Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 00 (2016) 000–000

www.elsevier.com/locate/procedia

The 5th International Conference on Through-life Engineering Services (TESConf 2016)

Outcome-based contracts – towards concurrently designing products and contracts

Peter Sandborn[a]*, Amir Kashani-Pour[a], Navid Goudarzi[a], Xin Lei[a]

[a]*CALCE – Center for Advanced Life Cycle Engineering, University of Maryland, College Park, MD 20742, USA*

* Corresponding author. Tel.: (301) 405-3167. *E-mail address:* sandborn@umd.edu

---

Abstract

Outcome-based contracts that pay for effectiveness and penalize performance shortcomings have been introduced to incentivize cost reduction efforts on the contractor side of product service systems (PSSs). Outcome-based contracting concepts are being used for PSS acquisitions in healthcare, energy, military systems and infrastructure. These contracts allow customers to pay only for the specific outcomes achieved (e.g., availability) rather than the workmanship and materials delivered.

Given the rise in interest in outcome-based contracts, it is incumbent upon the through-life engineering services (TES) community to determine how to design systems (including designing the sustainment of systems) to operate under these contract mechanisms, and to ultimately coordinate the system design with the design of the contract terms. Furthermore, sustainment decisions made under outcome-based contracts must target the optimum action for the population of systems managed under the contract, rather than the optimum action for an individual system. Today, outcome-based contract design is always performed separate from the engineering and TES design processes, and provided as a requirement to the design process, an approach that creates significant risks for all parties. For systems managed under outcome-based contracts, contract failure may mean significant money is spent by the customer (potentially the public) for either no outcome or inadequate outcome, or result in the contractor being driven out of business, which can lead to disaster for both parties.

Peer-review under responsibility of the Programme Committee of the 5th International Conference on Through-life Engineering Services (TESConf 2016).

Keywords: outcome-based contracts; contract engineering, availability contracts, product design, performance-based logistics, maintenance planning, life-cycle cost

---

1. Introduction

The product-service system (PSS) [1] industry deals with complex systems with stochastic features that have significant influence throughout the life-cycle of the system. These systems are increasingly being provided and managed via outcome-based contracts in which the customer purchases the performance of the product (rather than purchasing the product and/or purchasing specific product support activities). For example, Rolls-Royce introduced power-by-hour for its aircraft engines where maintenance, repair, and overhaul of the engines are all charged per hour of flight; and Michelin charges for truck tires per kilometer driven [2]. For complex safety, mission, and infrastructure systems, when the outcome-based contract becomes a competition between two parties, there is a significant risk that either the customer overpays (and/or does not get the performance they desire) or the contractor is driven out of business - if this is the case, then both sides lose.[1] To

---

[1] For example, in the case of the SR-125 highway in California, the public-private partnership (which is a form of outcome-based contract) drove the contractor (private sector) into bankruptcy in 2010; subsequently, the non-compete clause of the contract forced the State of California to buy back the toll-way, including its debt, creating a financial disaster for all parties and an unfinished/unusable toll road [3].

Peer-review under responsibility of the Programme Committee of the 5th International Conference on Through-life Engineering Services (TESConf 2016).

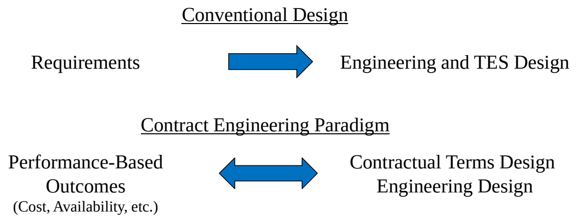

Fig. 1. Contract engineering concept.

design systems that can satisfy these types of outcome-based contracts, a new design paradigm in which engineering and contract design are integrated is needed (Fig. 1).

In a common maintenance contract with a pay-per-replacement/repair agreement, an original equipment manufacturer (OEM) has no incentive to change the system design to make the system more reliable or maintainable. In fact, the service provider might benefit from the system being less reliable. Alternatively, with an outcome-based availability contract mechanism where the customer only pays for the time that the system is operational, both the service provider and the OEM are motivated to improve the system reliability (and maintainability). The service literature has attempted to address the supply chain and inventory design portion of this paradigm shift [4], however, existing approaches are based on the assumption that OEMs are less incentivized than service providers to benefit from the freedom provided by such contracts.[2] By directly involving the OEM, an opportunity is created for engineering design (including but not limited to reliability), to address the contractual terms including outcome-based metrics and payment models.

Section 2 of this paper provides an introduction to outcome-based contracts. In Section 3 we discuss the ways in which engineering (PSS) design interacts with the design of contracts. Finally, Section 4 introduces the concept of contract engineering, which treats engineering, TES and contract design as a system design problem.

2. Outcome-based contracts

Outcome-based logistics (also referred to in the literature as “Performance Contracting” [6], “Availability Contracting”, “Contract for Availability” (CfA) [7], “Performance-Based Service Acquisition (PBSA)” [8], “Performance-Based Logistics (PBL)” [9], and “Performance-Based Contracting” [10]) refers to a group of strategies for system support that instead of contracting for goods and services/labor, a contractor delivers performance outcomes as defined by performance metric(s) for a system under contract.[3] The fundamental idea behind outcome-based contracting is reflected in a famous quote from Theodore Levitt [11]: “The customer doesn’t want a drilling machine; he wants a hole-in-the-wall.” Outcome-based contracts, pay for effectiveness (availability, readiness or other related performance measures) at a fixed rate, penalize performance shortcomings, and/or award gains beyond target goals.

Before providing background on relevant outcome-based contracts, it is useful to clearly distinguish outcome-based contracts from other common contract mechanisms that are applied to the support of products and systems (Table 1). Performance contracts are not warranties [12,13], lease agreements [14] or maintenance contracts [15], which are all break-fix guarantees. Rather these contracts are quantified “satisfaction guaranteed” contracts where “satisfaction” is a combination of outcomes received from the product, usually articulated as a time (e.g., operational availability, readiness), usage measure (e.g., miles), or an energy-based availability.

Table 1. Common mechanisms that are applied to the support of products and systems.

Contract mechanism	Examples	Key Characteristics	Support Provider Commitment
Break-fix guarantee	- Common warranties - Leases - Maintenance contracts	Definition of, or threshold for, failure	Replace or repair on failure
Satisfaction guarantee	- Warranties - Leases	Satisfaction is not quantified	Replace or repair if not satisfied
Outcome guarantee	- Outcome-based contracts (PBL, PPP, and PPA)	Carefully quantified “satisfaction”	Provider has the autonomy to meet required outcomes any way they like

“Outcome-based” contracting originated, because in many cases customers with high availability requirements are interested in buying the availability of a system, instead of actually buying the system itself [16]. In this class of contract, the customer pays for the delivered outcome, instead of paying for specific logistics activities, system reliability managements, or other tasks. Examples of outcome-based contracts include the Availability Transformation: Tornado Aircraft Contract–ATTAC [17]. Outcome-based contracting includes cost penalties that are evaluated for failing to fulfill a specified availability requirement in a defined time frame.

Product Service Systems (PSS) [1,18,19] is a common product management approach that can include elements of performance contracting. PSS provides both the product and its service/support based on the customer’s requirements, which could include an availability requirement. Lease contracts [20] are use-oriented PSS where the ownership of the product is usually retained by the service provider. A lease contract may indicate not only the basic product and service provided; but also, other use and operation constraints such as the failure rate threshold. In leasing agreements, the customer has an implicit expectation of a minimum availability, but the availability is generally not quantified contractually.

Public-private partnerships (PPPs) have been used to fund

---

[2] In some cases, the OEM and the service provider are the same “company”, however, even in these cases they are often different “organization” and may operate separately and represent separate profit centers within the company. Note, the contract and mechanism design for PSS presented in [5] clearly separates the two activities and we will also treat them as separate in this paper.

[3] In this paper we will use outcome-based to infer general contracts that may or may not use availability as their key performance measure, and availability-based when the performance measure is actually an availability.

and support civil infrastructure projects, most commonly highways in the United States [19], however, other projects including: buildings (e.g., schools, hospitals, high-density housing), bridges, tunnels, and water control projects have also been constructed and supported under PPPs. Availability payment models for civil infrastructure PPPs require the private sector to take responsibility for designing, building, financing, operating, and maintaining an asset. Under the "availability payment" concept, once the asset is available for use, the private sector begins receiving an annual payment for a contracted number of years based on meeting performance requirements [21]. The challenge in PPPs is to determine a payment plan (cost and timeline) that protects the public interest, i.e., does not overpay the private sector; but also, minimizes the risk that the asset will become unsupported [3].

A PPA (also called Energy Performance Contracting (EPC)) is defined as a long-term contract to buy electricity from a power plant.[4] PPAs secure the payment stream for a power producer and satisfy the purchaser's (often governmental) regulations/requirements for long-term electricity generation. A PPA defines a fixed price at which electricity is sold with optional annual escalation and a variety of time-of-delivery factors. The important parameters that are addressed in PPAs include: the levelized cost of energy [22] (with/without governmental incentives), length of the agreement, internal rate of return, net present value, and milestones [23]. Each of these parameters may be affected by other factors throughout a project. For example, the length of the agreement might be changed (or the agreement might be terminated) if the federal tax credit becomes unavailable, etc. A study that compared the structure of the lease and PPA contracts, and the timing of the payments in California shows a higher cost of current PPA contracts than leases, which reflects the importance of key contractual and performance parameters such as uncertainties in discount rate, reliability, demand, length of agreement, and size of the projects [24]. All of these require more robust and comprehensive models to further secure PPAs for both parties.

3. Contract-based system design

Traditionally, the contract and PSS parameters (including engineering and logistics) are designed separately, Fig. 1. Each may use the other as constraints, however, there is little interaction or iteration between the two sides. The need to enhance system reliability, maintainability, and logistics support has led to the articulation of the need for design that simultaneously includes economic and performance parameters, but this has not been done.[5] In this Section, the relevant approaches for designing contracts and products are briefly reviewed.

The correlation between contracts and product parameters in a PSS design process can be classified into the three categories described in the following sections.

3.1. Engineering/logistics design using fixed contract parameters

In this category, it is assumed that the contract parameters are fixed, and they are supplied as inputs to the PSS design (e.g., they may be constraints on the PSS design). Hence, the PSS parameters are designed to maximize the operating performance and functionality that satisfies the contract requirements.

Examples of product design processes (hardware and/or software) that include one or more contract parameters, e.g., cost constraints, length of support requirements, etc., are very common. Less common (but still in this category) are models that use availability constraints to design system parameters (usually logistics parameters).

Jazouli et al. [25,26] use an availability requirement to determine the required logistics parameters and reliability of a system. In this work, a direct method (as opposed to a search-based method) is developed that uses an availability requirement to determine system parameters. Figure 2 shows an example result from [25]. In this case a system health management approach called prognostics and health management (PHM) is being used to provide early warning of system failure.[6] Two system management solutions, one with PHM, and one without (unscheduled maintenance), are shown

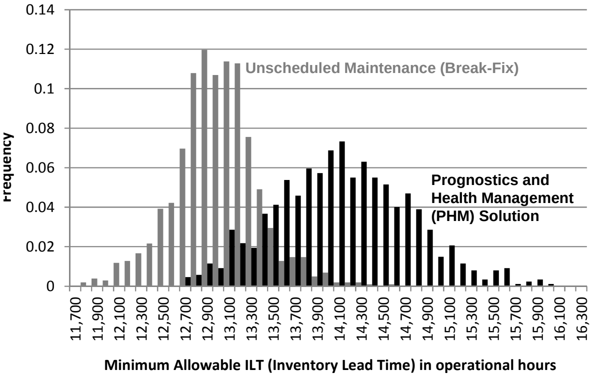

Fig. 2. Computed maximum allowable inventory lead time (ILT) for two different maintenance policies, [25].

---

[4] The wind energy in the wholesale market can be traded in the short-term through pool or bilateral contracts, or in the long-term through future markets or bilateral contracts (mainly PPAs). PPAs and Feed In Tariffs (FITs) are similar, both can be long-term contracts between energy sellers and buyers. However, there are several differences: PPAs are generally more suitable for commercial scale (e.g. wind farms), while FITs for smaller scale (e.g., home-owned wind turbines); PPAs often have constant or escalating prices, while FITs often have the prices that decline over time to encourage cost reduction.

[5] Note, recent interest in "resilient" systems is also articulating this need. Although there is a general agreement that resilience is the intrinsic ability of a system to resist disturbances, the questions is what is the "scope" of the system? In our opinion, designing resilient hardware and software (which is the focus of most resilient design activities) is necessary but not sufficient for creating resilient systems. For a system to be resilient requires: 1) reliable (or self-managing) hardware and software; 2) a resilient logistics plan (including supply chain and workforce management); 3) a resilient contract structure (the topic of this paper), and 4) resilient legislation (rules, laws, policy). This represents a broader scope than what is generally articulated in the academic literature, however, in practice, neglecting any of these elements potentially creates a legacy system with substantial (and potentially untenable) life-cycle support costs.

[6] PHM is similar to condition-based maintenance (CBM) and reliability-centered maintenance (RCM). PHM predicts the remaining useful life (RUL) of a system based on its condition and the expected future environmental stress that the system will see. The objective of PHM, CBM and RCM is to avoid expensive unscheduled (corrective) maintenance.

in Fig. 2. Both of the solutions satisfy exactly the same system availability requirement. The result in Fig. 2 shows that the data-driven PHM solution can meet the availability requirement for the system using a longer inventory lead time (ILT), which is significant, since a longer ILT costs less because it potentially allows a larger number of suppliers to be used and/or avoids premiums paid for rush orders.

The Jazouli et al. work demonstrates a particularly challenging problem with outcome-based contract constraints. Many of the constraints that are defined by outcome-based contract parameters, such as the availability, are straightforward to determine as the outputs of a simulation, but not easy to use as the input for a simulation. Practical design for real systems is often done using search-centric "simulation optimization" approaches [27] like discrete-event simulation and discrete-event simulation only runs forward in time, not backward (i.e., there are no practical discrete-event simulation methodologies that run backward in time). This makes outcome-based contract requirements difficult to include in logistics design.

Another notable effort that incorporates outcome-based contract requirements is the optimization of maintenance for wind farms that are managed under PPAs. In this case, the PPA terms are fixed (energy delivery requirement, and energy price), and the wind turbines in the farm are in various states of health (all have different predicted RULs). For wind farms, and in particular offshore wind farms, maintenance cannot be done continuously (there may be weeks or even months between maintenance opportunities depending the type of maintenance needed, the time of the year, and the location of the turbine). In this case the maintenance activities performed at a maintenance opportunity depends not only on the state of health of a particular turbine, but also on the state of health of other turbines, the energy delivered by the farm to date, and the terms of the PPA [28].

3.2. Contract design using fixed product parameters

In this category, the contract parameters are optimized for a given PSS. For example, the following contract parameters may be determined: the payment schedules (amount and timing) [3], profit sharing [29], the length of the contract [30], the contract mechanism [31,32], supply-chain parameters (inventory lead time,[7] backorder penalties, etc.) [33], and warranty design could be determined.[8]

The most common existing work in this category uses product failure rates to determine either downtime or demand for spare parts that is in turn used to optimize inventory management. Arora et al. [34] studied an integrated inventory and logistics model to minimize the total cost of supply-chain support. Nowicki et al. [32] developed a model that designs performance-based contracts with different lengths and contract fees. In [32], the contract design is based on a given product with a fixed initial reliability; further investment in improvements in the product's reliability under the proposed contract that create a win-win for the customer and contractor are explored through the optimal choice of contact length.

Hong et al. [31] employed mechanism design theory[9] to design an optimized maintenance service contract in which the uncertainties associated with customer actions, the system performance, and maintenance costs during the contract execution phase are accounted for. They assumed that the system design is fixed and determine the contract that maximizes the expected profit and provides a win-win incentive for the customer and contractor.

3.3. Concurrent design of the contract and the PSS

The concurrent design of both the contract and the PSS represents the ideal solution (for both the customer and contractor) for real applications. However, at this time there are no models that accurately assess and design outcome-based contracts that can deal with all the risks and uncertainties involved [35]. One proposed solution to fill this gap is to use engineering inputs and to find the engineering connections to current theoretical contract models [36]. This is in part due to the relatively short history of this class of contract, a lack of sufficient public data on different design contracts, and ignorance of the dynamic impact of uncertainties in the existing models.

The existing literature is focused on solving the problem from the contractor point of view and does not address the role of optimum contract design from the customer's viewpoint. While a few authors discuss the need for concurrent design, e.g., [32]; very few attempt to provide any type of solution to the problem [31], and in cases that claim to address both the customer and contractor, the solutions are primarily sensitivity analyses that ignore the asymmetry of information or moral hazard problem.[10]

Kashani et al. [37] reviewed existing analytical models in this space and developed a framework for the design of outcome-based contracts with consideration of engineering design and incentive structure, but do not actually implement a solution.

4. Contract Engineering

By utilizing outcome-based contracts, contractors introduce a high-level payment and requirements framework, however bottom-up engineering models addressing the underlying

---

[7] In Section 3.1 the inventory lead time (ILT) was considered to be a logistics parameter determined from an availability requirement. It is also possible that ILT is a contract parameter that is flowed down to subcontractors.

[8] Although we include warranty design in the list of possible contract design activities that could be driven by the product parameters, for most products that have warranties, the type of warranty and its length are determined by marketing, and are not based on the product's predicted reliability. More commonly, the warranty type and length (which are a contract) are passed to the engineering design to determine the appropriate warranty reserve fund, which would be an example of the first category discussed in Section 3.1.

[9] Mechanism design theory is an economic theory that seeks to determine when a particular strategy or contract mechanism will work efficiently.

[10] While there are some major manufacturers who appear to (or claim to) use an integrated approach in designing a concurrent contract and product parameters, they are unpublished and no details are available.

dynamics of the system and the integration of different sub-systems to meet these requirements need to be considered. The feasibility space of contracts and their requirements should be derived by considering the engineering systems with their physical constraints and uncertainties. The integration of engineering design and contract design represents a new paradigm that we call *contract engineering*, [37]. *Contract engineering* is not a payment structure based on a range of outcomes, rather it is a combination of the following used to discover the feasible regions of design that minimize the risks for both the contractor and the customer:

- <u>Mechanism Design</u>, choosing or designing the contract mechanism (contract structure) that allows the desired outcomes to be reached.
- <u>Contract/Firm Theory</u> designs contracts based on the chosen mechanism, using: incentives, information asymmetry, and outcome uncertainties.
- <u>Co-design</u> of the contract requirements and the system. In contract engineering, the mechanism is known and an enterprise-level valuation that includes both contractual and performance parameters studies of the impact of each element of the contract on different aspects of the design or operational decision making.

Contract engineering performs a dynamic simulation that contract theoretic works do not perform (contract theoretic solutions use simplified functions or constant values). Contract engineering will provide a more accurate and realistic estimation of system life-cycle cost by studying both contractual and performance parameters in an integrated cost-performance design model.

The objective of contract engineering is to give the procurement and acquisition managers the background that they need for assessing the existing cost and decision making models relevant to outcome-based contracting. Using the insight provided, managers can then aligned the models and methodologies they are using to outcome-based contracting, i.e., determine what models can assess the cost of guaranteed performance considering the integration of all sub-systems involved; understand the operational questions that common methods are not able to answer; can compare cost saving strategies to business-as-usual practices; and determine what knowledge acquisition personnel need to have to assess different cost models, i.e., to perform better negotiation and more accurate pricing.

5. Discussion

While the problem of incentivizing design improvement has been addressed by outcome-based contracts, it is not clear how much incentive is enough to motivate the designer to improve the performance to a specified level. When the contract plays a larger role in evaluating the system designer's performance, the need for integrating contract design and engineering design is higher. However, approaching contract design as a system design problem is missing from the engineering community. From the viewpoint of a system designer, the process of designing contractual terms that addresses performance metrics, the payment model, and performance assessment, represents a multidisciplinary design process that can be integrated into a broader engineering design process.

An integrated approach (i.e., contract engineering) that models incentives, uncertainties, and payments concurrent with the engineering system design and its optimization would enable more informed decision making for the acquisition and support of complex systems. The incentives and assessment structure of the contractual terms can influence the quality and reliability of the resulting system, especially for capital intensive projects (e.g., long-term infrastructure, complex system acquisition, etc.).

For many types of systems, an integrated contract engineering approach may result in a move away from product architectures that are driven by manufacturing limitations to architectures focused on the cost and ease of sustainment. It is also important to point out that for of outcome-based contracts, the requirements on the performance of the system (the outcome) are intentionally made at the top-most aggregate level of the system (or the PSS) in order to provide the contractor with the maximum amount of freedom to manage the system. While a specific set of requirements flowed down to the subsystems makes design more structured, outcome-based contracts do not micromanage at this level (which is the advantage of this sort of contracting to the contractors). Note, in Section 3.1, provides an example of how an availability requirement could be flowed down to subsystems or the supply chain.

Acknowledgements

Funding for portions of this paper was provided by the National Science Foundation Division of Civil, Mechanical and Manufacturing Innovation (Grant No. CMMI1538674).

References

[1] Vasantha GVA, Roy R, Lelah A, Brissaud D. A review of product-service systems design methodologies. Journal of Engineering Design 2012; 23:635-659.

[2] Van Ostaeyen J. Analysis of the business potential of product-service systems for investment goods. PhD Dissertation, KU Leuven; 2014.

[3] Sharma DK, Cui Q, Chen L, Lindly JK. Balancing private and public interests in public-private partnership contracts through optimization of equity capital structure. Transportation Research Record: Journal of the Transportation Research Board 2010; 2151:60-66.

[4] Harada G. Strategic and operational considerations for the implementation of performance based logistics (PBL) within the Japan maritime self defense force. http://calhoun.nps.edu/public/handle/10945/10526 (accessed May 31, 2016) 2010.

[5] Datta PP, Roy R. Incentive issues in performance-based outsourcing contracts in the UK defence industry: a simulation study. Production Planning & Control 2013; 24:359-374.

[6] Hansen SJ. Performance contracting: expanding horizons. The Fairmont Press, Inc; 2006. pp. 343.

[7] Hockley CJ, Smith JC, Lacey LJ. Contracting for availability and capability in the defence environment. in Ng I, Parry G, Wild P, McFarlane D, Tasker P. (Eds.). Decision engineering. London: Springer; 2011. pp. 237-256.

[8] Gansler JS, Lucyshyn W, Vorhis C. Performance-based services acquisition. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA555375 (accessed May 31, 2016) 2011.

[9] Boyce J, Banghart A. Performance based logistics and project point proof: a study of PBL effectiveness. Defense AT&L: Product Support Issue 2012; March-April.

[10] Selviaridis K, Wynstra F. Performance-based contracting: a literature review and future research directions. International Journal of Production Research 2015; 53:3505-3540.

[11] Levitt T. Production-line approach to service. Harvard Business Review 1972; 50:41-52.

[12] Blischke WRR, Murthy DNP. Product warranty management — I: a taxonomy for warranty policies. European Journal of Operational Research 1992; 62:127-148.

[13] Murthy DNP, Blischke WR. Warranty management and product manufacture. Springer; 2005.

[14] Yeh RH, Kao K-C, Chang WL. Preventive-maintenance policy for leased products under various maintenance costs. Expert Systems with Applications 2011; 38:3558-3562.

[15] Bowman RA, Schmee J. Pricing and managing a maintenance contract for a fleet of aircraft engines. Simulation 2001; 76:69-77.

[16] Ng ICL, Maull R, Yip N. Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: evidence from the defence industry. European Management Journal 2009; 27:377-387.

[17] BAE 61972 BAE Annual Report; 2008.

[18] Meier H, Roy R, Seliger G. Industrial product-service systems—IPS^2. CIRP Annals - Manufacturing Technology 2010; 59:607-627.

[19] Bankole OO, Roy R, Shehab E, Wardle P. Affordability assessment of industrial product-service system in the aerospace defense industry. Proceedings of the 1st CIRP Industrial Product-Service Systems (IPS2) Conference, Cranfield University 2009; pp. 230.

[20] Yeh RH, Kao K-C, Chang WL. Optimal preventive maintenance policy for leased equipment using failure rate reduction. Computers & Industrial Engineering 2009; 57:304-309.

[21] Gajurel A. Performance-based contracts for road projects. New Delhi: Springer India; 2014.

[22] Bruck M, Goudarzi N, Sandborn P. A levelized cost of energy (LCOE) model for wind farms that includes power purchase agreement (PPA) energy delivery limits. Proceedings of the ASME Power Conference, 2016 Charlotte, NC.

[23] Masini A, Menichetti E. Investment decisions in the renewable energy sector: an analysis of non-financial drivers. Technological Forecasting and Social Change 2013; 80:510-524.

[24] Davidson C, Steinberg D, Margolis R. Exploring the market for third-party-owned photovoltaic systems: insight from lease and power-purchase agreement contract structures and costs in California. Environmental Research Letters 2015; 10.

[25] Jazouli T, Sandborn P, Kashani-Pour A. A direct method for determining design and support parameters to meet an availability requirement. International Journal of Performability Engineering 2014; 10:211-225.

[26] Jazouli T, Sandborn P, Kashani-Pour A. A direct method for determining design and support parameters to meet an availability requirement - parameters affecting both downtime and uptime. International Journal of Performability Engineering 2014; 10:649-652.

[27] Amaran S, Sahinidis NV, Sharda B, Bury SJ. Simulation optimization: a review of algorithms and applications. 4OR-Q J Oper Res 2014; 12:301-333.

[28] Lei X, Sandborn P, Bakhshi R, Kashani-Pour A, Goudarzi N. PHM based predictive maintenance optimization for offshore wind farms. Proceedings of the IEEE Prognostics and Health Management 2015 Austin, TX.

[29] Hamidi M, Liao H, Szidarovszky F. A game-theoretic model for outsourcing maintenance services. Proceedings - Annual Reliability and Maintainability Symposium 2014.

[30] Deng Q, Zhang L, Cui Q, Jiang X. A simulation-based decision model for designing contract period in building energy performance contracting. Building and Environment 2014; 71:71–80.

[31] Hong S, Wernz C, Stillinger JD. Optimizing maintenance service contracts through mechanism design theory. Applied Mathematical Modelling 2015.

[32] Nowicki D, Kumar UD, Steudel HJ, Verma D. Spares provisioning under performance-based logistics contract: profit-centric approach. Journal of the Operational Research Society 2006; 59:342-352.

[33] Zhu Q, Fung RYK. Design and analysis of optimal incentive contracts between fourth-party and third-party logistics providers. Proceedings IEEE International Conference on Automation and Logistics, 2012; pp. 84-89.

[34] Arora V, Chan FTS, Tiwari MK. An integrated approach for logistic and vendor managed inventory in supply chain. Expert Systems with Applications 2010; 37:39-44.

[35] Rodrigues D, Erkoyuncu J, Starr A, Wilding S, Dibble A, Laity M. Review of the modelling approaches for availability contracts in the military context. Procedia CIRP 2015; 30:451-456.

[36] Hockley CJ, Smith JC, Lacey LJ. Contracting for availability and capability in the defence environment. Complex Engineering Service Systems. London: Springer; 2011; pp. 237–256.

[37] Kashani Pour AR, Sandborn P, Cui Q. Analytics of methods for designing availability-based sustainment contracts. Journal of Cost Analysis and Parametrics 2016; 9:69-91.