DEVELOPMENT OF AN OPERATIONS-DRIVEN COST MODEL FOR CONTINUOUS PROCESSES PART II: Retrofit process design application

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ABSTRACT

Pulp and paper companies need new methodologies to evaluate capital spending opportunities using improved cost models and available cost and process data. This paper presents an application of the operations-driven cost model presented in Part I (Laflamme-Mayer, M., Janssen, M., Stuart, P., Journal of Science & Technology for Forest Products and Processes, 1:1 (2011)) to a retrofit design case study defined at an existing integrated newsprint mill. The paper outlines the structure of the cost model and discusses its application to the analysis of a set of design alternatives. The operations-driven cost modelling approach significantly increases the granularity and transparency of the results obtained from a techno-economic study and permits the examination of critical design variables and operating variants.

INTRODUCTION

This paper is the second in a series that outlines the theoretical foundations and application of a new operations-driven cost modelling approach [1,2]. More specifically, it seeks to demonstrate the application of the operations-driven cost modelling approach to a retrofit design problem using the data and structure of an ABC-like cost accounting system. The objectives of this study were:

- To demonstrate the value of the operations-driven cost modelling approach in the evaluation of design alternatives for design decision making.
- To use the cost model to obtain insight into design alternatives by considering operating variants (established by, e.g., changing the production capacity of a design alternative or varying the steam production or demand of the mill) based on energy efficiency studies and analysis of production capacity change.
- To identify the benefits of using this approach compared to a rigorous but "classical" techno-economic analysis.

The case study considers the implementation of increased DIP pulp production and cogeneration at an existing integrated newsprint mill [3].

Retrofit Process Design and Cost modelling in the Pulp and Paper Industry

One of the opportunities stemming from the effective use of data from Information Management Systems (IMS) at pulp and paper mills lies within the field of retrofit process design. By using more detailed better-structured models, analytical tools, and methodologies with the data gathered by an IMS, better decisions can be design alternative for investment [4]. Manufacturing costs for retrofit design alternatives can be compared to current manufacturing costs using mill process and cost data in financial spreadsheet models, and the resulting NPVs for the alternatives can be calculated. Furthermore, more advanced analysis such as Monte Carlo risk analysis can be carried out to assess risks associated with key project variables and parameters [3,5].

Classical techno-economic studies in the pulp and paper industry typically use volume-based cost accounting data as

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the basis for modelling costs. These studies yield good information for decision-making for many design objectives, but can, however, lack the granularity (detail) and transparency (understanding of cause and effect) that would permit a more careful evaluation of design alternatives when required. Volume-based cost accounting was developed primarily for discrete manufacturing processes. The resource consumptions and activities needed to manufacture a product with such a process are known from routing information and bills of materials and can therefore be traced directly to the product, as is done in volume-based cost accounting. Continuous processes, such as pulp and paper processes, can be divided into main-line processing operations and converting and finishing operations. In main-line processing operations, costs are generated by the production process and its operating conditions. For instance, activities such as maintenance (which is a typical overhead cost) are linked to the production process, and the operating conditions determine the resource consumptions. This implies that cost-driver relationships for processing operations should be based on process-related aspects. To increase understanding of the cost implications of a particular retrofit design alternative to a continuous process, it is therefore of interest to use a cost accounting method that can capture these process-related aspects. Activity-based costing (ABC) is such a method and will increase both the transparency and the granularity of a cost model compared to a volume-based cost model.

Using ABC principles, cost accounting data can be systematically used for such applications as tracking production costs and cost variances to reduce production and quality variability [6] and the evaluation of retrofit design alternatives by systematically reconciling process and cost data. When a mill has an ABC-like system in place, opportunities for more advanced and sophisticated analysis can be exploited, such as decision-making for capital spending through sensitivity analysis, incremental and marginal cost analysis, or risk analysis. A cost model based on ABC can thus extract more relevant information for operational or design decision-making from the cost and process data that are available at a mill. The first paper in this series included a more in-depth discussion of ABC [1].

Integrated newsprint mill energy considerations and costs

Although a number of techniques are available for reducing TMP (thermo-mechanical pulping) energy consumption, they generally yield only marginal reductions compared to the implementation of de-inked pulp (DIP) production to replace TMP (assuming a constant production rate). However, by decreasing TMP production, the production of steam from the TMP plant (used principally for paper drying operations) is reduced. The mill must compensate for this loss of steam by increasing steam production in the boilers. Consequently, this increase can give rise to further capital spending requirements, leading to consideration of cogeneration at the mill. Cogeneration is the combined production of electrical (or mechanical) and thermal energy from the same primary energy source [7]. Energy efficiency studies can be carried out to optimize the profitability of a design alternative by, for example, reducing process steam demand. Pinch analysis can be used for thermal optimization and for definition and organization of energy efficiency projects by reducing both energy and water use at a mill [8,9,10]. Furthermore, marginal energy cost analysis helps to identify the operating conditions at which maximum profitability can be achieved.

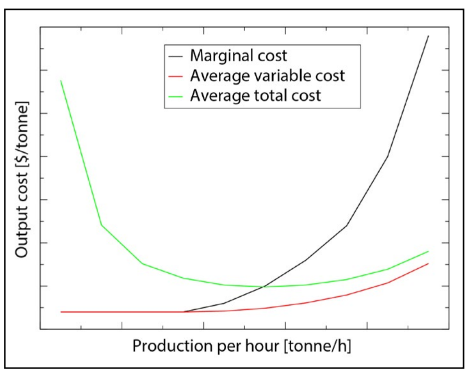


Fig. 1 - Illustration of marginal cost analysis. All costs are expressed on the same scale. The marginal cost curve shows that there is a drastic increase in the cost of producing one more tonne at higher production capacities. This is due to an increase in the variable cost per tonne produced. This is not as visible when considering the average total cost curve.

In marginal economics, both incremental manufacturing costs and revenues are seen as variable. This results in a more realistic view of how costs per unit produced change and may lead to the observation that unit manufacturing costs decrease at first, but then at some level start to rise as production increases (Fig. 1). There is therefore an optimum for capacity utilization [11]. Marginal cost analysis identifies operating scenarios that maximize the cash flow for a given investment and for different operating conditions. Furthermore, the use of production functions to characterize the (non-linear) resource behaviour of operations provides a more accurate view of manufacturing costs [12].

EXISTING MILL AND DESIGN ALTERNATIVES

Existing mill design

The existing mill on which this study is based consists of the following production units:

- 4 newsprint machines with a total average production of 1100 tonnes/day of newsprint;
- 2 TMP lines with a total average production of 925 tonnes/day of pulp;
- A DIP plant with a total average production of 175 tonnes/day of pulp, where 85% of the wastepaper used is old newspaper (ONP) and 15% is old magazine paper (OMG).

Furthermore, the following supporting processes are part of the base-case mill design:

- A wastewater treatment plant processing 50,000 m^3/day;
- A boiler plant producing 7850 GJ/day of steam;
- A back-pressure turbine generating only 0.4% of the total mill electricity demand.

De-inking and cogeneration design alternatives

The DIP plant process designs considered in the study would increase DIP production to either 550 tonnes/day (50%) or 1100 tonnes/day (100%) (Table 1). Both one-loop and two-loop DIP technologies were considered. A one-loop DIP system is a system that processes the recycled paper in one alkaline cleaning stage. A two-loop system has an additional second cleaning loop that operates under acidic conditions, making it a more rigorous cleaning process. The one-loop de-inked plant technology is the typical technology used in North America, and its capital cost is lower than that of a two-loop system with the same capacity. However, two-loop technology includes additional equipment that can compensate for the expected quality loss of recycled paper in the future [13]. The cogeneration designs studied here have the following characteristics (Table 2 and Fig. 2):

- Increase of biomass combustion capacity;
- Reactivation of idled turbines and implementation of new back-pressure turbines or condensing turbines.

In total, 18 alternatives were analyzed in this case study by considering all combinations of the 6 DIP and 3 cogeneration designs. The following naming convention for the design alternatives was used: Alternative {DIP design 1 to 6 as per Table 1}-{Cogeneration design A, B, or C as per Table 2}.

METHODOLOGY

After developing the operations-driven cost model for existing mill processes, the study methodology consisted of the following steps for each of the design alternatives (Fig. 3):

1. Calculation of mass and energy balances for each process flowsheet;
2. Calculation of total capital costs;
3. Modelling and calculation of operating costs for the design alternatives and operating variants;
4. Profitability calculations for the evaluation of the design alternatives and operating variants.

These four steps are discussed in more detail below. The model was developed using the Impact: EDC™ software package from 3C Software Inc. [14].

Capital cost estimates and mass and energy balances

The total capital cost and the mass and energy balance models were constructed as described in Janssen *et al.* [3], and the same hypothetical mill and design hypotheses

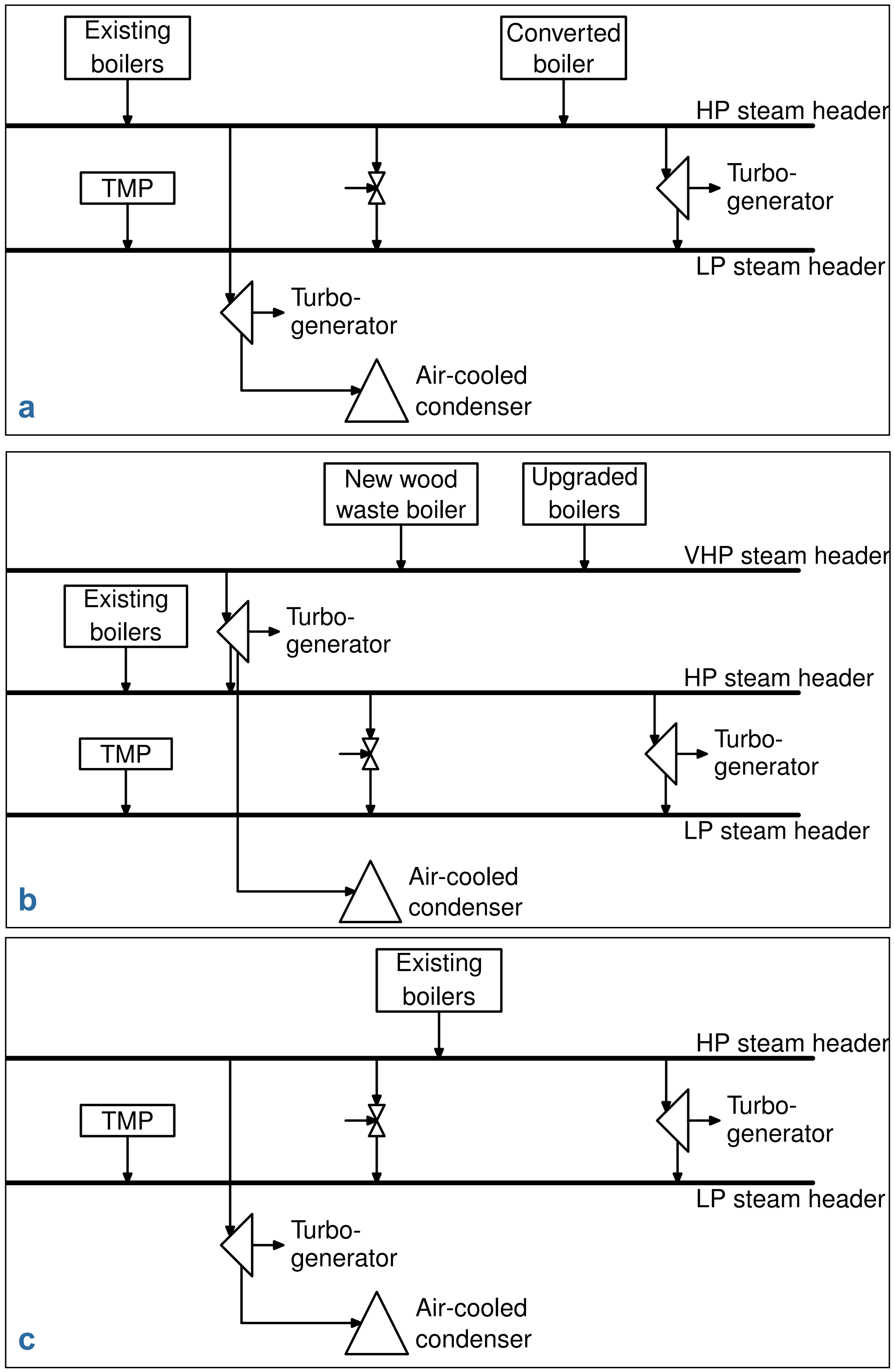


Fig. 2 - Cogeneration designs: a. design A, b. design B, and c. design C.

were assumed (steps 1 and 2 in Fig. 3). The mass and energy balance model was used to examine the impact of variations in steam generation in the boilers. Within this model, the amount of cogenerated power was also calculated. The results of these models for all 18 design alternatives were then connected to the operations-driven cost model.

Operations-driven cost model

Process design data generated by the mass and energy balances were used as inputs to the operations-driven cost model [1] (step 3 in Fig. 3). For calculation of variable costs, *Process Work Centres (PWCs)* were used to represent different mill processes. The PWCs were divided into production and support PWCs (Fig. 4). The overhead costs were calculated in the *Overheads Work Centre (OWC)*. The data used in this study (which were taken from the accounting system at an operating integrated newsprint

TABLE 1 *DIP plant designs*

Design	Technology and capacity
1	New 550 t/d DIP plant, 1-loop
2	New 550 t/d DIP plant, 2-loop
3	New 1100 t/d DIP plant, 1-loop
4	New 1100 t/d DIP plant, 2-loop
5	Increase to 550 t/d by adding a second line to the existing plant, 1-loop
6	Increase to 550 t/d by adding a second line to the existing plant, 2-loop

TABLE 2 *Cogeneration designs*

Design	Description	Steam production
Existing mill	All boilers operate at high pressure (HP) and only one turbine is in service	At HP: 90,000 tonnes/year
A	One natural gas boiler is converted to burn wood waste, and existing backpressure turbines kept in service.	At HP: 150,000 tonnes/year
B	New wood waste boiler (at very high pressure (VHP)) is installed. Three out of six boilers are upgraded to VHP operation. New backpressure turbine added.	At VHP: 130,000 tonnes/year At HP: 25,000 tonnes/year
C	New condensing turbine installed.	At HP: 100,000 tonnes/year

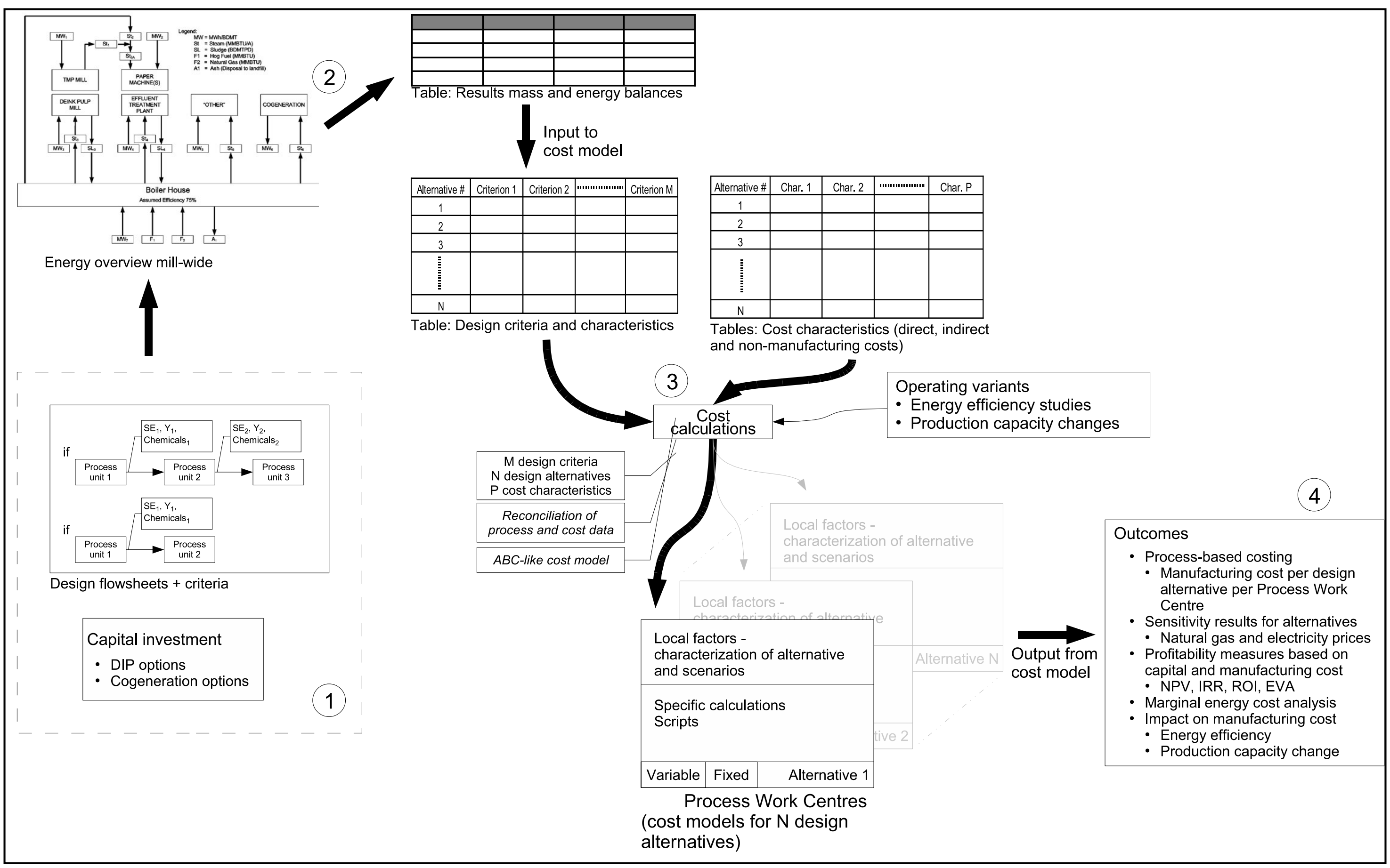


Fig. 3 - Operations-driven cost modelling approach.

mill) provided detailed information about the indirect manufacturing cost per *PWC* and could therefore be directly related to the *PWCs*. Specifically allocated non-manufacturing costs were distributed equally over the *PWCs* in a second-level allocation. Some overhead costs varied for different design alternatives and operating variants and were modeled in the *OWC*. For instance, due to changes in production volumes, the labour costs and headcount in the TMP and DIP *PWCs* were different. In the case study, the following *PWCs* had varying overhead costs: TMP, chip handling, DIP, turbines, and boilers.

Process design evaluation (step 4 in Fig. 3)

Evaluation of design alternatives: Various profitability metrics were calculated to evaluate the feasibility of the design alternatives, including net present value (NPV), internal rate of return (IRR), return on investment (ROI) and cumulated economic value added (EVA). The financial parameters were the same as used in Janssen *et al.* [3]. EVA is an estimate of the wealth creation potential from capital investments. It attempts to capture the true economic profitability of a company or project and accounts for the cost of capital [15]. Calculation of NPV is based only on cash flow, whereas EVA also takes into account the riskiness of an investment. Sensitivity analyses were carried out for electricity and natural gas prices.

Marginal energy cost analysis: In this analysis, the marginal steam cost (in $/GJ) and the incremental and marginal cost of power produced by cogeneration (in $/MWh) were calculated. This was done by first varying the steam production in the steam plant over a range of values. Each of these values represents an operating variant. Next, the total steam cost and turbine steam cost (i.e., the cost of steam used by turbines for cogeneration) were calculated using the steam price:

$$\text{Total steam cost}_i = \text{Steam produced}_i \cdot \text{Steam price}_i \qquad (1)$$

$$\text{Turbine steam cost}_i = \text{Turbine steam use}_i \cdot \text{Steam price}_i \qquad (2)$$

The steam price (The term "steam price" is used to indicate that the generated steam is sold internally by the Boilers *PWC* to the other *PWCs*. The cost of fuels used to generate the steam is thus routed to the *PWCs* where the steam is used.) was calculated based on the fuels used. Using difference equations, the marginal steam cost and marginal cost of generated power can be calculated as follows:

$$\text{Marginal steam cost} = \frac{\text{Total steam cost}_i - \text{Total steam cost}_{i\text{-}1}}{\text{Steam produced}_i - \text{Steam produced}_{i\text{-}1}} \qquad (3)$$

$$\text{Marginal cost of generated power} = \frac{\text{Turbine steam cost}_i - \text{Turbine steam cost}_{i\text{-}1}}{\text{Power generated}_i - \text{Power generated}_{i\text{-}1}} \qquad (4)$$

where *i* refers to an operating variant.

The incremental cost of generated power for each alternative was calculated relative to the existing mill:

$$\text{Incremental cost of generated power} = \frac{\text{Turbine steam cost}_{\text{alt.}} - \text{Turbine steam cost}_{\text{exist.}}}{\text{Power generated}_{\text{alt.}} - \text{Power generated}_{\text{exist.}}} \qquad (5)$$

where *alt.* refers to the retrofit design alternative under consideration.

Energy efficiency: The impact of increased energy efficiency in the process was considered in certain scenarios. This was done by reducing the steam use of the mill over a range of values up to $6.45 \cdot 10^5$ GJ/y, corresponding to a maximum reduction of 20% for the 100% DIP alternatives and of 25% for the 50% DIP

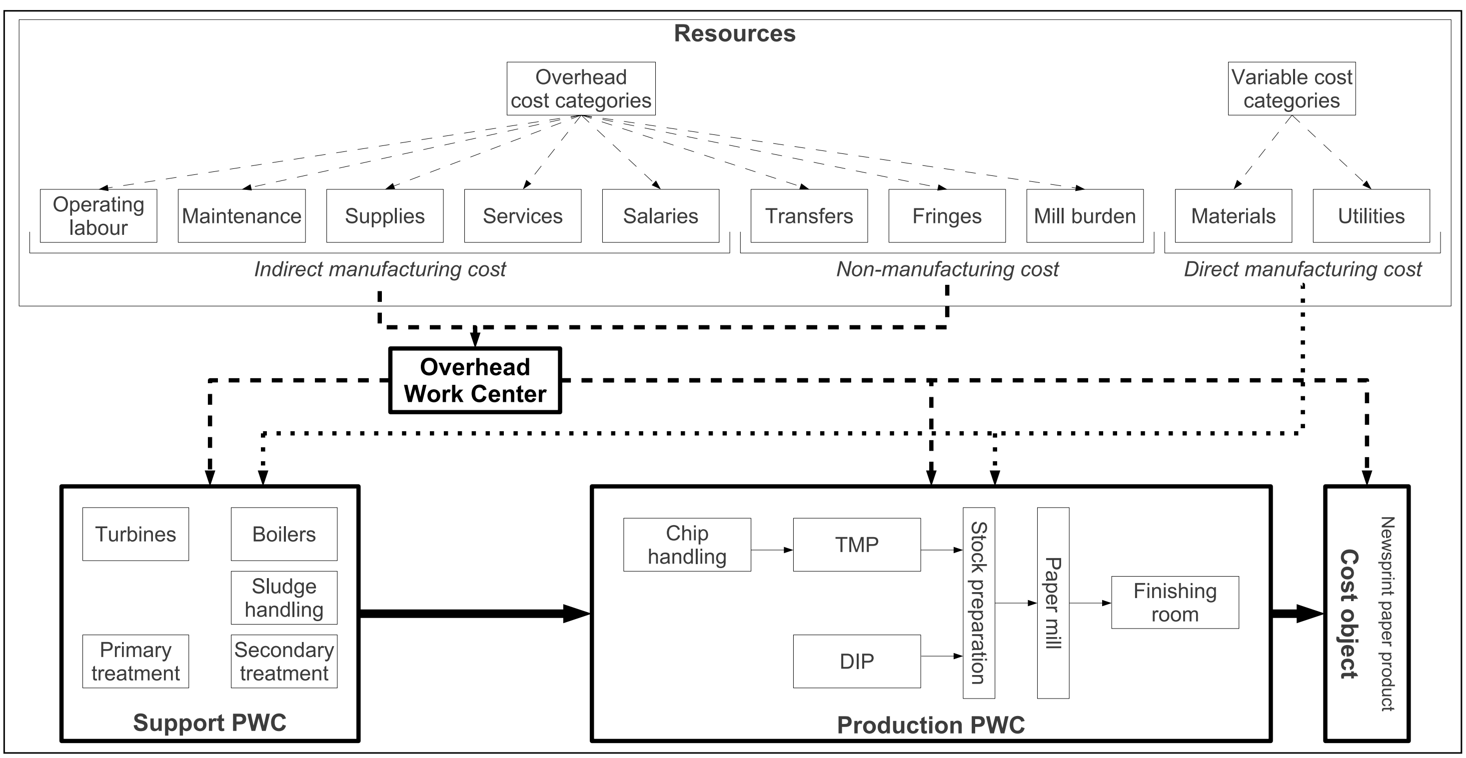


Fig. 4 - Cost categories and division of *PWCs* into production and support *PWCs*.

alternatives, followed by calculation of the marginal steam cost, cost of generated power, and profitability.

Production capacity change: Production functions were established to add non-linear resource behaviour resulting from a change in paper production. Functions for electricity and steam use on the paper machines were determined using the following assumptions (Fig.s 5 and 6):

- Base load steam: 30% of nominal use;
- Base load electricity: 70% of nominal use;
- Steam use for drying decreases by 1% per 10 tons of production increase.

The base load refers to the amount of steam or electricity used by the paper machine when no paper is produced. Causes of non-linearity in the paper machines include the steam condenser efficiency and the efficiencies of paper machine drives and pumps.

Production functions for the efficiency of the cogeneration designs were then determined (Fig. 7). Because no data were available for the boilers separately, these functions are composite functions describing all the boilers in a design. A quadratic relationship between steam production and efficiency was assumed [16], with maximum efficiency set to 75% for base-case steam production. This non-linear behaviour may be caused by moisture levels in the fuel and air, incomplete combustion, combustion of hydrogen (to water), and radiation [17]. Linear relationships were assumed with pulp production for electricity use in the TMP plant and with steam production for power generation in the turbines [17]. Furthermore, it was assumed that electricity use in the 100% DIP plants remains constant with changing de-inked pulp production because a constant volumetric rate is maintained.

RESULTS AND DISCUSSION

Manufacturing costs and profitability

The profitability of the design alternatives was calculated under the following

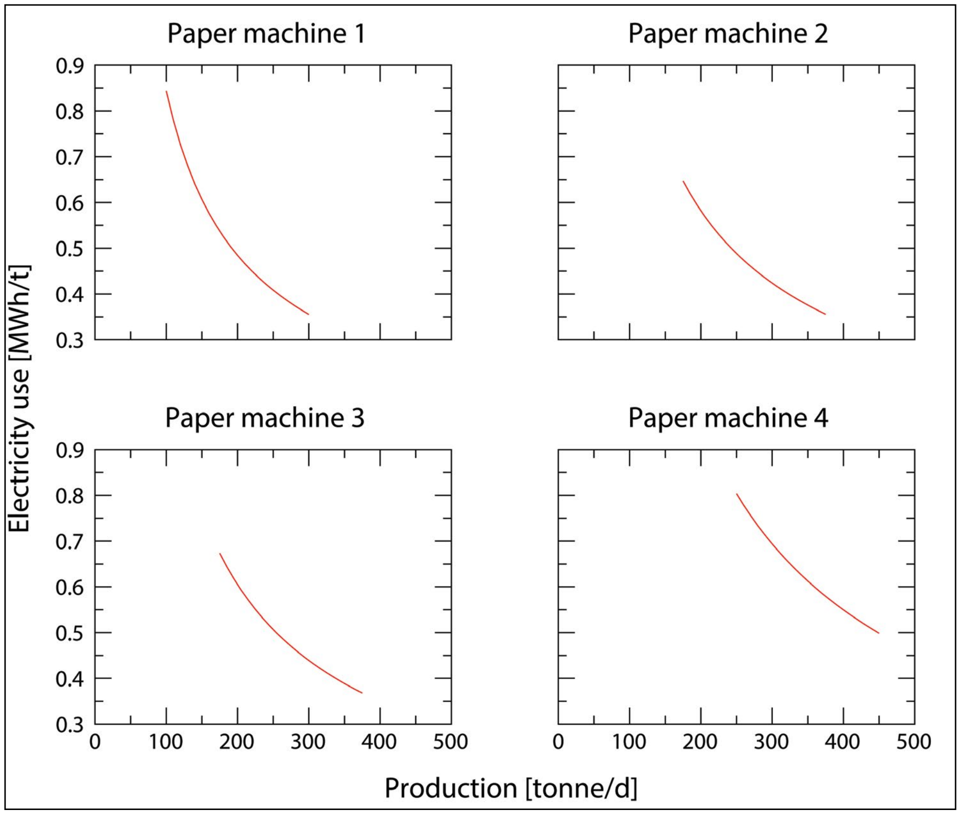


Fig. 5 - Production functions for electricity use in the paper machines.

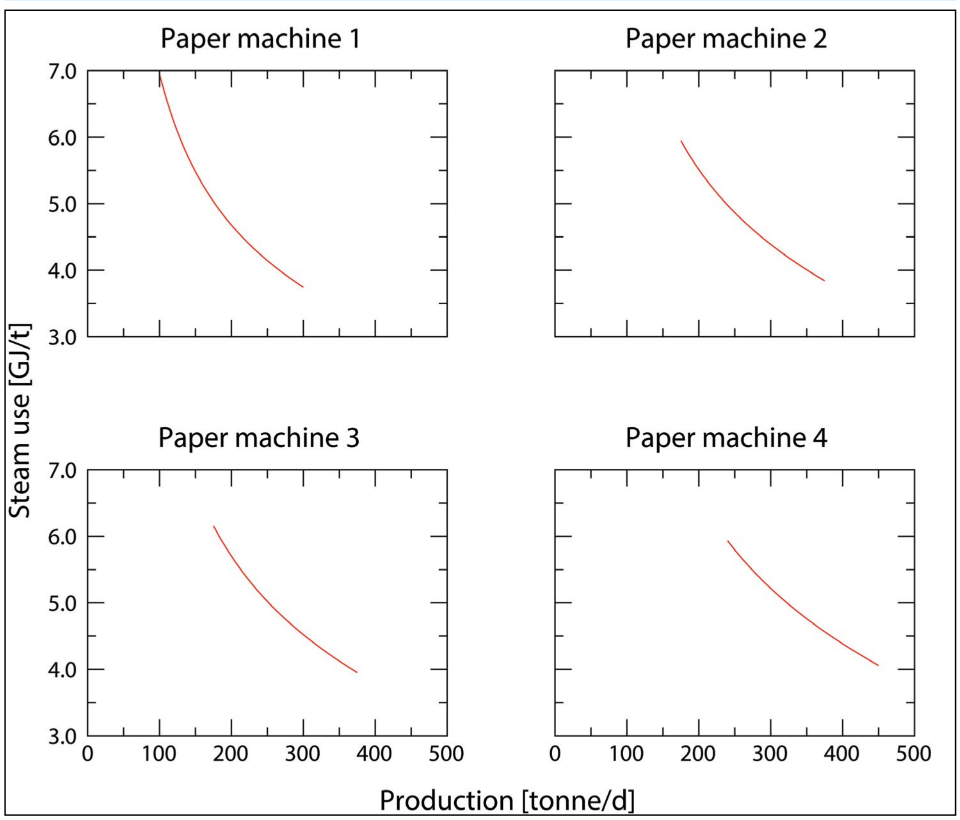


Fig. 6 - Production functions for steam use in the paper machines.

conditions:

- Declining balance method for depreciation with a fixed depreciation rate [18],
- Investment tax credit of $10/MWh of electricity generated based on renewable fuels [19],
- Sale of generated electricity to the grid at the nominal electricity price plus a 50% premium. This premium stimulates mills to sell their cogenerated power.

The manufacturing costs were split into direct and overhead costs and specified per *PWC* (Fig. 8). A negative value for a *PWC* cost indicates that this *PWC* is a profit centre. For instance, for alternative 1-A, the manufacturing cost is (310 – 37) + (217 – 18) = 472 $/tonne. The turbine work centre is an important profit centre because of sales of generated electricity to the grid. Therefore, the turbine *PWC* direct cost for each alternative is negative. The cost of fibre is the most significant cost for the TMP and DIP PWCs and depends on the implemented DIP capacity (50% or 100%) as well as the yield difference between the one-loop and two-loop designs (85% vs. 92%). Furthermore, there is a difference in steam consumption: the one-loop design uses 1.25 GJ/t and the two-loop design 2.25 GJ/t of waste paper used. This is caused by the use of extra steam in deflocculation for better pulp cleaning in the two-loop design. The deflocculation unit uses steam and electrical energy to break down dirt and stickies remaining in the pulp for easier removal in the second loop. The variation in direct cost for the paper mill *PWC* can be explained primarily by the variation in steam price because the paper mill is a large steam consumer. The steam price depends on the wood waste capacity of each cogeneration design and the amount of natural gas and sludge used for steam generation. One advantage of the operations-driven cost modelling approach is that a higher manufacturing cost for the paper mill *PWC* can be clearly traced back to higher steam prices resulting from an increase in the cost of natural gas. Using a volume-based cost model, this increase would only be reflected in the final product

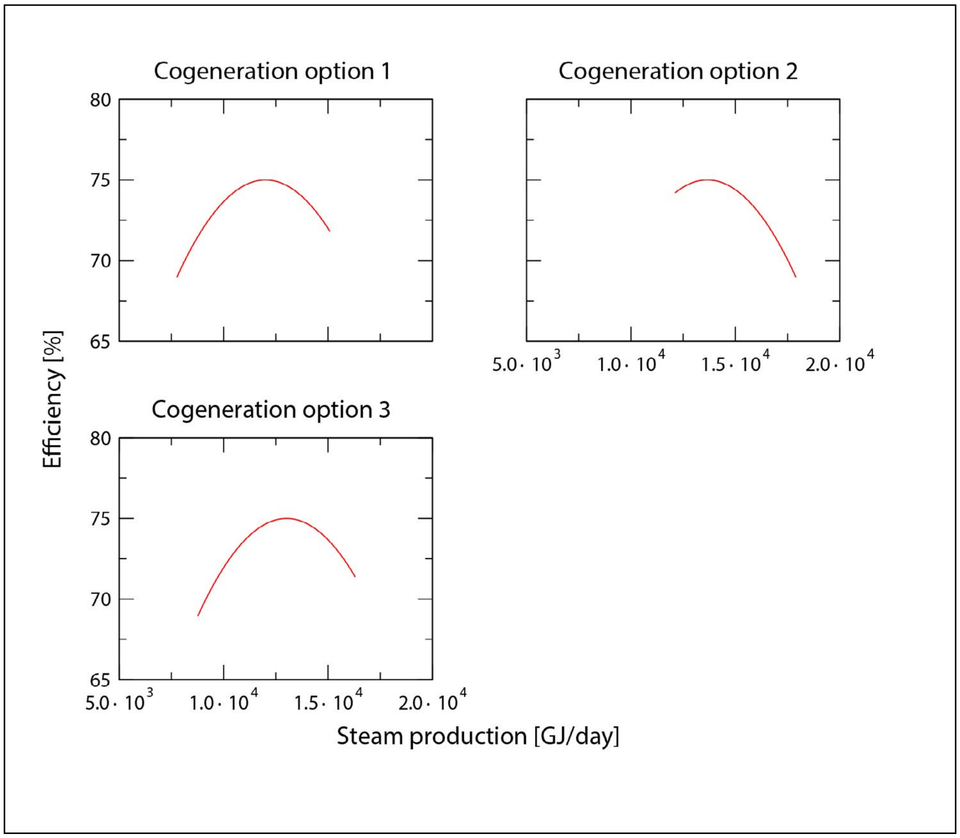


Fig. 7 - Efficiency functions for each cogeneration design.

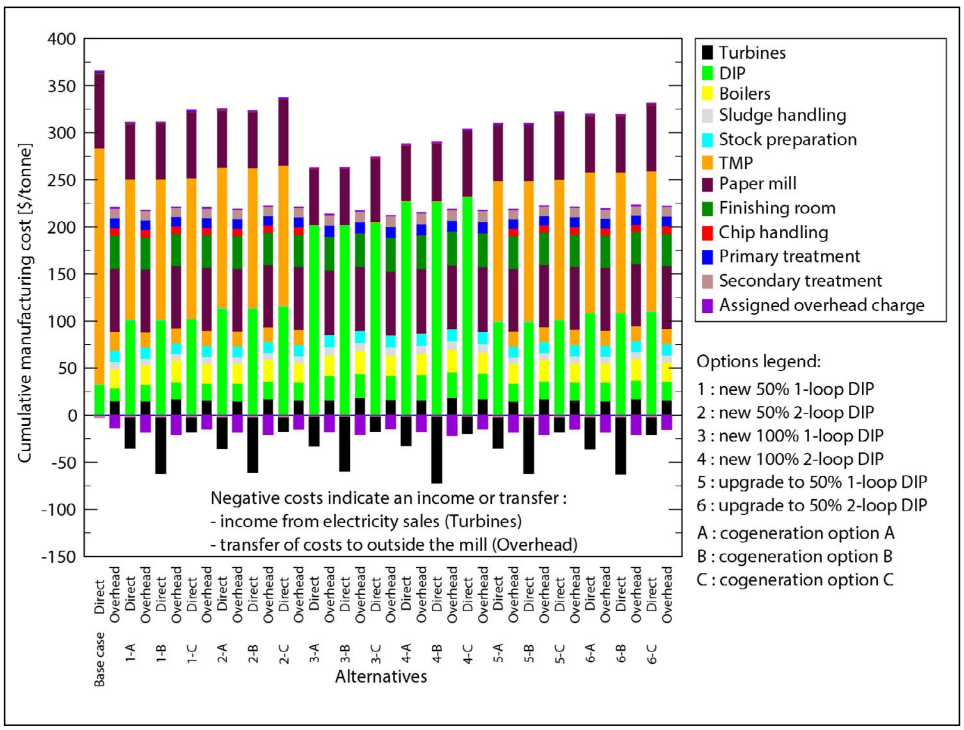


Fig. 8 - Manufacturing cost per tonne of newsprint for each design alternative and *PWC*.

manufacturing cost. The model would not be capable of determining directly which process unit is responsible for this increase and why the increase has occurred.

The overhead costs for each alternative show only small variations compared to direct costs (Fig. 8). These variations occur because of:

- Differences in the investment tax credit (ITC); the more power is generated based on renewable fuels, the more ITC is received;
- Differences in maintenance material and labour, operating labour, and supply costs and changes in headcount;
- Differences in the cost of mill heating, which varies with steam price.

For each *PWC,* the "assigned overhead charge" is the non-manufacturing cost that was assigned directly to the cost object, the newsprint paper produced. This cost is negative because it contains costs that are transferred to other facilities at the mill site. Using the operations-driven costing approach, the *PWCs* that contribute to a manufacturing cost change can be identified. At a more detailed level, the change in cost for each activity in these *PWCs* can be assessed

Based on the results of the profitability analysis (Fig. 9), the alternatives that had a positive value for all the criteria were retained and further analyzed. Alternative 3-A was most profitable, with an NPV of 82.3 M$ and an IRR of 8.1%.

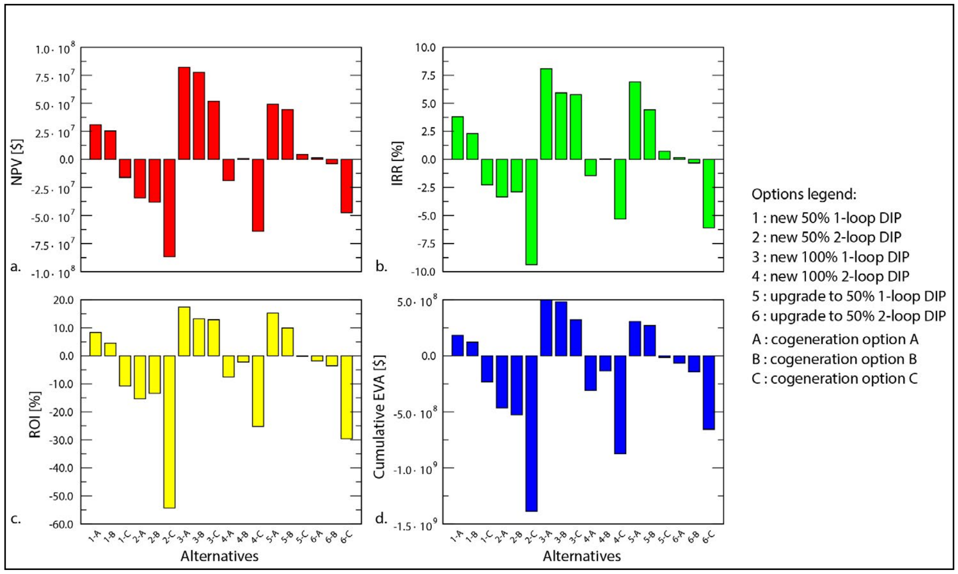


Fig. 9 - Profitability metrics for the design alternatives: a. NPV; b. IRR; c. ROI; d. cumulative EVA.

Sensitivity analyses were carried out to assess the impact of electricity and natural gas prices on the profitability of the design alternatives (results not shown). The natural gas and electricity consumption levels are lower for the design alternatives than for the existing mill, and therefore increased energy prices have a positive impact on profitability. Both electricity and natural gas prices influence the steam price and the incremental cost of generated power (Eq. 5) (Fig. 10). An electricity price change has a minor effect on both, even in the extreme case of a 100% change. However, an increase in the natural gas price results in a more significant change. The incremental cost of generated power can be reduced, change only a little, or increase depending on the steam price increase for the existing mill and the alternative.

Marginal energy cost analysis

Figure 11a shows the impact of changes in fuel on steam cost by plotting marginal and average steam costs at different steam production rates. For alternatives with cogeneration designs A and B, the marginal steam cost is lower than the average steam

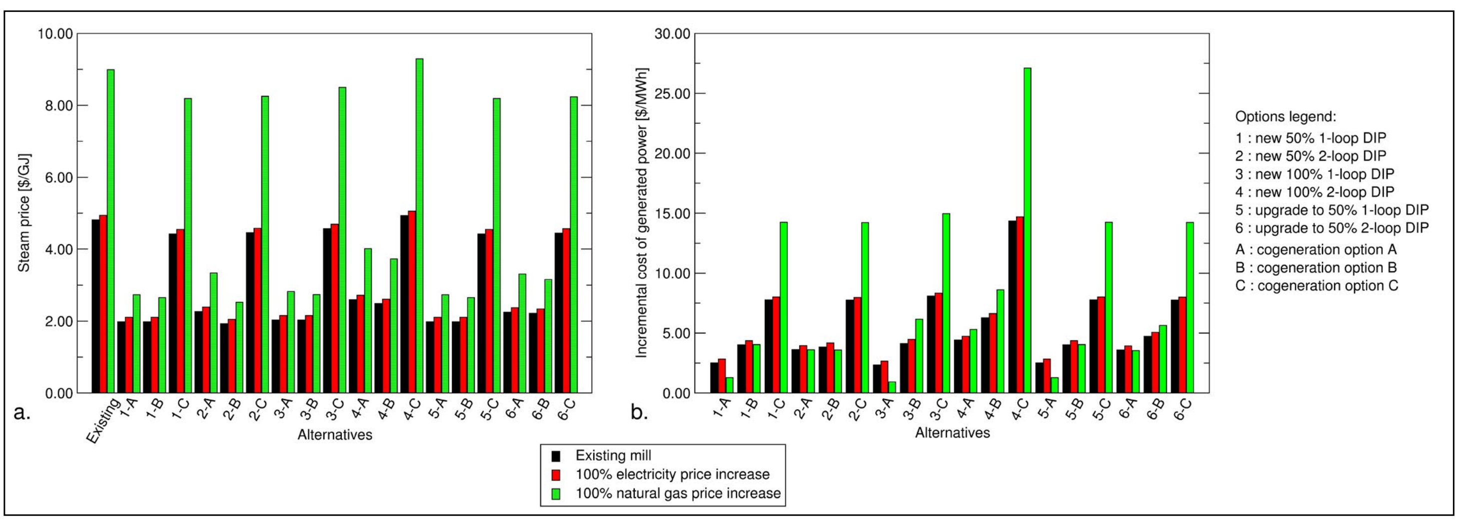
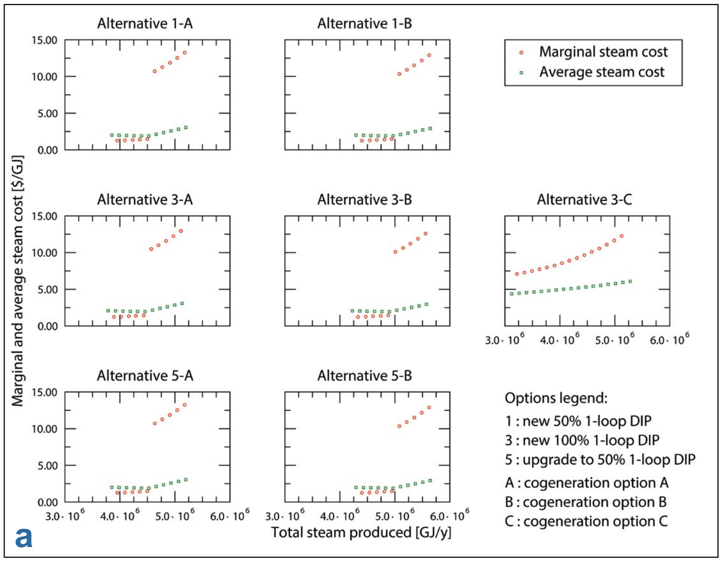


Fig. 10 - Effect of varying electricity and natural gas prices on: a. steam price and b. incremental cost of generated power.



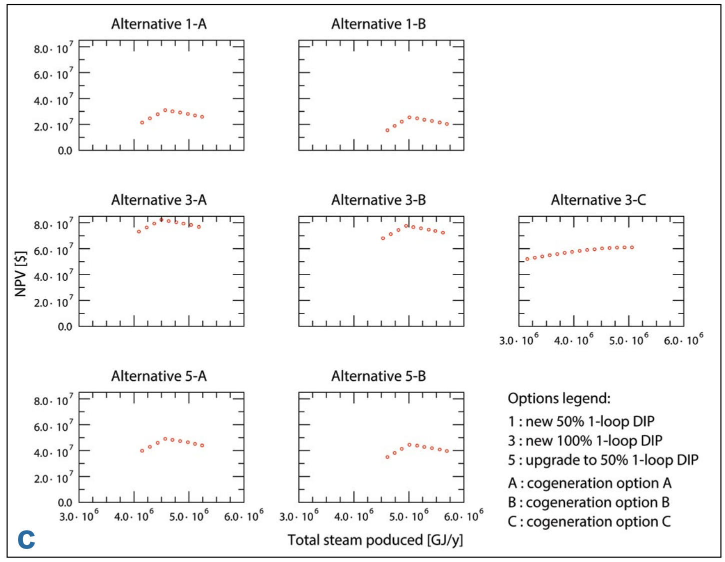
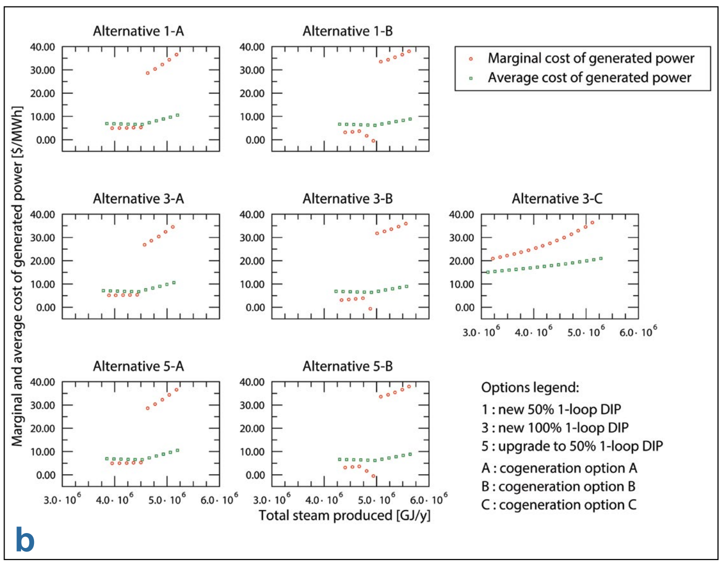


Fig. 11 - Marginal energy economics at constant process steam use: a. marginal steam cost; b. cost of generated power; c. NPV change.



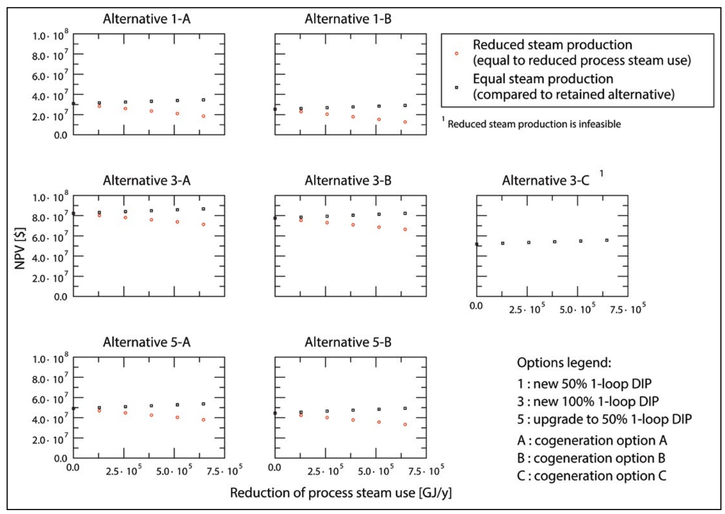


Fig. 12 - Impact of increased energy efficiency (decreased process steam use) for the base alternatives on the NPV.

cost when steam production is from wood waste (lower steam production rates). After natural gas is added to the fuel mix, the marginal steam cost is significantly higher than the average steam cost. For instance, the average steam cost in alternative 3-A is \$2.15/GJ until natural gas is added, after which the marginal cost jumps to \$10.50/GJ. Only alternative 3-C does not display a jump in the marginal steam cost and has a marginal steam cost higher than the average steam cost at all steam production rates because of natural gas use at these rates. The marginal cost of generated power shows a similar trend (Fig. 11b).

For the alternatives with cogeneration designs A and B, an optimal NPV is identified as a function of variant parameters, specifically when wood waste use is maximized and natural gas use is minimized. These results reflect the outcomes of the marginal energy cost analyses, i.e., these alternatives would start to lose money as soon as natural gas is required (Fig. 11c).

Energy efficiency

Increasing process energy efficiency does not result in a significant impact on marginal steam cost, nor on the incremental and marginal costs of generated power. However, the impact on profitability is more profound (Fig. 12). If steam production in the boilers is decreased by the same quantity as is conserved by the higher energy efficiency, then the NPV decreases significantly. The decrease in steam production leads to lower electricity generation, and therefore the mill receives less revenue from sale of this power. For instance, the NPV of alternative 3-A decreases from \$82.3 million to \$71.4 million when steam production in the boiler plant is decreased by 15%. The operations-driven approach can readily quantify such changes in profitability. If steam production in the boilers remains at the base operating level, the NPV increases with decreasing process steam use. For greatest profitability, the cogeneration potential should remain as high as possible while maintaining an optimal fuel mix.

Production capacity change

The paper-making process exhibits non-linear behaviour with regard to electricity and steam use by the paper machines and to boiler efficiency. The manufacturing costs for various production capacities have been calculated using the production functions (shown earlier in Figs. 5, 6, and 7) and using constant values for those production variables. The calculations were carried out for design alternatives 3-A and 5-A. Using production functions leads to different manufacturing costs (Fig.13). This difference is amplified as the production rate deviates from the base design specification (in this case, 1100 FMT/day for all paper machines). The overhead costs were not varied in these calculations.

The marginal manufacturing cost varied over the production range, resulting in non-linear behaviour of the manufacturing cost (Fig. 14) with production rate. This marginal cost was calculated using the following equations:

$$\text{Marginal manufacturing cost} = \frac{\text{Total manufacturing cost}_i - \text{Total manufacturing cost}_{i-1}}{\text{Production rate}_i - \text{Production rate}_{i-1}} \quad (6)$$

$$\text{Total manufacturing cost}_i = \text{Production rate}_i \cdot \text{Manufacturing cost}_i \quad (7)$$

where i refers to an operating variant.

The marginal manufacturing cost over the production range is higher for alternative 5-A than for the other scenarios. This implies that there is a significant impact of TMP operating costs (i.e., electricity use) on the marginal cost of the alternatives, because alternative 3-A produces no TMP pulp. For both alternatives, the marginal manufacturing costs stay well below the average manufacturing cost (Fig. 13), which indicates that increased paper

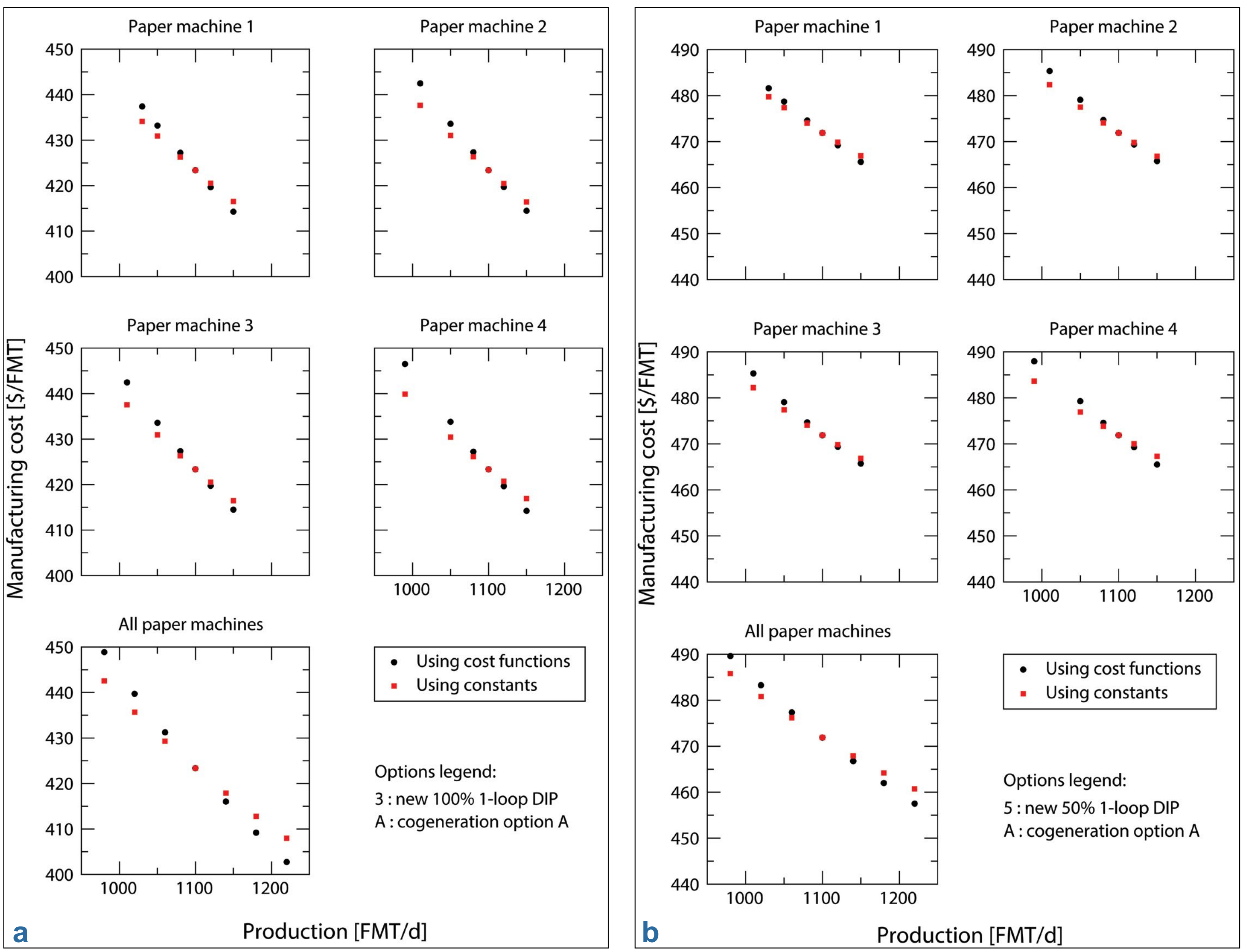


Fig. 13 - Manufacturing cost for: a. alternative 3-A; and b. alternative 5-A.

production leads to increased earnings at all production rates.

Comparison with conventional techno-economic approach

Janssen *et al.* [3] presented a techno-economic study for the same design problem as presented in this study. By comparing the operations-driven cost modelling approach used in this study with that using classical accounting data in the earlier techno-economic study, it is evident that:

- The transparency and granularity of the results increases because of the use of the ABC-like approach. Resources are related to cost objects through the activities performed in the defined *Process Work Centres*. In techno-economic studies, the resources are directly related to the cost object, i.e., the resource costs are paid for by the whole mill instead of by the process unit where the resource is used.
- The operations-driven approach enables detailed integration and reconciliation of the process and cost data in one model. The *PWCs* can be used to study a process at any level of detail, depending on the objective of the study and the availability and accuracy of data. This permits a more efficient and accurate description of changes in direct and overhead costs based on design changes. In a techno-economic study, the data are not captured in such a framework, and it is therefore less clear how to link design changes to cost changes.
- The current approach integrates the calculation of design variables that change with resource price, e.g., steam price. The costs of resource use can be traced back to the *PWCs* that use these resources indirectly, e.g., changing steam cost for the paper mill *PWC* as a function of varying natural gas price. Such changes are not so obviously taken into account in a techno-economic study.

CONCLUSIONS AND IMPLICATIONS

This study has sought to apply an operations-driven cost modelling approach to a large-scale retrofit design problem. It has.

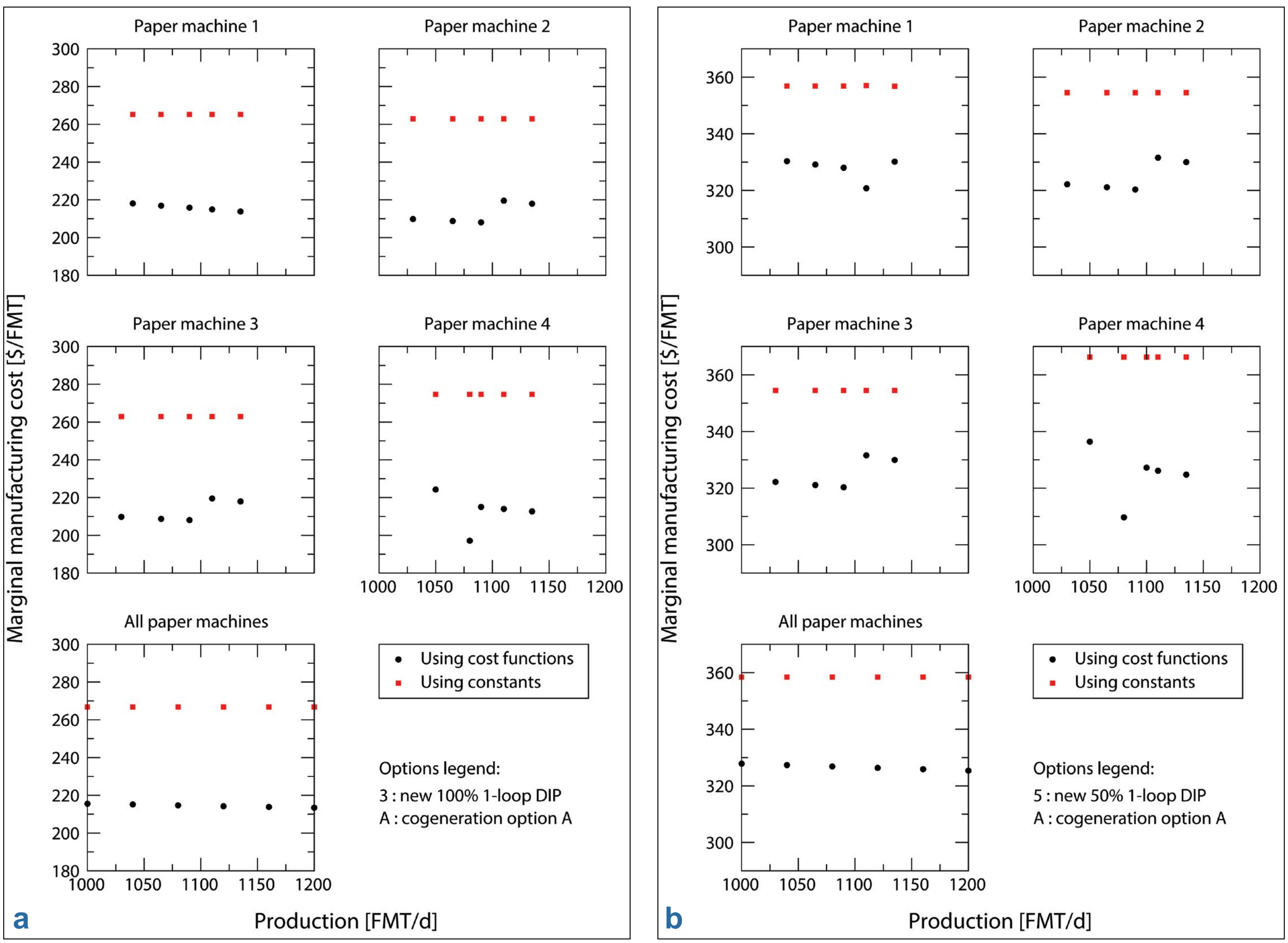


Fig. 14 - Marginal manufacturing cost for: a. alternative 3-A; and b. alternative 5-A.

considered the implementation of increased de-inked pulp production and cogeneration at an integrated newsprint mill.

First, the mass and energy balances and capital costs were calculated for all design alternatives. Next, the operations-driven cost model was used to calculate the operating costs and profitability of these alternatives. The profitable alternatives were identified, and marginal cost analyses and energy efficiency studies were carried out to analyze these alternatives in more depth.

The profitability analysis showed that a 100% DIP one-loop alternative was the most profitable (alternative 3-A) and that none of the two-loop DIP design alternatives was profitable. Marginal cost analysis quantified the negative effect of natural gas use on profitability due to its high price. Furthermore, an energy efficiency study showed that profitability increases only when maintaining steam production in the boiler plant while increasing the energy efficiency of the mill processes. This information can be used in the design decision-making process to account for operating conditions that are different from the design specifications.

The proposed cost modelling approach is better able than other methods to quantify cost implications of retrofit design changes due to its focus on mill processes. The approach readily permits carrying out marginal cost analysis and energy efficiency studies because of its ability to calculate cost variations by evaluating operating variables such as steam production rate.

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