Assimilating NASA Data into a Crop Production Estimation System: Risk Management

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Abstract – National Aeronautics and Space Administration (NASA) data and products are being assimilated into an existing decision support system (DSS) operated by the Production Estimates and Crop Assessment Division (PECAD) of the United States Department of Agriculture - Foreign Agricultural Service (USDA-FAS). The primary goal of PECAD is to disseminate global crop condition and agricultural production information for selected commodities. The perceived benefits of the assimilation of NASA data in PECAD's evolving DSS are: improved quality of crop assessment and production estimates and decisions, cost reduction and time savings. The main objectives of this research were to design a benchmarking strategy and develop a protocol that can help define DSS requirements and provide insight into the risks and mitigations that are critical factors for the adaptation and assimilation of enhancements to a DSS. Both qualitative and quantitative information were gathered to benchmark PECAD's present DSS using data from questionnaires and interviews. An interactive risk management tool (DDP-Defect Detection and Prevention) was used to 1) identify and formulate PECAD's DSS requirements, 2) estimate the impact of risks on the requirements, and 3) evaluate the effectiveness of mitigation factors that alleviate risks and enhance attainment of requirements. The DDP tool allowed us to evaluate mitigation scenarios that balanced and minimized the residual risk factors and achieved the best requirements attainment. Performance metrics were used to examine the effectiveness of the assimilation of NASA products into PECAD's DSS.

Keywords: Decision Support Systems, Benchmarking, MODIS.

1. INTRODUCTION

The role of Earth science data and models in agricultural monitoring and assessment continues to expand our ability to understand the effects that climate variability, landscape change, and anthropogenic and economic forces have upon agricultural production. This is particularly true as PECAD (Production Estimates and Crop Assessment Division) develops new initiatives directed at expanding U.S. agricultural exports, combating world hunger, monitoring global agricultural change, and improving U.S. crop condition and disaster assessments. For almost 30 years, NASA and the USDA have been collaborating through a series of projects that have worked to assimilate NASA products into PECAD's decision support system (DSS) thereby enhancing PECAD's DSS. In this study, the effectiveness of risk–reducing mitigations like the assimilation and utilization of NASA EOS data is evaluated using systematic benchmarking techniques. Benchmarking activities include performance metrics to measure the difference between the "as is" and the enhanced "to be" state. The Defect Detection and Prevention (DDP) risk management software tool developed by NASA's Jet Propulsion Laboratory (JPL) is employed to quantify the effectiveness of the enhancements, using risk balance and attainment of objectives as performance indicators.

1.1 PECAD's Decision Support System

PECAD analysts use a "convergence of evidence" approach in a DSS environment to estimate crop production for selected commodities for major agricultural regions of the world (Hutchinson et al., 2003). PECAD's decision making system uses satellite remote sensing data, meteorological data, and other data sources to drive crop models, derive information about general crop condition, and provide preliminary production estimates. These results are compared to FAS attaché crop reports, in-country sources, wire services, and analysts' personal knowledge (field trips) to estimate national crop production on or about the 10th day of each month. Several different satellite data sources, input databases, climate data, and crop models are analyzed for their impact on yield and area estimates at an appropriate regional level. National-level production is determined by summing the results of the changes in crop area and yield at the regional level. Through this process, PECAD has developed a historical database stretching back 20 years, enabling their expert analysts to compare current and prior conditions and bring a long-term perspective to their evaluations. Although individual preferences exist among analysts for certain information sources, they use a "convergence of independent evidence" solution, and do not rely exclusively on any single source due to limitations in temporal and spatial coverage, timeliness, accuracy and consistency of their input data (Figure 1). The World Agricultural Outlook Board (WAOB) and Interagency Commodity Estimates Committee (ICEC) must verify and endorse all final decisions about the global production forecasts.

PECAD's DSS has several user-friendly web interfaces which provide intuitive decision support tools (DST) to the analysts,

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such as CropExplorer (http://www.pecad.fas.usda.gov/cropexplorer/) and CADRE (Crop Assessment Data Retrieval & Evaluation). These tools provide communicative crop condition information for most agricultural regions in the world based on weather data and satellite imagery.

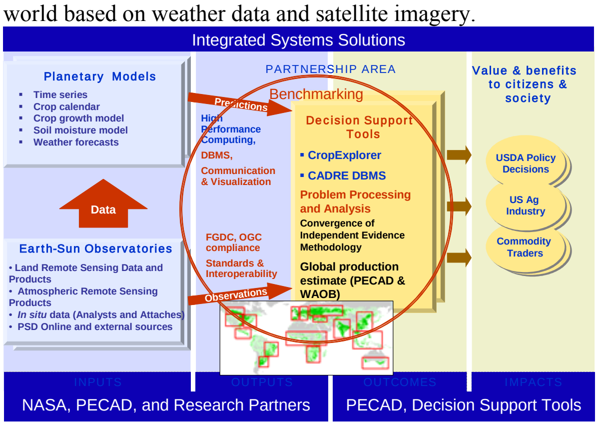

Figure 1. An Integrated Systems Solution Diagram: Analysts use PECAD's DSS to generate a global production estimate that is published monthly upon review by the WAOB. Many data inputs are based on NASA contributions.

PECAD's current development plan includes the migration from AVHRR (Advanced Very High Resolution Radiometer) to MODIS (Moderate Resolution Imaging Spectroradiometer) data, requiring investments in new image processing and GIS technologies. Both must be enabled to support the adoption of new NASA products.

2. DSS BENCHMARKING – RISK MANAGEMENT APPROACH

The outcome of the benchmarking process is intended to show how investments from USDA and NASA change PECAD's DSS. The DSS benchmarking process used metrics to indicate performance improvements and changes of the DSS based on current input of NASA's science, data and technology (state 1) in comparison with the state 2 DSS that incorporates new NASA data, science and technology (e.g. MODIS products) (Kaupp et al., 2003). Usability indicators and defined performance metrics are critical for assessing changes to the DSS. Both qualitative and quantitative information were gathered to benchmark the DSS. This involved the use of questionnaires and interviews, and risk assessment software. The PECAD-DSS description (Hutchinson et al., 2003) provided additional information about the current characteristics of PECAD's DSS and aided in the set-up of a benchmarking process and selection of performance indicators. The benchmarking process generally involves the following procedures and stages to assess performance-enhancing contributions that result from the assimilation of NASA data, science or technology in a DSS:

1. Involve users and experts in all stages of the enhancement process.

   "As is" → "To be" OR State 1 → State 2

2. Characterize state 1 or baseline the DSS including mandate, requirements/objectives of the DSS and its functioning.
3. Select performance and usability indicators to compare and analyze the "As is" and "To be" systems using an approach that involves user questionnaires and a software tool (DDP) adapted for benchmarking DSSs.
4. Evaluate "As is" DSS performance.
5. Plan assimilation process (transition), and formulate enhancements to the DSS ("To be").
6. Develop enhanced prototype with benchmarking partners and document information about the state-of-the-art of a DSS and its science, data and technology input.
7. Optimize prototype based on user and expert input and other constraints.
8. Evaluate performance of prototype or enhanced DSS ("To be") based on user feedback.
9. Compare performance of "As is" and "To be."

Based on our current work with NASA and PECAD, the following performance and usability metrics listed in Table 1 are considered.

DSS usability metrics (State 1 – State 2)	DSS performance metrics (State 1 – State 2)
• Ease of use (GUI, tools) • Frequency of use (e.g. Web statistics for 'CropExplorer') • System statistics • Learning curve (training) • Workload (more data, better models) • User needs (consistent data, value-added products) • User tasks (interactive, automated) • Documentation	• Attainment of mandate, objectives and requirements • Cost effectiveness (data sources, DSS tools) • User needs (data quality, consistency, timeliness, data mining) • Organizational needs (information technology, expertise) • System performance (accuracy, timeliness, system statistics) • Bottlenecks (network)

Table 1: DSS Usability and Performance Metrics Under Consideration (State 1 → State 2)

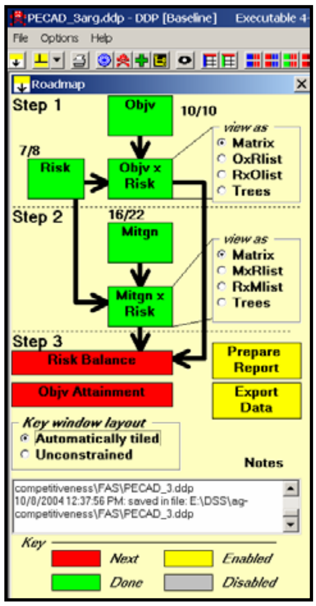

Figure 2: Representative screen shot of the roadmap of DDP's main GUI.

The focus of this research is the DDP strategy, a system engineering approach to the benchmarking process. The DDP tool has been adapted to aid in the DSS benchmarking process. The DDP process is intended to facilitate benchmarking and risk management over the entire DSS project life cycle beginning with data, science and technology assimilation decisions all the way through operations. The DDP process aims to determine (1) the DSS requirements/objectives and their importance, (2) the risk factors and their impact on attaining requirements/objectives, and (3) the effectiveness of mitigating factors that will attain the objectives and reduce the risks. A representative graphical user interface of the DDP software is presented in Figure 2.

The DDP process is accomplished using six processing steps:

1. Identify all goals, requirements or Objectives of the DSS for state 1 (+ state 2) and rate their relative importance.
2. List the Risk factors (their *a priori* likelihood of occurring is initially assumed to be equal) which affect attainment of Objectives or limit DSS effectiveness (e.g. lack of data, usefulness of tools).
3. Establish Mitigations (e.g. assimilated NASA products) that reduce the Risks and improve attainment of Objectives.
4. Appraise the impacts of the Risks on the DSS Objectives (i.e., if a Risk occurs, how much loss in attainment of Objectives would it cause).
5. Assess the effectiveness of the Mitigating factors at preventing or reducing the likelihood of the Risks.
6. Balance the residual Risk profile with a selection of Mitigations and run Objective-attainment scenarios.

The impact of risks on meeting requirements and the effectiveness of mitigations in reducing risks were obtained by designing a survey for PECAD's analysts. Not all risks and mitigation factors were clearly associated with all the requirements. That is, the impact of some risks on some requirements could be marked as "none" or "unknown". Similarly, the effectiveness of particular mitigation factors to reduce particular risks could be "none" or "unknown" as well. An example of one of the thirty-seven questions and answers used to establish relationships among Objectives, Risks and Mitigations is given below:

"What is or would be the level of impact from not having continuous access to national level multi-spectral observations (e.g. AVHRR-like) on crop area estimates:

	None	Low	Med.	High	Unknown
a) Early in the crop growing-season?	**x**	**O**	**O**	**O**	**O**
b) Late in the crop growing-season?	**O**	**O**	**O**	**x**	**O "**

The answers to this survey were translated into relative values of 0, 0.1, 0.5, 0.9, and * for None, Low, Medium, High and Unknown respectively. Consequently, the geometric means of these values were entered into the DDP tool, resulting in an Objective x Risk impact matrix, and a Mitigation x Risk effectiveness matrix (Figure 2). The matrices were used to evaluate risk balance scenarios and attainment of Objectives. The relative importance of PECAD's requirements and objectives was determined through discussion with PECAD collaborators.

The purpose of DDP is to systematically quantify the performance differences between state1 and state 2 of the DSS. The DDP tool is utilized to prioritize the Objectives, weight the impact of the Risks, and evaluate the effect of various Mitigation combinations at reducing these Risks while attaining the Objectives. By simple mathematical operations, the potential impact of a given Risk and the effectiveness of a collection of Mitigations results in a residual Risk profile and visualization of attainment of specific Objectives. The outcome of the DDP process allows for the quantification of NASA contributions (mitigation factors) in terms of enhanced attainment of Objectives or reduction of Risks between state 1 and state 2 and future "to be" states.

Important to note is that production estimates for each country, commodity and season are derived differently based on the usability and availability of information sources for each country and the preferences of the individual analyst. Results from validation and verification efforts can provide analysts a measure of confidence in the products. Results from the currently ongoing benchmarking activities will be used to determine the contribution of the proposed enhancements to the system and evaluate it with respect to the current state of the DSS. It should be noted that the benchmarking process is best done by including all aspects of the DSS (management, users, tools, Information Technology, and data sources) as the assimilation of a product will affect overall system performance and that of individual components (e.g. user interface, knowledge and problem processing system) of the DSS.

3. RESULTS AND DISCUSSION

Interviews, discussions and surveys allowed for the discovery of PECAD's goals and objectives, risk factors that could get in the way of attaining their goals, and mitigation factors that are in place or are planned to reduce the risks.

PECAD's primary objectives are to provide accurate monthly production numbers by commodity and country and present evidence to the World Agricultural Outlook Board (WAOB) to support these estimates. PECAD is also required to provide automated analytical products to external customers (i.e., the rest of the world) and have an *ad-hoc* analysis capability to disseminate timely global crop condition and production information.

Risks to meeting PECAD's mission that we identified include: (1) lack of continuous access to national- and regional-level multispectral observations (e.g. AVHRR, MODIS), (2) the delay in receiving timely remote sensing data, (3) obstacles to operational use of remote sensing data within PECAD (i.e. facilities, tools, and training), and (4) the lack of baseline or historical information specific to agricultural regions.

The impact of these risks on PECAD's mission can be minimized through integration of mitigation factors such as PECAD resources (analysts, attaché field data, ground truth, and external data sources) and NASA data products. The mitigations that are currently being implemented include:

- Remote sensing products such as MODIS Rapid Response Products, MODIS vegetation index products, surface reflectance data, a crop mask, and TRMM

(Tropical Rainfall Measuring Mission) precipitation data, and reservoir height data.

- Expansion of the current suite of tools for production assessments and early warning of crop conditions.
- Extending the CADRE and CropExplorer decision support tools and models.

The assessments from the surveys and interviews were implemented in the DDP tool to examine the effectiveness of the mitigations to retire risks and attain objectives.

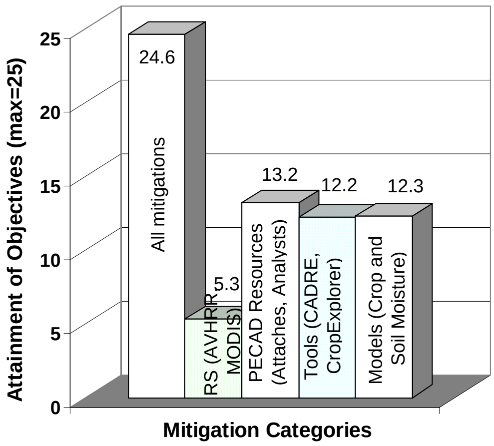

Figure 3. Attainment levels of PECAD's objectives for several mitigation categories.

Figure 3 shows the attainment of PECAD's objectives for different mitigation categories after applying the DDP tool. The sum of the attainment of the four mitigation categories (5.3+13.2+12.2+12.3 = 43) exceeds the attainment of "all mitigations" (24.6) applied at the same time. Basically, simultaneous use of mitigations provides a marginal benefit depending on the number of mitigations applied and their effectiveness. Mitigations can also work synergistically when the benefit (attainment of objectives) of two single mitigations is less than the benefit of the pair of mitigations used simultaneously. For example, the attainment of objectives by mitigating risks with trained analysts and MODIS rapid response data is 2.86 out of 25, while the attainments for the single mitigations are 0.89 and 0.47 respectively. Figure 4 shows the corresponding risk balance after applying the two mitigation factors. Risks 1 through 7 are reduced by mitigating them with the analysts. Risks 3, 10, and 13 are significantly reduced by implementing the MODIS rapid response data. It should be noted that the use of the data is most enhanced when the data visualization and extraction tools are integrated in the system.

4. CONCLUSIONS

The DDP software is a powerful tool to consistently manage and analyze risk and benchmark PECAD's DSS. The DDP tool elicited many constructive discussions and helped direct the benchmarking thought process in a risk management context. From this first-time application of the DDP tool we learned that the survey questions will need to be explicit to reduce ambiguity and overlap in the risk and mitigation factors. Since NASA enhancements to PECAD's DSS are currently at various stages of implementation (e.g. between state 1 and state 2), the results presented here will be complemented with annual repeat surveys or when most state 2 enhancements are implemented. The approach to measure the difference in performance of the DSS between State 1 and State 2 will be presented in a forthcoming benchmarking report and will be based on performance indicators like risk balance and objective attainment using the current PECAD-DDP application as a baseline.

5. ACKNOWLEDGEMENTS

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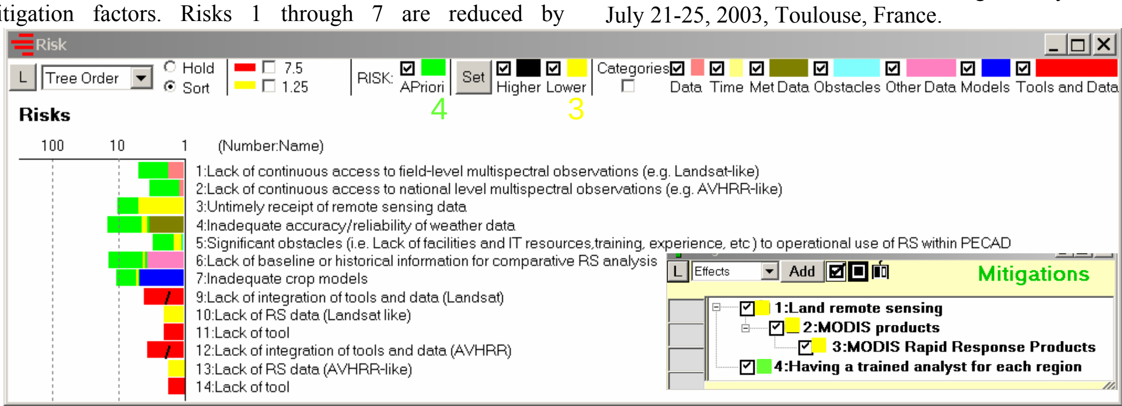

Figure 4. Risk balance after Mitigations "MODIS Rapid Response Products (3)" and "Having a trained analyst for each region (4)" were applied to reduce the risk by the yellow and green amounts respectively.