2016 NDIA GROUND VEHICLE SYSTEMS ENGINEERING AND TECHNOLOGY SYMPOSIUM
SYSTEMS ENGINEERING (SE) TECHNICAL SESSION
AUGUST 2-4, 2016 – NOVI, MICHIGAN

EVOLVING PRODUCT SUPPORT WITH PREDICTIVE ANALYSIS

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ABSTRACT

Defense programs require accurate estimates of future asset performance and cost to manage the life cycles of both new and aging platforms. Traditional forecasting techniques and business intelligence applications typically fall short. Simulation-driven predictive analysis can deliver detailed insights that extend well beyond traditional methods. Advances in computing power and data management technologies now unshackle asset managers from the limitations of traditional forecasting. Clockwork's simulation platform and predictive analysis approach leverages experience developed through serving defense programs. A case study on the allocation of maintenance resources illustrates this technique. Balancing manpower levels across multiple echelons and multiple geographic locations is accomplished after running nearly one thousand simulation scenarios—each spanning the full life cycle of the complete set of weapons systems. Historical data is merely a starting point—the distinctive, compelling value emerges from volumes of data about the future—not just the past. Powerful predictive solutions are driven by accurate representation of future performance and a structured approach that generates meaningful insights about the future. The simulation-driven predictive analysis platform applied by Clockwork Solutions illustrates the power available to asset managers that seek accuracy and detail that exceed traditional predictive methods.

INTRODUCTION

To gain insights into future asset performance and cost, defense programs often rely heavily on historical data. Traditional forecasting techniques and business intelligence (BI) applications are applied to develop understanding from historical data. These methods typically fall short. The assumptions required for use of traditional historical forecasting are restrictive. Constant failure rates for asset components assume away the effects of aging. Over-simplified maintenance modeling removes needed detail from critical processes. A purely-historical view is unable to capture upcoming changes to the program including part upgrades, adjustments to maintenance concepts, and new life-extension programs. Simulation-driven predictive analysis can help develop insights well beyond traditional methods.

Clockwork applies a high-resolution, discrete event simulation platform to vastly improve the accuracy of insights on future asset performance and cost. A case study on the allocation of maintenance resources illustrates this technique. Clockwork's predictive models include multi-indentured representations of each serialized platform with serialized components and part-tracking along with a holistic representation of the global supply chain, multi-echelon maintenance, complex operations to capture the effects and relationships between multiple simultaneous physical phenomena.

SIMULATION-DRIVEN PRESCRIPTIVE ANALYTICS VS. TRADITIONAL FORECASTING

Simulation-driven predictive analysis provides a capability that far surpasses traditional forecasting tools. Though past performance, Clockwork has demonstrated the accuracy and depth of its predictive simulation platform and prescriptive analytics vs. widely-used traditional forecasting methods.

Traditional Forecasting Lacks Precision and Detail

Traditional forecasting, using historical demand, maintenance, readiness, and cost data, has been used for many years in attempts to estimate future inventory requirements, fleet performance, budgets and revenue. Over the last thirty years, Clockwork has observed this practice fail to deliver the precision and agility required of leading enterprises and effective asset management programs. The reason for this shortfall is simple: the past does not represent the future in dynamic operations that must respond to changing maintenance practices, aging equipment, engineering innovations, reliability improvements, and highly variable world-wide operations.

The past does not equal the future for asset performance management in these seemingly chaotic environments. Often, future does note resemble the past at all. Yet traditional, historical forecasting attempts to shape trend

lines, force moving averages, and smooth out variability. These methods miss a key point: the variability in metrics must be accurately measured and represented with detail—not smoothed and flattened away.

Over-simplifying assumptions in traditional forecasting create models of components and assets that do not age, process that never change, and environments that are certain. For clear, accurate decision support, predictive modeling must capture these complicating factors in detail. Yet, tradition forecasting is too restricted to meet this call.

These traditional, historical methods include many time series forecasting techniques and related models that are severely limited when applied to complex systems: exponential smoothing, moving average, Bayesian forecasting, trend models, segmentation, regression, cross-sectional forecasting, extrapolation, queuing theory analysis, etc.

In simple systems that reach steady state like modeling the lunch rush through a cafeteria, or predicting the number of tellers needed at a bank, traditional forecasting can work. In a controlled, sterile academic classroom, these models play a role in demonstrating simplified systems. However, when mission readiness, defense budgets, warfighting capability, and corporate bottom-lines are at stake, traditional forecasting must be replaced by precise and mature predictive models and that yield efficient and effective prescriptive actions.

Success through Demonstrated Accuracy

Clockwork's approach leverages thirty years of predictive simulation experience developed through serving defense programs in the Army, Marine Corps, Air Force and Navy—from fighter aircraft, to tactical generators; from artillery to tanks, heavy trucks, and MRAPs. Aerospace and defense OEMs such as Raytheon, Honeywell, and Oshkosh have relied on Clockwork's technology and services. In commercial industries, Clockwork has supported customers in upstream and downstream oil and gas such as Transocean, Ensco, and Shell.

Clockwork's predictive analysis technology informs the best tactics and strategy by detailing the impact of today's decisions on future readiness and cost. Using discrete event simulation, Clockwork maps future performance and cost across the entire life-cycle of capital intensive assets. This detailed, verifiable view of future outcomes is used by asset managers to balance trade-offs and accurately mitigate risks.

Advances in computing power and data management technologies now unshackle asset managers from the limitations of traditional forecasting. Clockwork is combining extensive experience in predictive modeling with advanced data storage and processors to deliver a web application that leverages cloud technology including grid computing. A comparison of traditional forecasting and Clockwork's technology is summarized in the table below:

Clockwork's Simulation-Driven Predictive Analysis	Traditional Historical Forecasting
Focuses on assets, their components, operations, and activities that sustain these assets through both planned and unplanned maintenance. Models a holistic and detailed asset lifecycle including components, operation, reliability, maintenance, sustainment, and supply.	Views demands in isolation. **Fails to connect assets operations to performance metrics** and costs in an accurate and detailed manner.
Future insights defined through the power of predictive simulation. Generates volumes of future metrics that define set of possible outcomes to include new strategies, environments, and fleet management challenges not encountered in the past. Specifies detailed future outcomes with time-based KPIs to enable well-informed decisions and prescribe effective actions.	**Relies entirely on historical data; limited to examining the past.** Forecasts are tightly coupled to past events. This fundamental flaw creates a gap between forecasts and actual observations in dynamic systems where the future does not equal the past.
Leverages many replications of possible future outcomes to allow a **deep understanding of risk, uncertainty, and confidence** in reported metrics.	**Fails to separate natural variability from meaningful relationships** because only one set of historical data exists (i.e. not possible to repeat the past to generate new outcomes).
Eliminates the need for over-simplifying assumptions. Explicitly quantifies and represents reliability, maintenance tasks, shipment delays, repair effectiveness, and other sources of uncertainty. Models aging on a component level. Includes complex, probabilistic age modeling including independent component aging and restoration, updating of age distributions based on failure or maintenance events.	**Requires many over-simplifying assumptions** about the nature of inputs that include uncertainty. Uses static time models; assumes that asset, parts, and components do not age over years of operation. Assumes maintenance is unchanging over time

Table 1. Simulation-driven predictive analysis vs. traditional forecasting.

Predictive Analysis for Asset Total Life cycle Management

As life-extension programs, engineering changes and sustainment efforts are applied to the defense programs, simulation-driven predictive analysis enables evaluation of strategies using reliability, maintenance, availability, and O&S costs as decision variables and in comparative metrics. This predictive analysis informs decisions related to affordability, trade-offs, should-cost and will-cost estimates, initial spares procurement, and development of maintenance and sustainment strategies. The figure below delineates the application of predictive product support across the full life cycle of defense programs.

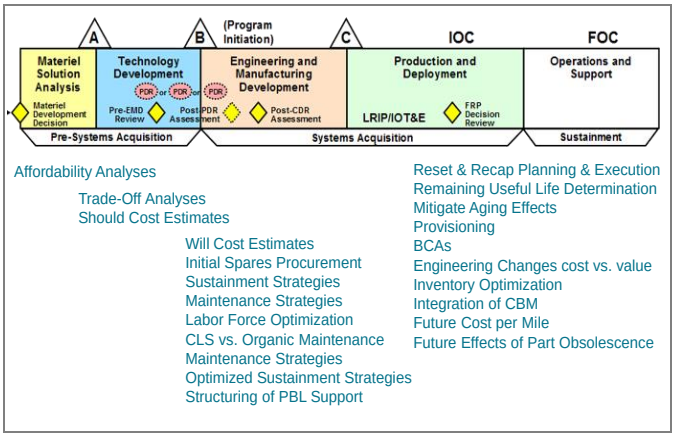

Figure 1: Predictive product support across asset life cycle.

Clockwork's predictive analysis capability supports:

- Affordability Analyses
- Trade-Off Analyses
- Should Cost Estimates
- Will Cost Estimates
- Initial Spares Procurement
- Evaluation & Development of Sustainment Strategies
- Evaluation & Development of Maintenance Strategies

OPTIMIZING MAINTENANCE MANPOWER: EVOLVING BEYOND FORCE REDUCTIONS

Defense programs are evolving as they operate into a future environment that demands increased effectiveness while implementing intense reductions in costs and manpower. Balancing maintenance manpower, equipment readiness, and tightly constrained budgets presents new layered, difficult challenges for PMs, PdMs and PSMs. Emerging from two prolonged ground wars, PEOs and their defense programs now shift their attention to resetting the force.

Clockwork's simulation platform operates each asset over its full life while measuring future events related to failures, maintenance, downtime, inventory requirements, and costs. Each asset component is modeled as a first-class simulation entity. Maintenance tasks are modeled in detail: They include part inspections, removals, component tear-down and rebuild, and part installation.

Each part is tracked as it is removed, shipped, repaired, placed on a shelf, installed into various assets over time, and ultimately condemned. Two or three-level maintenance concepts are detailed across the O (organizational), I (intermediate), and D (depot) levels. Supply chains including part sources, order lead times, delays, and shipping times are represented in detail. Inventory allocation, engineering changes, and life-extension programs are detailed. New part buys, asset acquisitions and retirements as well as detailed operational schedules are included in these predictive models.

Clockwork's technology has advanced over three decades beginning with leading nuclear physicists at Los Alamos National Laboratory. From this initial work, emerged a powerful predictive modeling and simulation technology to maximize asset availability and uptime while significantly reducing costs in capital intensive industries. This technology has been applied to solve the complex problems in aerospace and defense, power and energy as well as manufacturing. The combination of predictive modeling and high-resolution discrete event simulation is especially well-suited to asset performance management and life cycle management problems (Dubi 2006).

Clockwork's predictive modeling and analysis gives PEOs and program offices the ability to plan far in advance while maintaining optimal parts inventory and maintenance capacity. Recently Clockwork completed a maintenance manpower optimization to help modernize the product support strategy for a critical, joint ground combat system.

Adapting to Evolving Maintenance and Resource Constraints with Predictive Analysis

Analysis of limited maintenance resources while evaluating options to evolve the supporting maintenance concept across global operations for a new weapon system yields valuable results. This recent evaluation examines distribution of maintenance workload and personnel in a clear example of applying Clockwork's technology to successfully move past reset obstacles and into future readiness. The ground combat equipment managed by this defense program office requires three echelon maintenance across multiple geographic locations. Maintenance manpower realignment seeks to balance workload and maximize mission-readiness.

The objective is to leverage limited data, with gaps and imperfections, in the development of predictive analysis and optimization to achieve desired outcomes:

- Optimize maintenance structure to level workload across multiple echelons and various geographic locations—after applying force reductions.
- Balance the utilization of maintainers between the intermediate and organizational levels by minimizing utilization imbalance.

This predictive modeling analysis identifies optimal placement of maintenance personnel to balance workload and optimize performance across the enterprise. The entire inventory of weapon systems is modeled—every major component and each minor part is detailed and tracked for all individual serialized assets. Thousands of pieces of equipment are loaded in the high-resolution simulation and operated into the future. Every hour of operation, every mile driven, and each round fired is simulated day-to-day, across the future remaining lifecycle of the asset fleet—spanning decades.

Generating Insights on the Future

As the weapons systems are operated into the future, metrics are tallied for every part failure, equipment inspection, repair, part condemnation, shipment, and new part buy. Equipment tear-down times and part installations are timed. Planned and unplanned maintenance is evaluated, and the work required by maintainers is tallied. Maintenance bays, tools, and personnel are assigned to repair tasks then freed up as time moves forward. The high-resolution simulation produces volumes of data that would otherwise not exist. This output details time-based future metrics and the uncertainty

From that simulation output, Clockwork maps the work accomplished at each location over time and compares workload imbalances between each Level of Maintenance (LOM). Each of the points that make up the following graph represents operating the entire equipment set in the inventory for decades, and replicating those simulations dozens of times to measure the uncertainty around each metric. By running hundreds of these simulation scenarios, future outcomes are revealed: the behavior of maintenance, logistics, and supply systems emerges; the readiness of equipment is mapped out, and associated costs are tallied.

The workforce is balanced by minimizing the difference in personnel utilization across the organizational and intermediate LOM. The lowest point on each graph shows the optimal workload balance. Two units are balanced with 70% of their workforce at the organizational LOM. One of the three units evaluated is operating under different conditions, and requires a dissimilar configuration. Because the pool of maintainers is smaller and the operational tempo is higher, Unit C is better served by setting 55-60% of its workforce at the organizational level.

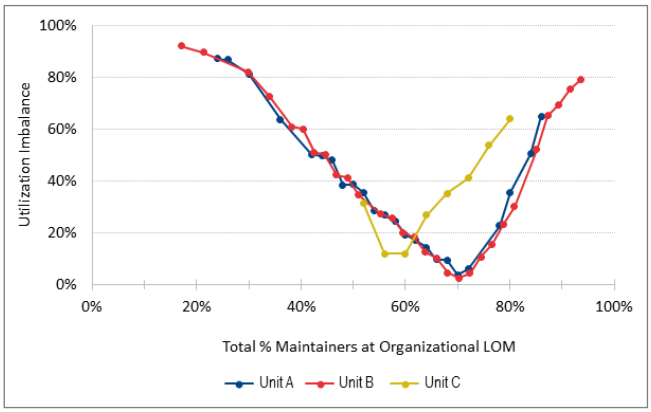

Figure 2: Utilization imbalance across 3 sample units.

From this point, Clockwork evaluates specific manpower configurations at each location and finds that the optimal solution can be attained by moving as few as thirty maintainers across maintenance echelons and geographic locations. This personnel adjustment results 38% to 49% drop in utilization imbalance and a reduction in repair cycle time of seven days.

Overcoming Data Gaps and the Effects of Future Uncertainty

Because defense programs operate into a future of shifting uncertainties, this solution now must be put through the same stresses that will challenge PMs, PdMs and PSMs in years to come. Hundreds of additional predictive scenarios are assembled, and more volumes of data are collected as these future operations unfold in the simulation.

Data gaps are closed with this extended analysis. Operational tempo varies over the simulated lifecycles. The duration of the workday and manpower levels are adjusted with each new scenario. The results now include a third dimension, and produce a mapping of the future result space.

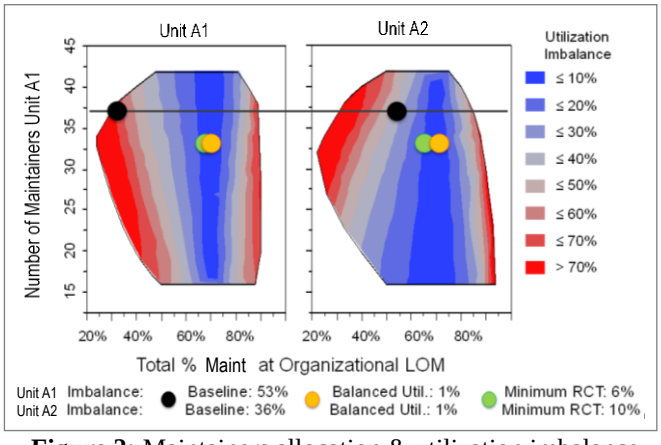

Figure 2: Maintainers allocation & utilization imbalance.

The graph above depicts the contours of this result space. The objective is to minimize the utilization imbalance for personnel across levels of maintenance (optimal solutions shown in yellow). A secondary goal is to minimize repair cycle time (optimal solution shown in green). From these results, Clockwork shows that both objectives can be accomplished with similar solutions. Also, it is clear the current manpower configuration (shown as the baseline in black) is far from optimal.

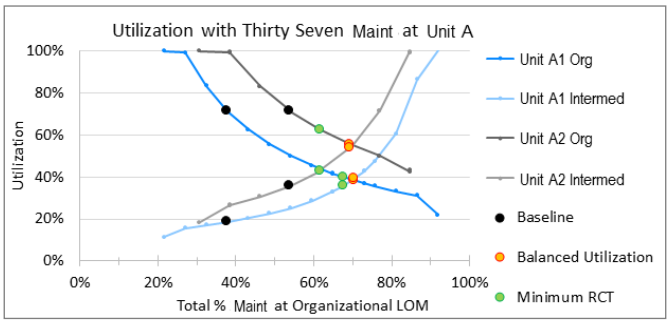

Figure 3: Various allocations of 37 maintainers at Unit A.

The solutions developed under expected future conditions are now tested across a wide range of possibilities to ensure that the manpower configuration will withstand changing environment and varying requirements. Balancing manpower levels across multiple echelons and multiple geographic locations is accomplished after running nearly one thousand simulation scenarios—each spanning the full life cycle of the complete set of weapons systems. Every simulation scenario tracks all parts and components and every maintenance action. The resulting vast quantity of output data produces insights sought by decision makers—after Clockwork applies data mining and other penetrating predictive techniques.

Detailed analysis of the result space that maps output metrics and decision outcomes to input factors is achieved by combining high-resolution discrete event simulation with advanced design of experiments techniques such as Nearly Orthogonal Latin Hypercubes (NOLH). Clockwork often employs this technique to efficiently examine large, complex sets of input factors and their effects on predictive metrics. The advantages of these designs are discussed the references (Cioppa and Lucas 2007; Sanchez, Sanchez, and Wan 2014).

PREDICTIVE ANALYSIS TRANSCENDS BUSINESS CHALLENGES IN THE EVOLUTION OF NATIONAL SECURITY

Effective manpower, maintenance, and asset performance strategies are rarely as simple as trimming a fixed percentage of personnel and assets across the board. Simulation-based predictive analysis is a powerful process employed to make sense of complex operations in uncertain future conditions.

Clockwork enables many defense programs to evaluate difficult questions and formulate effective strategies that control costs while maximizing performance and readiness in future operations.

Over the last few years, Clockwork delivered billions in cost avoidance across programs spanning Air Force aircraft: B-1, B-2, C-5, C-130, C-135, F-16; Army Aviation: UH-60, OH-58, and AH-64; Marine Corps Aviation: V-22; Marine Corps Ground Programs: LAV, ITV, MPC, AAV, M1A1, M777, LVSR, MTVR, M9ACE, HMMWV and EFV; and MRAP fleets: M-ATV, Buffalo, Cougar, Caiman, RG-31, RG-33, and MaxxPro+.

The current national security environment requires predictive decision support that is complete, evolving, iterative, and time-dependent. This predictive capability must be imbedded in sustainment practices to navigate through the complexities that face PEOs and program offices in their product support efforts. National security challenges are evolving rapidly. Today, they include:

- Exiting prolonged ground wars that accelerated aging effects on current equipment inventories.
- Shrinking manpower, in some cases to pre-WWII levels producing the smallest force levels since 1940.
- Re-addressing national security strategy objective of two simultaneous Major Regional Conflicts.
- Relying on severely understaffed maintenance depots.
- A budget that will shrink by more than $75 billion over the next two years.
- Increasing focus on special operations forces, improved agility, and cyberwarfare.
- Deep reduction in capital intensive assets from ships to helicopters to weapon systems.
- Transfer of assets between active forces national guard and reserves.

Mining enterprise historical data simply falls short in the evaluation of future costs and performance in the face of uncertainty. Historical data is merely a starting point—the distinctive, compelling value emerges from volumes of data about the future—not just the past. Solely gathering data and presenting it graphically through BI and traditional trend analysis misses the mark. Data mining and BI can produce impressive slice & dice dashboards and displays. Yet, Big Data efforts fall short when they stop at gathering and displaying enterprise history.

Powerful predictive solutions are driven by accurate representation of future performance and a structured approach that generates meaningful insights about the future—as delivered by Clockwork.

Clockwork Solutions

Clockwork is a global leader of predictive analysis solutions for Asset Performance Management (APM) to improve availability and reduce repair parts inventory and maintenance costs of capital intensive assets. Clockwork leads the way in accurately predicting the impact of part obsolescence; equipment aging; resource allocation; as well as strategies for equipment overhauls, and engineering changes.

Clockwork has thirty years of experience serving the needs of the Aerospace and Defense, Energy, Heavy Machinery and Transportation industries by providing cutting edge solutions to help analyze their data, giving them visibility to each phase of an asset's life cycle, resulting in billions worth of savings.

Clockwork's predictive analysis software and services have been leveraged to enhance program management and product support across DoD. Clockwork has delivered analysis for fleets within the DoD including those in: Marine Corps PEO Land Systems, Marine Corps Systems Command (MCSC), Naval Sea Systems Command (NAVSEA) PEO Integrated Warfare Systems (IWS), Army Communications- Electronics Command (CECOM), the Army Aviation and Missile Life Cycle Management Command (AMCOM), and the Air Force Life Cycle Management Center (AFLCMC). More information available at: www.clockwork-solutions.com.

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