Analysis of performance based contracts for capital equipment and manufacturing systems

Synopsis

Performance-based contracting (PBC) is emerging as a preferred procurement and sustenance strategy across industries such as aerospace, defense, utility, mining, and petrochemicals. The nature of PBC varies between industries, mostly differentiated through the performance metrics and service level agreements used. For example, a commercial airline may use despatch reliability as a performance metric, whereas, restaurant chains such as Dominos use on-time delivery as performance metric. According to a study by Accenture in year 2003, support and maintenance services generate 25% of revenues across all manufacturing companies in U.S. but account for 40% - 50% of the profits. Also for many capital equipment, sustenance/support cost is 80% of the total cost of ownership. Since the support is provided by OEMs (original equipment manufacturers) in most cases and consumed by the customers (users of the equipment), the two parties need to get into agreement or contract. Maintenance support in industries like aerospace and defense have been using contracts like “fixed-price", “cost-plus", “time and material”. In the last decade, Performance-Based Contracting has replaced traditional contracts in many industry sectors. Under PBC, the supplier of the equipment is compensated based on performance realizations such as equipment uptime, response time and so on. In the U.S. Department of Defense (DOD), PBC is referred to as Performance-Based Logistics (PBL) with the following five performance metrics:

1. Operational availability

2. Mission reliability

3. Cost per unit usage

4. Logistics footprint

5. Logistics response time

U.K. Ministry of Defense (MOD) uses “operational availability" objective of PBL in an agreement called “Availability Contract". For example, the defense contractor is paid based on the number of flying hours of a fighter aircraft. Existing evidence suggest that availability contracting has emerged as an enormous success for the MOD. In non-defence sector, such as commercial airlines

PBC is implemented using flying hours metric, the amount customer (airline owner) pays is proportional to the number of hours the aircraft is used.

Under PBC, customer transfers significant proportion of the risk associated with equipment sustenance to original equipment manufacturer (OEM) because OEM is responsible for maintenance resources (manpower, spares, maintenance equipment, tools etc.). OEM's income under a PBC is uncertain due to penalty the OEM has to pay in case the service level agreements are not met by them.

The primary objectives of the thesis are to analyze performance-based contract and in particular availability contract under different contexts. The first essay (problem) analyses availability contract between a single customer and single OEM but, OEM is not penalized directly for less equipment availability. Instead OEM is incentivized via prescript "more availability leads to more revenue". The problem studies OEM's net profit function in detail and provide results on meanvariance analysis, Value at Risk (VaR) analysis, marginal analysis, and multi-period net profit analysis using time-series models. The essay also provides empirical evidence (via data collected from a mining and construction company) for the major assumptions made in the model development. In addition this essay also compares availability contract with traditional cost-plus contract and shows that under availability contract, equipment availability as well as supplier's net profit improves whereas customer's cost reduces. Further, it is shown that a risk-averse customer tries to incentivize the supplier for higher equipment availability by paying higher revenue.

Since "operational availability" is a key performance measure in PBC, an important task is prediction of operational availability. Capital equipment undergoes several maintenance tasks during its operational life and an important gap in the literature is the prediction of operational availability under hierarchical maintenance policies. Complex equipment such as aircraft has hierarchical scheduled maintenance activities such as A, B, C and D checks. The time to complete the maintenance of B check is higher than A check, and when a system undergoes B check, A check is inherited (that is, A check is also carried out as part of the B check). The second essay integrates unscheduled maintenance and hierarchical scheduled maintenances in the classical operational availability formula. Using this new operational availability framework, a method of computing the operational availability of equipment is provided. This essay also provides the equipment maintenance provider with bounds on equipment operational availability, i.e., the maximum and minimum equipment availability that he/she can expect. Further the optimal contract duration that maximizes equipment operational availability under hierarchical scheduled maintenance framework is found. This essay demonstrates that optimal contract duration is nondecreasing function of spares on hand and increasing function of “inherent system component availability”.

The third essay analyses the OEM’s side of the problem under a PBC where the OEM is subject to linear penalty scheme when he fails to meet agreed performance target. The linear penalty scheme charges the OEM for per unit deviation of “achieved equipment availability” below target availability. Under this penalty scheme, the optimal equipment availability provided by OEM is found. When OEM fails to meet target availability, the customer also incurs additional cost. The customer in this problem decides “price of the contract” and “target availability”. This essay shows that the supplier can be incentivized to provide more equipment availability by higher per unit revenue or higher per unit penalty. Optimal price of availability contract set by customer is increasing function of per unit revenue earned by him and decreasing function of the linear penalty amount levied on supplier. Further, the optimal performance target decreases as per unit additional cost paid by customer increases. The optimal performance target increases as “per unit penalty” earned from supplier and “per unit revenue” earned by customer increases.

The first three essays analyze different aspects of availability contract for after-sales maintenance. The fourth essay analyses a manufacturing performance-based contract between customer and OEM. Under this contract, the supplier agrees for certain performance on the product manufactured (such as thickness of sheet metal) using the equipment supplied by the OEM. This essay uses absorbing state Markov chain theory to model the cost incurred by OEM when target performance is not achieved. Using the absorbing Markov chain framework, the optimal technical specification parameter or design parameter (example: reliability) of the equipment is found along with optimal revenue for OEM. This essay demonstrates that “production cost” has more significant impact on optimal equipment design reliability than “design cost” of equipment. Further, lower value of design parameter can be compensated by increasing knowledge of repair technicians.