
This item was submitted to [Loughborough's Research Repository](#) by the author.
Items in Figshare are protected by copyright, with all rights reserved, unless otherwise indicated.

Cutting cost in service systems: are you running with scissors?

PLEASE CITE THE PUBLISHED VERSION

<http://dx.doi.org/10.1002/jsc.1981>

PUBLISHER

© John Wiley & Sons, Ltd

VERSION

AM (Accepted Manuscript)

PUBLISHER STATEMENT

This work is made available according to the conditions of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International (CC BY-NC-ND 4.0) licence. Full details of this licence are available at: <https://creativecommons.org/licenses/by-nc-nd/4.0/>

LICENCE

CC BY-NC-ND 4.0

REPOSITORY RECORD

Thenent, Nils E., Ettore Settanni, Glenn Parry, Yee M. Goh, and Linda B. Newnes. 2019. "Cutting Cost in Service Systems: Are You Running with Scissors?". figshare. <https://hdl.handle.net/2134/17066>.

1 **Cutting cost in service systems: Are you running with**
2 **scissors?**¹

3 Nils E. Thenent
4 Department of Mechanical Engineering, University of Bath, Bath, United Kingdom

5 Ettore Settanni
6 Department of Mechanical Engineering, University of Bath, Bath, United Kingdom

7 Glenn Parry
8 Faculty of Business & Law, University of the West of England, Bristol, United Kingdom

9 Yee Mey Goh
10 Wolfson School of Mechanical and Manufacturing Engineering, Loughborough
11 University, Loughborough, United Kingdom

12 Linda B. Newnes
13 Department of Mechanical Engineering, University of Bath, Bath, United Kingdom

14 **Correspondence to:**

15 Nils E. Thenent
16 Department of Mechanical Engineering
17 University of Bath
18 Claverton Down Campus
19 Bath, BA2 7AY
20 United Kingdom
21 e-mail: N.E.Thenent@bath.ac.uk

¹ J.E.L. classification codes: D21 (Firm Behavior); D83 (Search; Learning; Information and Knowledge; Communication; Belief); M21 (Business economics); Z10 Cultural Economics; Economic Sociology; Economic Anthropology: General; B41 (Economic Methodology);
E.F.M. classification codes: 760 (Methodological issues)

22 **One sentence summary:**

23 A rigorous link between the domains of cost estimation, systems theory and
24 accident investigation reveals fundamental epistemological limitations of commonly
25 employed cost models when dealing with the characteristics of systems, particularly
26 service systems, which may hinder the ability to take appropriate action for cost
27 reductions.

28 **Key points:**

- 29 1. The ability to take action, in particular related to cost reductions in service
30 systems, is strongly influenced by the understanding (epistemological
31 assumptions) underlying a decision-support tool, in this case a cost estimate.
- 32 2. A managerial perspective of cost estimation which neglects the essential
33 characteristics of service systems may drive behaviour which is locally
34 optimised but creates tension or failure at the system level.
- 35 3. Cost cutting decisions that are based on a flawed understanding of the
36 situation can lead to counter-intuitive outcomes for organisations; hence
37 practical guidance is needed to help managers consciously consider the
38 underlying epistemological assumptions in a given situation.
- 39

40 1 Introduction

41 A desire for cost savings is often identified by key executives as leading customers to adopt
42 services offered by organisations that have ‘servitized’ (Aston Business School, 2013). Yet, as
43 identified in this article through a systemic theoretical insight, there are potentially disruptive
44 mismatches between 1) the nature of the delivery systems underpinning the innovative service
45 offering in companies that have servitized and 2) the methodological foundations of the
46 approaches for the evaluation of the costs associated with these systems for decision making
47 purposes. Statements such as “*Customers of servitization are reducing costs by up to 25-30%*”
48 are based upon subjective judgments and many key questions are not addressed such as
49 ‘which cost is meant?’, ‘how are costs determined?’ and ‘for what purpose was the cost
50 computed?’. In the defence sector servitization frequently translates into contractual
51 arrangements to guarantee asset-related performance, particularly asset availability. Claims
52 related to the cost-effectiveness of these arrangements, which may eventually result in their
53 practical implementation, are often made in the absence of sound business model analyses
54 (GAO, 2008). In such cases as, for example, Pratt & Whitney’s F117 engines powering the US
55 Air Force’s fleet of C-17A airlifters there has been a move back to transactional approaches to
56 maintenance in the hope that more competition in the support contract bidding phase drives
57 prices down (Trimble, 2013). However, it is acknowledged that in times of pressure on defence
58 budgets apparently straightforward initiatives for saving money may prove ineffective since
59 they compromise the ability to deliver capability when needed. For example, cuts in training
60 and maintenance, reduction of force structure and cancellations of equipment programs which
61 are already under way may eventually drive up an asset’s unit cost (Chinn, 2013).

62 In the public eye, cost tends to be addressed as something to fear and forecast (much as an
63 adverse meteorological event), not something to understand and manage. This is particularly
64 evident, for example, in the case of the F-35 Joint Strike Fighter (Coghlan, 2012, Fulghum *et al.*,

65 2011). Cost estimators and modellers in turn have long been concerned with predicting how
66 much something costs using aggregate data and drawing on past experience of cost outturns,
67 rarely asking why it will cost that much (Dean, 1993). This approach may give the impression
68 that progress in understanding and controlling cost is being made despite the fact that the
69 problem is only partially understood. The drawback in cost prediction for projects is typically a
70 “fire fighting” approach to project problem resolution, resulting in a chance that, as and when
71 the desired results are delivered, the asset is provided late and at a higher cost than planned
72 (Burge, 2010).

73 This article suggests that the key to address these concerns is to build on a defensible
74 conceptual representation of the socio-technical system underlying successful service delivery,
75 as an integral part of the cost estimating process. This is demonstrated through a trans-
76 disciplinary research approach, characterised by problem focus, evolving methodology and
77 collaboration (Wickson, Carew & Russell, 2006). The problem at stake is that the
78 methodological choices in costing advanced services, such as availability or other types of
79 performance, delivered through a product-service-system may hinder rather than raise cost
80 consciousness for informed decision making. A methodology to face such a problem has to
81 respond to and reflect the specific problem and context under investigation. The development
82 of such methodology, which is discussed in this paper, is through collaboration between
83 authors having different expertise, and dialogue with industrial and institutional stakeholders.

84

85 The remainder of the paper discusses the characteristics of service systems, their associated
86 costs and different perspectives on costs. A clarification of the links between action and
87 understanding leads to the identification of an epistemological conflict in the perception of
88 cost in service systems. It is concluded that epistemology is highly relevant for managerial
89 decision making. Finally, future and on-going work is outlined.

90 2 Why service systems have their peculiarities

91 Manufacturers that have 'servitized' offer advanced services that are critical to their
92 customers' core business processes through incentivised contracting mechanisms such as
93 availability or performance-based contracts. For these providers servitization involves
94 innovation of their internal capabilities in operations, and the service delivery system is just as
95 important as the service offering itself (Baines & Lightfoot, 2013). This section provides
96 theoretical insight into such a service delivery system from a 'system thinking' perspective,
97 highlighting the aspects that may be a challenge for costing advanced services.

98 2.1 Seeing Service System as 'systems'

99 Advanced services are delivered by a "knowledge-intensive socio-technical system" sometimes
100 referred to as Product Service System (Meier, Roy & Seliger, 2010; Baines & Lightfoot, 2013). A
101 PSS being a particular case of system it exhibits common characteristics of systems (Blanchard,
102 2008, Wasson, 2006, Burge, 2010), in particular:

- 103 a) It consists of multiple elements (or components),
- 104 b) Its elements are interacting with each other,
- 105 c) It has a purpose.

106 Also, a PSS is a special case of service systems. According to Wang *et al.* (2013) *service systems*
107 exhibit distinguishing features such as a network infrastructure; a substance (the types of
108 which include material, human/animal, energy and knowledge) flowing over such an
109 infrastructure; and a protocol for the management (coordination, leading, planning and
110 control) of both the structure and the substance.

111 Central to the concept of a service system is that it enables the customer to attain a result, or
112 beneficial outcome, through a combination of activities and resources, including assets, to
113 which both the service provider and the customer contribute (Ng *et al.*, 2011).

114 2.2 *Service systems are socio-technical systems*

115 Service systems are socio-technical systems due to the coexistence of physical and human
116 components. This has long suggested that service system analysis should be approached as a
117 social construction and that their technical representation should contain indications about
118 potential functions, interaction between actors and functionalities and flows of events
119 (Morelli, 2002).

120 Whilst methodologies like System Engineering aim at deriving possible solutions by applying
121 techniques to a well-defined problem, a defensible intellectual process of thinking about a
122 socio-technical system has to start by defining, not a problem but a situation that is
123 problematic (Wilson, 2001). Dekker (2011) highlights the difficulty, when analysing a socio-
124 technical system, of clearly identifying what is actually affected by an action and what is not.
125 Hence, the boundaries between the “*system of interest*” (Wasson, 2006) and the exogenous
126 components that affect or are affected by it (that is, the environment) should be determined
127 by the purpose of the system description (what shall be examined and why), not by the system
128 itself.

129 Drawing the system boundaries allows a distinction between what are deemed uncontrollable
130 external events (originating with the environment) and controllable internal events. The
131 former are the subject of “*forecasting*” whilst the latter are the subject of “*decision making*”
132 (Makridakis, Wheelwright & Hyndman, 1998). In the context of ‘servitization’ the boundary
133 defining lens is the *enterprise*, which “*imposes a holistic management or research perspective*
134 *on a complex system of interconnected and interdependent activities undertaken by a diverse*
135 *network of stakeholders for the achievement of a common significant purpose*” (Purchase et
136 *al.*, 2011). However, only when all stakeholders involved share a common interest in taking
137 action towards a common purpose – also by sharing financial information and insight of each
138 other’s processes (Romano & Formentini, 2012) – does the enterprise provide a reasonable

139 scope for the analysis. An in-depth discussion of how to create potentially efficient governance
140 relations within the enterprise in the presence of stakeholders with heterogeneous goals is
141 beyond the scope of this paper. The interested reader is referred to (Tirole, 2001) for a
142 theoretical baseline, and (Kim, Cohen & Netessine, 2007) for a specific discussion concerning
143 availability-based contracts.

144 In socio-technical systems there is no reasonable prospect of gaining complete knowledge
145 about the whole system (Hollnagel, 2012). Hence, local decision-making is always based on
146 incomplete knowledge about the whole system and actions undertaken to optimally fulfil
147 locally visible goals are prone to manifest in global system tensions or even failure (Snook,
148 2002, Dekker, 2011).

149 *2.3 Service systems exhibit emergent properties*

150 Importantly, it is not possible to deduce the properties and behaviour of the whole system
151 from the properties and behaviour of its constituting elements in isolation (Burge, 2010). This
152 has significant implications for the investigation of a system and its components as it excludes
153 the possibility of capturing and superimposing individual components' characteristics to
154 successfully describe the total system. Only when brought together and interacting with each
155 other do emergent properties arise (Dekker, 2011, Burge, 2010). These may not even be
156 predicable when looking at the complete system as their occurrence is based upon
157 relationships between the components that may not be known, or knowable (Dekker, 2011).
158 Some of these relationships may be intended or not, they may however only exist temporarily
159 and can therefore be difficult or impossible to comprehend (Perrow, 1984). Hence, an
160 understanding can only be acquired when the system is examined over time, and any
161 investigation of a system can only provide a snapshot in time. In principle, this applies to cost
162 as well – for example, through the concept of 'cost image' (Lindholm & Suomala, 2007).

163 2.4 *Not all outcomes of a system are desired*

164 There are multiple ways of approaching socio-technical systems. Bartolomei *et al.* (2012)
165 provide an overview and framework. In the authors' opinions, however, the field of accident
166 investigation provides insight into socio-technical systems that can be of particular interest for
167 the analysis of service systems. Both domains are concerned with outcomes: accident
168 investigation focuses on undesired outcomes in the form of accidents or incidents, where
169 service systems deal with doing something 'right' from the customer viewpoint (hence
170 delivering value in-use) or dealing with the consequences of failing to do so.

171 Two outstanding contributions in the field of accident investigation relate to large-scale multi-
172 organisational delivery systems that produced highly undesired outcomes: "*The Challenger*
173 *Launch Decision*" (Vaughan, 1997) deals with the explosion of the Challenger Space Shuttle
174 shortly after lift-off in 1986. "*Friendly Fire*" (Snook, 2002) concerns the shooting down of two
175 U.S. Army helicopters by two U.S. Air Force fighter jets in 1994. Both works were motivated by
176 the lack of insight the preceding investigations were able to provide.

177 The failure to send a shuttle into space and return it safely back to earth was attributed to a
178 single malfunctioning component and the conditions for such component being "allowed" to
179 malfunction were blamed on flawed decision making processes and individual managers
180 making the wrong decisions (Vaughan, 1997). Vaughan contradicts these findings and gives
181 insights into why people have acted in the way they did and what the information available at
182 the time before the launch *meant* to those involved. In this way she provides a much more
183 elaborate analysis of the systemic conditions that enabled the outcome.

184 In the other example, the failure to provide safe transportation in northern Iraq, the official
185 investigation could not show a single culprit or "*smoking gun*" (Snook, 2002). Snook's account
186 of the events draws on detailed descriptions of the actions in their respective context. He
187 concludes that to make sense of the events a wider view, across organisational boundaries,

188 was required and that any analysis on a single level will miss the mechanism affecting the
189 outcome.

190 A key lesson that can be learned from these analysis of socio-technical systems is that the way
191 we look at phenomena not only influences, but determines what we are able to see and in the
192 end determines what we are able to find (Dekker, 2006, 2011). This is also known as the
193 “*What-You-Look-For-Is-What-You-Find*” principle (Hollnagel, 2012). Therefore, the model we
194 apply in our view on the relationship between cost and the service system is a determinant for
195 what we are able to find and ultimately do about it.

196 **3 Costing service systems**

197 A firm transforming to a role as service system provider is concerned with the cost of
198 delivering results (Tukker & Tischner, 2006). However, in sectors like defence, the emphasis is
199 placed on quantifying how much has been spent in a certain time-span for the acquisition of
200 capabilities, usually categorised aggregately according to their nature as labour, equipment,
201 materials types etc. (Anagboso & Spence, 2009). By setting the focus of cost analysis on the
202 acquisition of the capabilities acquired (inputs), little or no insight is given at the level of
203 accomplishment (outcomes) pursued as a result of a certain endeavour and its intermediate
204 results (output) (Doost, 1996). A practical example is provided by a recent article on the UK
205 tactical intelligence capabilities namely the Ministry of Defence (MoD)’s Watchkeeper
206 unmanned air system (UAS) programme (Hoyle, 2013). First and foremost, the program is
207 identified in terms of what has been spent on the procurement of a number of aircraft that
208 were not operational. However, as the focus shifts on the target acquisition and
209 reconnaissance services in Afghanistan, it becomes clear that for this to be achieved another
210 UAS had to be leased.

211 Categorising costs without considering the underlying demand for jobs to be done can be
212 particularly insidious, as Emblemsvåg (2003) points out. This way of categorising provides no
213 indication of whether a reduction of spending in any of these categories erodes the company's
214 future ability to deliver value by meeting customer demand. This, in turn, may trigger more
215 cost cutting – a phenomenon addressed as “*death spiral*” (Chinn (2013) provides an example
216 concerning military-equipment acquisition). In a downturn, companies' intent of cutting costs
217 may inadvertently result in damaging the fabric of their business by cutting “*muscle*” instead of
218 “*fat*” (George, 2010, Coyne, Coyne & Coyne, 2010).

219 A closer look at the direction taken in academia regarding how to cost services and service
220 systems reveals that the approaches proposed so far lack orientation toward the results that a
221 service system is meant to deliver (Settanni *et al.*, 2011). Often, the cost of a service system is
222 identified with the cost of the in-service phase of a durable product (see for example, Datta &
223 Roy, 2010, Huang, Newnes & Parry, 2012, Jazouli & Sandborn, 2011). Even when a systems
224 approach is explicitly claimed in cost estimation, it is not the case that a representation and
225 modelling of the system structure, elements and purpose explicitly play a role (see for example
226 Hart *et al.*, 2012, Valerdi, 2011).

227 Approaches like Activity Based Costing have been recommended for the service industry,
228 where the performance and cost of business processes, especially those experienced directly
229 by customer, is crucial for competitive differentiation (Edwards, 1999, Rotch, 1990). The
230 foundation of these approaches is a focus on activities or operations within the enterprise that
231 are structured according to their logical order and dependence, and are aimed to produce a
232 specific result which is of value to internal or external customers (Hansen & Mowen, 2003). To
233 the authors' knowledge, however, only Kimita *et al.* (2009) have proposed a service system
234 costing model based on a representation of a functional service structure, where functions are

235 realized by both human activities and product behaviours that are performed to deliver value
236 with the customer.

237 The underlying principle is that costs cannot be managed – only activities can (McNair, 1990).
238 Therefore, in this case a cost estimate is an attention focusing device (Cooper, 1990), raising
239 cost consciousness by continuously monitoring the behaviour of the relevant cost over time
240 (Lindholm & Suomala, 2007).

241 **4 What is your cost model?**

242 Cost modelling has been defined as an a priori analysis that maps the characteristic features of
243 a product, the conditions for its manufacture and use into a forecast of monetary
244 expenditures, irrespective from whom (provider, customer, etc.) the monetary resources will
245 be required (Sandborn, 2013). An overview of issues and approaches in cost modelling is
246 outside the scope of this paper and can be found elsewhere (Curran, Raghunathan & Price,
247 2004). Here, “What is your cost model?” is a re-interpretation of the question “*What is your*
248 *accident model?*” asked by Dekker (2006) to sensitise for the impact of our preferred view on
249 what we are able to see.

250 *4.1 Cost is an intrinsic property of products*

251 A common view on cost is to assume that cost is a dependent variable that has the propensity
252 to be related statistically to the technical attributes used by the designers to characterise a
253 product or service instance, or other features of a project. This is the view adopted in
254 parametric cost models (see for example, Pugh, Faddy & Curran, 2010). The relationship
255 between cost and these characteristics is typically one of statistical correlation, derived
256 through extensive records of historical data. This model’s use is typically focussed on speed of
257 results, and allows changes in product’s features through redesign to translate directly and
258 immediately into changes in its unit cost. For example, Valerdi, Merrill & Maloney (2005) adopt

259 this model to calculate the yearly cost of an Unmanned Aerial Vehicle as a function of its
260 payload weight and endurance.

261 This cost model implicitly reflects an assumption which is commonly made in the literature: a
262 significant portion of a product's cost is locked-in at its design (commonly quoted statistics are
263 typically beyond 80%, see for example Newnes *et al.*, 2008). This assumption suggests, even in
264 the absence of empirical evidence, that focus should be on product development, whilst
265 diverting attention away from actions that can be taken in manufacturing or other
266 downstream activities including use (Cooper & Slagmulder, 2004, Labro, 2006). Placing the
267 responsibility for the costs incurred while the product is deployed exclusively on the designer
268 creates the expectation that cost can be treated as an independent variable, just like any other
269 engineering unit in the design process (see for example, Nicolai & Carichner, 2010).

270 Being based on a direct relationship between design features and cost (per unit, per year etc.),
271 this cost model also promotes an idealised approach to product design which overlooks the
272 challenge of cost allocation within the existing business environment (Barton, Love & Taylor,
273 2001). Predefined and known cost figures for the system or component under investigation are
274 expected to be retrieved rather than computed. For example, Romero Rojo *et al.* (2012)
275 propose a model of avionic obsolescence cost for use in service-system contracts in which the
276 base cost of resolving an obsolescence issue must be known.

277 4.2 *Cost is a necessary evil due to cost drivers*

278 Another view on cost rests on an understanding of "cost drivers" as something to drive out and
279 get rid of or minimise. The expression "cost driver" is recurring in both literature and practice,
280 but often misinterpreted. As Stump (1989) points out, cost drivers are often improperly used
281 as synonyms for the cost categories in which costs are classified; the most expensive (high
282 value) item in a product; or the quantifiable product features discussed in the previous section
283 –like weight, etc. – which can be statistically related to the unit cost of a product. For example,

284 Erkoyuncu *et al.* (2011) identify failure rate, turnaround time, repair cost, LRU (Line
285 Replaceable Unit) cost, and labour availability as “...*typical cost drivers that arise at the bidding*
286 *stage of a contract for availability*”.

287 Underpinning this view on cost is that cost drivers are decision elements that have
288 instantaneous cash flow consequences. These decision elements are usually considered in
289 isolation. Cooper calls these models “*spending models*” (Cooper, 1990). Maintenance, for
290 example, is frequently dismissed as a necessary evil. In such view maintenance efforts are
291 unwelcome activities that drive costs therefore they should be avoided. The positive
292 contribution of maintenance to the final delivery of an outcome, for example sustaining
293 production in a manufacturing plant, is simply neglected (Kelly, 2006, Sherwin, 2000).
294 For example, Browning & Heath (2009) demonstrate, with a case study of the F-22 production
295 line, that cutting cost can remove the necessary conditions for successful delivery of desired
296 outcome in the absence of an understanding how the system works.

297 4.3 *Cost is an emergent property of a system*

298 Finally, cost can be viewed as determined primarily by the dynamic behaviour of the system
299 delivering products (or services) (Storck, 2010). In this case cost is an “emergent property”,
300 and effective cost analysis must rely upon a consistent and transparent representation of the
301 context within which products and services are designed and delivered (Field, Kirchain & Roth,
302 2007).

303 Similarly, van der Merwe (2007) highlights that insight is needed into the quantitative flow of
304 goods and services consumed and produced by the enterprise, whereas money is a meta-
305 language providing a corresponding value representation of the quantitative flow.

306 In this case the knowledge required for the costing operation is more than just data and
307 information (e.g. regarding a product’s cost and technical characteristics), rather, focus is on

308 what the information represents, how to handle it and most importantly what action to take
309 (Naylor, Griffiths & Naim, 2001).

310 Models of virtual cost flows based on means (enabling conditions) and ends (desired
311 outcomes) relationships within a system of interrelated operations have been developed, for
312 example, in the field of material and energy flow costing (Möller, 2010). Another example is
313 the application of Functional Analysis, which bases cost analysis on the functions or services
314 provided through the activities performed within an enterprise and how they are achieved
315 (Yoshikawa, Innes & Mitchell, 1994).

316 In this view, “cost drivers” are causal events which determine “why” work takes place and how
317 much effort must be expended to carry out the work (Emblemsvåg, 2003). They measure the
318 frequency and intensity of the demands placed on activities performed within an organisation,
319 hence sometimes they express the output of an activity (Raffish & Turney, 1991).

320 This view of cost drivers allows initiatives for cost reduction to be centred on improved
321 efficiency, which measures the use of resources in activities performed in order to deliver an
322 outcome (Neely, Gregory & Platts, 2005).

323 *4.4 Comparison of perspectives*

324 Table 1 provides a simple example of how the perspective taken towards costing may shape
325 the understanding and action of an organisation, taking the example of the Watchkeeper UAS
326 program. Depending on the perspective of the individual, what is being delivered by the
327 program ranges from a quantity of unmanned aircraft to tactical intelligence. In the latter case
328 the Watchkeeper UAS may only be one option to deliver the outcome. Therefore, the costs
329 incurred would not be attributed to individual assets, but rather to the activities required to
330 deliver intelligence. The achievement of certification, more precisely the time needed to get
331 there, is an example for a program cost driver. Consequently, reducing the time to certification
332 leads to cost reductions.

333 **Table 1 Different views on cost applied to the Watchkeeper (Hoyle, 2013) example.**

334 This example shows that the rationale for making decisions depends on the view we have on a
335 phenomenon. Based on our perspective the meaning something has for us changes and so do
336 our options for taking action.

337 **5 No understanding, no action**

338 One aspect which is rarely highlighted is why a cost estimate is carried out. Table 2 presents
339 some insight derived from selected academic references.

340 **Table 2 Why cost estimation?**

341 Often, the purpose is the generation of a one-time cost estimate independent of specific
342 organisational and industrial settings, sometimes referred to as should-cost estimating (Ellram,
343 1996). A limitation associated with this purpose is that insight may appear to be less important
344 than *“providing a number”* that will get approval, e.g. for budgeting purposes (Keller, Collopy &
345 Componation, 2014). Underlying a service enterprise, also commonly referred to as Product
346 Service System (PSS), is typically an intent to benefit from long-term strategic alliances, which
347 requires an advanced service provider to understand the whole life cost of a PSS contract
348 (Meier, Roy & Seliger, 2010). The purpose of assessing the cost of an advanced service
349 provided through a PSS should be to provide information to support taking action for
350 continuously meeting contracted levels of performance. This is consistent with the call for a
351 shift of focus on methods of controlling cost, *“...rather than the futile attempt to predict it”*
352 (Keller, Collopy & Componation, 2014). Crucially, information provides insight and
353 understanding only when it is placed in context (Glazer, 1998).

354 5.1 *Understanding directs action to change a situation*

355 Figure 1 illustrates that understanding and actions are intertwined in a continuous process
356 over time. Understanding evolves through continuous updates, taken from available
357 environmental clues about the situation. Understanding is then tested through action in the
358 real world to compare the expected with the actual outcome. Only when an understanding of
359 a situation – including the interactions with the environment – is present can we determine
360 what needs to be known to solve a problem (Ackoff, 1989). How well we understand a
361 phenomenon determines our abilities to anticipate or infer the future behaviour of a system
362 and accordingly whether the actions we undertake can lead to the results we desire. System
363 understanding will only emerge through intellectual effort (Burge, 2010) and costing can only
364 be insightful when it is based on an understanding of the whole delivery system.

365 **Figure 1 Actions are directed by understanding which evolves through update.**
366 **(Adapted from Dekker, 2006)**

367 Attempts to predict properties by reducing the system to characteristics of individual
368 components, or aggregated system characteristics (e.g. Valerdi, 2011), clearly contradict the
369 very foundation of what a system is considered to be. This is namely the inability to derive the
370 system behaviour from its components in isolation, or by neglecting the constituent
371 relationships. Such attempts confirm the observation made by Dekker (2011) that the analysis
372 of systems often remains “*depressingly*” componential.

373 5.2 *Shared understanding through visualisation*

374 It is recognised that in practice it is difficult to give adequate visibility to the processes involved
375 in the delivery of the final outcome of a service system (Batista, Smart & Maull, 2008, Datta &
376 Roy, 2011, Ng & Nudurupati, 2010). They are therefore particularly prone to local adaption and
377 pragmatism by managers tasked to deliver local goals, but whose actions can ultimately lead to

378 the breakdown of the whole. Considering that through the adaption of local habits (Vaughan,
379 1997, Snook, 2002) informal processes develop that no longer correspond to the –well
380 intended, but static – formulation of official, or formal processes (Christensen & Kaufman,
381 2009), maintaining a dynamic common understanding of these local behaviours is imperative.
382 The value of information, or in this particular case a cost estimate, is dependent on the
383 meaning it has for the receiver, which is a result of social processes (Jakubik, 2011). However,
384 from a project management perspective consensus about a situation among different
385 stakeholders cannot be imposed; rather, it has to be built (Conklin, 2006). Pictures and
386 diagrams, in short visualisation, are means to facilitate communication (Cooke, 1994) and to
387 achieve a shared understanding among a larger group about the same problem domain (Bell &
388 Badiru, 1993, Snyder *et al.*, 1992). Concept maps are particularly useful to illustrate
389 relationships between elements. They can be more or less formal and may or may not exhibit a
390 hierarchical structure. Interlinks between the elements can be in the form of prepositional
391 phrases, such as ‘is a result of’, ‘leads to’, or the like (Davies, 2011).
392 The Functional Resonance Analysis Method (FRAM) (Hollnagel, 2012) is an approach, to
393 explain outcomes by interactions between system elements. It has been developed for
394 accident investigation and risk analysis. As such it is equipped to deal with socio-technical
395 systems to provide insights into why and how they normally succeed and occasionally fail. One
396 of its foundations is the assumption that success and failure exist for the same reasons. For
397 service provision this viewpoint is highly valuable as the insights provided include the enabling
398 conditions as well as threats for the delivery to be successful. It can capture phenomena across
399 levels, be they individual or organisational. Hence, it is suitable for use in identifying holistic
400 phenomena of socio-technical system (Hollnagel, 2012), such as how the adaption of local
401 practices can lead to global misalignments and ultimately failure (Snook, 2002).

402 **6 “Houston, we have an epistemological problem!”**

403 The above discussion has taken us from outcomes delivered by service systems, through the
404 characteristics of systems and the reasons for estimating costs, over possible views on costs to
405 the link between understanding and taking action, which ultimately is the purpose of cost
406 estimation. The creation of understanding is rooted in how we make sense of the world.
407 Perhaps, one of the most effective ways of expressing this is in the words of Dekker:

408 *“If the worldview behind these explanations remains invisible to us, [...] we will never be*
409 *able to discover just how it influences our own rationalities. We will not be able to*
410 *question it, nor our own assumptions. We might simply assume this is the only way to*
411 *look at the world. And that is a severe restriction [...].*
412 *Applying this worldview, after all, leads to particular results [...]. It necessarily excludes*
413 *other readings and other results. By not considering those (and not even knowing that*
414 *we can consider those alternatives) we may well short-change ourselves.” (Dekker, 2011)*

415

416 Ways of “understanding and explaining how we know what we know” is the essence of
417 epistemology (Crotty, 1998). Its German translation *Erkenntnistheorie* is, although more
418 explanatory terminology-wise, hampered by the fact that there is no direct translation of the
419 word *Erkenntnis* (Gabriel, 2013). It comprises concepts such as insight, knowledge,
420 understanding and making sense. Therefore, epistemology is what determines how we gain
421 understanding about the world or a situation (as expressed in section 5 “No understanding, no
422 action”).

423 Table 3 shows how our underlying epistemology shapes the way we look at phenomena and
424 may try to tackle them through actions. It is based on two distinct frames of assumptions
425 about the world we live in or the phenomena we want to investigate, dualism versus duality
426 (Schultze & Stabell, 2004). A worldview of dualism or polarities assumes either/or

427 relationships. For example, success and failure are two distinctive and mutually exclusive
428 phenomena and so are service-centric and product-centric worldviews, as well as product cost
429 and service cost estimation techniques (for example Huang, Newnes & Parry, 2012). These
430 categories would be considered as complementing each other in an epistemology based on
431 dualities. With reference to the previous examples, it has been highlighted how failure and
432 success exist for the same reasons (Hollnagel, 2012); also it has been suggested that service
433 system costing should exploit the commonalities between products and service rather than
434 exacerbating their differences (Thenent, Settanni & Newnes, 2012). Park, Geum & Lee (2012)
435 highlight that in the marketing orientated view on PSS products can be separated from
436 services, whilst in engineering-oriented perspective they are organically integrated to provide
437 the outcomes that customers want. Also, the discussion in section 2 “Why service systems
438 have their peculiarities” has shown that service systems exhibit emergent phenomena
439 consistent with a ‘both/and’ epistemology, such as the inability to gain complete knowledge
440 about them, and success and failure being having the same roots. There is enough evidence in
441 the literature to claim that for service systems approaches that attempt to explain the system
442 behaviour by the characteristics of separated components only provide limited, if any, insight
443 (Wang *et al.*, 2013).

444 **Table 3 Underlying epistemology: dualism versus duality (Adapted from Schultze &**
445 **Stabell, 2004)**

446 Evidently, the views on cost discussed in section 4 “What is your cost model?” reflect different
447 epistemological standpoints. Understanding cost as an emergent property of a system of
448 interrelated activities (Field, Kirchain & Roth, 2007) undertaken to achieve a purpose suggests
449 costs being rooted in practices, *how* the delivery system works. Conversely, cost being
450 considered as intrinsic property of a product is based on a direct and knowable relation
451 between the product’s characteristics, for example through a breakdown structure and its

452 costs (see for example Castagne *et al.*, 2008). Similarly, cost drivers assume a direct causal
453 relationship between specific properties of a delivery system (or product) and costs. These
454 properties can be influenced independently of each other to achieve cost minimisation i.e.
455 eliminate non-value adding costs (see for example Cai *et al.*, 2008). It is the authors' opinion
456 that the literature on costing service-systems endorses an 'either/or' epistemology
457 (contrasting product to service cost estimation techniques) to a 'both/and' situation (a service-
458 system). It does so by focusing on isolated 'pockets of comprehensive knowledge' about the
459 technical system element (the product) of what *should* be considered as a socio technical
460 system.

461 Such an approach is not without risk. When we take actions based on an understanding
462 derived through an 'either/or' epistemology to a 'both/and' context we cannot expect that the
463 situation changes in the intended way. In fact, we may easily remove the conditions for the
464 system to deliver its function (Browning & Heath, 2009). Therefore, before a tool for decision
465 support is employed one should ask whether the assumptions underlying such tool are indeed
466 appropriate for the situation at hand.

467 When defining the boundaries of the system of interest, a sharp distinction between complete
468 knowledge within the boundaries, and the absence of any knowledge outside of the
469 boundaries should not be expected. Rather, varying degrees of incomplete knowledge will
470 shape *blurred boundaries* around the system under investigation. The boundaries, as stated in
471 section 2.2 "Service systems are socio-technical systems" are reasonably defined according to
472 the purpose of the system investigation which also drives the required knowledge within these
473 boundaries. "Opaqueness" is the term used by George (2010) to describe the differing insights
474 different stakeholders have about the same phenomenon, in his example business processes.
475 Depending on the knowledge required appropriate methods need to be employed. A database
476 rich of product data may not provide the desired insight into labour-intensive business

477 processes that are shared with the customer, such as typical for service systems (Ng *et al.*,
478 2011). Interviews by contrast are well suited to unveil not only what is happening, but also *why*
479 and *how* things are done (Naylor, Griffiths & Naim, 2001).
480 It is shown by George (2010) that high performing companies approach cost reduction
481 opportunities based on diagnostics and understanding, whereas average performers
482 arbitrarily. We should therefore critically question what is known about cost and how it is
483 known. In the absence of an agreed framework that reflects the epistemological needs of cost
484 estimation for service systems practical advice can only be focused on how to approach a
485 situation. Table 4 summarises the aspects discussed above to provide guidance for what needs
486 to be known and how it can be known. To avoid applying unsuitable methods careful
487 consideration should always be paid to the underlying assumptions about the situation at
488 hand, as shown in Table 3.

489 **Table 4 What needs to be known to estimate the cost of a service system?**

490 **7 Conclusion and future work**

491 Management decisions are frequently based upon distinct worldviews on costs that are
492 reinforced by experts, but insightful costing remains a challenge. As systems rather than
493 products are procured some of the weaknesses of the standard approaches to cost modelling
494 deserve more attention. The way a cost is to be used has an impact upon the way it might be
495 calculated. Further, the perceptions of different managers will influence how costs are built up
496 within a cost model and there are no guarantees that the different elements of the cost
497 models are all built upon a shared set of common assumptions. A greater understanding of
498 what we know and how we know it, the epistemology, is required. The relationship between
499 underlying epistemology and cost modelling approaches shows that philosophical grounding is
500 not just something for those in the ivory towers of academia. Instead, it has important

501 practical relevance for managers as epistemology determines the chosen view on the world
502 and accordingly influences what managers are able to do and what they may try and change.
503 This is in line with previous findings in the field of engineering and service science (Batista,
504 Smart & Maull, 2008, Emblemståg & Bras, 2000).
505 Methods to deal with these challenges are available, such as FRAM, although not in the field of
506 cost estimation. Therefore further work is required to adapt these methods to the needs of
507 cost estimation while retaining philosophical consistency. A case study is currently underway
508 that aims to deliver a practical approach including a proof-of-concept of a computational
509 structure which is based on a qualitative representation of the service system.

510 **Acknowledgements**

511 The authors gratefully acknowledge the support provided by the Department of Mechanical
512 Engineering at the University of Bath and the Engineering and Physical Sciences Research
513 Council (EPSRC) for funding the research under the Innovative electronics Manufacturing
514 Research Centre (IeMRC), Grant Offer Letter SP/02/09/10, Costing For Avionics Through Life
515 Availability (CATA).

516 **References**

- 517 Ackoff RL. 1989. From Data To Wisdom. *Journal of Applied Systems Analysis* 16: 3–9
- 518 Anagboso M, Spence A. 2009. Measuring Defence. *Economic & Labour Market Review* 3 (1):
519 44–52
- 520 Aston Business School. 2013. *Servitization impact study. How UK based manufacturing*
521 *organisations are transforming themselves to compete through advanced services*: Aston
522 University, United Kingdom

523 Baines T, Lightfoot H. 2013. *Made to serve. How manufacturers can compete through*
524 *servitization and product-service systems*. Hoboken, N.J, Chichester: Wiley; John Wiley
525 [distributor]

526 Bartolomei JE, Hastings DE, Neufville R de, Rhodes DH. 2012. Engineering Systems Multiple-
527 Domain Matrix: An organizing framework for modeling large-scale complex systems. *Syst.*
528 *Engin.* 15 (1): 41–61

529 Barton JA, Love DM, Taylor GD. 2001. Design determines 70% of cost? A review of implications
530 for design evaluation. *Journal of Engineering Design* 12 (1): 47–58

531 Batista L, Smart A, Maull R. 2008. The systemic perspective of service processes: underlying
532 theory, architecture and approach. *Production Planning & Control* 19 (5): 535–44

533 Bell PM, Badiru AB. 1993. Concept mapping as a knowledge acquisition tool in the
534 development of a fuzzy rule-based expert system. *Computers & Industrial Engineering* 25
535 (1–4): 115–18. <http://www.sciencedirect.com/science/article/pii/0360835293902340>

536 Blanchard BS. 2008. *System Engineering Management*: John Wiley & Sons. 4th

537 Boito M, Cook CR, Graser JC. 2009. *Contractor logistics support in the U.S. Air Force*. Santa
538 Monica, CA: RAND

539 Browning TR, Heath RD. 2009. Reconceptualizing the effects of lean on production costs with
540 evidence from the F-22 program. *Journal of Operations Management* 27 (1): 23–44

541 Burge SE. 2010. Systems Engineering. Using Systems Thinking to Design Better Aerospace
542 Systems. In *Encyclopedia of Aerospace Engineering*, R Blockley, W Shyy (eds.): John Wiley &
543 Sons, Ltd, pp. 1–24

544 Cai Z, Sun S, Si S, Yannou B. 2008. Maintenance Management System Based on Bayesian
545 Networks. *International Seminar on Business and Information Management (ISBIM '08)* 2:
546 42–45. 10.1109/ISBIM.2008.28

547 Castagne S, Curran R, Rothwell A, Price M, Benard E, Raghunathan S. 2008. A generic tool for
548 cost estimating in aircraft design. *Research in Engineering Design* 18 (4): 149–62

549 Chinn D. 2013. *Preserving combat power when defense budgets are falling*.
550 [http://www.mckinsey.com/insights/public_sector/preserving_combat_power_when_defe](http://www.mckinsey.com/insights/public_sector/preserving_combat_power_when_defense_budgets_are_falling)
551 [nse_budgets_are_falling](http://www.mckinsey.com/insights/public_sector/preserving_combat_power_when_defense_budgets_are_falling)

552 Christensen CM, Kaufman SP. 2009. Assessing your organization's capabilities: resources,
553 processes and priorities. In *Strategic management of technology and innovation*, RA
554 Burgelman, CM Christensen, SC Wheelwright (eds.). New York, USA: McGraw-Hill
555 Companies, Inc. 5th ed., pp. 153–64

556 Coghlan T. 2012. MoD turns to France as fears grow over fighter jet choice. *The Times*, Jan. 26:
557 16

558 Conklin EJ. 2006. *Dialogue mapping. Building shared understanding of wicked problems*.
559 Chichester, England, Hoboken, NJ: Wiley

560 Cooke NJ. 1994. Varieties of knowledge elicitation techniques. *International Journal of Human-*
561 *Computer Studies* 41 (6): 801–49.
562 <http://www.sciencedirect.com/science/article/pii/S1071581984710834>

563 Cooper R. 1990. Explicating the logic of ABC. *Management Accounting* 68 (10): 58–60

564 Cooper R, Slagmulder R. 2004. Achieving full-cycle cost management. *SLOAN MANAGE REV* 46
565 (1): 45–52

566 Coyne KP, Coyne ST, Coyne EJ, SR. 2010. When You've Got to Cut Costs Now. *Harvard Business*
567 *Review* 88 (5): 74–82

568 Crotty M. 1998. *The foundations of social research. Meaning and perspective in the research*
569 *process*. London: Sage Publications

570 Curran R, Raghunathan S, Price M. 2004. Review of aerospace engineering cost modelling: The
571 genetic causal approach. *Prog Aerosp Sci* 40 (8): 487–534

572 Datta PP, Roy R. 2010. Cost modelling techniques for availability type service support
573 contracts: A literature review and empirical study. *CIRP J. Manuf. Sci. Technol.* 3 (2): 142–
574 57

575 Datta PP, Roy R. 2011. Operations strategy for the effective delivery of integrated industrial
576 product-service offerings: Two exploratory defence industry case studies. *IJOPM* 31 (5):
577 579–603

578 Davies M. 2011. Concept mapping, mind mapping and argument mapping: what are the
579 differences and do they matter? *Higher Education* 62 (3): 279–301. 10.1007/s10734-010-
580 9387-6

581 Dean EB. 1993. Why Does It Cost How Much? AIAA Paper 93-3966. *Proceedings of the AIAA*
582 *Aircraft Design, Systems, and Operations Meeting*

583 Dekker SW. 2006. *The field guide to understanding human error*. Aldershot, England,
584 Burlington, VT: Ashgate

585 Dekker SW. 2011. *Drift into failure. From hunting broken components to understanding*
586 *complex systems*. Farnham, Burlington, VT: Ashgate Pub.

587 Doost RK. 1996. Input, output, outcome: simply a change in orientation. *Managerial Auditing*
588 *Journal* 11 (7): 12–15

589 Edwards JB, ed. 1999. *Cost management for service industries*. New York: Warren, Gorham &
590 Lamont

591 Ellram LM. 1996. A Structured Method for Applying Purchasing cost Management Tools.
592 *International Journal of Purchasing & Materials Management* 32 (1): 11–19.
593 <http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=9602073191&site=eho>
594 st-live

595 Emblemståg J. 2003. *Life-cycle costing. Using activity-based costing and Monte Carlo methods*
596 *to manage future costs and risks*. Hoboken, N.J: Wiley

597 Emblemsvåg J, Bras B. 2000. Process thinking — a new paradigm for science and engineering.
598 *Futures* 32 (7): 635–54.
599 <http://www.sciencedirect.com/science/article/pii/S0016328700000136>

600 Erkoyuncu JA, Roy R, Datta PP, Wardle P, Murphy F. 2011. Service uncertainty and cost for
601 product service systems. In *Complex engineering service systems. Concepts and research*,
602 ICL Ng, GC Parry, P Wild, D McFarlane, P Tasker (eds.). Berlin: Springer, pp. 129–46

603 Field F, Kirchain R, Roth R. 2007. Process cost modeling: Strategic engineering and economic
604 evaluation of materials technologies. *JOM-J MIN MET MAT S* 59 (10): 21–32

605 Fulghum DA, Warwick G, Wall R, Ben-David A. 2011. Cost Fears. *Aviation Week & Space*
606 *Technology* 173 (10): 2–7.
607 [http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=60621425&site=ehost-](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=60621425&site=ehost-live)
608 [live](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=60621425&site=ehost-live)

609 Gabriel M. 2013. Wissen und Erkenntnis. Essay. *Aus Politik und Zeitgeschichte* 18-20 (63): 3–9.
610 <http://www.bpb.de/apuz/158649/wissen>

611 GAO. 2008. Improved analysis and cost data needed to evaluate the cost-effectiveness of
612 Performance Based Logistics. GAO-09-41 Report, Washington, DC

613 George MO. 2010. *The lean six sigma guide to doing more with less. Cut costs, reduce waste,*
614 *and lower your overhead.* Hoboken, N.J: John Wiley & Sons

615 Glazer R. 1998. Measuring the Knower: Towards a Theory of Knowledge Equity. *California*
616 *Management Review* 40 (3): 175–94.
617 [http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=738863&site=ehost-](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=738863&site=ehost-live)
618 [live](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=738863&site=ehost-live)

619 Hansen DR, Mowen MM. 2003. *Cost management. Accounting and control.* Mason, Ohio, USA:
620 Thomson/South-Western. 4th ed.

- 621 Hart CG, He Z, Sbragio R, Vlahopoulos N. 2012. An advanced cost estimation methodology for
622 engineering systems. *Syst. Engin.* 15 (1): 28–40
- 623 Hollnagel E. 2012. *FRAM, the functional resonance analysis method. Modelling complex socio-*
624 *technical systems.* Farnham, Surrey, UK England, Burlington, VT: Ashgate
- 625 Hoyle C. 2013. *UK reveals expenditure on delayed Watchkeeper programme.*
626 [http://www.flightglobal.com/news/articles/uk-reveals-expenditure-on-delayed-](http://www.flightglobal.com/news/articles/uk-reveals-expenditure-on-delayed-watchkeeper-programme-380779/)
627 [watchkeeper-programme-380779/](http://www.flightglobal.com/news/articles/uk-reveals-expenditure-on-delayed-watchkeeper-programme-380779/)
- 628 Huang XX, Newnes LB, Parry GC. 2012. The adaptation of product cost estimation techniques
629 to estimate the cost of service. *Int J Comput Integrated Manuf* 25 (4-5): 417–31
- 630 Jakubik M. 2011. Becoming to know. Shifting the knowledge creation paradigm. *Journal of*
631 *knowledge management* 15 (3): 374–402
- 632 Jazouli T, Sandborn P. 2011. Using PHM to meet availability-based contracting requirements.
633 *Proceedings of the Annual Conference of the Prognostics and Health Management Society*
- 634 Keller S, Collopy P, Componation P. 2014. What is wrong with space system cost models? A
635 survey and assessment of cost estimating approaches. *Acta Astronautica* 93 (0): 345–51.
636 <http://www.sciencedirect.com/science/article/pii/S0094576513002464>
- 637 Kelly A. 2006. *Plant maintenance management set.* Oxford: Butterworth-Heinemann
- 638 Kim S, Cohen MA, Netessine S. 2007. Performance Contracting in After-Sales Service Supply
639 Chains. *Management Science* 53 (12): 1843–58.
640 [http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=27879629&site=ehost-](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=27879629&site=ehost-live)
641 [live](http://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=27879629&site=ehost-live)
- 642 Kimita K, Hara T, Shimomura Y, Arai T. 2009. Cost evaluation method for service design based
643 on Activity Based Costing. *Proceedings of the 7th International Conference on*
644 *Manufacturing Research (ICMR '09)*

645 Labro E. 2006. Is a focus on collaborative product development warranted from a cost
646 commitment perspective? *Supply Chain Management: An International Journal* 11 (6):
647 503–09

648 Lindholm A, Suomala P. 2007. Learning by costing: Sharpening cost image through life cycle
649 costing? *International Journal of Productivity and Performance Management* 56 (8): 651–
650 72

651 Makridakis SG, Wheelwright SC, Hyndman RJ. 1998. *Forecasting. Methods and applications*.
652 New York: John Wiley & Sons. 3rd ed.

653 McNair CJ. 1990. Interdependence and control: traditional vs. Activity-Based responsibility
654 accounting. *Journal of Cost Management* 4 (2): 15–24

655 Meier H, Roy R, Seliger G. 2010. Industrial Product-Service Systems—IPS2. *CIRP Ann-Manuf.*
656 *Technol.* 59 (2): 607–27

657 Möller A. 2010. Material and Energy Flow-Based Cost Accounting. *CHEM ENG TECHNOL* 33 (4):
658 567–72. <http://dx.doi.org/10.1002/ceat.200900491>

659 Morelli N. 2002. Designing Product/Service Systems: A Methodological Exploration. *Design*
660 *Issues* 18 (3): 3–17. <http://www.jstor.org/stable/1512062>

661 Naylor JB, Griffiths J, Naim MM. 2001. Knowledge-based system for estimating steel plant
662 performance. *IJOPM* 21 (7): 1000–19

663 Neely A, Gregory M, Platts K. 2005. Performance measurement system design: A literature
664 review and research agenda. *IJOPM* 25 (12): 1228–63

665 Newnes LB, Mileham AR, Cheung WM, Marsh R, Lanham JD, Saravi ME, Bradbery RW. 2008.
666 Predicting the whole-life cost of a product at the conceptual design stage. *Journal of*
667 *Engineering Design* 19 (2): 99–112

668 Ng ICL, Nudurupati SS. 2010. Outcome-based service contracts in the defence industry -
669 mitigating the challenges. *J Serv Manage* 21 (5): 656–74.

670 <http://gateway.isiknowledge.com/gateway/Gateway.cgi?GWVersion=2&SrcAuth=Research>
671 [Soft&SrcApp=EndNote&DestLinkType=FullRecord&DestApp=WOS&KeyUT=000285794400](http://gateway.isiknowledge.com/gateway/Gateway.cgi?GWVersion=2&SrcAuth=Research)
672 005

673 Ng ICL, Parry GC, Wild P, McFarlane D, Tasker P, eds. 2011b. *Complex engineering service*
674 *systems. Concepts and research*. Berlin: Springer

675 Nicolai LM, Carichner GE. 2010. *Fundamentals of Aircraft and Airship Design*. Volume I -
676 Aircraft Design: American Institute of Aeronautics and Astronautics

677 Park Y, Geum Y, Lee H. 2012. Toward integration of products and services: Taxonomy and
678 typology. *Journal of Engineering and Technology Management* 29 (4): 528–45.
679 <http://www.sciencedirect.com/science/article/pii/S0923474812000343>

680 Perrow C. 1984. *Normal accidents. Living with high-risk technologies*. with a new afterword
681 and a postscript on the Y2K problem. Princeton, NJ: Princeton University Press

682 Pugh PG, Faddy D, Curran R. 2010. Project Management: Cost Forecasting. In *Encyclopedia of*
683 *Aerospace Engineering*, R Blockley, W Shyy (eds.): John Wiley & Sons, Ltd

684 Purchase V, Parry GC, Valerdi R, Nightingale D, Mills J. 2011. Enterprise Transformation: Why
685 Are We Interested, What Is It, and What Are the Challenges? *Journal of Enterprise*
686 *Transformation* 1 (1): 14–33

687 Raffish N, Turney PBB. 1991. Glossary of Activity-based Management. *Journal of Cost*
688 *Management* 5 (3)

689 Romano P, Formentini M. 2012. Designing and implementing open book accounting in buyer-
690 supplier dyads: A framework for supplier selection and motivation. *Int J Prod Econ* 137 (1):
691 68–83

692 Romero Rojo FJ, Roy R, Shehab E, Cheruvu K, Mason P. 2012. A cost estimating framework for
693 electronic, electrical and electromechanical (EEE) components obsolescence within the

694 use-oriented product–service systems contracts. *Proceedings of the Institution of*
695 *Mechanical Engineers, Part B: Journal of Engineering Manufacture* 226 (1): 154–66

696 Rotch W. 1990. Activity-Based Costing in service industries. *Journal of Cost Management* 4 (2):
697 4–14

698 Sandborn P. 2013. *Cost Analysis of Electronic Systems*. Singapore: World Scientific Publishing
699 Co. Pte. Ltd.

700 Schultze U, Stabell C. 2004. Knowing What You Don't Know? Discourses and Contradictions in
701 Knowledge Management Research. *Journal of Management Studies* 41 (4): 549–73

702 Settanni E, Newnes LB, Thenent NE, Parry GC, Goh YM. 2011. Through-life costing
703 methodology for use in product-service-systems

704 Sherwin D. 2000. A review of overall models for maintenance management. *Journal of Quality*
705 *in Maintenance Engineering* 6 (3): 138–64. <http://dx.doi.org/10.1108/13552510010341171>

706 Snook SA. 2002. *Friendly fire. The accidental shootdown of U.S. Black Hawks over Northern*
707 *Iraq*. Princeton, N.J. [etc.]: Princeton University Press

708 Snyder DE, McNeese MD, Zaff BS, Gomes M. 1992. Knowledge acquisition of tactical air-to-
709 ground mission information using concept mapping. *Proceedings of the IEEE 1992 National*
710 *Aerospace and Electronics Conference*, IEEE, pp. 668–674 vol.2

711 Storck J. 2010. Exploring improvement trajectories with dynamic process cost modelling: a
712 case from the steel industry. *International Journal of Production Research. International*
713 *Journal of Production Research* 48 (12): 3493–511

714 Stump EJ. 1989. “Cost Driver” Confusion. *Journal of Parametrics* 9 (3): 11–12

715 Thenent NE, Settanni E, Newnes LB. 2012. Know what you need to know. The role of
716 technological knowledge in product service systems. ESDA2012-82791. *The ASME 2012*
717 *11th Biennial Conference on Engineering Systems Design and Analysis (ESDA2012)*, ASME:
718 ASME

719 Tirole J. 2001. Corporate Governance. *Econometrica* 69 (1): 1–35.
720 <http://dx.doi.org/10.1111/1468-0262.00177>

721 Trimble S. 2013. *MROAM: USAF breaks up P&W monopoly on C-17 engine services.*
722 [http://www.flightglobal.com/news/articles/mroam-usaf-breaks-up-pw-monopoly-on-c-17-](http://www.flightglobal.com/news/articles/mroam-usaf-breaks-up-pw-monopoly-on-c-17-engine-services-384715/)
723 [engine-services-384715/](http://www.flightglobal.com/news/articles/mroam-usaf-breaks-up-pw-monopoly-on-c-17-engine-services-384715/)

724 Tukker A, Tischner U. 2006. Product-services as a research field: past, present and future.
725 Reflections from a decade of research. *J Clean Prod* 14 (17): 1552–56.
726 <http://www.sciencedirect.com/science/article/pii/S0959652606000862>

727 Valerdi R. 2011. Heuristics for Systems Engineering Cost Estimation. *Systems Journal*, IEEE.
728 *Systems Journal, IEEE DOI - 10.1109/JSYST.2010.2065131* 5 (1): 91–98

729 Valerdi R, Merrill J, Maloney P. 2005. Cost Metrics for Unmanned Aerial Vehicles. *Proceedings*
730 *of the AIAA 16th Lighter-Than-Air Systems Technology Conference and Balloon Systems*
731 *Conference, AIAA*

732 van der Merwe A. 2007. Management accounting philosophy II: The cornerstones of
733 restoration. *Cost Management* 21 (5): 26–33

734 Vaughan D. 1997. *The Challenger launch decision. Risky technology, culture, and deviance at*
735 *NASA.* Chicago, Ill., USA: University of Chicago Press. Pbk. ed.

736 Wang J, Wang H. F., Zhang WJ, Ip W.H., Furuta K. 2013. On a Unified Definition of the Service
737 System: What is its Identity? *IEEE Systems Journal* in press

738 Wasson CS. 2006. *System Analysis, Design, and Development. Concepts, Principles, and*
739 *Practices:* John Wiley & Sons

740 Wickson F, Carew AL, Russell AW. 2006. Transdisciplinary research: characteristics, quandaries
741 and quality. *Futures* 38 (9): 1046–59.
742 <http://www.sciencedirect.com/science/article/pii/S0016328706000553>

- 743 Wilson B. 2001. *Soft systems methodology. Conceptual model building and its contribution.*
744 Chichester, New York: Wiley
- 745 Yoshikawa T, Innes J, Mitchell F. 1994. Functional analysis of activity-based cost information.
746 *Journal of Cost Management* (Spring): 40–48
- 747

748 **Authors' biographies**

749 Nils E. Thenent

750 Nils Thenent is currently involved in the Costing for Avionic Through-Life Availability
751 (CATA) at the University of Bath as a researcher. He is an aerospace engineer with
752 expertise in the fields of avionics maintenance and aircraft design. Nils has been working
753 with major aerospace companies, such as Lufthansa Technik, Pratt & Whitney Canada, GE
754 Aviation and BAE Systems, and has presented his research at national and international
755 conferences. His research interests include research methodology, socio-technical systems,
756 aviation safety, aircraft technology and aviation management.

757

758 Ettore Settanni

759 Ettore Settanni is a post doctoral researcher at the University of Bath and is the
760 lead researcher in the research project Costing for Avionic Through-Life Availability
761 (CATA) working with Defence Equipment and Support (DE&S), GE Aviation and
762 Military Air Information, BAE Systems. He provides inter-disciplinary methodological
763 expertise for assessing and modelling the Through Life Costs of product-service-
764 systems.

765

766 Glenn Parry

767 Glenn Parry works with both multi-national and SME firms, exploring how they
768 create and capture value with their partners and customers. The impact of his work
769 includes a £5k SME grant which generated £100k of revenue, creating 1 job and
770 securing 2 others and the Lean tools for Core Competence Analysis he developed
771 enabled the case company to increase market share from 5% to ~80%. Glenn has
772 expertise in Lean, Service, Business Models and Value. He publishes in leading

773 journals and his Paper "Music business models and piracy" was selected as one of
774 the Outstanding Papers of 2013.

775

776 Yee Mey Goh

777 Yee Mey Goh is a Senior Lecturer in Wolfson School of Mechanical and
778 Manufacturing Engineering, Loughborough University. She is an associate member
779 of the Design Society and a member of scientific committee for a number of
780 international conferences (ASME IDETC/CIE, ICED, DESIGN and EP&DE).

781

782 Linda B. Newnes

783 Linda Newnes is Head of Costing Research at the University of Bath. She models
784 costs for the design, manufacture and use of products, such as long-life electronic
785 systems and aircraft. Her drive is to assess how to sustain the design and
786 manufacture of these products in terms of through-life-costs (TLC) and assisting
787 industry partners with capability in design, manufacturing and service. Linda has
788 embedded her research into industry – identifying a 63% cost saving, has run
789 costing seminars for industry and currently represents academia on the Joint
790 Industry/MoD Whole Life Cost working group. She has published over 105 peer
791 reviewed papers, 2 Industrial research reports and 3 book chapters.