Hanford River Protection Project Lifecycle Cost Modeling Tool to Enhance Mission Planning – 13396

Gary Dunford*, David Williams** and Rick Smith***
*AEM Consulting, LLC, 1201 Jadwin Avenue, Richland, WA 99352
**WIT, Inc., 11173 Oak Fern Court, San Diego, CA 92131
***Knowledge Systems Design, Inc., 13595 Quaker Hill Cross Rd, Nevada City, CA 95959

ABSTRACT

The Lifecycle Cost Model (LCM) Tool is an overall systems model that incorporates budget, and schedule impacts for the entire lifecycle of the River Protection Project (RPP) mission, and is replacing the Hanford Tank Waste Operations Simulator (HTWOS) model as the foundation of the RPP system planning process**.** Currently, the DOE frequently requests HTWOS simulations of alternative technical and programmatic strategies for completing the RPP mission. Analysis of technical and programmatic changes can be performed with HTWOS; however, lifecycle costs and schedules were previously generated by manual transfer of time-based data from HTWOS to Primavera P6.[1] The LCM Tool automates the preparation of lifecycle costs and schedules and is needed to provide timely turnaround capability for RPP mission alternative analyses.

LCM is the simulation component of the LCM Tool. The simulation component is a replacement of the HTWOS model with new capability to support lifecycle cost modeling. It is currently deployed in G2[2], but has been designed to work in any full object-oriented language with an extensive feature set focused on networking and cross-platform compatibility. The LCM retains existing HTWOS functionality needed to support system planning and alternatives studies going forward. In addition, it incorporates new functionality, coding improvements that streamline programming and model maintenance, and capability to input/export data to/from the LCM using the LCM Database (LCMDB).

The LCM Cost/Schedule (LCMCS) contains cost and schedule data and logic. The LCMCS is used to generate lifecycle costs and schedules for waste retrieval and processing scenarios. It uses time-based output data from the LCM to produce the logic ties in Primavera P6 necessary for shifting activities.

The LCM Tool is evolving to address the needs of decision makers who want to understand the broad spectrum of risks facing complex organizations like DOE-RPP to understand how near-term programmatic decisions affect lifecycle costs and commitments.

INTRODUCTION

The DOE tank farms at Hanford contain approximately 212 million liters of radioactive and chemically hazardous wastes, much of which originated during the reprocessing of spent nuclear fuel to produce plutonium for national defense programs. The mission of the DOE River Protection Project (RPP) is to protect the Columbia River by eliminating the risk to the environment posed by this waste. Successful management of the RPP requires coordination of multiple government contractors who are responsible for the design, construction, operation, and maintenance of facilities and support services. Efforts associated with mission analysis and strategic planning, particularly the development and issuance of the RPP System Plan [1] are essential to this coordination.

---

[1] Primavera is a registered trademark and P6 is a trademark of Oracle Corporation, Redwood Shores, California.
[2] G2 is a registered trademark of Gensym Corporation, Austin, Texas.

The RPP System Plan [1] provides the basis for alignment of program costs, scope, and schedules from upper-tier contracts to individual operating plans. Updates are made to the RPP System Plan to reflect recent progress, current plans, responses to emergent issues, changes in the regulatory environment, and budgeting constraints. The Hanford Tank Waste Operations Simulator (HTWOS) has been the foundation of the RPP system planning process, providing a model that integrates technical parameters with programmatic planning considerations. The HTWOS is a dynamic flowsheet simulator and mass balance model that calculates the flow of both discrete and continuous events occurring during the storage, retrieval, supplemental treatment, pretreatment, and vitrification of Hanford tank waste. By simulating the overall RPP mission, the HTWOS can forecast outcomes of changes to baseline assumptions, and sensitivities to alternative retrieval and waste staging strategies, new proposed technologies, and changes to the planned dates of facility availabilities. The results of HTWOS runs include projections for key mission metrics such as quantities of HLW and LAW glass canisters, total sodium requirements of the system, and dates for completion of retrieval and treatment milestones. These metrics are used in mission analysis applications and are included for the scenarios evaluated in system planning to help guide decisions on how to manage the overall project. Any changes or upgrades made to the HTWOS model that improve the accuracy of the underlying assumptions add fidelity to the model projections, thereby improving its ability to support mission planning. Likewise, any further development to the model that increases the number and kinds of outputs generated provides a broader basis for scenario analysis and gives decision makers a more complete view of mission impacts. To this end, a new overall systems model that incorporates mass balance and budget and schedule impacts for the entire lifecycle of the RPP mission, known as the Lifecycle Cost Model (LCM) Tool has been developed and is currently undergoing acceptance testing.

The LCM is the simulation component of the LCM Tool, which also includes a structured query language (SQL) server database referred to as the Lifecycle Cost Model Database (LCMDB) and a cost and schedule component known as the Lifecycle Cost Model Cost/Schedule (LCMCS) (Figure 1). The simulation component is a replacement for the HTWOS model with new capability to support lifecycle cost modeling. The LCM retains existing HTWOS functionality needed to support system planning and alternatives studies. In addition, it incorporates new functionality (e.g., discrete event scheduling, external application interface capability, advanced planning), coding improvements that streamline programming and model maintenance, and capability to input/export data to/from the LCMDB.

The LCMDB functions include storage of model inputs for model run configuration, storage of model results as an output repository, integration of LCM and LCMCS, report generation, and data management. Storage of model input parameters and output within the database will also facilitate analysis of LCM model output and support the model verification and validation (V&V) process.

The LCMCS contains cost and schedule data and logic. The LCMCS is used to generate lifecycle costs and schedules for waste retrieval and processing scenarios using time-based output from the LCM and cost estimate data loaded into the LCMCS from the performance measurement baseline (PMB) to create the logic ties in Primavera P6[3] necessary for shifting activities.

The flow of input and output data occurs as follows. LCM scenarios are developed from various combinations of assumptions and success criteria, and the input parameters required for those scenarios are entered into the LCMDB. The LCM user interface is used to enter LCM model run configuration settings into the LCMDB.

[3] Primavera is a registered trademark and P6 is a trademark of Oracle Corporation, Redwood Shores, California.

The resulting LCM data will be processed in the LCMDB for input into the LCMCS. After the LCM has been run, LCM-generated single-shell tank (SST) and double-shell tank (DST) transfer dates, durations, quantities, and Waste Treatment and Immobilization Plant (WTP) HLW and LAW transfer dates and transfer counts that affect RPP schedule activities will be collected in the LCMDB. The LCMCS uses an open database connectivity (ODBC) interface to read from the LCMDB and write to Primavera[4]. The LCMCS is comprised of the Primavera[4] ODBC user/database interface, resource-loaded Primavera P6[5] schedule, and a cost processing tool for applying escalation and ramp-down programmed within Excel.[6]

The requirements for the LCM simulation and database components, with respect to their functions for system planning are discussed in the next section. Following the system requirements is a discussion of the primary design elements of the LCM tool that support these requirements.

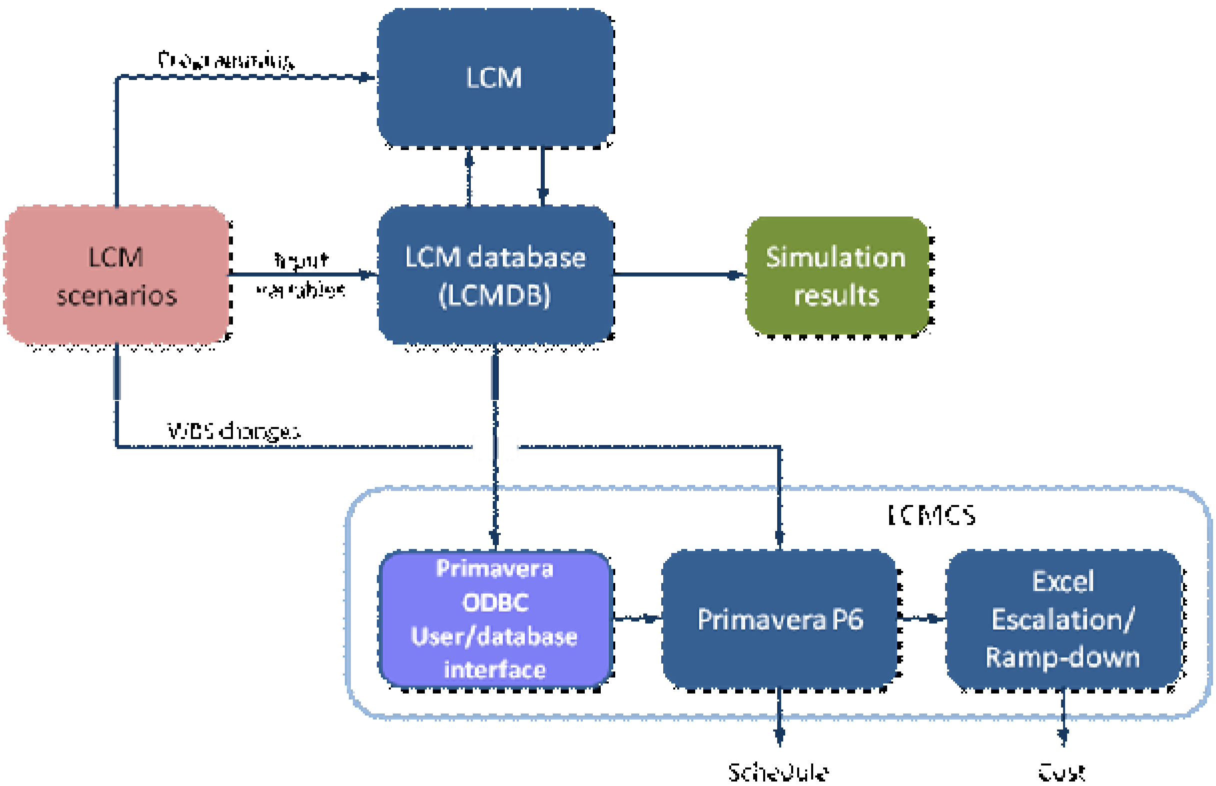

Fig. 1. The primary components and high-level data flows of the LCM Tool.

[4] Primavera is a registered trademark of Oracle Corporation, Redwood Shores, California

[5] Primavera is a registered trademark and P6 is a trademark of Oracle Corporation, Redwood Shores, California.

[6] Excel is a registered trademark of the Microsoft Corporation, Redmond, Washington.

LCM TOOL SYSTEM MODELING REQUIREMENTS

The following modeling requirements provide the basis for the design of the LCM simulation capabilities.

Operational Representation

To accurately simulate the complex operations required for the DOE RPP, the simulation model provides a natural mapping from operations into internal simulation structures. Groups are used in LCM to represent the set of objects to which a particular operation applies. The groups provide a useful way to understand and manipulate the structure and behavior of an object. LCM also supports multiple classification of an object; where an object can be a member of multiple groups at any one moment. In addition, LCM supports dynamic classification where objects can change membership over time.

Predictive and Reactive Maintenance: Reliability, Availability, and Maintainability

LCM has been designed with the capability to add scheduled maintenance outages and equipment upgrades that dynamically impact the reliability, availability, and maintainability (RAM) of equipment and/or operations. With the addition of RAM data, LCM will have the capability to improve process efficiency by its ability to evaluate system bottlenecks and conduct what-if scenarios. LCM is structured to dynamically adapt to process changes.

Integrated Risk Analysis

LCM has been designed to support integrated risk analysis. It can be used to establish a risk picture; compare different alternatives and solutions in terms of risk; identify factors, conditions, activities, systems, components, etc. that are important (critical) with respect to risk; and demonstrate the effect of mitigation measures on risk. This risk analysis capability is critical for the DOE RPP as the cost to fix problems in a project of this size tend to scale exponentially. The cost to fix or mitigate a defect can grow by thousands of times as the project progresses from early requirements and design phases through construction, operations, and maintenance phases. Data generated by the LCM simulation provides a basis for:

- Choosing between various alternative solutions and activities while in the planning phase of a system
- Choosing between alternative designs for a solution or a measure
- Drawing conclusions on whether specific solutions and measures meet stated requirements
- Documenting an acceptable safety and risk level

Figure 2 indicates the important role of risk analysis in the definition phases of any project. This system engineering project phase diagram indicates the areas where the risk analysis capabilities of the LCM can be applied to support DOE RPP. The LCM risk analysis capabilities are particularly valuable in the project design phases. LCM generated data can identify cost and management risks that support the definition of a risk management plan. In developing concept of operations, the LCM can provide data to evaluate the risk for different configurations or operational scenarios. During later development phases, the LCM data can provide more detailed risk information such as waste composition, equipment throughput requirements, off-nominal volumes, equipment utilization, and other data that support accurate, quantitative, technical risk analysis. This risk analysis capability has been, and will continue to be, a priority in the design and implementation of LCM.

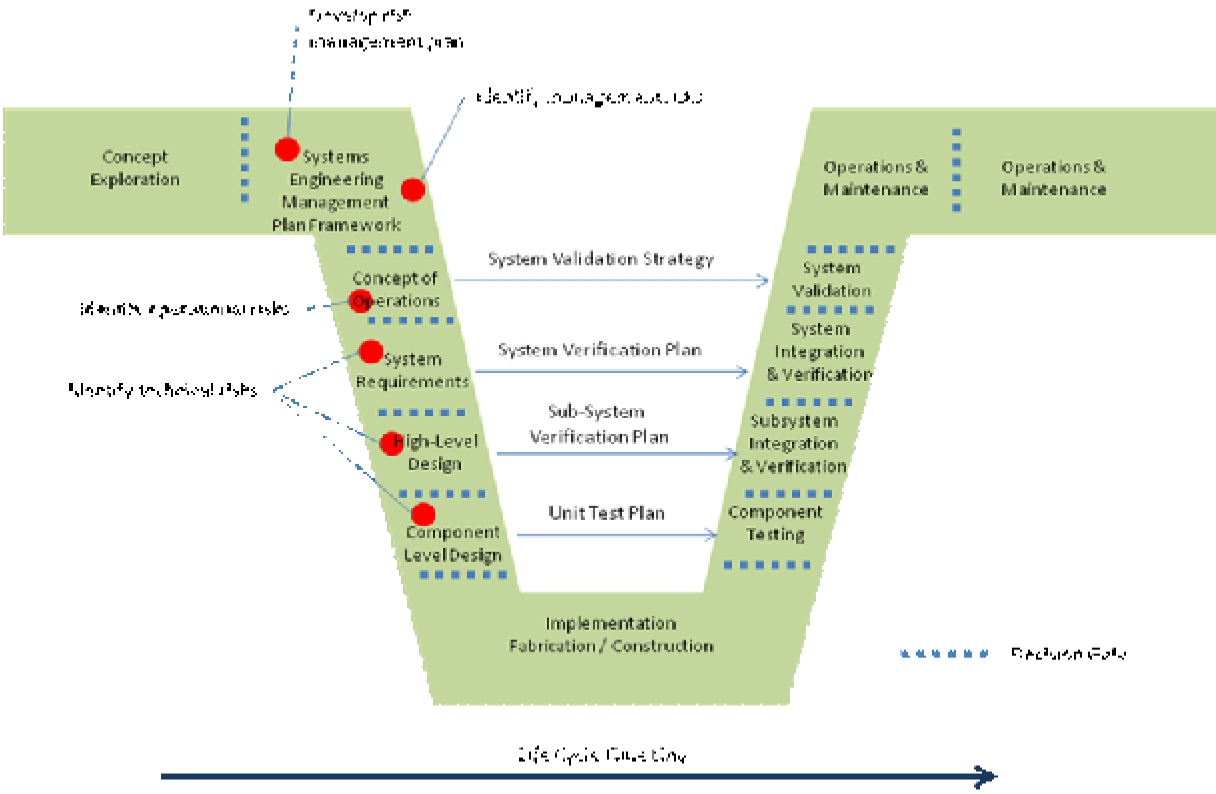

Fig. 2. Role of risk analysis in standard systems engineering project phases.

Project Management Decision Support

LCM it is intended to support the analysis involved in decision-making processes, not to replace it. Most decision-making processes supported by LCM are based on decision analysis, most commonly multi-criteria decision making (MCDM). MCDM involves evaluating and combining the characteristics of alternatives based on two or more criteria or attributes in order to rank, sort, or choose from among the alternatives. In addition to helping decision-makers to rank, sort, or choose from among alternatives, LCM is designed to support a variety of MCDM methods, including:

- Time analysis and time optimization
- Sensitivity analysis and fuzzy logic calculations
- Risk aversion measurement
- Group evaluation (teamwork)
- Graphic or visual presentation tools

LCM SIMULATION ARCHITECTURE

LCM has implemented an evolutionary new architecture according to the system performance requirements presented above. A few of the major advances include:

- Separating the simulation, animation, data analysis, and operational planning logic. This allows subject matter experts to make operational changes to LCM through database views that can be accessed through the web
- Implementing advanced analytical techniques that manually or dynamically enable different analytical methods to be implemented with independent levels of fidelity
- Use of enterprise databases for input, output, and automated verification and validation
- Open architecture to enable LCM to programmatically interface with existing applications and/or users
- Performance and efficiency enhancements that currently allow LCM to complete an overview run of the current ~40 year life cycle at a10 second fidelity on a laptop in under 2 hours
- Open source design where every operation is able to be verified and validated by subject matter experts

The primary element of the LCM Tool is the LCM simulation element. This element implements a model of the Hanford infrastructure as well as a means to simulate the execution of a given system plan within the infrastructure. The data generated by this simulation element drives the results from the LCMCS component of the LCM Tool.

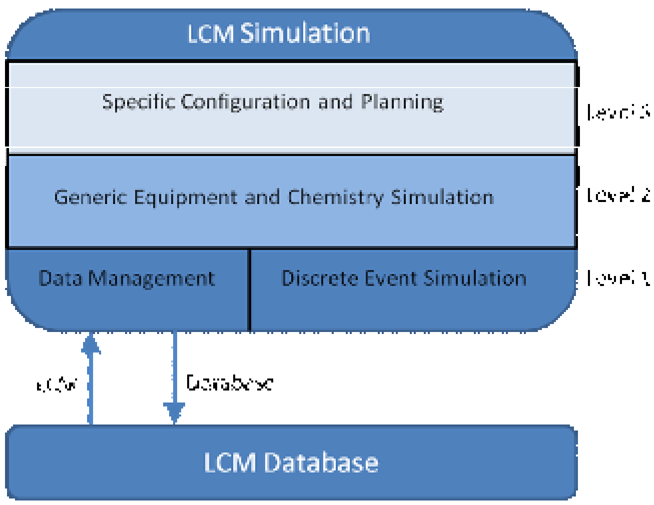

Fig. 3. LCM Layered Design Approach

To support the implementation of the variety of proposed scenarios required, a flexible simulation environment that could be readily adapted to simulate newly proposed equipment, operations, or planning guidance was used. A layered design approach, as illustrated in Figure 3, was used to provide the necessary flexibility and simulation fidelity. At the lowest level, level 1, is a discrete event simulation engine. This robust engine manages scheduled activities as well as a resource conflict resolution scheme to ensure resource constraints are respected. Also at this low level, a data management layer supports all the necessary interaction with the database. This data management layer insulates the model objects from detailed database interactions and allows a single, consistent data management scheme throughout all model objects. The next layer up, level 2, consists of a set of generic simulation objects. This general simulation layer implements the standard behavior needed to model the typical process equipment and chemistry associated with the Hanford infrastructure and system plans. The third and final layer implements specific plans or planning logic necessary to execute a given scenario.

This layered architecture provides the flexibility needed to implement and accurately simulate the variety of potential scenarios and concepts for exploring and characterizing the complex technical and programmatic options available for completing the Hanford mission. Typically, implementing new scenarios only requires changes to the level 3 software structures, and in many cases this high level logic includes configuration parameters that allow the overall system planning to be changed by altering the values of specific configuration parameters.

Level 1 - Discrete Event Simulator

At level 1, the LCM model operates as a dynamic event simulator by evaluating current conditions of both the source and destination vessels (e.g., looking at the current conditions of the remaining tanks in a tank farm system and determining the next action for both the source and destination tanks). While other techniques could also be used, the LCM is based on a discrete event simulation approach. The LCM technique is to use event-based actions to trigger programming steps. For example, a transfer from one tank to another can be modeled as an initial event at the start of transfer and a second event at the end of transfer. Using a set of technical and programmatic assumptions, LCM calculates the flow of events that occur during the retrieval, storage, pretreatment, vitrification, and supplemental treatment of RPP tank waste.

As LCM tracks the transfer of material from one process vessel to the next, it also functions as a continuous simulator. LCM simulates process steps until prescribed conditions are reached based on equipment capacities, safety limitations, or programmatic constraints from current plans or business strategies.

Level 1 - Data Management

Another key design element of the LCM simulation is its consistent data handling environment. This data management infrastructure makes it easy to both report data from the simulation as well as manage input configuration data.

The LCMDB uses an enterprise level database providing the access control, visibility, and reporting necessary for the large datasets produced in mission analysis simulations. This level of database integration allows subject matter experts to make operational changes to LCM through database views that can be accessed through the web. In addition, automated reporting tools can provide detailed analysis views of specific scenarios or comparison data aggregated across multiple scenarios.

A current baseline mission run with all data exported can generate up to 30 GB of records in the database. The database organization can then be exploited to implement in-depth analysis required for mission decision support. For example, mass flows are easily computed for arbitrary boundaries of interest. Detailed information down to the chemical reaction level can be extracted for all operations that occur during a mission. Resource requirements and timing for all operations can be used to generate accurate cost profiles. In addition to the decision support analysis, the detailed data set provides the basis for accurate V&V of all simulated operations. The LCMDB environment enables programming that implements automated V&V.

Level 2 – Generic Simulation Objects

At level 2, the RPP flowsheet is represented by objects in the LCM. Each object is an instance of an equipment class that is created according to the characteristics and functionalities of that equipment. A class is a defined data structure that has an associated representation. Classes have attributes, which define the inherited and locally defined properties of the class. Class hierarchies are used to capture the relationship between equipment types used for process operations.

An object-oriented model structure system is ideal for developing and deploying applications based on objects that:

- Represent a process, both graphically and conceptually
- Monitor the relationships between objects and the simulation environment
- Maintain continuous awareness of the current process simulation
- Evaluate in real-time and make processing decisions based on simulation process data

This approach helps to minimize the required coding and maintain alignment with the actual entities being modeled. The object-oriented model approach also supports the required flexibility for alternatives analysis. Behaviors and attributes can be modified in specific classes, and subclasses can be custom-fit to new scenarios.

The activity class represents the primary operations required to accomplish the RPP mission. For example, one subclass of activity is a tank transfer that moves a specified volume of liquid from a source tank to a destination tank. When it executes this activity, the object updates the volumes in the source and destination tanks; calculations are performed to determine the material transferred and new compositions at the destination tank. The methods of the various activity subclasses are where the primary process is coded to simulate the system operations. The LCM performs discrete material tracking calculations based on prescribed initial conditions, boundary conditions, and operating input. A material balance is achieved by the tracking for each storage, pumping, separation, reaction, and phase change, etc. for every active unit at each event step.

Multiple classes of activities are created to mirror the multiple types of operations to be simulated as part of the RPP mission. Subclasses of an activity handle the different operations, such as tank transfers, WTP unit operations, and evaporator operations. Specific subclasses of tank transfer activities exist to handle different types of tank transfers (e.g., recycle transfers). In addition to operations, specialized activity classes handle simulation behavior (e.g., radionuclide decay calculations).

Throughout the design of the LCM, a very strong object oriented software orientation was followed to ensure modularity. This approach allows the addition, subtraction, or modification of different modeling elements without disturbing the remaining simulation. This object oriented approach also supports integration with other applications. For example, some complex chemistry calculations can be coded within the simulation environment or can be implemented in a specialized application and integrated through a standardized application interface. No changes are required in the rest of the simulation to use one or the other of these chemistry models.

Level 3 – Specific Configuration and Planning Logic

The top-level layer requires the most flexibility as it embodies the planning logic that drives how thousands of detailed operations unfold during the long-term Hanford mission. This planning logic must mimic human decision making during the mission and respond to situations that develop within the overall system in a plausible, defined manner. To implement this high-level logic a variety of knowledge representations are used.

Planning logic includes high level conceptual constructs that help mimic human decision making. For example, various equipment resources can be put into planning groups and treated as a collection at the planning level. The planning groups are flexible, allowing resources to be dynamically moved between different planning groups, and thus behave differently. Planning logic also includes high level operations objects that encapsulate specific planning decisions. This organization of the logic allows the planning logic to be easily altered at specific planning operations without disturbing the rest of the planning logic. For example, a set of operations are used to capture the planning decisions necessary to manage the tank transfers that implement the HLW transfers.

DISCUSSION

DOE Complex Planning and Process Modeling Software – What makes LCM Different?

LCM is different from existing DOE Complex planning and process modeling software because it has an integrated planning tool structure designed to support system planning. It is a tool developed for rapid analysis of alternative retrieval, blending, and processing scenarios with respect to technical constraints. LCM is designed to support:

- Upgraded methods to include a systematic approach to uncertainty management and error propagation, and factor in the relationship of uncertainty to cost and schedule
- Additional modules that include cost, account for process chemistry, account for waste acceptance, and capture process changes in the tank farms, WTP, and future facilities
- Additional functionality that addresses the plant/process RAM for WTP and the Tank Farm to improve life-cycle analysis, evaluate system bottlenecks, conduct “what-if” scenarios and improve process efficiency

Future Plans for the LCM Tool

In order to advance the RPP mission, address known challenges and reduce programmatic risk, future plans are to incorporate into the LCM Tool the capability to:

- Leverage previous and future functional analyses to achieve life-cycle cost and effectiveness objectives
- Identify, analyze, and evaluate physical architecture and operational decisions
- Compare baselines to operational, technical and architectural requirements
- Identify mission challenges and risks
- Provide path forward recommendations
- Perform cost and schedule analysis
- Integrate risk management and decision analysis

These capabilities are not useful unless the information they produce is easily accessible by RPP personnel. Therefore, LCM has been designed to work with industry standard customizable web-based tools that allow drill down capabilities through user interfaces like dashboards. An example of an existing web based dashboard with drill down capabilities is shown in Figure 4.

Fig. 4. DSP's SharePoint-powered decision support dashboard.

The purpose of the LCM dashboard will be to provide RPP personnel instant access and understanding of the metrics that are important to them. The LCM dashboard will also highlight specific data and allow decision makers to drill down and inspect specific items. In addition, it will consolidate data from disparate data sources, including the major components of the LCM tool and other applications. RPP personnel are currently using web-based interfaces provided with the LCMDB to access and drill down through LCM data.

Future plans for LCM include the capabilities to:

- Improve and automate processes:
    - Provides a reference configuration for the process and system architecture as the system plan evolves
    - Provides analysis of alternative inputs and options defined in terms of user defined operational outcomes
    - Identifies bottlenecks in operational processes and analyses proposed measures to mitigate or eliminate them
    - Identifies potential gaps in capabilities and capacity
    - Identifies potential requirements
- Understand possible outcomes –Utility Analysis:
    - Identifies the biggest "bang for the buck" spending in operational outcome terms

  - Helps compare the benefits of investing in one program/alternative versus another
- Improves procurement decisions:
  - Helps identify consequences prior to expending resources
  - Identifies potential new or undocumented requirements
- Improves understanding of how the future may impact the system:
  - Identifies potential improvements in technology, processes, and applications
  - Identifies standards – migration and integration issues; future potential states
  - How can I ensure my business processes are agile enough to handle varying demand and resource levels in the future?
- Identify and justify budget requirements:
  - Helps RPP personnel identify and justify indirect impacts such as volume and capability requirements and training needs
  - Identifies resources needed to meet required service levels for new operations
  - Helps RPP personnel to articulate the operational impacts of budget restrictions
  - Helps RPP personnel to adapt and develop the best solution in a resource constrained environment

LCM has an important future role helping RPP personnel understand and improve operational processes as well as justify resources needed to implement or modify them. Most importantly, it will help RPP personnel understand the implications of change and the potential outcomes in terms of operational impacts directly relevant to their mission. These operational terms could be as diverse as speed of process, cost, or optimization and uncertainty analysis. A key element of LCM is its flexibility for rapid design and implementation of generic process activities tailored to react in ways representative of RPP's current and future specific and unique processes.

Integrated Risk Management and Decision Analysis

The LCM Tool is evolving to address the needs of various decision makers, who want to understand the broad spectrum of risks facing complex organizations like DOE RPP to ensure that they are appropriately managed. Specifically, the LCM Tool has the capability to analyze these areas of risk:

- Programmatic Risks - by providing cost estimates and schedules, using the LCMCS component of the LCM Tool, to estimate yearly costs for comparison to mission budget.
- Technical Risks – by providing dynamic flowsheet simulation and mass balance capabilities which show the stream by stream impact of technical changes on stream composition and quantity.
- Regulatory Risks – by providing dynamic flowsheet simulation and mass balance capabilities for estimating the disposition and quantity of radionuclides in the Tank Farms, WTP, and supplemental treatment facilities.
- Cost and Schedule Risks – by providing cost estimates and schedules, using the LCMCS component of the LCM Tool, for alternative waste retrieval and processing options.
- Environmental Risks - by providing dynamic flowsheet simulation and mass balance capabilities for estimating the disposition and quantity of radionuclides in offgas, liquid, and solid waste effluent streams.
- Performance – by providing dynamic flowsheet simulation and mass balance capabilities for estimating the amount of immobilized waste produced and the duration the mission.

CONCLUSIONS

The LCM Tool is an overall systems model that incorporates budget, and schedule impacts for the entire lifecycle of the RPP mission, and is replacing the HTWOS model as the foundation of the RPP system planning process**.** DOE frequently requests analyses of alternative technical and programmatic strategies for completing the RPP mission. These analyses will be performed with the LCM Tool. The LCM Tool automates the preparation of lifecycle costs and schedules and is needed to provide timely turnaround capability for RPP mission alternative analyses.

LCM is the simulation component of the LCM Tool. The simulation component is a replacement of the HTWOS model with new capability to support lifecycle cost modeling. It is currently deployed in G2[7] but has been designed to work in any full object-oriented language with an extensive feature set focused on networking and cross-platform compatibility. The LCM retains existing HTWOS functionality needed to support system planning and alternatives studies going forward. In addition, it incorporates new functionality, coding improvements that streamline programming and model maintenance, and capability to input/export data to/from the LCMDB. LCM is designed to support uncertainty analysis, sensitivity analysis and feasibility/optimization of retrieval, blending, and processing with respect to appropriate constraints (e.g., cost, glass properties, etc.).

The LCM Tool is evolving to address the needs of decision makers who want to understand the broad spectrum of risks facing complex organizations like DOE-RPP to ensure that risks are appropriately managed.

REFERENCES

1. Certa et al, 2011, *River Protection Project System Plan,* Rev. 6, ORP-11242, Washington River Protection Solutions, LLC, Richland, Washington.

[7] G2 is a registered trademark of Gensym Corporation, Austin, Texas.