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# INTEGRATED ENVIRONMENTAL AND ECONOMIC PERFORMANCE ASSESSMENT

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## ABSTRACT

Our research group seeks to understand how corporations can effect long-term commitments to economic prosperity and sustainability; and in particular, how such corporate commitments cascade through the organization and are implemented from the boardroom to the shop floor of the manufacturing facility. Our long-term goal is to examine the corporation from a sustainability perspective, where we would define “performance” as the relative effectiveness of a mill or enterprise in transforming its capital resources – financial, technological, natural, and social – into value-added products and processes. Using the funds provided by the Center for Paper Business and Industry Studies, our group is exploring the development of decision support tools that provide simultaneous views of production, economic, and environmental data from a paper mill. Our hypothesis is that tools that efficiently align production, economic, and environmental data will provide greater insight into the dynamic relationship between economic and environmental effects of proposed changes (technological and/or operational) in a mill and, thereby, allow for more informed decisions involving trade-offs. The focus of this presentation is on two case studies that explore the potential for integrated production, economic, and environmental performance assessments to support decision making by mill managers.

## INTRODUCTION

Using case studies at two newsprint mills, our team examined two approaches to integrating production, environmental, and economic performance data. The first case (at Newsprint Mill One) focused on options for expanding de-inking operations, and the second case (at Newsprint Mill Two) focused on the effects of various scenarios for wet end control. The first case study employed a tool for efficiently integrating data from process information systems, accounting systems, and a mill process model (Pacific Simulation’s WinGEMS™) into an activity-based cost model of the mill. The second case study examined the use of simple Microsoft® Excel-based spreadsheets for developing a steady-state, mass-balance model of the paper machine and calculating aggregate economic and environmental effects of various control scenarios. We anticipate completing both case studies in the 2003-2004 academic year. The purpose of this presentation is to illustrate how such tools can integrate production, accounting, and environmental data at a pulp and paper mill.

## DECISION MAKING CONTEXT FOR A U.S. PULP AND PAPER MILL

The pulp and paper industry is a commodities industry, sensitive to supply and demand and the shifting domestic and global market influences on price and cost. A significant factor shaping the context of the U.S. paper industry is its relatively low operating rate, defined as the

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ratio of the amount of paper produced by the industry to its overall production capacity.[1] Overcapacity in the pulp and paper industry leads to cutthroat pricing and, consequently, losses of cost savings from productivity gains to the customer.[2] As the most capital intensive industry sector in the U.S. (spending $130,000 per employee per year in plant and equipment), the pulp and paper industry has limited opportunities for investment in new, more efficient technologies.[3-5] Today, the industry's machines tend to be older and smaller than those of their competitors in Europe and Asia. As a result, U.S. paper producers tend to have higher fixed costs per ton of paper produced. In addition, the newer European machines are less polluting, making the European firms less vulnerable than the Americans to increasing costs of environmental regulation and control.[1,6,7] In the context of excess production capacity, high fixed costs, cutthroat pricing schemes, and increasing competition from foreign imports, the typical response of the industry has been to make more paper, ignoring the high marginal cost implications of the law of diminishing returns.[2]

Environmental regulation impacts the U.S. pulp and paper industry in every aspect of the product life-cycle: from forest management, to pulp and paper manufacture, to paper recycling and disposal. Forest management practices, and the methods used to harvest and transport trees to supply the mills, affect the availability and effectiveness of important ecosystem services.[8] Over the past ten years, the forest products industry has made "important strides" in its stewardship of forest resources. Over 200 organizations, representing over 100 million acres of forested lands, participate in the Sustainable Forestry Initiative (SFI), the "most comprehensive expression of the forest products industry's collective effort to improve forest management on its lands."[3] Participants in SFI apply rigorous standards for perpetual growth and harvesting of trees while providing for the protection of wildlife, plants, soil and water quality.[9]

Pulp and paper manufacturing is resource intensive and generates significant amounts of solid wastes, air emissions, and discharges to water. The industry is the third largest user of fossil fuel energy and the largest user of industrial process water among U.S. manufacturers.[10,11] It generates billions of tons of non-hazardous wastewater and sludge,[12] and is one of the largest sources of chemical releases reported under the U.S. EPA Toxic Release Inventory. The specific list of chemicals released by any particular mill, of course, depends on the types of production processes employed. On an industry-wide basis, nearly half of the TRI releases are methanol, a by-product of the pulping process, which accounts for over 50% of the industry's releases to air and 40% of releases to water. Other substances released by the industry include acids, chlorinated compounds, ammonia, and priority air pollutants associated with combustion ($SO_x$, $NO_x$, and particulates).[10]

In 1999, consumers in the U.S. generated 88.1 million tons of paper and board product wastes, of which 42.9 tons (or 48.7%) was recovered for recycling.[12] While post-consumer recycling efforts have been successful, the strategy to develop broad and sustainable markets for recycled content products has been weak, leading to an excess supply of deinked pulp (estimated at 360,000 tons per year). With respect to relative pricing of recycled-content versus virgin-content products, one study found that the production costs varied "from mill to mill, depending on configuration and pulp sources."[13] Nonetheless, many recycled paper products are available at comparable prices to virgin papers. The issue again is overcapacity for the current level of demand. In spite of closures of several de-inking and recycled paper mills in the past couple of years, a survey of mill managers found that the remaining mills are running at less than full capacity.[13]

The pulp and paper industry's environmental performance has improved dramatically since 1970. One summary of the industry's environmental performance found that while the industry increased total production of pulp and paper by 67% between 1970 and 1993, it reduced water consumption by about 70%, air releases of sulfur compounds by over 90%, and wastewater discharges of dioxin (from bleached chemical pulp mills since 1988) by 92%. These improvements came at a significant cost of over $10 billion in capital investments since 1970. On an annual basis, pollution control measures cost the industry over $1 billion, or roughly $10 to $50 per ton of production (cost varies by size and type of mill).[3]

To the individual mill manager, investments in pollution abatement technologies may be viewed as "unproductive," meaning that they have "no marketable and therefore quantifiable effect in terms of productivity."[7] In addition to the capital cost, Porter (1995) would add the cost of non-value added activities associated with regulatory compliance, including operation and maintenance of equipment, permitting, and reporting.[14] Using data from the paper industry in the U.S., Canada, and Germany, Conrad and Morrison (1989) tested this assertion by assessing the impact of investments in pollution abatement technology on growth in productivity between 1960 and 1980. By separating "unproductive" capital from production capital costs, they found that environmental regulation and investments in pollution abatement technologies did have a "depressing effect" on growth.[7] This finding, however, does not consider other potential positive effects associated with compliance with environmental regulations[15] or improvements in technologies that also enhance production efficiencies. Repetto et *al.* (1997) found that when they calculated such revised "multifactor productivity" levels for the pulp and paper industry between 1970 and 1990, the resultant growth levels were more than twice that attained through traditional productivity analysis methods.[16]

Concerns about investment in "unproductive" pollution abatement capital are really concerns about the investments foregone. Capital expenditures on pollution abatement result in a loss of productive capital, also referred to as the "abatement capital constraint."[17] It is uncertain whether the pulp and paper industry, if free from this constraint, would have invested the capital in facility expansions or efficiency improvements.[5,18] For the pulp and paper industry as a whole, the opportunity cost of environmental compliance may have had a positive, yet perverse, effect by limiting the industry's ability to build additional capacity. "Every penny spent on complying with green rules probably means a penny less spent on building n [more] mills" [thus adding to the overcapacity issue].[6] But at the mill level, the cost of environmental compliance would be more immediate and perceived as beneficial only if the capital investments for environmental compliance reduced production costs or raised the value of salable outputs (a so-called "win-win" scenario).[16]

This win-win scenario is also called the "Porter Hypothesis." Porter and Van der Linde (1995; 2000) argue that, when "properly designed," environmental regulation can inspire innovation that allows "companies to use a range of inputs more productively---from raw materials to energy to labor---thus offsetting the costs of improving environmental impact and ending the stalemate."[14] Porter and Van der Linde shift the opportunity-cost discussion away from the costs associated with pollution abatement and towards the "opportunity costs of pollution---wasted resources, wasted effort, and diminished product value to the customer."[14] In the pulp and paper industry, for example, they cite the innovations in bleaching processes (e.g., improved cooking and washing processes, or replacement of chlorine with oxygen, ozone or peroxide) achieved in response to the regulation of dioxin from chlorine bleaching processes.[14] Boyd and McClelland (1999) conducted an extensive analysis of data from the pulp and paper industry to evaluate the Porter Hypothesis and found that "paper industry input use and pollution could be reduced anywhere from 2% to 8% without adverse effects [on productive output], but that the constraints from mandated environmental investments reduce productivity from 1% to 4%."[17]

Porter suggests that a strategy aimed at "enhanced resource productivity" will make companies more competitive. Two significant impediments to using environmental issues for competitive advantage are ignorance about direct and indirect environmental impacts, and the limitations of conventional accounting systems for tracking environmental costs.[14,19] Information technologies, however, are key enabling technologies that will improve the ability of companies to identify and quantify win-win capital investment and operational improvement opportunities through improved access to and analysis of production, environmental and accounting information.[20] Fortunately, the pulp and paper industry has invested significantly in process information systems[21] and in some cases, enterprise-wide data management and decision support systems.[22,23] We believe that the information infrastructure existing in many paper mills could support a shift in strategy from environmental compliance to enhanced resource productivity by supporting the identification of Porter's win-win scenarios through integrated production, environmental and economic assessments.[24-26] Ultimately, we believe that the ability to embed corporate and facility-level environmental priorities (expressed through principles, goals, indicators and performance metrics) into decision support systems will facilitate the communication and implementation of a corporate commitment to profitability and sustainability from the boardroom to the shop floor.

## APPROACHES TO INTEGRATING DATA AT THE MILL

Using case studies at two newsprint mills, our team examined two approaches to integrating production, environmental, and economic performance data, for the purpose of identifying Porter's win-win scenarios related to technology or operational changes at a mill. The first case (at Newsprint Mill One) is focused on options for expanding de-inking operations, and the second case (at Newsprint Mill Two) is focused on the effects of various scenarios for wet end control. The first case study employs a tool for efficiently integrating data from a mill mass balance, accounting systems, and a mill process model (Pacific Simulation's WinGEMS™) into an activity-based cost model of the mill. The second case study examines the use of simple

Microsoft® Excel-based spreadsheets for developing a steady-state, mass-balance model of the paper machine and calculating aggregate economic and environmental effects of various control scenarios. We anticipate completing both case studies in the 2003-2004 academic year.

Metrics for Sustainability in the Pulp and Paper Industry.

Environmental performance metrics inform mill management as to whether inputs to the mill are efficiently converted into salable output (products). In studying how a corporation implements a strategy for sustainability, we find it useful to situate the company's use of environmental metrics in the context of the environmental metrics generally used in the industry. We have compiled a comprehensive list of sustainability metrics for use by corporations in general, and for corporations in the pulp and paper sector specifically, from several widely recognized sources. The general sustainability metrics and indicators used in this study include those suggested by various non-government organizations such as the Coalition for Environmentally Responsible Economies (CERES), the International Organization for Standardization (ISO), the National Academy of Engineering (NAE), and the United Nations Environment Program (UNEP) as well as those in use by various multi-national corporations.[4,27-29]

The pulp and paper industry uses two primary categories of metrics: those associated with forestry management and those for pulp and paper production. Forestry management metrics are related to the harvesting of trees to supply the mills, including measures of forest ecosystem health and the impacts of transportation. The scope of our work is limited to the metrics related to the production, recycling and disposal of pulp and paper. These metrics measure the impacts of the paper making process from the time the raw materials arrive at the mill until the point these products are either recycled or sent to landfills as waste.

The NAE (1999) classifies environmental metrics used in the production of pulp and paper into two categories: (1) resource-related and (2) environmental-burden related. In our studies, we classify the metrics further using a system laid out by the ISO 14031 standard. According to this system, metrics can be grouped into three areas: operational, management, and environmental condition:

| | |
|---|---|
| Operational Metrics | "generally measure potential environmental burden in terms of inputs and outputs of materials and energy." |
| Management Metrics | "metrics designed to inform management and support decision making on the expenditure of time, money, and manpower required to maintain or improve a company's environmental performance." |
| Environmental Condition Metrics | "seek to provide information on the health of the environment and how it is changing."[4] |

For the case studies reported in this paper, we use only the operational metrics since these are the most appropriate for informing mill managers on resource productivity in the pulp and paper manufacturing processes. Management metrics are important, but they mostly measure the *efforts* of the corporate or facility organization as opposed to the environmental/operational performance of the technological system. Environmental condition metrics are also important for understanding the relationship between operational and managerial performance and their impact on the environment. Unfortunately, "the fewest number of robust metrics have been developed and implemented" to assess environmental condition.[4] This is true not only for the pulp and paper sector, but also for other industrial sectors in general. We also reviewed the environment, health and safety reports of four major companies in the pulp and paper sector. For operational metrics in pulp and paper manufacturing, we found the NAE framework to be the most comprehensive of the indicator/metric frameworks mentioned earlier. The NAE indicator/metric set is used in this study to compare and benchmark the environmental priorities of the case study corporations and facilities with the broader industry practice. It is not intended to evaluate or assess the appropriateness, suitability, or success of the environmental management approaches or indicators used by the companies.

Models to support decision making.

We embedded the appropriate environmental performance metrics used by each company into the models developed for the case studies. The models were developed using existing information technology and decision support systems in the mills. The Activity-Based Costing and Environmental Management (ABCEM) model developed for the first case study and the mass balance model built for the second case study have been implemented in MS Excel because of its flexibility and widespread availability in organizations.[30] Our experience has been that most manufacturing facilities, including pulp and paper mills, have and use regularly MS Excel software for a variety of purposes. In addition, data from other systems in the mill can usually be transferred to and from MS Excel with ease. Such systems include real-time process information systems (such as OSIsoft™ PI System™), plant-wide simulation models (in WinGEMS™), and existing accounting systems that use MS Excel. The benefits of this approach will be explored in the first case study.

Evaluation criteria.

In both case studies, we use integrated models to explore scenarios for technological or operational changes at the mill. We compare the performance (costs and benefits, economic and environmental) of the manufacturing process as currently configured and operated to the performance of several alternative production configurations. Such simulations, when validated with actual process data, can provide valuable information for capital investment or operational decisions. Decision making can be improved by decision support systems which allow for quick and reliable analyses of several alternatives. The evaluation criteria for the decision support systems developed and evaluated in our studies reflect our interest in enabling companies to operate more profitably and in more environmentally sound ways. Such decision support systems should:

1. Allow for (and support) the communication of commitments to sustainability from the corporate level down to the appropriate business units.
2. Align production and accounting data. Ideally, environmental impact data would also be included.

3. Provide insight not readily gained from independent production, accounting, and environmental analyses. In other words, it reveals the dynamic relationships among cost, productivity and environmental impact.
4. Reduces the time required for the analysis of alternatives.

For the two case studies presented in this paper, we will examine the extent to which the decision support approaches (or models) meet the first three evaluation criteria listed above. Future work may include examination of the models and their impact on the efficiency with which alternatives may be analyzed.

## CASE STUDY 1: DIP EXPANSION AT NEWSPRINT MILL ONE

In Newsprint Mill One, we developed a model (or, decision support system) that integrates mass balance data, output from a WinGEMS™ model of the mill, and data from the mill's accounting system into an ABCEM format. We used the model to explore scenarios regarding expanding the de-inking plant (DIP) capacity from the current level of 175 bone dry metric tons (BDMT) per day to 350, 500, or 1100 BDMT per day. Newsprint Mill One employs 625 people and produces approximately 1100 metric tons of newsprint per day. The expansion of the DIP capacity is intended as a ton-for-ton replacement for virgin fiber input (TMP), and therefore is a move toward enhanced natural resource productivity rather than a net expansion of capacity. In Newsprint Mill One, there are four main production activities in the plant (de-inking plant, thermal-mechanical pulping, paper forming, and finishing) and four main support activities (boiler house, water network, effluent treatment, and power production). The de-inking plant is where the recycled newsprint and magazines are pulped and the ink is removed.

Our goal is to demonstrate how ABCEM can be used to support a decision for expanding DIP capacity so as to enhance resource productivity—making the project as attractive as possible from both monetary and environmental perspectives. The practical goal is to determine the best way to expand the DIP capacity, in both financial and environmental terms (i.e., identify win-win scenarios). The performance of the de-inking plant as it exists today will be compared to a model of one or more new de-inking plant configurations being designed through joint efforts of researchers at other organizations. The comparison will be along financial and environmental dimensions with environmental performance measured by a set of environmental metrics. As such, the ABCEM decision support system will meet our *first evaluation criterion* (supports the communication of commitments to sustainability from the corporate level down to the appropriate business units) in the following way. The ABCEM and WinGEMS™ models are set up to calculate the environmental metrics of interest, such as water use, energy use (biomass, fossil fuel, purchased electricity), and greenhouse gas emissions. Figure 1 shows a schematic of the decision support system. Note that the "costs" of the product can be in financial or environmental terms. The metrics used in the analysis of the various scenarios enable management to identify the impacts of the project on the environmental priorities they report to corporate and external stakeholders.

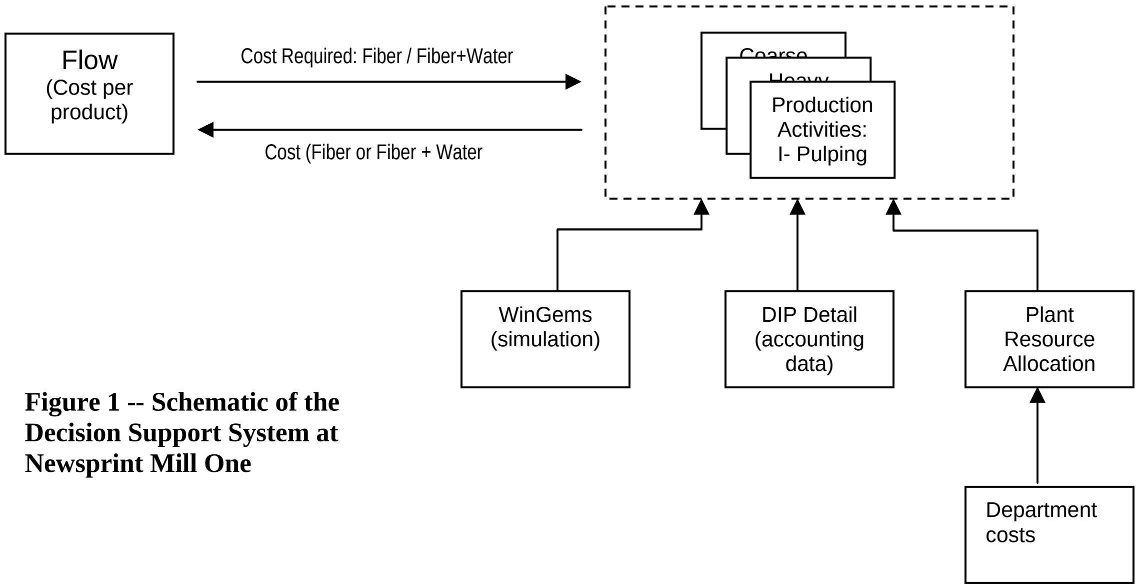


**Figure 1 -- Schematic of the Decision Support System at Newsprint Mill One**

Corporation One owns Newsprint Mill One. Corporation One's strategy for cascading its corporate commitment to sustainability is the use of Environmental Management Programs (EMPs). Corporation One has two EMPs: one focusing on manufacturing facilities and one focusing on forest operations. This paper focuses on the environmental management plan used in manufacturing operations. The manufacturing EMP is a plan to minimize the environmental impact of manufacturing activities by 2008. The program establishes objectives and targets in six key areas: air, water, noise, energy consumption, greenhouse gas emissions, and fiber utilization/waste management, and performance in these areas is tracked by a set of metrics. As previously mentioned, the NAE metric framework is used as our benchmark for operational metrics in pulp and paper manufacturing. Table 1 shows a comparison of performance metrics from three sources: the National Academy of Engineering's set of operational metrics for pulp and paper manufacturing (NAE, 1999), Corporation One's *corporate* environmental performance metrics, and those being used by the Newsprint Mill One *facility*. Note that these metric sets include measures of resource efficiency (such as energy consumption, fiber utilization, and water use).

**Table 1 – Environmental Performance Metric Framework Comparison[31,32]**

| NAE on Performance Metrics for Industry (1999) | Corporation One | Newsprint Mill One |
|---|---|---|
| Environmental Incidents (Violation notices, citizen complaints) | % Compliance | % Compliance |
| Permit Excesses | % Compliance | % Compliance |
| Energy – renewable | **none specified** | Eliminate use of Fossil Fuels |
| Energy – nonrenewable | Energy Consumption | Energy Consumption and Costs |
| Wood Waste | Fiber utilization | Fiber utilization |
| Solid Waste – nonhazardous | Reduce, Reuse, Recycle waste (incl. hazardous); Eliminate waste disposal sites, secure existing ones | Reduce, Reuse, Recycle waste (incl. hazardous); Eliminate waste disposal sites, secure existing ones |
| Solid Waste – hazardous | | |
| Air (particulate, VOC, NOx, SOx, etc.) | Air emissions | **none specified** |
| Percent Yield | Fiber utilization | Fiber utilization |
| Water Use | **none specified** | Reduce water consumption |
| Water (AOX, COD, BOD, TSS, color, etc.) | Effluent Concentrations | Reduce Discharges (BOD, COD, TN, TP, TSS) |
| | | |
| Metrics not in NAE (1999) | Noise Levels | Noise Levels |
| | Greenhouse gas emisisons | Greenhouse gas emisisons |

Newsprint Mill One (at the *corporate* and *facility* level) employs a set of operational environmental performance metrics in their manufacturing operations that is consistent with the NAE metric set for the pulp and paper sector. It employs most of NAE's eleven metrics and also tracks two additional metrics. As can be seen in Table 1, at the *corporate level*, Newsprint Company One has two apparent gaps in environmental performance metrics: renewable energy and water use. Interestingly, at the *facility level*, Newsprint Mill One addresses these gaps through its goals to eliminate the use of fossil fuels and to reduce water consumption per ton of newsprint; however, the mill does not appear to have any specific tracking of air emissions (though the mill is subject to air emissions regulations). In addition, at the corporate level and the facility level, Newsprint Company One tracks two metrics not covered in the NAE metric framework: noise levels and greenhouse gas emissions. As part of their management strategy, Newsprint Mill One has committed to review all new projects with respect to their environmental metrics. Expanding the DIP capacity is one such project, and the integrated environmental and economic analysis performed by the research team enables such an evaluation because the model includes the mill's chosen environmental metrics.

The integrated analysis performed by the research team will enable the evaluation of scenarios for the de-inking plant (and is extendable to any other operational area of the mill). Expansion of the de-inking plant affects several of Newsprint Mill One's environmental metrics as listed in Table 1: energy (renewable and non-renewable), greenhouse gas emissions, water consumption, and solid waste (hazardous and non-hazardous). These metrics can be daily or yearly totals or can be normalized per ton of pulp. The ABCEM model allows for comparison of the base case scenario to the expanded DIP capacity scenarios, thereby allowing the plant managers to review the impact that an expansion of the De-inking Plant would have on the plant-wide environmental targets. Of particular value is the concurrent environmental and economic analysis of the DIP capacity expansion, enabling identification of win-win scenarios where possible and trade-off analyses where these objectives are in conflict. The system meets our *second evaluation criterion* (aligning production and accounting data) through the direct importation of accounting data into the ABCEM model which acts as a post-processor to the production data as simulated in WinGEMS™.

To date, all of the main production and support activities have been modeled and linked together in one WinGEMS™ file. The ABCEM spreadsheet model has been fully created and connected to existing mill accounting data. In addition, the ABCEM model has been designed with the ability to connect to the WinGEMS™ model, although at this time data is transferred manually from WinGEMS™ to ABCEM. The DIP, originally modeled as one activity, has been broken down into nine sub-activities plus two supporting activities: gray water recycling and effluent treatment (not the same supporting activities as those in the whole mill model). The WinGEMS™ model has been successfully created for all DIP sub-activities and supporting activities, and the ABCEM model has been created for the nine main sub-activities and the supporting activities. The ABCEM has also been verified against accounting data and mass and energy balance data. Next, the new DIP configurations (with new capacity of 350-1100 BDMT/day) will be modeled in WinGEMS™ and ABCEM. (The modeling effort should go much quicker for the redesign because the models have been created in a modular fashion, enabling relatively simple substitution of newer technologies for existing ones, or the elimination of existing technologies considered obsolete.) At that point, the new DIP configurations can be compared to the current configuration along both financial and environmental dimensions (using the aforementioned environmental metrics). It is this ability to simultaneously consider the production, economic, and environmental impacts of the proposed DIP configurations that fulfills our *third evaluation criterion* (providing insight not readily apparent from independent analyses).

## CASE STUDY 2: EXPLORING SCENARIOS FOR WET END CONTROL AT NEWSPRINT MILL TWO

Our second case study focused on exploring options for improving a mill's economic and environmental performance through *wet end control* of a paper machine. This case study was conducted at Newsprint Mill Two, which employs 390 people, produces approximately 1300 metric tons of newsprint per day, and is part of a global pulp and paper corporation (Corporation Two). The decision support system used in this case study consists of a steady-state mass balance model created in MS Excel. The decision analysis process is sequential: (1) the physical production data (mass flow results) for the two scenarios (before and after wet-end control) are derived using the mass-balance model, and (2) material cost data from accounting is then used to assess the production costs.

The wet end of the paper machine contains fiber in solution with a large amount of water. Other chemicals essential to the paper making process such as clay, retention aid, charge control agent, and dyes are added here as well. In the newsprint production process, the paper machine essentially separates water from fiber, transforming pulp slurry at the headbox into air dry paper at the end of the paper machine. Improper wet end control causes the build up of fines (mostly small fibers) in the system, which must be purged to maintain proper freeness (ability to drain water) in the headbox (final stage before the pulp slurry is fed to the wire). When the fines are purged, water and fiber, along with other components of the white water are lost, resulting in economic costs (for makeup water, fiber, etc.) and environmental burden (through increased natural resource needs). There are several other paper machine operating parameters, such as steam, bleach usage, and strength/optical quality, which can also be affected. The goal of the work at Newsprint Mill Two is to determine the environmental and economic benefits of wet end control on the paper machine.

Corporation Two's strategy for implementing its commitment to sustainability to the facility level is through the use of a corporate-wide Environmental Management System (EMS) based on the ISO14001 standards. The company will complete implementation of its EMS in all of its manufacturing operations by the end of 2003.[33] As part of its corporate-wide EMS, Corporation Two articulates corporate environmental values and policies and translates them into environmental goals and targets. As seen in Table 2, Newsprint Mill Two tracks some key environmental metrics such as energy, solid waste, and fresh water per ton of newsprint. Corporation Two employs most of the NAE metric framework for operational metrics for pulp and paper production, with the addition of two metrics, CO2 equivalent (for greenhouse gas effects) and soil contamination. Less information is available on the mill-level environmental objectives due in part to the present efforts to align the mill-level EMS with the corporate-level EMS.

**Table 2 -- Environmental Performance Metric Framework Comparison for Newsprint Mill Two[33,34]**

| NAE on Performance Metrics for Industry (1999) | Corporation Two | Newsprint Mill Two |
|---|---|---|
| Environmental Incidents (Violation notices, citizen complaints) | Closely Watched Number (CWN) - spills and incidents where reg. parameters exceeded | **none specified** |
| Permit Excesses | | **none specified** |
| Energy – renewable | **none specified** | **none specified** |
| Energy – nonrenewable | Energy per ton | Energy per ton |
| Wood Waste | **none specified** | Fiber utilization |
| Solid Waste – nonhazardous | Production and management of solid and hazardous wastes | Solid waste/ton |
| Solid Waste – hazardous | | Chemicals/ton |
| Air (particulate, VOC, NOx, SOx, etc.) | Air emissions | **none specified** |
| Percent Yield | **none specified** | **none specified** |
| Water Use | **none specified** | Freshwater usage |
| Water (AOX, COD, BOD, TSS, color, etc.) | Mill Effluent | **none specified** |
| | | |
| Metrics not in NAE (1999) | CO2 equivalent (CO2, NO2, CH4) | **none specified** |
| | Soil contamination | **none specified** |

The EMS guidelines of Newsprint Company Two require a facility-level management review (at least annually) of its own environmental performance. This review process includes the collection of appropriate information and covers audit results, incidents, and process changes.[34] Implementing wet end control would require changes that are subject to the management review of environmental performance. Our model can support the decision to implement (or not) wet end control because of its ability to capture and report several environmental performance metrics shown in Table 2. Currently, the model captures fresh water use, fiber utilization, and clay usage, and will soon include energy usage and chemical usage (retention chemicals and bleach). The model enables comparison between the two scenarios, before and after wet-end control, enabling plant management to understand the potential impact that the project would have on the facility's financial and environmental targets.

A steady-state mass-balance model of a paper machine was built in MS Excel. (The mass constituents were water, fiber, and fines.) The Solver feature was used when values could not be derived explicitly. The model was validated using process data on three products (27 lb., 30 lb., and 32 lb. paper). We have run two scenarios on the model – one without wet end control and one with wet end control. Various production, environmental, and economic performance metrics were then calculated as discussed below and seen in Table 3. The numbers used in this discussion and in Table 3 have been disguised to protect confidentiality, though the percentage changes have been preserved. It was determined that at the paper machine's current state (without retention control), 1422 gallons per minute (gpm) of fresh water were being used, and 2.04 metric tons per day (MTPD) of clay and 4.30 MTPD of fiber were being lost. The predicted headbox freeness was 25 Canadian Standard Freeness (CSF). If it is possible to control the tray consistency in such a manner that the fines % leaving with the finished newsprint is equal to the fines % incoming from thermo-mechanical pulp (TMP) and recycled newsprint (RNP) (a theoretically purge free system), then the fresh water usage drops to 1364 gpm, the clay and fiber losses drop to 0.81 MTPD and 1.71 MTPD, respectively, and the freeness is raised to 31 CSF. Fiber savings are also realized because the RNP and TMP flows were reduced. (RNP decreased from 1029 gpm to 970 gpm, and TMP decreased from 1215 gpm to 1175 gpm.) The reduction in fiber loss and clay loss results in a significant savings per year.

**Table 3 – Comparison of Wet-end Before and After Simulated Control (numbers disguised)**

| | Before Wet End Control | After Wet End Control | Results of Wet End Control |
|---|---|---|---|
| Fresh water flow | 1422 gpm | 1364 gpm | -4.0% |
| Clay usage | 2.04 MTPD | 0.81 MTPD | -60.2% |
| Fiber loss | 4.30 MTPD | 1.71 MTPD | -60.2% |
| Headbox freeness | 25 CSF | 31 CSF | +21.4% |
| RNP flow | 1029 gpm | 970 gpm | -5.7% |
| TMP flow | 1215 gpm | 1175 gpm | -3.3% |

The fresh water usage did not drop significantly according to this model. This is because the fresh water, as defined by this model, is mainly supplying RNP's water needs rather than the paper mill's needs. However, the sewer stream did drop by a little over 145 gpm. This drop in water loss might contribute to less makeup used water elsewhere, perhaps in TMP. The solids losses were reduced by 60%, and the freeness was raised by 21%.

As can be seen, the MS Excel model supports the communication of corporate sustainability commitments down to the appropriate business level (the mill) by enabling the evaluation of the project through several environmental metrics, such as fresh water usage, fiber loss, and clay usage. In so doing, it meets our *first evaluation criterion*. The financial impacts of wet end control were calculated using traditional accounting methods (with historical, aggregate financial data) instead of detailed activity-based costing methods. This provided some quick estimates on potential economic savings related to wet end control, but does not really fulfill our *second evaluation criterion* of aligning production and accounting data. Also, though the connections to financial data are not automated, analyzing the impacts of wet end control using this simple MS Excel -based model does provide some insight into the production and environmental impacts that may not otherwise be gained and so partly meets our *third evaluation criterion*.

As of the writing of this paper, the only mass constituents included in the model were water, fiber, and fines. However, chemical savings could be determined by including the retention chemicals and their effect on retention. Also, a correlation between % fines and sheet strength, between TMP strength and sheet strength, and between TMP energy and TMP strength could quantify the energy savings. Additionally, correlations between sheet ash, brightness, and bleach usage could quantify bleach savings. These model enhancements are planned during the 2003-4 academic year.

## DISCUSSION

Through the two case studies presented here, we have seen two different approaches for evaluating the economic, environmental and production impacts of simulated changes to pulp and paper production processes. The first case involved leveraging three existing though disparate mill data sets (from WinGEMS™, an accounting system, and mass balance information) into a decision support system implemented as an ABCEM model in MS Excel. This system is capable of detailed production simulation and subsequent financial and environmental analysis. Through the use of scenarios, future production process configurations (of the de-inking plant in this case) can be compared to one another and to the current production configuration to determine the best alternative in terms of financial and environmental performance as it relates to facility and corporate objectives and targets for chosen performance metrics. A major advantage of this system is that it provides insight not readily gained from the independent analysis of production, economic, and environmental conditions. It is especially useful in helping facility level managers relate the impacts of a potential project to corporate commitments to environmental improvement and sustainability. This is important for companies interested in adopting an enhanced resource productivity strategy for economic and environmental performance.

This detailed system does however take considerable time and expertise to implement, and a pulp and paper mill may have constraints on its capacity to create detailed simulation models (as in WinGEMS™) and to link various sources of data together into a decision support system as seen in the first case study. If so, insight can still be gained through the simpler, engineering-based model of production processes as seen in the second case study, as it enables simulation of different scenarios through the manipulation of parameters. Even though the system is less robust than that used in the first case study, this is a good starting point for integrated economic and environmental analysis of proposed projects.

## CONCLUSIONS AND FUTURE WORK

The two case studies will be completed in the coming academic year. For Newsprint Mill One (capacity expansion of the de-inking plant), three potential de-inking plant configurations are currently being developed. When finished, one configuration will be chosen for analysis and a decision made based on the financial, production, and environmental impact. For the case study of Newsprint Mill Two (wet end control), energy, retention chemical and bleach savings can be introduced into the model once some correlations between key parameters have been established. Again, a financial and environmental impact analysis will be performed to determine how to proceed with the project.

ABCEM is useful for allocating portions of plant-wide costs and environmental burden to various activities, such as in our case study of the de-inking plant, but is not necessarily required for this type of analysis as we saw in the second case study. What is indispensable are the performance metrics that inform mill management of their progress towards an enhanced resource productivity strategy. It is one thing to calculate some environmental burdens based on the process and simulation data available and quite another to relate this information to meaningful plant- and corporate-level environmental targets. To do this, the data must be re-aggregated at the project and plant level. This can be challenging because of the different functional units tracked in various parts of the mill, such as a metric ton of newsprint versus a bone dry metric ton of de-inked pulp. The ability to convert between these functional units is critical in completing the performance feedback loop, and addressing this need up front will strengthen future analyses.

The pulp and paper industry is familiar with detailed simulation and analysis tools at the level of the plant processes. What is missing is a way to weave into this analysis the corporate and plant-level environmental objectives and targets to help identify win-win scenarios. To different degrees, both systems presented here enable the integrated analysis of environmental and economic performance of projects at various levels, from unit process changes to capital investment decisions (and potentially the introduction of new products).

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## REFERENCES

1. Cody, H. M. Understanding the paper market. *American Printer*, 8 (2001).

2. Anonymous. Business: Commodities get big. *The Economist* **352**, 47-48 (1999).

3. Environmental Defense Fund. *Paper Task Force Recommendations for Purchasing and Using Environmentally Preferable Paper* (Environmental Defense Fund, New York, 1995).

4. National Academy of Engineering. *Industrial Environmental Performance Metrics* (National Academy Press, Washington, DC, 1999).

5. Butner, R. E. & Stapley, C. E. Capital effectiveness of the paper industry. *TAPPI Journal* **80**, 155-165 (1997).

6. Anonymous. Paper and pulp: Unfolding? *The Economist* **334**, 59-60 (1995).

7. Conrad, K. & Morrison, C. J. The Impact of Pollution Abatement Investment on Productivity Change: An Empirical Comparison of the U.S., Germany, and Canada. *Southern Economic Journal* **55**, 684-698 (1989).

8. Huston, M. A. & Marland, G. Carbon management and biodiversity. *Journal of Environmental Management* **67**, 77 (2003).

9. American Forest & Paper Association. *Sustainable Forestry Initiative Program: 8th Annual Progress Report* (American Forest and Paper Association, Washington, D.C., 2003).

10. Environmental Protection Agency. *EPA Office of Compliance Sector Notebook Project: Profile of the Pulp and Paper Industry* (U.S. Environmental Protection Agency, Washington, D.C., 1995).

11. Energy Information Association. *Forest Products Industry Analysis Brief* (Energy Information Association, 2000).

12. Department of Energy Office of Industrial Technologies. *Forest Products Industry Profile* (Office of Industrial Technologies, 2002).

13. Gleason, G., Kinsella, S. & Mill, V. Recycled Paper: Plenty Available---Not Let's all Use It! *Resource Recycling*, 1-3 (2002).

14. Porter, M. E. & Linde, C. V. D. in *Harvard Business Review on Business and Environment* 131-167 (Harvard Business School Press, Boston, MA, 2000).

15. Irland, L. C., Adams, D., Alig, R., Betz, C. J. & al, e. Assessing socioeconomic impacts of climate change on US forests, wood-product markets, and forest recreation. *Bioscience* **51**, 753 (2001).

16. Repetto, R., Rothman, D., Faeth, P. & Austin, D. Has environmental protection really reduced productivity growth? *Challenge* **40**, 46-57 (1997).

17. Boyd, G. A. & McClelland, J. D. The impact of environmental constraints on productivity improvement in integrated paper plants. *Journal of Environmental Economics and Management* **38**, 121 (1999).

18. Phillips, R. B. Impact of capital-spending on paper-industry profitability. *TAPPI Journal* **80**, 145-152 (1997).

19. Ilinitch, A. Y., Soderstrom, N. S. & Thomas, T. E. Measuring corporate environmental performance. *Journal of Accounting and Public Policy* **17**, 383 (1998).

20. Allenby, B. R. in *Information Systems and the Environment* (eds. Richards, D. J., Allenby, B. R. & Compton, W. D.) 15-44 (National Academy Press, Washington, D.C., 2001).

21. Fadum, O.-K. The process information renaissance. *TAPPI Journal* **79**, 69-74 (1996).

22. Shaw, M. Linking control and information networks offers unique process insight for Gulf States. *Pulp & Paper* **73**, 39 (1999).

23. Yeager, R. L. Millwide information: the pulp & paper 'killer app'. *PIMA's Papermaker* **80**, 34 (1998).

24. Epstein, M. J. *Measuring Corporate Environmental Performance: Best Practices for Costing and Managing and Effective Environmental Strategy* (Irwin Professional Publishing, Chicago, 1996).

25. Epstein, M. J. Improving environmental management with full environmental cost accounting. *Environmental Quality Management* **6**, 11 (1996).

26. Epstein, M. J. You've got a great environmental strategy--now what? *Business Horizons* **39**, 53 (1996).

27. United Nations Environment Programme (UNEP). *Agenda 21* (2002), URL: http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm

28. International Organization for Standardization (ISO). *International Standard ISO 14031, Environmental management - Environmental performance evaluation - guidelines* (1999).

29. Coalition for Environmentally Responsible Economies (CERES). *The CERES Principles* (2002), URL: http://www.ceres.org/our_work/principles.htm.

30. Emblemsvag, J. & Bras, B. *Activity Based Cost and Environmental Management: a Different Approach to ISO 14000 Compliance* (Kluwer Academic Publishers, Norwell, Massachussetts, 2000).

31. Environmental Manager. *Newsprint Mill One - EMS* (2003).

32. *Corporation One 2002 Annual Environmental Report* (2002).

33. *Sustainability Report (Corporation Two)* (2002).

34. *Report on value and environmental excellence (Corporation Two)* (2001).