NPS-AM-14-C11P09R01-041

PROCEEDINGS
OF THE
ELEVENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM

WEDNESDAY SESSIONS
VOLUME I

A New "Availability-Payment" Model for Pricing Performance-Based Logistics Contracts

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Published April 30, 2014

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

Panel 9. Contract Design for Successful Public–Private Partnerships

Wednesday, May 14, 2014	
3:30 p.m. – 5:00 p.m.	**Chair: Fred Thompson,** Professor, Atkinson Graduate School of Management, Willamette University ***A New "Availability-Payment" Model for Pricing Performance-Based Logistics Contracts*** Amir KashaniPour, University of Maryland Xinyan Zhu, University of Maryland Peter Sandborn, University of Maryland Qingbin Cui, University of Maryland ***System Dynamics and Management Science Approaches Toward Increasing Acquisition Process Efficiency*** Joachim Block, UniBwM Heinrich Buch, UniBwM Bo Hu, UniBwM Armin Leopold, UniBwM Stefan Pickl, UniBwM ***The Construction of Defense Department Contracts in Thin Markets*** Trevor Brown, Ohio State University Yong Woon Kim, Ohio State University Alex Roberts, Ohio State University Daniel Albalate, University of Barcelona

A New "Availability-Payment" Model for Pricing Performance-Based Logistics Contracts

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Abstract

This paper describes the adoption and extension of "availability payment" concepts currently in use for civil infrastructure Public–Private Partnerships (PPPs) to contract design and pricing for Performance-Based Logistics (PBL) contracts. Availability payment models for civil infrastructure PPPs require the private sector to take responsibility for designing, building, financing, operating, and maintaining an asset (most commonly highways). 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. The challenge in PPPs is to determine a payment plan (amount and length of time) that protects the public interest, that is, does not overpay the private sector, but also minimizes that risk that the asset will become unsupported. In this paper, we focus on availability as the key required outcome and introduce a stochastic availability requirement into PBL contract structures.

The model developed in this paper uses an affine controller to drive a discrete event simulator (Petri net) that produces availability and cost measures. The model is used to explore the optimum availability assessment window (length of time over which availability should be assessed) for a PBL contract.

Introduction

Acquisition process efficiency and success across a system's life cycle requires the development and implementation of best-value, long-term, outcome-based product support strategies that leverage performance-based agreements with both industry and government product support providers (Kobren, 2011). This is reflected in DoD Directive 5000.01, Enclosure 1, Paragraph E1.1.29, which states, "The Program Manager (PM) shall be the single point of accountability for accomplishing program objectives for total life-cycle systems management, including sustainment, survivability, safety, and affordability. PMs shall consider supportability, life cycle costs, performance, and schedule comparable in making program decisions. Planning for Operation and Support and the estimation of total ownership costs shall begin as early as possible. Supportability, a key component of performance, shall be considered throughout the system life cycle." Popular vehicles for accomplishing this directive are performance-based product support arrangements.

Performance-based logistics (PBL) and similar mechanisms have become popular for contracting the sustainment of military systems in the United States and Europe. Performance-based logistics (also referred to as performance-based life-cycle product support) refers to a group of strategies for system support that instead of contracting for goods and services, a contractor delivers performance outcomes as defined by performance metric(s) for a system or product (Gansler et al., 2011). PBL thinking is reflected in a famous quote from Theodore Levitt (Levitt, 1972): "The customer really doesn't want a drilling machine, he wants a hole-in-the-wall." PBL and similar outcome-based contracts pay for effectiveness (availability, readiness and/or other related performance measures) at a fixed rate, penalize performance shortcomings, and/or award gains beyond target goals. Under PBL, the contractor (system supporter) often commits to providing the current performance level at a lower cost, or an increased performance at a cost similar to that previously achieved under a non-PBL approach.

PBL has become the U.S. DoD's preferred support strategy for weapons systems. PBL contracts are normally executed at three levels: component level, subsystem level, and system or platform level. Subsystem-level contracts are the most prevalent form of PBL. In a subsystem PBL contract, a contractor is tasked with sustaining a subsystem over a period of 5–10 years—often the subsystem has previously been supported via a non-PBL contract.

Many of today's PBL contracts use what is referred to as public–private partnerships (PPPs). In a subsystem PBL a PPP could mean that the contractor partners with a government owned and staffed maintenance facility. The contractor brings in their best practices and manages the facility, and the contractor is responsible for the outcome. In this work we propose the adaptation of a PPP model from the civil infrastructure discipline for PBL contact pricing. PPPs in the civil infrastructure area (e.g., highway construction and support) have a different structure than those traditionally used in PBL. Civil infrastructure PPPs require the private sector to take responsibility for designing, building, financing, operating and maintaining an asset, which is a much broader view than today's subsystem PBL PPPs in use in the U.S. Department of Defense.

A significant challenge with PBL contracts is to determine the contract requirements and price that protects the public interest, i.e., does not overpay the private sector, but also minimizes that risk that the asset will become unsupported. Subsystem PBL contracts are generally priced based on: 1) estimating how many units will need repair, 2) how much it will cost for each repair, and 3) how the number of units requiring repair and/or the repair cost will decrease over time as a result of design and/or maintenance improvements made by the contractor. If greater than projected improvements are realized the money saved is shared with the contractor according to a schedule negotiated in the contract ("gain share"). Meeting or exceeding target performance may also allow the contractor to add additional years to the contract ("award term"). With subsystem PBL contacts, it is reasonably straightforward for the customer to demonstrate a benefit by determining what it would cost to support the system doing business as usual (no improvements, non-PBL contract) compared to the cost of a PBL contract, e.g., often pre-PBL support and performance experience exists. However, for new system acquisition, where there is no sustainment history; and for platform-level PBL, the PBL contract pricing problem is much more complex and it is unclear how to optimally apply PBL contract mechanisms. For example, a recent study of PBL effectiveness (Boyce & Banghart, 2012), reported on the cost of 21 PBL contracts where in 9 out of 9 component and subsystem-level PBL contracts the cost decreased, but for platform-level (called system-level by Boyce and Banghart) PBL 6 out of 12 contracts resulted in either cost increases or indeterminable cost changes.

Public Private Partnerships (PPPs)

Before addressing how civil infrastructure PPPs can be applied to PBL, we need to briefly describe how PPPs and availability payment mechanisms work in the civil infrastructure world (most commonly for the construction and support of highways). Due to a growing demand for better infrastructure and insufficient federal funds, PPPs are increasingly used in transportation infrastructure development. A PPP in civil infrastructure field can be broadly defined as a long-term agreement between public and private sectors for mutual benefit (USDOT, 2004). This agreement generally defines mutually accepted performance outcomes or results for infrastructure assets rather than providing detailed descriptions of the materials, equipment, and level of workmanship. The practice in the transportation industry shows that the PPP approach enables the public sector to transfer responsibilities and risks that can be efficiently managed by the private sector while retaining the risks that can be better managed by the public sector. The payment mechanisms used in PPP contracts are classified into two categories: toll based approach (user fee) and performance-based non-toll based approach. Tolling allows the private sector to collect tolls and to bear the risk associated with low throughput. In projects where tolling is not a suitable option non-tolling mechanisms, or typically called Availability Payment, can be used.

An Availability Payment mechanism is a performance-based infrastructure procurement where the private sector's reimbursement is coupled to performance specifications. The private sector becomes eligible to receive predetermined payments called Maximum Availability Payments (MAPs) only when the asset is fully operational. If during the operations, the private sector fails to keep the infrastructure available physically or qualitative, appropriate deductions (or penalties) are applied and thus the private sector receives adjusted project payments. An Availability Payment mechanism requires the private sector to perform and comply with the performance standards set in the contract. The performance standards can require the physical availability of the asset (for example: open highway lanes) and the quality of services of the asset (for example, peak hour throughput, adequate lighting, and pavement serviceability).

Comparison of PBL and PPPs

PBL and Availability Payment PPPs share many inherent characteristics. In both cases the public and private sector objectives are aligned towards ensuring better value for the end users/public. These contracts are long term in nature and demand the private sector to play a major role in meeting the objectives of the system or project. The private sector bears the majority of project or system risks and is encouraged to pursue innovative processes and methods. Table 1 summarizes the similarity and difference between these contracts. Although the procurement contracts are operated by different public agencies and targeted on different assets, they all must be well-designed and priced to ensure adequate protection of public interest. In the defense industry, the challenge becomes much greater considering the complexity and uncertainty of defense acquisition programs. While current practices may be effective at the component and subsystem levels, pricing a PBL contract becomes more difficult for a new system acquisition where no prior estimates of any kind are unavailable. Therefore, developing and introducing innovative methods and best practices in civil infrastructure PPPs have great potential to significantly improve DoD PBL contract acquisition.

Table 1. **Mapping of Availability Payment Contracts to PBL Contracts**

	DoD PBL Contracts	Availability Payment PPP Contracts
Performance	Availability, Reliability, Downtime, Outcome, Variances from Goals	Physical and qualitative availability, Serviceability, Resilience, and others
Incentive	Contractor rewarded for performance exceeding expectations	Typically not used; in some cases, incentives are used for qualify materials up to 5% of total construction cost
Penalty	Penalized for not meeting performance criteria and non-availability	Penalized for not meeting performance criteria and non-availability
Pricing	Bidding	Engineer Estimate and Bidding
Value for Money	Benchmarking—compare to non-PBL contracts; Market Research	Value for Money analysis to consider unique characteristics of infrastructure project
Contract Term	Medium to Long-term (5 year base contract followed by a 5 year extension)—Duration based on regulations	Long-term (Minimum 10 year and maximum 99 years), duration based on the value for money analysis
Renegotiation	Allowed and possible	May be Allowed

Model Development

This section adapts and extends "availability payment" concepts currently in use for civil infrastructure PPPs to contract design and pricing for PBL contracts. The model development explores and demonstrates the merit of the civil infrastructure PPP approach for platform-level PBL and new acquisition subsystem PBL contracts. We have focused on availability as the key required outcome and introduce a stochastic and layered availability requirement into the proposed civil infrastructure PPP based PBL contract structure.

There are several approaches that can be used to simulate the contractual process along the sustainment work flow. Emulating reality in detail and deriving the optimum strategies are two necessary activities for developing the best contract requirements. Existing methods can be classified into two groups: (1) addressing events within the system (event-based); and (2) the dynamical behavior of the system (time-based).

Integration of an event-based system with a time-synchronous system for simulation is being pursued in this activity. It should be noted that this area of research is not well developed and there are few existing works on synchronization of time-based and event-based methods. The outcome-based orientation of our problem places more emphasize on selecting the proper time frames to evaluate the performance. Meanwhile the nature of reliability and maintenance actions are generally event based.

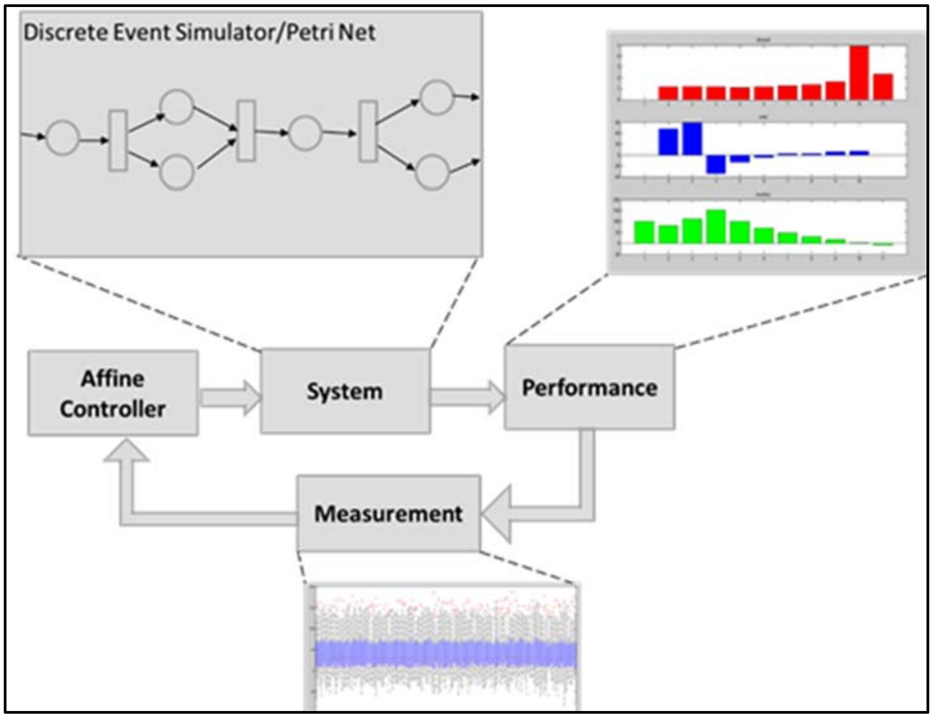

Figure 1. Model Integration Architecture

The goal of the analysis approach is to maintain the preparedness of the system, which translates into insuring a minimum level of availability at all times. For the support of a fielded system this requires management of parts in such a way as to minimize the backorder and holding (inventory position), which will ideally be close to zero after responding to demands in each period. The model involves the integration of the event-based structure (demand generation) with a time-based controller (see Figure 1). The time-based controller uses the historical demand data in equal periods of time to determine new order sizes. Demands are generated by a discrete event simulator that simulates the behavior of the system in time.

As Figure 1 shows, the architecture of the analysis approach is based upon a discrete event retranslation of the process, however the controller only communicates with this model in a time-based regime. Also the performance measurement of the system is a separate activity that considers each simulation path and feeds the controller with a different objective function based on the situation.

The selection of a demand distribution is of great importance. In civil infrastructure (highway management) the demand is selected to represent the condition of pavement or roads, which generally has a slow dynamic, while for operational purposes systems under PBL contracts consist of parts with a variety of failure rates. Modeling the demand distribution for design purposes has a direct effect on the optimality of the result.

The availability and several cost factors are chosen as the parameters that the controller needs to control. The demand distribution is derived from the reliability of the parts and the controller action orders new parts for replacement. Control action is defined as an affine function,[1] in which we are using previous demands to estimate the new order. Making the control action affine makes comparison of different control policies that can be described by affine functions straightforward, e.g., Model Predictive Controller or Greedy Algorithms. These are common methodologies that use demand forecasting for planning future inventory support. The controller builds a model from a number of samples in the past and then predicts the next demand and the analysis window moves forward in time as more information is gathered.

Discrete Event Simulation (DES)

Because of the complexity and stochastic nature of real world applications, developing mathematical models of the system under study is far from trivial and assessment of their performance is equally difficult. Models that are accurate enough to adequately represent system behavior often cannot be analyzed using, for example, methods based on the theory of continuous-time Markov chains on a finite or countable infinite state space. DES is capable of representing the timeline of the life of different parts and subsystems with fewer restrictions. One can add any number of variables and parameters to the model without the need to change the structure of model. DES provides a visual indication of what happens to the fleet and each socket. Most importantly, this model provides a probabilistic sensitivity analysis.

DES has the ability to indicate how a supply chain performs and behaves over time when different rules and policies are applied. Testing different scenarios by adjusting parameters and procedures means that supply chain performance and behavior can be explored.

We use a DES model of the platform including its maintenance and we test the controller performance for the system. The parts in this system go from operational to faulty and then based on the availability requirements at any specific time they will be selected for maintenance or replacement. Also a model of the inventory is provided within the same scheme and different performance measures can be extracted from this model.

Petri nets are a DES approach developed for capturing concurrency and synchronization properties. Petri nets are graphical representations and mathematical tools for formal specification of complex systems (Haas and Shedler, 1986). Formal models like Petri net models have a number of advantages over simply writing simulation codes or DESs. They can be easily and automatically verified for deadlocks, conflict of conditions, catastrophic states, and logical errors in reliability-based design projects (Bertolini et al., 2006).

Figure 2 shows the graphical representation of the maintenance network connected to the inventory and Original Equipment Manufacturer (OEM) used in this paper. The input to the Petri net in Figure 2 is the parts inventory (and inventory policies, e.g., reorder threshold, order size, etc.). The net generates maintenance demands via sampling failure distributions for the system's parts and uses the inventory to support the system's

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[1] Affine in the context of nonlinear systems means the control appears linearly (where the nonlinearity with respect to the state is automatically implied).

maintenance requests. The net produces a time series (and cost) of the system's failure, maintenance, and operation.

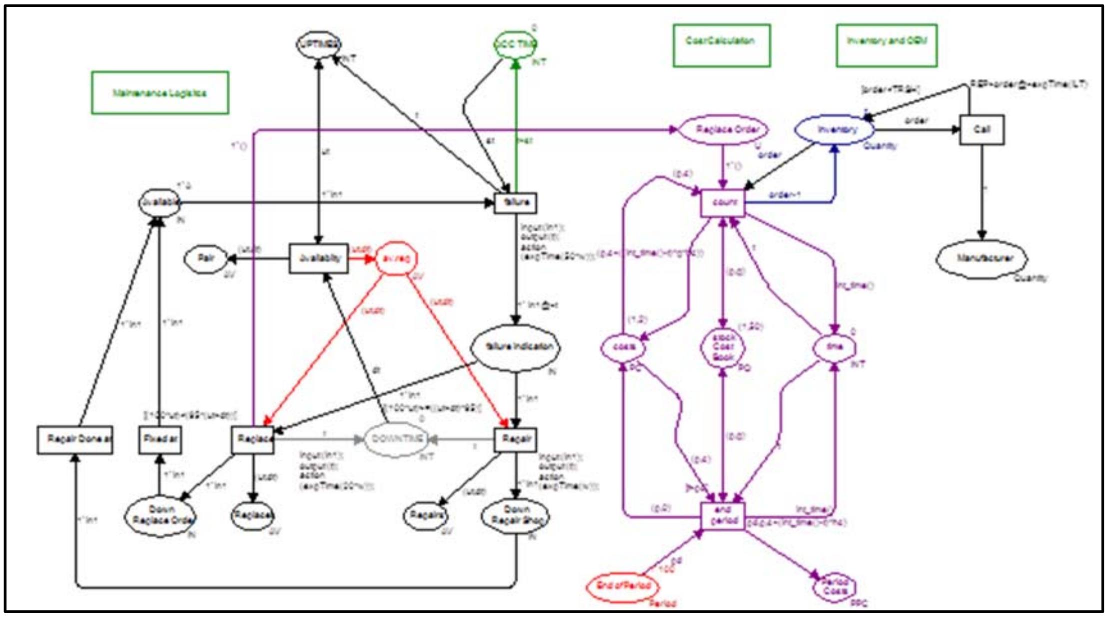

Figure 2. Petri Net Representation of the System

Performance Measurement

The customer's goals can be described by system parameters or functions that we call performance factors. The performance factors are generally defined by the contract terms, and observable contractor decisions (control parameters in the model) or outcomes of the contractor's actions. However, in some cases the customer needs to measure and define secondary functions of these parameters (e.g., operational availability as the ratio of uptime to total operational time, and the ratio of inventory to back-log). Based on the performance factors used by the customer, different measurements and calculations need to be done with the outputs from the DES model (Doerr et al., 2004).[2]

The availability as a function of uptime and the total operation time is a popular measure to system preparedness. By measuring availability of different parts and subsystems we can directly determine the availability of the whole systems. This makes the availability the most important factor for measuring performance of contractors to support complex platforms (Cuthbertson and Piotrowicz, 2011). Due the accumulative nature of availability (how it is accumulated along the timeline), we also need to look for the role of the time assessment window in the measurement system.[3] If the time assessment window is too long, then contractor actions near the end of the window will have little impact on the availability measurement (contractors will be inclined to "drop the ball" late in the window

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[2] Note, these functions can increase the complexity to the contractor and can also be "gamed," which means they can be satisfied in ways that do not guarantee the achievement of the performance-based contract.
[3] The time assessment window refers to the period of time over which the availability is assessed, e.g., monthly, quarterly, annually, etc.

because nothing they do will change the result). Alternatively, if windows are too short, contractors are penalized for the initial condition of the system and the inventory. Alternatively stated, the size of the assessment window will determine the sensitivity of contractor performance actions to different interruptions and eventually affect the contractor's risk-taking attitude. Optimization of the assessment window size is a primary goal of the model discussed in this paper.

Controller Mechanism

Special attention was paid exploring the decision-making process, and building the corresponding two-level stochastic model. The control-feedback mechanism for availability contracts is based on the established affine control model shown in Figures 3 and 4 (Skaf and Boyd, 2010). The model aims to determine the optimal incentives/disincentives in an availability contract so that the customer can expect the best performance or availability given the long-term budget constraint while the contractor maintains a steady revenue (with profit).

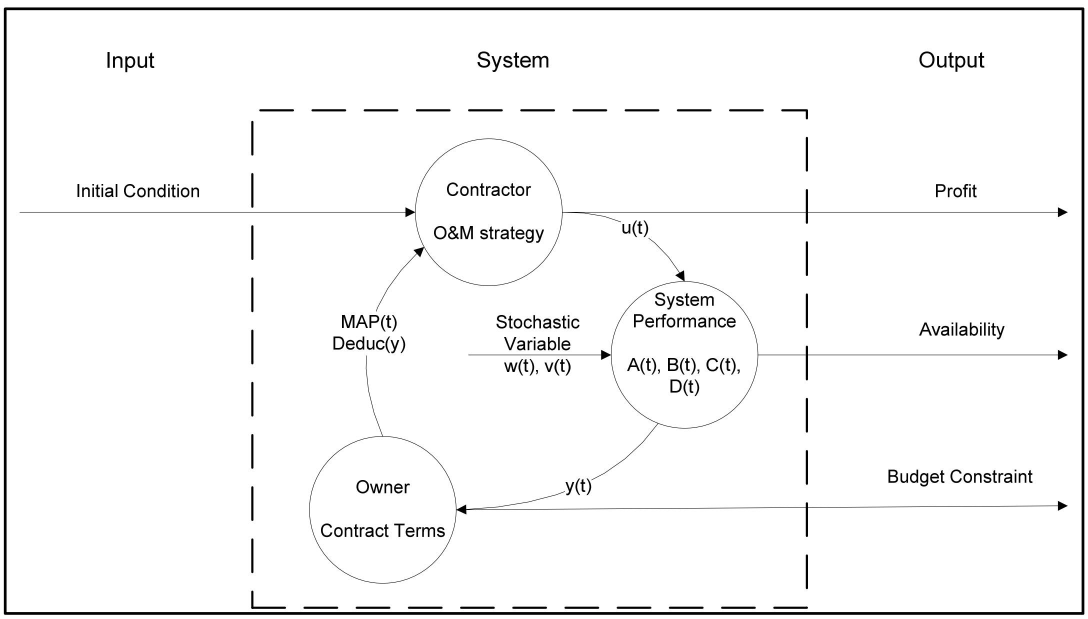

Figure 3. Affine Controller Model for Availability Contract

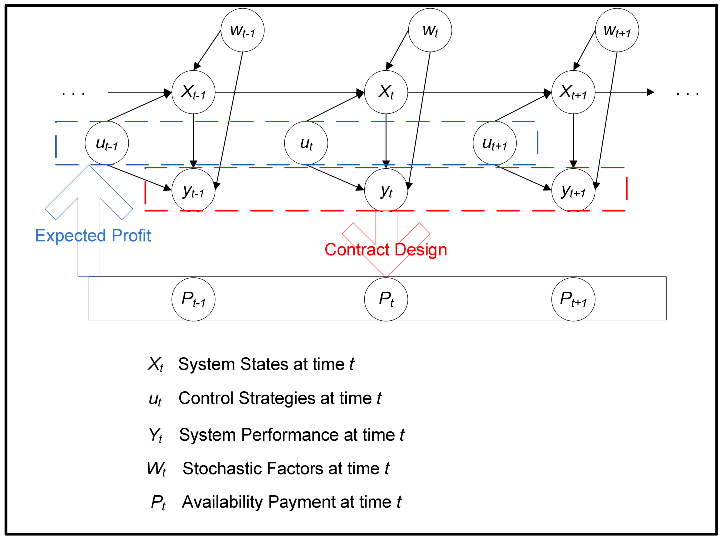

Figure 4. Affine Mechanism for Availability Contract

The following model shows the general form of the optimization process of an availability-based PPP contract:

$$\sum_{t=1}^{T} y_t^* \tag{1}$$

$$MAP_t - Deduction\ (y_t^*) \leq Budget(t), t = 1, \ldots, T$$

Where y_t^* solves problems ($t = 1, \ldots, T$)

$$\max \sum_{t=1}^{T} \left(\frac{E[MAP_t - Deduction(y_t) - Cost_t]}{(1+i)^t} \right) \tag{2}$$

subject to:

$$Deduction(y_t) - Cost_t \leq \ \eta MAP_t, t = 1, \ldots, T$$

where y_t is the availability of the project at each time period t (which comes from the DES and must be within the feasible domain for the system model); i is the discount rate; T is the assessment window; η is the penalty ratio; and MAP_t and $Deduction(\cdot)$ are decision variables for contract design for level one (public sector) problem. Given the detailed contract, the private sector (level two) must decide on the best y_t^* for each time t to optimize its overall profit.

In PPP contracts and models y represents the condition of the road, which comes from a linear model that is accounting for deterioration in terms of disturbance (Sharma et al., 2010). Road deterioration dynamics are captured with linear models and generally have slow dynamics and smooth behavior. PPP contracts are long and the effect of the transient behavior of the system can be ignored. However, PBL contracts for the mission critical systems are dealing with systems with non-linear behavior and variety of internal dynamics. In PBL, systems failures cause discontinuities in the behavior and the deterioration of the system, which come from many different parts whose reliability are modeled in the DES (Petri net). Design space explorations using a variety of search methods and optimization methods is a common approach in contract-based designs (Nuzzo et al., 2014). In our method every decision or solution needs to be checked for feasibility of physical system realization.

The first level is the contract design from the public sector's perspective seeks to maintain the best availability of the system given the long-term budget constraints. The first level problem is solved based on the recourse solution of the second level optimization, which represents the private sector's behavior during the system operation. For the second-level problem, the main objective is to maximize profit, which depends on the operational strategy and contract terms such as the Maximum Availability Payments (MAPs) and deduction adjustments.

Analysis Results

A model that supports contract design negotiations can help both parties to identify the effect of each contract term and requirement on the possible result of the contract (Wijk et al., 2011). Among the stochastic factors that need to be included in this model are the ranges of actions the contractor can take in response to incentives. Also, as previously identified, the availability assessment time window (T) is an important factor. We assumed that contractor can be modeled by an optimum affine controller. This controller represents the behavior of the decision-maker using the historical data and minimizing risk and cost for future assessment windows. It should be noted that the controller we used is proven to be optimum for a given T for such systems (Skaf & Boyd, 2010), however it is not clear what the best T is for providing an overall performance optimum. We assume that if the controller will satisfy the availability requirements the cost is also important to the customer. Where cost refers to the cost of the inventory (procurement of parts, handling costs, and cost of money).

It has been observed that the contractor is concerned about the risk at each decision instance. So we need to be able to trade-off the optimum T for the customer and the contractor. Intuitively it is more beneficial to the contractor to receive a larger T because: (1) more information is better, (2) less noise effect will be present, and (3) there is more time to compensate for problems, however, the customer wants less variability and more preparedness.

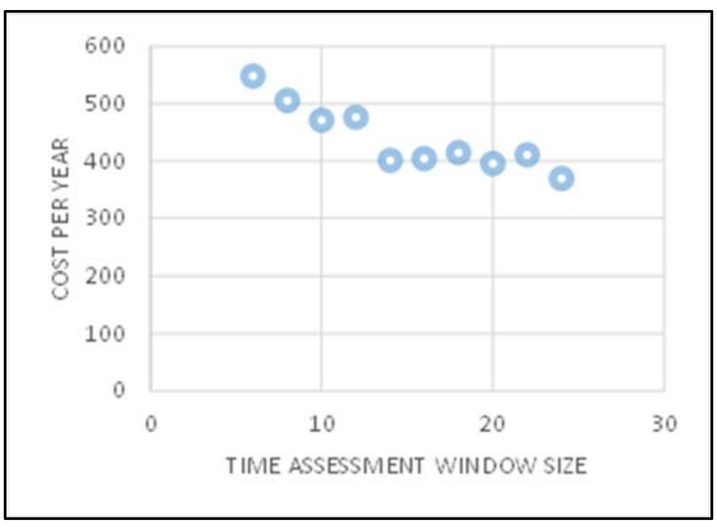

Figure 5. Cost Per Year Using Various Time-Assessment Windows in the Controller

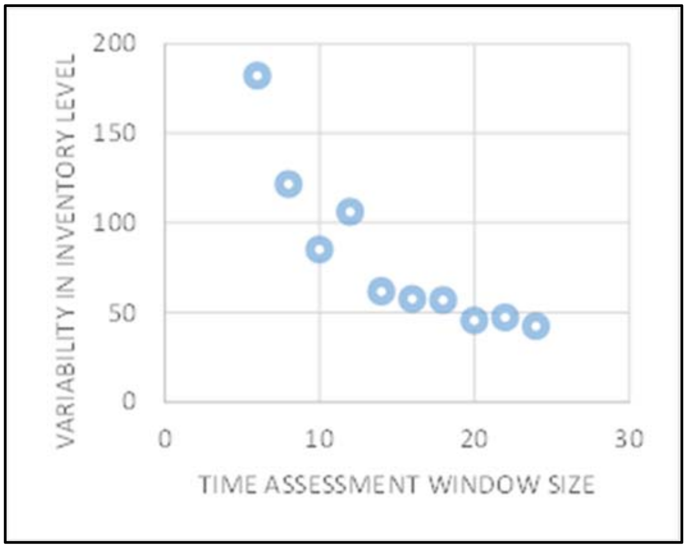

Figure 6. Variance of Inventory Level

In the model described in this paper we are using the affine controller to optimize the availability in an indirect way. We can extend the controller to directly target availability, however in practice the most important control variables for contractors for maintaining availability are supply chain, and inventory management and reliability parameters. An availability model can be created as a meta-model based on these control parameters. In our analysis we assumed that reliability (and thereby demand) is not a control parameter, however in reality PBL is designed to incentivize OEMs to improve their reliability (Guajardo et al., 2012) and the effect could be captured in the model (but is not today).

Figure 5 shows, total cost per period versus the availability assessment window. Using the proposed affine controller scheme for controlling the availability we observed: (1) with a longer time window the effect of optimization on cost per period from the contractor side will become more tangible for the customer; and (2) beyond some certain level, the improvement will become negligible.

Figure 6 shows that by increasing the time-assessment window size the variability in the performance of the controller will decrease, which is due to access to more information that results in better modeling, and the effect of sensitivity to small changes in demand. Figure 6 also shows that there is no need to increase T indefinitely and there is a threshold beyond which choosing a larger window size can result in any desired variability for a given performance level.

Discussion and Conclusions

In this paper we have established a stochastic model that could be used to design the detailed terms in availability contracts; and created a methodology that extends PPP modeling to PBL contract design. Special attention has been paid to exploring the control mechanism between the public and private sector in availability contracts. The methodology combines a dynamic modeling strategy (affine controller) and event-based system (Petri-net model) to capture the complexity of the problem.

The affine-controller mechanism is the key to balancing the conflicting objectives of different parties in availability contracts. During the contract period, the private sector tries to maximize their long-term profit based on the given contract terms and their own sustainment strategies. Alternatively, the public sector is trying to incentivize the private party to maintain the specified performance level.

The model aims to provide guidance for better design and negotiation of availability contracts, and is expected to help both parties understand the essential purpose of the partnership, and seek their mutual interest more efficiently. Specifically the model could be used to find the optimum time windows for assessing the contractor's efforts (i.e., measuring availability) - this is a key factor that determines the constraints for a contractor's design process and requires determining the length of the time window and the starting point for the first assessment. Longer assessment and sampling windows cause more fluctuation to appear in the middle time periods, but the prediction of demand will be more accurate. The length of the assessment window translates directly to the length of time over which availability is measured for contract assessment purposes.

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