Activity-Based Costing Applied To Automotive Manufacturing

Paul Jurek, Bert Bras, Tina Guldberg, Jim D'Arcy, Seog-Chan Oh, Stephan Biller

[1] ***Abstract*--This paper discusses a novel model, based on Activity-Based Costing, developed to analyze and predict energy usage in the manufacturing industry. In this approach, we have modified a cost management tool called Activity-Based Costing (ABC) to include environmental aspects along with costs metrics. A case study was performed on a General Motors (GM) manufacturing facility to evaluate Demand and Response offers from a local utility company to demonstrate the utility of this approach. This study resulted in an ABC predictive energy model which can be used with emerging Smart Grid opportunities to provide a competitive advantage to the manufacturing industry.**

***Index Terms*-- Automobile Manufacture, Energy, Energy Management, Mechanical Systems, Modeling, Load Modeling, Research and Development**

I. Introduction

Manufacturing processes are typically complex and consume large amounts of resources. Energy monitoring within the processes is typically performed only at a high level because the metering devices required for this cost thousand dollars and the information gained at the sub-system level is incomparable in value. Modeling of these systems can be achieved, but the complexity of these systems results in high costs in time and information to create these models. Stochastic approaches to predicting the facilities energy have been applied in the past, but these leave little understanding as to the causes of the energy usage by the system. This "black box" approach to the energy management of a facility limits the company's ability to understand where energy is used, how to prioritize improvement efforts, and how to curb their energy usage. The goal of this project was to solve these issues and create a model which provided insight to the causes of energy usage for better understanding of the system.

Energy costs are steadily rising and are predicted to continue this trend going into the future. At the same time, utility companies are beginning to implement Smart Grid technologies to increase the efficiency of energy distribution. One resulting program to emerge from these new technologies is Demand and Response contracting. This program allows customers to obtain a discount on their utility costs in return for reducing their energy usage during specified times. If a company is able to understand their processes well enough to change and meet the energy levels of the contract, they can gain a competitive advantage and reduce operating costs.

One way to determine if a specific Demand and Response offer is viable for the company is to use Activity-Based Costing (ABC) to model the energy usage of the facility. ABC offers a proven structure for evaluating the cost of processes and products in both the financial and industrial sectors. This method can be modified to include both economic and environmental factors [1]. By applying ABC to the manufacturing sector, we are able to overcome limited metering devices to determine the energy distribution within the process. This allows the prediction of energy loads in the future which is useful for effectively evaluating Demand and Response offers from the utility company.

General Motors (GM) is one of the largest automaker in the world. A case study was conducted at one of GM's vehicle assembly plants as part of exploratory research project to examine where the ABC model shows its value, especially focusing on its potential to determine expected energy use in a plant for varying production schedules in order to evaluate Demand and Response offers. The following describes the creation and application of an ABC energy model to the Paint-Shop of a GM automotive manufacturing facility. The first section gives a background on ABC, general Paint-Shop operations, Smart Grid technologies, and the Demand and Response program. The second section then presents results of a study applying the ABC model to a General Motor's automotive manufacturing facility. The final section describes a situation where this predicted information can be used to take advantage of the Demand and Response program.

II. Materials and Method

A. Activity-Based Costing (ABC)

Activity-Based Costing is an accounting method used to trace costs to a product or process of an organization. Rather than assigning costs directly to the products, they are assigned to the activities performed by the company. Then, the cost of the products are calculated by determining how much each product uses each activity [2]. This method requires knowledge of the process to determine the distribution of costs. The resulting data leads to visibility into the causes of costs in the process and even allows for predictions of costs for future scenarios [3].

The ABC method is preferred over Volume Based Costing, which traces resources directly to cost objects. The ABC

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method traces resources to activities then to cost objects for a more accurate cost distribution. A cost object is typically a product or process, while the activities are discrete actions which must be performed to create the cost objects. Resources are objects used by the activities which result in costs such as equipment, labor, materials, etc. The basic idea of ABC is that cost objects consume activities which consume resources and the consumption of these resources results in costs (Figure 1). This method requires additional knowledge of the process, but ends up producing more meaningful results. These results show both the true costs of products and provide insight as to why the products cost what they do. This provides opportunities to implement improvements and to predict future costs.

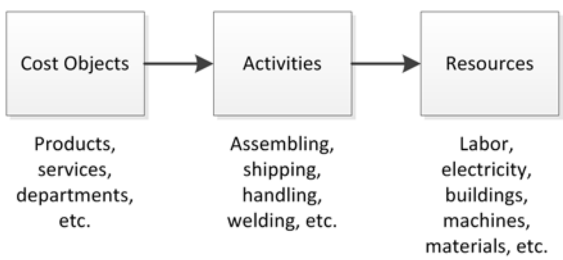

Figure 1 – ABC distribution chain

Drivers are used to trace resources to activities and activities to cost objects. Resource drivers trace the resources to the activities and activity drivers trace the activities to the cost objects. These drivers represent the causes of consumption and thus allow for accurate distribution along the ABC chain. Figure 2 lists some common examples of resource and activity drivers. It is important that these drivers be correlated to the actual causes of consumption by the objects. This allows for accurate tracing and a better understanding of the costs of the system.

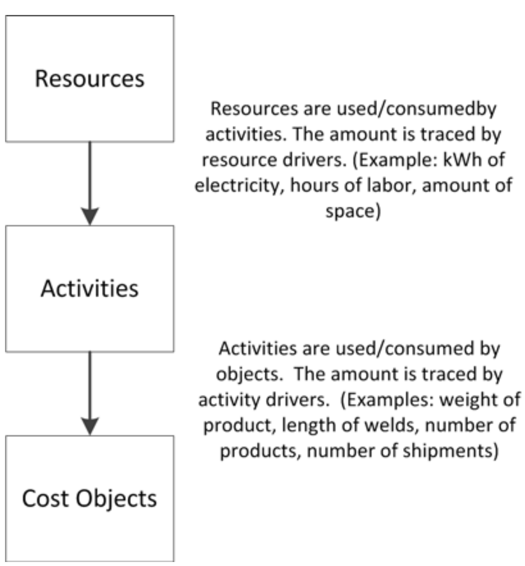

Figure 2 - Tracing of Resource and Activity Consumption using Resource and Activity Drivers [1]

The ABC method was developed by accountants in the financial sector to help distribute overhead costs more accurately [3]. As a result, the costs in the ABC method are typically associated with monetary values. However, this method can easily be modified to include additional costs such as environmental factors [1]. This is because ABC measures the amount of resources consumed by the products. From this amount, one can use the specific costs or environmental impact of the resource to calculate the total cost. For example, a product may consume 2MWH of electricity which has a specific cost of $100.00 per MWH. The specific environmental impact may be 10 kg CO2 per MWH. Thus, the total costs of this product in monetary and environmental aspects would be $200.00 (Table 1) and 20 kg CO2 released (Table 2). With this expansion to environmental factors, this method has been successfully utilized in the manufacturing industry to perform Life Cycle Assessments (LCA) [4] on the manufacturing processes.

TABLE 1 - ABC COST CALCULATIONS

		Monetary	
Resource	Resource Amount	Specific Cost	Total Cost
Electricity	2 (MWh)	100 ($/MWh)	200 ($)

TABLE 2 – ABC ENVIRONMENTAL CALCULATIONS

		Environmental	
Resource	Resource Amount	Specific Cost	Total Cost
Electricity	2 (MWh)	10 (kg CO2/MWh)	20 (kg CO2)

There are numerous examples of ABC application to the manufacturing industry [4]. A successful study on process improvement has been performed using the ABC method, which shows the flexibility of ABC to include environmental metrics [5]. More comprehensive applications involving environmental issues to evaluate the sustainability of manufacturing industries have also been performed [1]. These examples show that the ABC method can be applied to the manufacturing industry and expanded beyond showing just traditional costs.

B. Automotive Industry: The Paint Shop

The manufacturing process of an automobile is split into three departments:

1. Body Shop
2. Paint Shop
3. General Assembly

The body shop transforms the raw materials into the structure of the vehicle. Then the paint shop applies a protective and visual coating to the product. Finally general assembly assembles all sub-components [6] into the vehicle such as the engine and seats. Of these three processes, the paint shop consumes a majority of the energy in this process which can be up to 60% of the total amount used during the manufacturing process [7]. Due to its large share of energy usage, the paint shop was chosen as the domain of this study. A more detailed description of the paint shop follows.

Painting the automobile is a very complex process and requires many sub-processes and stages (Figure 3). Generally, there are five distinct processes performed within the paint shop which could be seen as cost objects in an ABC model:

1. Pretreatment of Product
2. Application of ELPO
3. Sealing Application
4. Paint Booth
5. Post-Paint Repairs (including cavity wax)

The pretreatment stage cleanses contaminants from the product which may have been collected in the body shop. This is performed over a series of water and cleaning solution rinses. These are usually performed in a combination of rinse and spray application methods to get optimal results [6]. Also in this stage is where a phosphate coating is applied to the vehicle to provide a layer of protective coating and assist in the application of the paint layers. After the pretreatment, the product is cleaned and prepped to move onto next stage.

The Electro Coat Primer Operation (ELPO) applies a layer of charged primer solution to the vehicle to increase the effectiveness of the paint application in the later stages. The product will remain in the charged solution for a specified period of time to build the appropriate layer thickness across the surface. The solution must be circulated to avoid settling of the particles. The solution is then baked onto the vehicle and the product is processed to the next stage.

After the ELPO application, the product moves to the sealing line where the seams of the product are sealed to protect against weather effects. A majority of these tasks are performed by robots, but there are some aspects which require human operators to perform. The sealants are then baked onto the product as it moves to the paint booth for the coating application.

In the paint booth, primer, basecoat, and topcoat are applied to the vehicle. The application of these layers is performed by robots to provide a consistent layer of paint to the product. This stage is very sensitive to temperature and humidity, so the environment is tightly controlled within the paint booth. Also, a large amount of air is circulating through the paint booth during operations to help capture overspray from the painting robots.

Finally, the post paint stage is performed where the vehicle is inspected for any defects and the cavity wax is applied. If any defects are detected, the product is either fixed in a repair zone or reinserted into the line to go through the process again. These defects can be very costly to companies as they double the amount of activities which some of their products consume resulting in higher costs and time per vehicle.

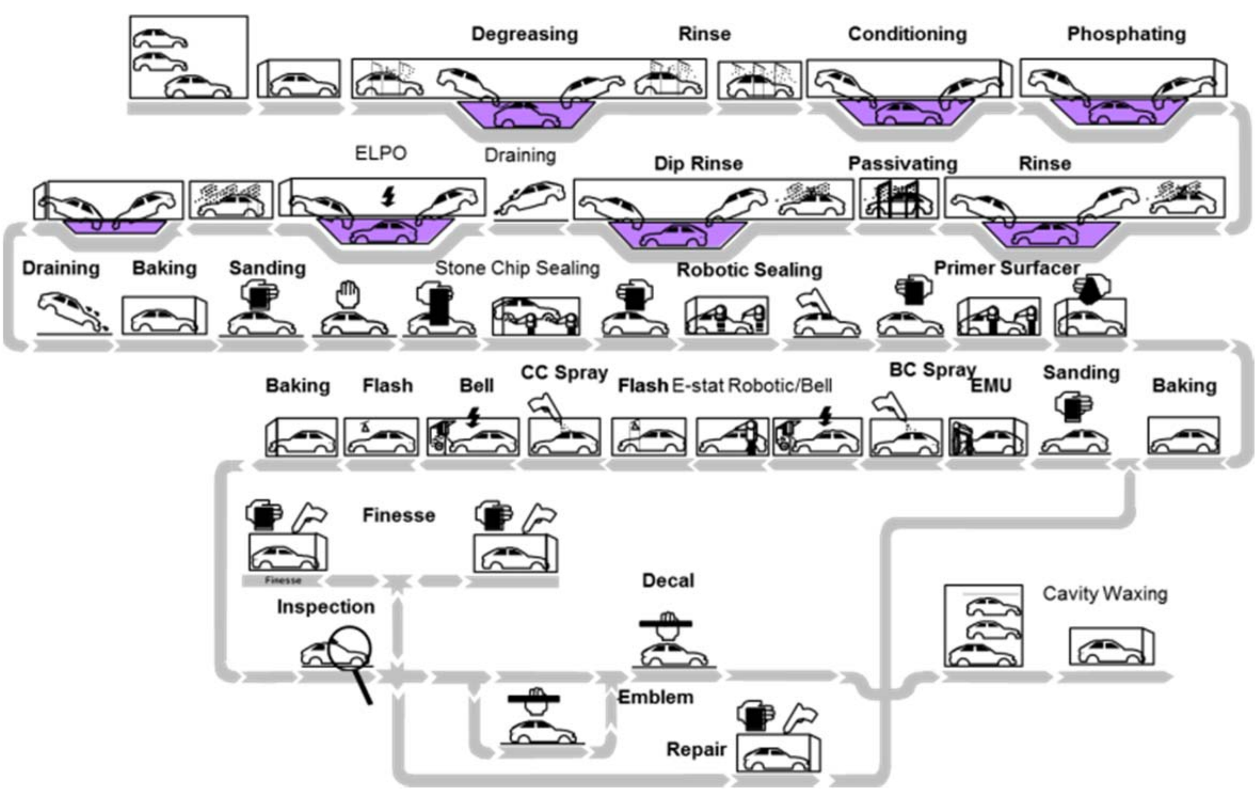

Figure 3 – Product Flow in Paint Process

Each of these processes performs common activities such as moving the product on conveyer belts, controlling the environment conditions such as temperature and humidity, and operating robots. In an ABC model, these can be seen as the activities which consume the resources. As most these activities require equipment to be performed, the resources used by the activities can be seen as the resources used by the associated pieces of equipment, such as electricity or natural gas. Looking at the system in this way provides a basis to develop an ABC model for the paint system of an automotive manufacturing facility. The paint system is not continuously running as it must be put in alternative states from production depending on the production schedule. There are five distinct states which the paint system can be in at any given time and each state has a different energy load characteristic. These states are shown in a Universal Modeling Language (UML) state diagram in Figure 4 along with the transition options from each state. The varying loads for each state must be considered when creating a predictive model to ensure accurate results.

The production state of the system is that in which vehicles are being produced on the assembly line. This state is a high consumer of resources due to most equipment in the facility running at high levels when in this state. During a normal work days, there will be times such as lunch or between shifts when the system can be put in a setback state to save energy. In this state, the equipment of the system is turned down to a lower level or off until production resumes again. If there is an extended period in which the system does not need to run, the system can be put in the shutdown state, in which only a few limited systems are running. This is due to requirements such as minimum air flow, tank turnover for the fluids of the system, and emergency lighting. In this state, the system uses minimal energy.

To transfer from shutdown to a higher level state which uses more energy, the system is put into a startup state. This state is a high consumer of energy because the system is operated at high levels to quickly increase system conditions to operating conditions. This is similar the time when a vehicle accelerates, in which it requires more gas than when cruising or parked. The final state is the maintenance state, in which the system has minimal system requirements for the necessary repairs to be performed. All these states use resources at different loads so it is important to consider these states and the production schedule if using an ABC model for prediction purposes.

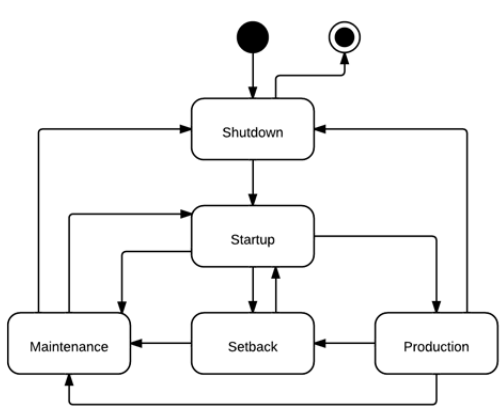

Figure 4 – UML State Diagram of Paint System Operating States

III. SMART GRID DESCRIPTION/DEMAND AND RESPONSE

The main objective of the Smart Grid is to achieve and facilitate interoperable collaboration between energy producer and consumer and to take advantage of benefits of the collaboration, including more efficient distribution of all energy resources, and engagement of energy use patterns in support of business and personal objectives. The most distinct example of market-based interaction in the Smart Grid is the energy Demand and Response program. For a better understanding of the energy Demand and Response program, a simple motivating scenario is described below between an industry customer like GM and local utility company (LUC):

(1)LUC's call option offer: LUC offers to an industry customer a call option offer according to a predefined energy Demand and Response program. The option has an option premium price of \$20/kW and a strike price of \$1/kW per hour for actual energy load curtailments. The option allows exercise at any time during the life of the option that is in the months of June through September. The option is constrained to be exercised during peak hours (12 noon to 8 pm) of weekdays and up to 20 hours per month.

(2) Customer's acceptance of the offer: The industry customer agrees to provide 200kW of load curtailment for a monthly payment of \$4,000 (= \$20/kW × 200kW) for the 4 months of June through September totaling \$16,000.

(3) LUC's exercise of the option: Once the option is contracted, on a certain date in July, the LUC falls into a situation where the overall energy demand increases rapidly and so it needs to exercise the option. The LUC then commands the industrial customer to curtail 200kW from 2 pm to 6 pm.

(4) Customer's load curtailment of usage: According to the contract, the industry customer reduces 200kW from its contracted baseline usage rate. Whether the customer abides by the command is verified through reading of metering devices later on. If the load curtailment is not achieved, the customer is subject to penalty. If the reduction is made per contract, the customer is paid \$800 (= 200kW×4hour×\$1/kW per hour)

This motivating scenario shows that if the industry customer accepts the offer they will be paid both an option premium to participate and a strike price for any requested energy load curtailments. However, it is immediately evident that the acceptance of the offer (i.e., agreement with energy load curtailments) should not adversely affect the customer's productivity or throughput performance or reliability of their mission-critical business processes. To address this issue, Oh *et al*. (2011) studied about the assessment of demand response options using stochastic programming where they proposed an optimal stochastic programming model in such a way that the economic values under the demand response scheme is maximized while the mission critical manufacturing processes are not sacrificed for that maximization [8]. A case study targeting on one of GM's vehicle assembly plants is described in the following section to examine whether the ABC model can address this Demand and Response challenge imposed on industry energy consumer.

IV. Case Study

This case study looked at the usage of four different resources throughout the paint shop. The goal was to understand the drivers of the resource usage in order to create a predictive model for future operations. The resulting ABC model can be used to predict future energy loads given a specific operation schedule and to identify areas of high resource usage to target with future improvement efforts. The focus of the results presented in this paper is on the electricity resource, but a similar process and structure was applied to the other three resources to get similar results.

The resources tracked in this model were compressed air, electricity, natural gas, and water. These were chosen because the use of these resources has the largest impact on the surrounding community. Also, there was readily available information relating to these resources. All four of these resources are provided by local utilities and are the likely to be connected to demand and response contracts in the future. It should be noted that at this GM facility, methane vented from a local landfill is being used to replace natural gas, thus reducing the effect on the environment [9]. Again, this paper will focus on the electricity resource, but the same structure exists for the other three resources.

There were a total of 55 activities identified in the process of painting the vehicle. These were broken down into 11 basic activities (Table 3) each with five discrete states (Table 4). This breakdown of activities was chosen to simplify the model and to correspond to the information which described the operation schedule of the facility. A typical schedule would provide details of the number of hours operated in each state. This would be affected by various factors including the number and length of working shifts.

Table 3 - Activities in Paint Line

Activities
A1 – Air Abatement
A2 – Light Building
A3 – Air Conditioning
A4 – Liquid Heating
A5 – Manual Sealing
A6 – Moving Air
A7 – Moving Liquid
A8 – Moving Product
A9 – Operating Robot
A10 – Lighting Process
A11 – Repairing Product

Table 4 – Example of Activity States

Level 1	**Level 2**
A3 – Air Conditioning	A3.1 – Startup Air Conditioning
	A3.2 – Production Air Conditioning
	A3.3 – Setback Air Conditioning
	A3.4 – Maintenance Air Conditioning
	A3.5 – Shutdown Air Conditioning

The five cost objects chosen in this model correspond to the main sub-processes of the paint shop described above. These along with their relation to the activities and resources can be seen in Figure 5. The cost objects were chosen to be the sub-processes rather than the products going through the line because the products made at this facility are nearly identical. This would result in little difference in their determined costs. It was determined that the resulting cost of each sub-process would be much more valuable to the company.

As the main goal of this model was to predict the overall use of electricity for evaluation of Demand and Response offers, all these cost objects could be combined into one which would be the Paint Shop. However, splitting the cost objects up into these sub processes had a benefit of providing additional useful information to the GM faculty design team. As each person of the design team is specialized in one of these areas, it allowed them to better understand how much energy their section of the system consumed. This has the benefit of guiding these design teams in improvement projects to help reduce energy consumption.

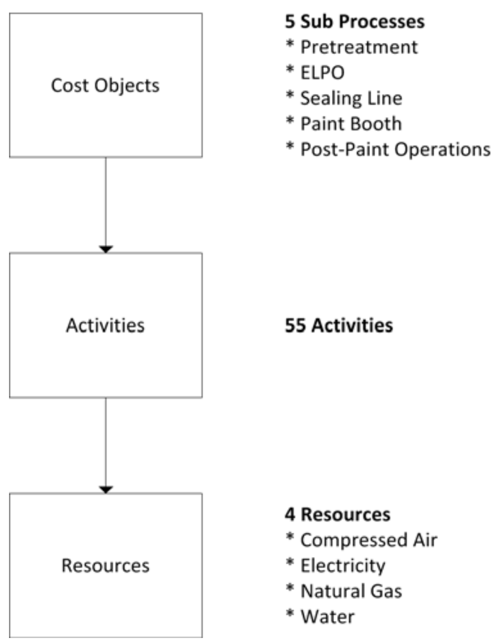

Figure 5 - ABC elements for GM Paint Shop Model

During the data gathering phase, a Bill of Equipment (BOE) was created which included all pieces of equipment in the Paint Shop. This BOE included a short description of each piece of equipment i along with the load ratings R_{ij} for each state j. With the assumption that all pieces of equipment must be in one of the five states (Figure 4) and that the whole system was in a single state at any given time, the total electricity load can be predicted for a future set of time. With the operation hours H known for each state, simple math (Eq. 1) can be performed to calculate the expected electricity load L for that future period.

$$L = \sum_i \sum_j R_{ij} H_{ij} \qquad \text{Eq. 1}$$

With the BOE, the energy rate for each state can easily be determined. Our study results provide some insight into how the operation schedule affects to total energy use. As expected, the startup and production states use the highest amount of electricity, but it was surprising to see that the setback state still uses a significant amount of energy. This information can be used by operation planning personnel to try and avoid these setback states. Our study results also provide the predicted distribution of operation hours for a month of operation and the estimated resulting power consumption from this operation schedule. From this view of the model, it is easy to see that the high load rate of the production state along with its large number of state hours lead this to be the largest consumer of electricity. If an improvement effort were to be made to reduce electricity usage, it should be targeted at the production state as this would have the largest impact on the total electricity use.

An interesting question that the ABC model is able to answer is why these states result in the energy. By using the BOE again to specify which activity each piece of equipment is associated with, the rate of electricity use by each activity can be uncovered. For example, the rate of energy use by the top five activities in the production state for the target GM plant are: (1) move air (2) move liquid (3) heat liquid (4) operate robot and (5) move products. This view can provide valuable insight into why each state consumes. The operations team can easily identify that moving air throughout the facility is their largest consumer of electricity, and can focus on installing more efficient fans throughout the facility to reduce their electrical load. This can be shown for each state, but this has not been included in this paper as it follows a similar process.

With Equation 1, the total electrical load can be calculated for a given system and some interesting pieces of information can be derived with the ABC model. However, with the Demand and Response program, a company must reduce this baseline energy consumption by a specified amount. This is where the ABC model shows its true value by providing a tool to evaluate different energy reducing activities. The following describes a possible scenario where the local utility company requests that the company reduce their electrical consumption by a specific amount for a specific time period during the middle of the day. Two possible options are analyzed with the ABC model to determine if the company should accept the proposal or not.

Given the scenario discussed, one option to meet the load reduction requirement is to change the state of the system to reduce energy load. This could be accomplished if manufactured numbers are not mission critical at the time or if one area has a large buffer that could be filled, and then part of the system could be put in an alternative state while the buffer is filled. For example, a shift of the entire system to the setback state will save some amount of electricity usage while a complete shutdown of the system will save considerable electricity use. It is likely that every system will not have the flexibility to change states due to business constraints, but this was presented as an example of the options provided by the ABC model.

A second option is to modify the process or activities within the paint shop to reduce electricity usage. Our study identified the top five electricity users as mentioned above. Using this data, one can target certain activities to reduce in order to meet the load curtailment requirements. It could be determined to cut the amount of air or liquid moved for a short period of time in order to save in electricity costs. Often the operation specifications of the paint shop are given in ranges allowing flexibility in the actual values of these activities. A possible solution would be to reduce air flow within the entire paint shop to cut the energy usage, and with the ABC model you can determine how much energy you would save for this reduction in air flow.

With a proposed Demand and Response offer from the utility company, General Motors can use this model to evaluate two options which reduce the energy load. They can either change the state of the system or modify the consumption of activities by the system. It is likely that option two will have to be performed, thus this model allows the evaluation of changes GM can make to their manufacturing process to meet the requirements of the offer. Using this model, they can evaluate if they are able to remain within operating specifications while still meeting the electricity reduction requirements. If possible, the offer will be accepted. However, if this is not possible, the offer will be rejected.

In addition to allowing evaluation of Demand and Response offers, the resulting data allows for targeting of future improvements. It is likely that a combination of improvements in the different activities will be necessary to meet this corporate goal, but this allows for prioritization which will result in added value to the final product.

V. Conclusion

In this paper, an Activity-Based Costing (ABC) energy model of the automotive paint shop was created and used to evaluate Demand and Response offers. This model expanded on previous research to specialize in evaluating Demand and Response offers. Smart grid implementation will offer the opportunity to reduce the cost of electricity to customers, but requires the customer to have an understanding of their energy usage and its causes. The ABC model presented here provides that knowledge to the customer along with a mechanism to prioritize future improvement efforts to meet corporate energy reduction strategies.

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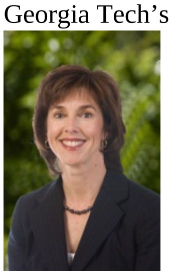
VII. Biographies

Paul Jurek was born in Waterloo, Iowa on November 4, 1987. He is a graduate student at the Georgia Institute of Technology and will complete his Masters of Science in Mechancial Engineering in 2011. He received his Bachelor of Science degree from the Georgia Institute of Technology in Mechanical Engineering.

His employment experience includes John Deere and General Motors. His research and interest is in suistainable design and manufacturing.

Dr. Bert Bras is a Professor at the George W. Woodruff School of Mechanical Engineering at the Georgia Institute of Technology since September 1992. His research focus is on sustainable design and manufacturing, including design for recycling and remanufacture, bio-inspired design, and life-cycle analysis. He has authored and co-authored over a 150 publications. He was named the 1996 Engineer of the Year in Education by the Georgia Society of Professional Engineers and received the 2007 Georgia Tech Outstanding Interdisciplinary Activities Award. In 1999-2000, he was part of a group of experts charged by the National Science Foundation and Department of Energy with evaluating the state-of-the-art in environmentally benign manufacturing. From 2001-2004 he served as Director of Georgia Tech's Institute for Sustainable Development.



Tina Guldberg was born in Michigan, on July 1, 1967. She graduated from the University of Michigan after studying Mechanical Engineering.

Her employment experience includes Ford Motor Company and Georgia Institute of Technology. Her special fields of interest include sustainable design and manufacturing. She currently has research collaborations with Ford, GM, and Boeing Research and Technology in the sustainable design and manufacturing area.

Dr. Jim D'Arcy is a General Motors Fellow in the Manufacturing Systems Research Lab at the GM R&D Center in Warren, Michigan. Since 1978 he has conducted research in support of health, safety, and environmental initiatives in manufacturing and environmental health. Dr. D'Arcy is board certified in toxicology and comprehensive practice of industrial hygiene. He is the recipient of the Frank A. Patty and GM Safety Fellow awards for his initiatives to protect worker health. He holds BS and MS degrees in chemistry from Oakland University and a Ph.D. in industrial health from the University Of Michigan School Of Public Health.

Dr. Seog-Chan Oh received the BS and MS degrees from Dongguk University in 1993 and 1996, respectively, and the PhD degree from Pennsylvania State University in 2006. Before he began his PhD studies, he was an IT consultant for seven years at Daewoo Information Systems. Dr. Oh has been a senior researcher at the General Motors Research and Development Center since 2007. His research interests include wireless manufacturing, network-centric manufacturing, and sustainable manufacturing.

Dr. Stephan Biller is a General Motors Fellow and the Global Group Manager for sustainable manufacturing systems in the Manufacturing Systems Research Lab at GM R&D in Warren, Michigan, USA. Directing internal and external global teams, he has been responsible for the development of the global real-time optimized information enterprise and sustainable manufacturing systems. His technical accomplishments and innovation leadership have earned him distinguished GM awards, including five "Boss" Kettering Awards, GM's highest corporate innovation award. Dr. Biller served as senior editor of Production and Operations Management from 2005-2008. He is currently an associate editor of the Journal of Manufacturing Systems and a guest editor for a special issue on "Automation in Green Manufacturing" of IEEE Transactions on Automation, Science, and Engineering. He holds a degree in electrical engineering from the Technical University of Aachen, Germany, a Ph.D. in Industrial Engineering and Management Science from Northwestern University, and an MBA from the University of Michigan – Ann Arbor.