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Rebekah Drake
Wichita State University

Mehmet Bayram Yildirim
Wichita State University, bayram.yildirim@wichita.edu

Janet Twomey
Wichita State University

Lawrence Whitman
Wichita State University, larry.whitman@wichita.edu

Jamal Ahmad
Wichita State University

Prashant Lodhia
Wichita State University

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Data Collection Framework On Energy Consumption In Manufacturing

Rebekah Drake, Dr. Mehmet Bayram Yildirim, Dr. Janet Twomey, Dr. Lawrence Whitman, Dr. Jamal Ahmad, Prashant Lodhia

Industrial and Manufacturing Department
Wichita State University
Wichita, KS, 67220, USA

Abstract:
In this paper, we propose a framework to characterize the energy consumption of machines and their subcomponents (e.g., spindle, coolant pump, controller, heater, hydraulic system in injection molding machine, motors in these components). This framework serves as a key component in describing the environmental impacts of decisions in manufacturing operations design and control, especially at the sub-cellular level. Furthermore, the proposed framework can be utilized to investigate the inter-relationship of operational decisions and environmental impacts within a manufacturing plant. The paper concludes with examples of the proposed framework for energy data collection on a CNC milling machine.

Keywords: Energy Efficient Scheduling**,** Power Consumption, Sustainable Manufacturing, Green Manufacturing

1. Introduction/Problem Statement
The goal of many modern manufacturers is to decrease the cost of production by any means possible while ensuring quality and customer satisfaction. The traditional methods to achieve this goal include efficient selection of suppliers and optimization of production schedule and supply chain through coordination. Another cost factor that one should consider is energy consumption. The current trend in increasing cost of energy enforces production planners to minimize energy consumption in a manufacturing environment.

Gutowski et al. notes [1] that in the Toyota Motor Corporation (a mass production environment), 85.2% of the energy is used in non-machining operations which are not directly related to production of parts. Kordonowy [2] characterizes the power consumption of a mill, lathe, and injection molding machine by analyzing the background runtime operations of machining (i.e., spindle, jog, coolant pump, computers and fans, etc.). They found that over 30% of the energy input into the system during machining is consumed by these background processes. However, these calculations consider the whole system as opposed to a developed model for each process. Haapala et al. [3] propose a model to predict the waste and energy associated with manufacturing through the development of models and software which calculate theoretical waste. However, these models rely on specific energy calculations without validation from real data collection. Dahmus and Gutowski [4] observe that total energy requirement for the active removal of material can be quite small compared to the background process needed for operating a machine. In all of the above references, the energy consumption calculations are based on aggregate observations.

The objective of this paper is to provide a framework for characterizing the energy consumption of a machine and its subcomponents in determining the energy waste (i.e., determine the power usage in detailed observations). This can be utilized to investigate the inter-relationship of operational decisions and environmental impacts within a manufacturing plant.

2. A Framework for Energy Consumption in a Machine
The characterization of energy consumption of a machine is an six-step process. These steps are:

1. Initialize
2. Configure the Measuring Device
3. Capture the Total System Power
4. Analyze the Total System Power
5. Determine Subsystems of Primary Focus

6. Capture and Analyze Subsystem Behavior

Before describing these steps in detail, in order to provide a basis and clarify terminology, the following definitions are essential in the context of the framework for energy consumption model: A *system* is a group of subsystems which converts input to output (i.e., milling machine, injection molding machine, lathe). A *subsystem* is a group of components acting together (i.e., spindle, coolant pump, ATC in milling/turning machine, heater, hydraulic system in injection molding machine). A *component* is a part of a subsystem consuming power (i.e., motors in spindle/coolant pump/ATC; Heating coil in heater). *Fixed energy consumption* is the energy usage associated with activity which consumes variable power over a fixed time duration while the *variable energy consumption* is the energy usage associated with activity which consumes *constant power* over a variable time duration. Fixed energy consumption is usually associated with the initial spike in power consumption at the time of machine start-up whereas the variable energy consumption occurs when the machine and/or its sub-components run (see Figure 1, variable energy consumption over different periods of time, while having the same fixed energy consumption at the start-up).

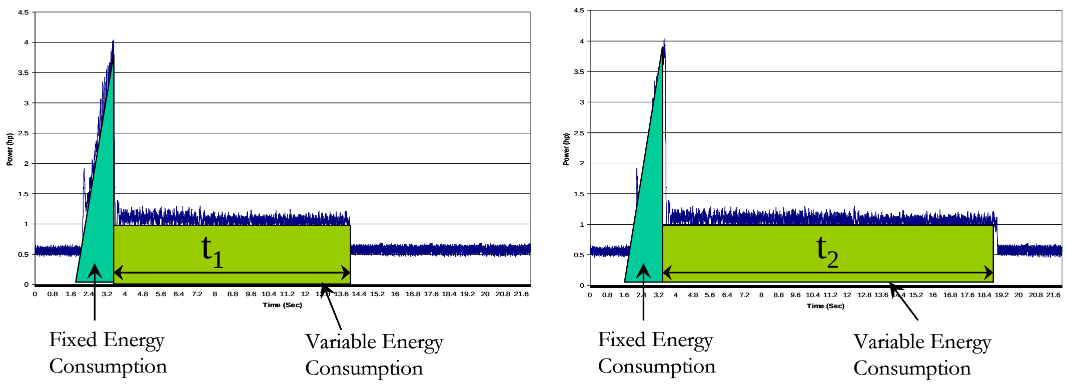

Figure 1: Fixed Energy Consumption vs. Variable Energy Consumption

1. Initialize

Before any data are collected, the bounds of the system must first be defined. The system is essentially the complete process which is being modeled. However, the subsystems must be distinguished from the components of the system. The subsystems are major groups of components which can be modeled during data collection. For example, in a CNC Milling machine (e.g., the Fadal CNC milling machine), two of the subsystems are the coolant pump and spindle. One component of the spindle subsystem is the spindle motor. It should be noted that some of the subsystems may be external; however, this must be considered in the bounds of the system. In the above example, the coolant pump is an external subsystem which is essential for the system to operate.

2. Configure the Measuring Device

In order to collect power data over time on a system, a power measuring device and data logger should be utilized. This device should be connected to the system's main power box. All subsystems must draw power through this power box. If this is not possible (i.e., if there are some external subsystems), there should be a power measuring device and data logger connected to each external subsystem(s) and to the system. The power measuring device that is being utilized in this paper (Figure 2) is manufactured by Load Controls Incorporated (http://www.loadcontrols.com/products/pdfs/portable_power_data.pdf). Once the device is connected to the system, as seen above in Figure 3, the sampling rate must be set with respect to the desired level of accuracy (e.g., 50 samples/sec).

Figure 2: Load Controls Portable Power Cell

Figure 3: Power Measuring Device Connected to Fadal CNC Machine

3. Capture the Total System Power

In order to capture the power consumption of each subsystem over time, a part must be designed such that each subsystem is utilized in a defined sequential order during each part run. Using this part design, the machine is run *n* times to collect *n* data sets (e.g., five data sets) while tracking the power consumption of the sequential activities in the system with respect to time (e.g. horizontal/vertical moves, drilling, tool changes, etc.).

4. Analyze the Total System Power

Using the data collected from the trial run(s), plot the power with respect to time (Power Plot). For example, in the power plot of Figure 4, the power measuring device collects and logs the power consumption over time. The Power plot reveals the power of the system as each subsystem is utilized. As seen in Figure 4, the sequential activities required to machine the sample part are correlated with the spikes in the power draw. Note that by calculating the area under the power plot, the energy consumption required to machine one part can be determined.

5. Determine Subsystems of Primary Focus

Using the information gathered from the Power Plot, analyze the subsystems based on the level of significance that the subsystem contributes to the total system power. For example, in Figure 4, the start-up takes 9.5 seconds. In this example, the subsystems of focus are the coolant pump, the spindle, and rapid movement of axis.

6. Capture and Analyze Subsystem Behavior

To characterize the energy consumption of other subsystem, the experimental data must be captured using the power meter. The subsystem’s behavior must be analyzed to determine fixed energy and variable energy for that subsystem.

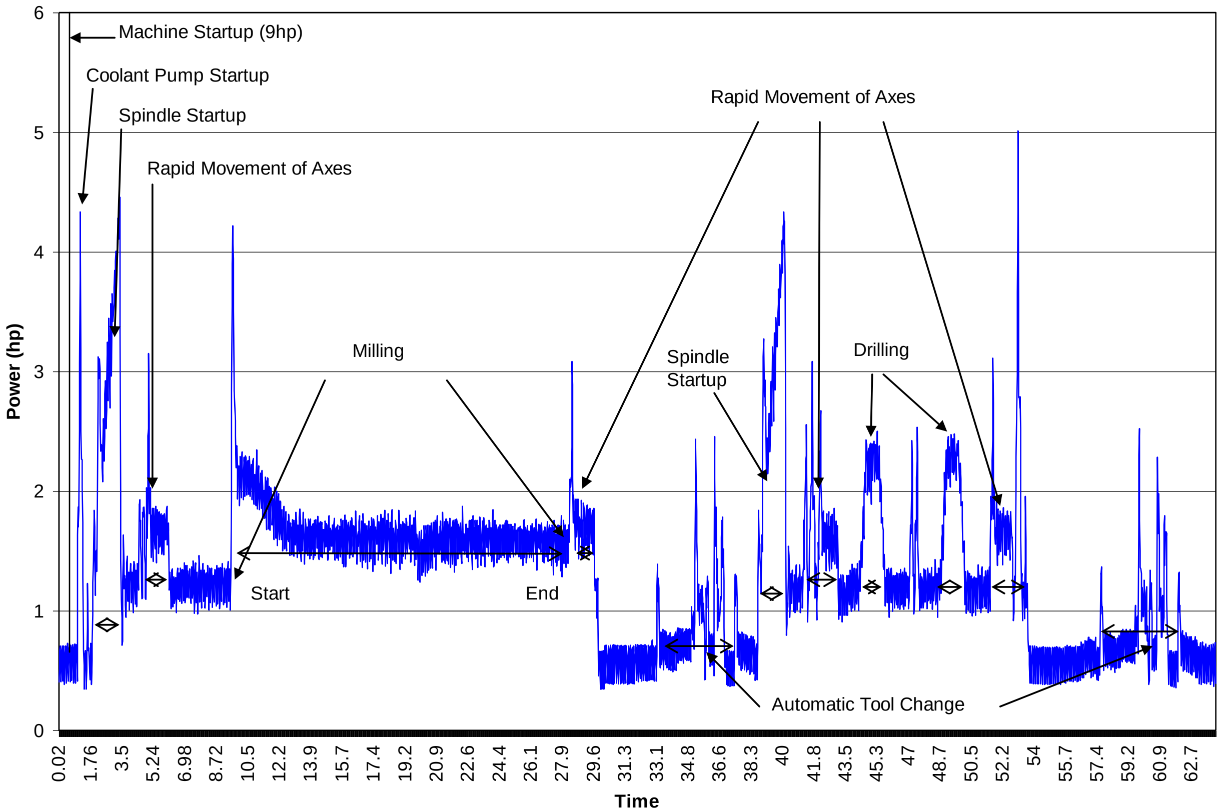

Figure 4: Power Plot for CNC Mill

Using the proposed framework, Figure 6 displays that most of the energy consumption is utilized in the machine controller. Additionally, energy consumed by the spindle makes up 35% of the total energy consumption for that part. The energy required to remove the material from a part (i.e., the tip energy) is 19% of the total energy consumed by the milling machine. To have an energy efficient milling process, therefore, alternatives should be focused on milling machine designs which minimize the power consumption by the lights, controls and spindle in order to decrease the overall energy consumption.

Once the power consumption for each system/component/subsystem is characterized, one can easily determine the energy requirement for producing a part. For example, in order to minimize the cost of production, it may be required that the machines remain on and idle for 2 hours in the middle of the day. However, this could be consuming more energy compared to turning off the machine instead of keeping it idle and powering it up when needed.

By using the proposed framework, one can integrate the behavior of the each subsystem and model the energy consumption of any part having the same type of material that will be processed on that machine. Using the framework, one can predict the system's behavior in terms of energy consumption.

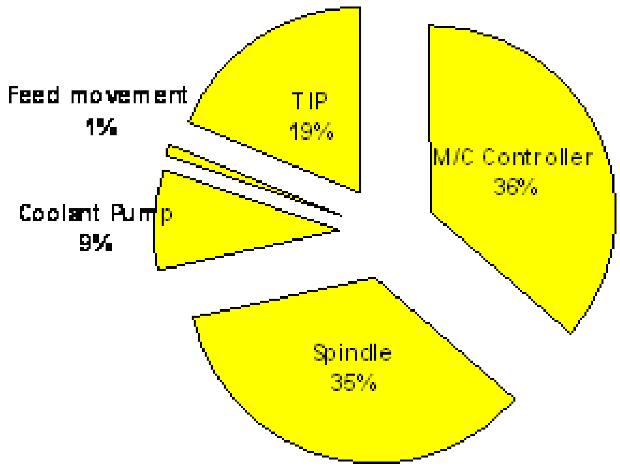

Figure 6: Energy Distribution for Milling Process

3. Conclusion and Future Research

As fossil fuels and natural resources continue to deplete, sustainability of current resources becomes increasingly important. The framework provided applies to the sub-cellular level, considering only one machine. However, using this model as a basis, advances can be made to minimize energy consumption on the production and eventually supply chain levels.

This framework is key component of ongoing research conducted by the Green Manufacturing Group at Wichita State University in Wichita, KS. Currently the group is investigating the inter-relationship between operational decisions and environmental impacts within the manufacturing plant. The outcome will provide valuable insight into operational methods for mitigating environmental impacts. The resulting detailed analysis of energy consumption will be used in the design of novel manufacturing equipment controllers that reduce environmental impacts by taking into account the shop floor operations. If successfully applied, this framework could dramatically help manufacturing companies develop scheduling plans with positive environmental and economic results.

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