance, thus reducing risk.

2.3.7 The Role of Standards, Procedures, and Codes of Practice in TES

Underpinning all of the above is the role of standards, procedures, guidance notes, and codes of practice. Whilst there are a plethora of such guidance for the supporting aforementioned technologies which form the constituent elements of TES, there are no such contributions that deal with TES directly. Shaw and Tasker [46] seek to address this issue with their ongoing work with the UK-BSI. Whilst research into, and the development of, such standards is very much a current work in progress no explicit accreditations are obtainable for TES with the nearest related standard being PASS55 [47] which deals with and offers 28 aspects of good Asset Management supported by the ISO 55,000 series of standards. This is seen as a major opportunity for the community of practitioners and future research as ‘*first past the post*’ has the potential to define the concept and the terms of accreditation.

2.4 Conclusion

This chapter has informed the reader of the evolutionary process of service support for manufactured complex engineering products from basic MRO activities triggered by component failure to real time condition based maintenance and management facilitated by IVHM generic applications. Through-life Engineering Services (TES) was introduced as a holistic concept around 2010 and sought to “*guarantee the required and predictable performance of an engineering system…(or product)… throughout its expected operational life with the optimum cost*” [27]. Whilst there have been numerous contributions to the literature relative to TES no definitive identity has emerged. This chapter has, in consideration to other product support concepts and initiatives, sought to offer a definition of TES which addresses its *content*, *dimension*, and *purpose*. Whilst further work is to be done by the community of researchers and practitioners in the field to develop further the definition offered and generate a taxonomy for the concept, the author offers this contribution as an identity from which the concept can develop.

The following chapters written by experts in the field, and the contents therein, serve to illustrate the scope and depth of TES and the ability of the concept to facilitate effective Product Service Systems through a process of *servitization* whilst mitigating the risk to the revenue obtained by the use of the product (or its availability) through the application of technology. The author suggests that TES’ are the foundation of a Technology Enabled Service Delivery System.

References

1. Mont O (2000) Product service systems; final report for IIIEE, Lund University, Lund
2. Tukker A, Tischner U (2006) Product-services as a research field: past, present and future. Reflections from a decade of research. J Clean Prod 14(17):1552–1556
3. Baines TS, Lightfoot HW, Evans S, Neely A, Greenough R, Peppard J et al (2007) State-of-the-art in product-service systems. Proc Inst Mech Eng Part B J Eng Manuf 221:1543–1552
4. Vandermerwe S, Rada J (1988) Servitization of business: adding value by adding services. Eur Manag J 6(4):314–324
5. Neely A (2008) Exploring the financial consequences of the servitization of manufacturing. Oper Manage Resour 1:103–118
6. Treacy M, Wiersema F (1997) The discipline of market leaders: choose your customers, narrow your focus, dominate your market. Expanded addition edn: Perseus Book Group, New York

7. Cohen MA (2007) Power by the hour: can paying only for performance redefine how products are sold and serviced? Available at http://knowledge.wharton.upenn.edu/article.cfm?articleid=1665. Accessed Nov 2007
8. Pinjala S, Pintelon L, Vereeche A (2006) An empirical investigation on the relationship between business and maintenance strategies. Int J Economics 104(1):214–229
9. Waeyenburgh G, Pintelon L (2002) A framework for maintenance concept development. Int J Economics 77(3):299–313
10. Aurich JC, Fuchs C, Wagenknecht C (2006) Life cycle oriented design of technical product-service systems. J Clean Prod 14:1480–1494
11. Aurich J, Fuchs C, Barbian P (2004) An approach to the design of technical product service systems. Industrie Manage 20(5):13–16
12. Johnstone S, Dainty A (2008) Integrating products and services through life: an aerospace experience. Int J Oper Prod Manage 29(5):520–538
13. Savage G (2010) Dealing with crisis–solving engineering failures in Formula 1 motor racing. Eng Fail Anal 17:760–770
14. Baxter D, Roy R, Doultsinou A, Gao J, Kalta M (2009) A knowledge management framework to support product-service systems design. Int J Comput Integr Manuf 22(12):1073–1088
15. Holguin L (2005) IEEE conditioned based maintenance (CBM). Autotestcon 2005:188–193
16. Chatterjee SK (2008) Condition-based maintenance management: enhances reliability. Chem Eng 115(12):46
17. Gulledge T, Hiroshige S, Iyer R (2010) Condition-based maintenance and the product improvement process. Comput Ind 61(9):813–832
18. Jennions IK (ed) (2011) Integrated vehicle health management: perspectives on an emerging field. SAE International, Warrendale
19. GE's IVHM technology for Business Aviation. Available at: http://ge-aviation.jesiii.net/2013/08/26/watch-aircraft-health-management-system-ivhm-business-aviation-ge-aviation. Accessed 06 Jan 2012
20. National Aeronautics and Space Administration (NASA) (1992) Research and technology goals and objectives for integrated vehicle health management (IVHM). NASA-CR-192656
21. Aurich JC, Fuchs C, DeVries M (2004) An approach to life cycle oriented technical service design. CIRP Annals-Manuf Technol 53(1):151–154
22. Harrison A (2006) Design for service: harmonising product design with a services strategy. In: Proceedings of GT2006 ASME turbo expo 2006: power for land, sea, and air
23. Jagtap S, Johnson A (2010) Requirements and use of in-service information in an engineering redesign task: case studies from the aerospace industry. J Am Soc Inf Sci Technol 61 (12):2442–2460
24. Jagtap S, Johnson A (2011) In-service information required by engineering designers. Res Eng Design 22:207–221
25. Roy R, Shehab E, Hockley C, Khan S (eds) (2012) In: Proceedings of the 1st international conference on through-life engineering services: enduring and cost-effective engineering support solutions. Cranfield University, Cranfield
26. Roy R, Tiwari A, Shaw A, Bell C, Phillips P (2013) In: Proceedings of the 2nd International through-life engineering services conference, 5 and 6 Nov 2013. Elsevier, London
27. Roy R, Shaw A, Erkoyuncu JA, Redding L (2013) Through-life engineering services. Meas Control 46(6):172–175
28. Tukker A, Tischner U (eds) (2006) New business for old europe: product-service development, competitiveness and sustainability. Greenleaf Publishing Ltd, Sheffield
29. Davenport TH, Prusak L (1998) Working knowledge: how organisations manage what they know. Harvard Business School Press, Cambridge
30. Jagtap S, Johnson A (2011) In-service information required by engineering designers. Res Eng Design 22(4):207–221
31. Easterby-Smith M, Lyles MA (2011) Handbook or organizational learning and knowledge management, 2nd edn. Wiley, New york

32. Nonaka I (1994) The dynamic theory of organizational knowledge creation. Organ Sci 5 (1):14–37
33. Zack MH (1999) Managing codified knowledge. Sloan Manag Rev 40(4):45–58
34. Nonaka I, Toyama R, Konno N (2000) SECI, Ba, and leadership: a unified model of dynamic knowledge creation. Long Range Plan 33:5–34
35. Stokes M (2001) Managing engineering knowledge: MOKA methodology for knowledge based engineering applications. MOKA Consortium, London
36. Gupta S, Garg D (2011) Comparison of semantic and syntactic information retrieval system on the basis of precision and recall. Int J Data Eng 2(3):93–101
37. Mountney S (2009) Acquisition and shaping of innovative manufacturing knowledge for preliminary designcranfield university. Cranfield, Bedfordshire
38. Szykman S, Sriram RD, Regli WC (2001) The role of knowledge in next generation product development systems. ASME J Comput Inf Sci Eng 1(1):3–11
39. Doultsinou A (2010) Service knowledge capture and re-use in support of design. PhD Thesis, Cranfield University, Cranfield, UK
40. Hauschild M, Jeswiet J, Alting L (2005) From life cycle assessment to sustainable production: status and perspectives. CIRP Annals-Manuf Technol 54(2):1–21
41. Service Provision for Industrial Product Service Systems (2012). In: Proceedings of the 1st international conference on through-life engineering services: enduring and cost effective engineering support solutions
42. Adrian N, Snow D (2007) Quality tools, teamwork lead to a boeing system redesign. Qual Prog 40(11):43
43. Xu J, Xun Xu, Xie SQ (2010) A comprehensive review on recent developments in quality function deployment. Int J Prod Quality Manage 6(4):457–494
44. Tan KH, Platts K (2003) Linking objectives to actions: a decision support approach based on cause-effect linkages. Decision Sci 34(3):569–594
45. Pecht M, Dasgupta A (1995) Physics-of-failure: an approach to reliable product development. J Inst Environmental Sci 38(5):30–34
46. Through-life Engineering Services Standards Development (2012). In: Proceedings of the 1st international conference on through-life engineering services-enduring and cost-effective engineering support solutions
47. Institution of Asset Management (2014) What is PASS%. Available at https://theiam.org/products-and-services/pas-55/what-pas55. Accessed June 2014

http://www.springer.com/978-3-319-12110-9

Through-life Engineering Services
Motivation, Theory, and Practice
Redding, L.; Roy, R. (Eds.)
2015, XVI, 457 p. 162 illus., Hardcover
ISBN: 978-3-319-12110-9