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Design and Initial Approach of a Print Energy Life-cycle Decision Tool

The environmental impacts associated with the entire print value chain include, but are not limited to, deforestation, emissions, water consumption, solid waste production, energy consumption, and air pollution. There has been growing interest and activity by the print industry to address these issues by understanding and reducing these impacts through prudent design and process decisions (Carli, 2007; Chadwick, 2008; Cross, 2008; Kemper, 2008). However, in order to effectively reduce these impacts, it is important that the appropriate metrics, methods and tools be available to enable good decision-making. A consistent need expressed by the print industry is the development of standardized sustainability assessments that would allow the comparison of different printing technologies, printing platforms, printing products and printing value chains.

This month's research paper, *Design and Initial Approach of a Print Energy Life-cycle Decision Tool* (PICRM-2010-03), by Elvis Montero, J. Scott Hawker, Ph.D., Marcos Esterman, Ph.D., and Sandra Rothenberg, Ph.D., is part of a larger research effort by the Sustainable Print Systems Laboratory (SPSL) at RIT. The goal of this larger research effort is two-fold:

1. to understand and characterize the metrics and methods employed by the printing industry to measure, track and integrate sustainability into their business practices;
2. to develop methods and tools to aid the print industry to become more sustainable.

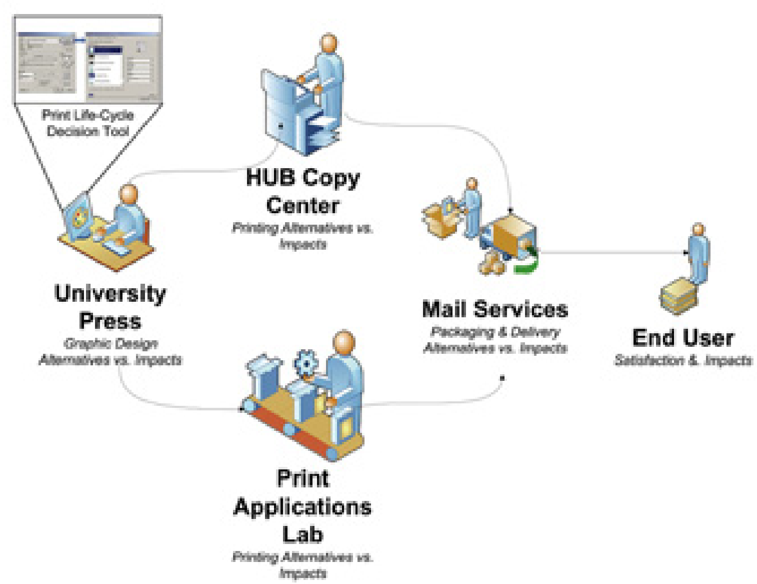
The focus of this monograph is the latter, in which the preliminary design of a print energy life-cycle decision tool is detailed as prototype for other life-cycle decisions tools.

Introduction

The need for a print life-cycle decision tool that provides users with information on the impacts of their print choices has been identified by several authors (Curtin, 2008; Jones, 2008). Print providers have recognized this, and have started to provide some tools to consumers, with a focus on carbon (see Appendix A in the full monograph). While a variety of tools exist, there are some limitations. First, the reported outcomes tend to report averages and do not include factors such as the location and environment of the user. Second, the requirements and characteristics of the documents to be printed and their final purpose are not factored in the decision. Lastly, the information is not integrated in any way into the print decision itself.

Figure 1 presents the authors' vision for a print life-cycle decision tool that addresses these limitations, in which the user would be presented with information on the impact of a print job from a number of perspectives. Using RIT printers as a test bed, this IT tool would analyze the impact of a document before it is printed; namely, the program would examine the alternatives of printing the document, any possible alternatives to this action and the end result in economic, quality and environmental terms.

Figure 1: Print Life-Cycle Decision Tool Test Bed
click to view image larger



The test bed proposed in Figure 1 poses a significant challenge and encompasses a large-scale research project. Thus, as a first step it was decided to focus on a small portion of this project: the measurement and integration of energy/power consumption into the print decision. After the direct associated costs of printing, energy is the sustainability metric that is perhaps of the most

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interest to the average consumer, since it is easily translatable into money and is a potential source of greenhouse gas emissions.

System Requirements

Given the constraints above, it was decided that the system should provide the capabilities summarized below.

- Provide a way for the user to enter the following print request attributes:
  - Document reference (i.e. file to print)
  - The desired printer from the devices registered on the system
  - Number of copies
  - Pages (all or a range)
  - Media type
  - Print quality
  - Document color
  - Desired print quality (e.g. draft mode, paper selection, etc.)
- Provide an energy model of supported printer(s).
- Provide a way for the user to modify print request attributes and request new energy computations.
- Provide a way for the user to create an energy consumption report.
- Designed in such a way that allows it to be expandable.

User Interface

There are three different views associated with the user interface: job creation, historical reporting, and the energy model details. Figure 2 shows the job creation interface for users, Figure 3 shows the historical reporting view for administrators, and Figure 3 shows the energy model details for developers.

Figure 2: Powergy for a printed Word document
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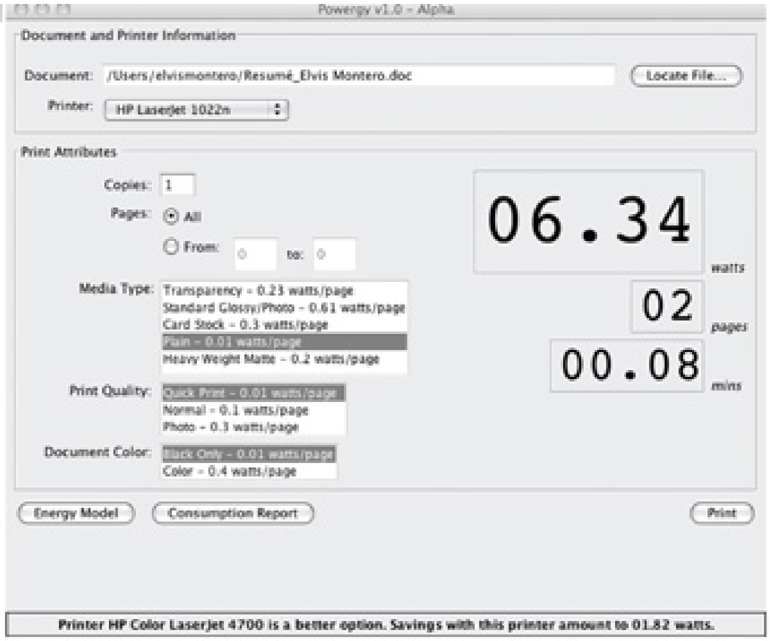

Figure 3: Powergy reporting historical energy consumption
[click to view image larger]

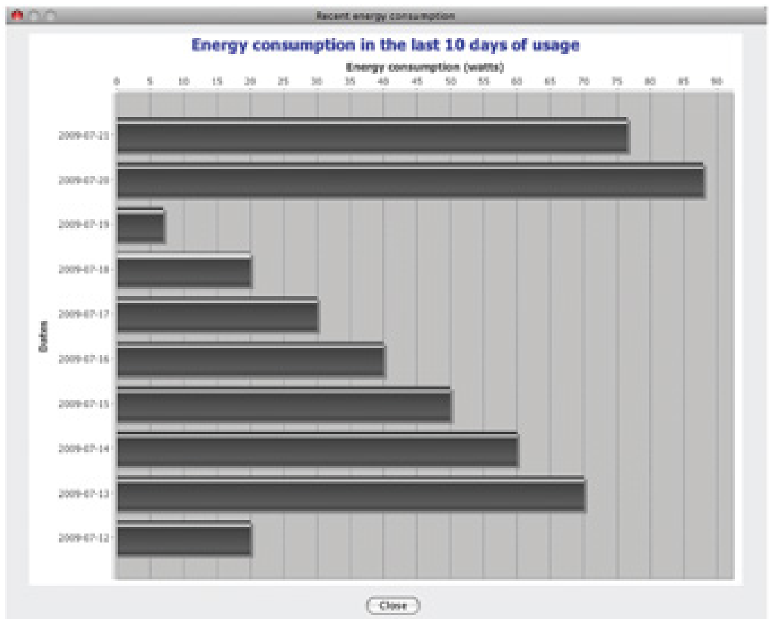

Figure 4: The elements from the energy model of Figure 2 used to compute the energy estimate
[click to view image larger]

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Dedicated to the study of major business environment influences in the printing industry precipitated by new technologies and societal changes, the Printing Industry Center at RIT addresses the concerns of the printing industry through educational outreach and research initiatives.

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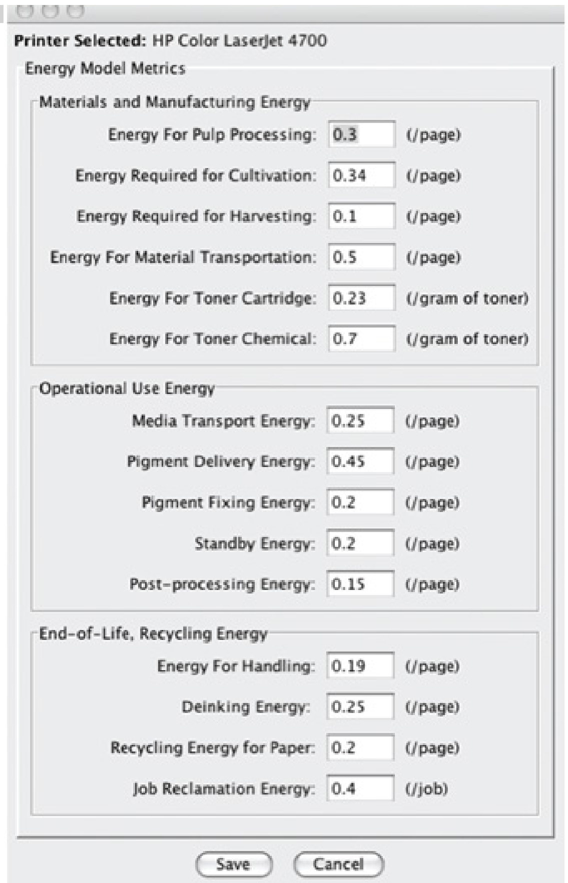

Development of Powergy

Energy Model Abstraction

In order to provide a sound estimate of the energy consumption of a print job, an energy model is required that enumerates what elements must be taken into account prior to running the computations. The energy consumed when a document is printed is more than just the printer's active power consumption. In order to ground this discussion in an actual example, Table 1 shows the main elements that were used in the development of this prototype. It was decided to break the energy model down into two dimensions. One dimension handles a typical life-cycle breakdown, where the energy consumption associated with various life-cycle stages needs to be accounted for. The second dimension that was used was a breakdown as a function of print value chain agents. This is not the only way to decompose the model, but for our purposes this provided a useful breakdown.

Table 1: Energy Model Dimensional Elements
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		Value Chain Agent				
		...	Device	Print Job	Document	Page
Life-Cycle	Materials Extraction					Forestry
	Materials Processing					Pulp Processing
	Manufacture					
	Use					
	End of Life					

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This breakdown allowed for the tracking of energy consumption at various levels of aggregation and abstraction. For example, at the lowest level, there are page-level attributes that are of interest to track. Coupling this abstraction with the life-cycle dimension, it is now possible to isolate the elements that consume energy during the harvesting of the trees, the processing of the trees, the manufacture of paper, the transport energy while it is being printed on, etc. Similarly, this same kind of energy accounting can be done at the document-level, the job-level, the device-level, and other yet to be defined abstractions. As an example of the yet-to-be-defined category, there are activities that are associated with the order fulfillment process of the entire job that might include accumulation and packaging of all of the printed documents, delivery and potentially storage and retrieval. All of these activities would contribute to the consumption of energy. The goal was to have an implementation architecture that is flexible enough to handle not only the current metrics, but yet-to-be-defined metrics as well.

With this abstraction in mind, Powergy uses a software abstraction that sums the multiple sources of energy that reside within a single entity. That entity could be a single number, an equation or a more complex relationship composed of an aggregation of entities. The software design pattern used to abstract this concept is called the composite pattern (Lasater, 2007). The composite pattern allows us to deal with collections of objects and single objects as if they had consistent behavior. This is accomplished by allowing energy metric elements and aggregations of energy metric elements to be derived from the same base class. Figure 5 illustrates the pattern as implemented in the code (the application's complete class diagram can be found in Appendix B in the full monograph).

Figure 5: Composite pattern's implementation
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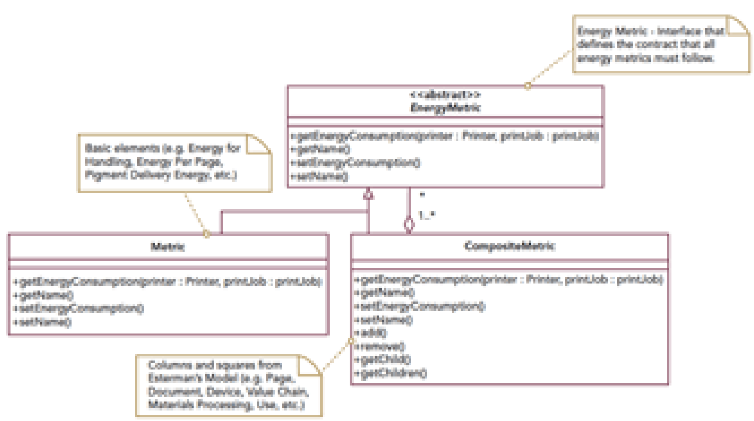

Architectural Modules

With the discussion from the previous section in mind, this section will discuss the architectural modules needed to calculate the energy consumption, as shown in Figure 6. Each component will be briefly discussed below.

Adviser
The adviser serves two functions. It is the user interface that allows the user to interact with the application and enter the appropriate data. Its second function is to orchestrate the energy calculation and act on the resulting calculation. In this particular implementation, the adviser is simply a reporting mechanism. However, in the future it could just as easily make recommendations to the user based on embedded algorithms. Taking that a step further, automated actions and controls could be taken to optimize the performance metric of interest. While these actions will not be possible in the immediate future, the structure is in place to allow it to happen.

Energy Model
The energy model was discussed in quite some detail in the previous sections. What will be highlighted here is that the energy model has been separated from the device and value chain and is itself a stand-alone component. The reason for doing this is that it will allow flexibility in the future for the advisor to perform more sophisticated energy calculations. For example, one could envision that there is an embedded energy model in the device that has been provided by the device manufacturer. It is also feasible that a third party has also developed an energy model for the same device. The advisor could rely on one or the other or perform a calculation based on crosschecking between the models. The basic idea is that those calculation details would reside within the abstraction developed in the previous section and could be easily carried out irrespective of the source of the data.

Printer, Print Job, Document
These are all separate abstractions that contain data that would feed the energy model. For example, the printer could report out information regarding the amount of time that it has been idle, the state of the device (toner remaining, life of components, etc.), all of which would make for more accurate estimates. From the document one would derive the amount of pigment materials needed, the number and types of media. These are representative of state variables.

Figure 6: Component diagram presenting Powergy's architectural view*
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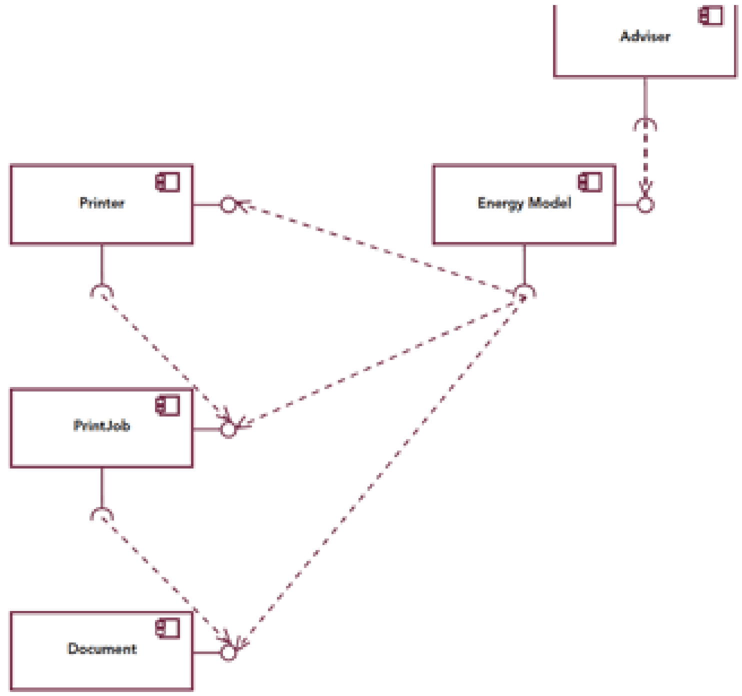

**The interrelationships between the components underline the dependencies necessary to estimate energy consumption.*

A solution such as the one outlined above is beneficial for several reasons. First, it increases independence between components. A printer does not need to specify its energy model. Similarly, a print job need not know about a printer, and a document need not know about a print job. This low coupling means changes in one part of the system minimally impacts other components. Second, as a direct consequence of this separation, the resulting code is easier to maintain and extend, thereby decreasing the time required to update the application. Third, a developer can easily add new energy metrics, modify their computations, and add new aggregations. Further, an end user can easily modify the energy model values for new printers. Last, this approach makes the code more likely to have functional cohesion (i.e. logically related parts of a module are grouped together since they all make for a single, well-defined task), which is a highly desirable trait to have in any software.

For a more in-depth discussion of each of the components and the technologies used in development, please read the full monograph.

Summary

Powergy is the first step towards the full realization of a print life-cycle decision tool. As developed, Powergy focuses on energy consumption. But the processes, architecture and overall idea can be applied to expand the application and incorporate other estimates as well. For instance, in order to estimate water consumption or solid waste produced, one would need a water consumption model and a solid waste model. These models would

have all the classes and the logic required to interact with any devices necessary (i.e. *Printer* in this case) for estimating consumption based on the attributes obtained from the printer, the document and the print job. The models are required because they provide the rules that dictate how to compute an estimate, as well as what attributes are required from each component to perform the calculations. Aforementioned models would then communicate the estimate to the Adviser. Finally, the Adviser would then present the estimate to the user.

Presently, the application is able to notify end users about the energy estimate of their decisions. Powergy is essentially reacting to end users' selections, and recalculating the estimated energy consumption after interactions with the UI have taken place. Yet, the application is actually not suggesting better courses of action based on those selections (with the exception of a small disclaimer at the bottom of the main form, which highlights the most frugal of the printers). Advising or suggesting more efficient printer and print job attributes to the end user is the second stage. A move from solely informing to advising would be ideal. The third and last stage—automatically deciding—is the idyllic goal. This sapient-like system would have to entertain many different possibilities and react according to end users' intent. The second or third stage would be the next logical, evolutionary step for a print energy life-cycle decision tool such as Powergy. The energy model was designed and implemented to make this progression straightforward without having to modify the energy model.

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