

Proceedings of the 2011 Winter Simulation Conference S. Jain, R.R. Creasey, J. Himmelspach, K.P. White, and M. Fu, eds. The cost for the cost object in activities is all driven by a "cost-driver" in a manufacturing environment. Examples of cost drivers are weight, size, and time, or combination of weight multiplied by transportation distance. The connection of activities in a DES model will be direct without any big implementation difficulties.

**Cost Classification.** There are a couple of levels where costs for a product can originate. Costs then allocate from a high level down to a lower level depending on activities by a lower level, or equally as a static cost. For example, facility costs can be allocated to the batch level or unit product level directly depending on the actual area usage of the batches at the facility.

- o Unit level, each time a cost object uses an activity, e.g. processed in a machine.
- o Batch level, each time a batch use an activity, e.g. store in temporary storage.
- o Product level, supporting activities for all of the products, e.g. product marketing.
- o Facility level, overhead cost for the facility where the unit currently is.

In a DES model, this allocation is a direct implementation step. The location for the product in the model is a direct base for collection of different costs in multiple layers and activities. The costs can then be allocated down or summed up in the level hierarchy to analyze costs at different levels.

894 Andersson, Skoogh, and Johansson Identify cost allocation methods is to connect costs to activities. It is especially important to establish a method to allocate overhead costs that apply to the facility level. Analyzes on how overhead costs should be applied to either the individual unit or product is vital for a good ABC analyze. Analyzes of the cost result is a key strength of ABC modeling. In ABC, it is possible to track down the origins or sources of the costs. The DES approach would add extra dimensions and features to analyze the cost of activities in more detail. The DES model could show if there are major variations in costs for individual products and analyze the robustness of the system (Gunasekaran 1999).

**3 ENVIRONMENTAL CALCULATIONS USING ACTIVITY BASED COST** Emblemssvag and Bras (2000) developed a method to include environmental impact analysis in ABC modeling. The method has been tested but it is rarely used in practice. Emblemssvag and Bras (2000) stated five purposes to use their method instead of the standardized LCA (ISO 14041 and ISO 14044) method (European Commission 2010). The purposes are:

- o Their method yields results that are simpler to compare, which should eliminate one of the biggest criticisms against LCA.
- o The method is able to analyze costs and environmental effects at the same time based on well-proven techniques from ABC method.
- o ABC is the only approach that has been demonstrated to handle overhead costs in a credible way.
- o LCA focuses on one product at a time, whereas ABC is able to address all products at the same time.

Focusing on only one product could miss economy-of-scale effects, which in turn could lead to wrong conclusions. (Emblemssvag and Bras 2000)

- o The approach takes advantage of well-proven experiences and matured ABC techniques. Studies have been performed analyzing the best practice on how to decide on the allocation of climate cost to individual units. One of the most common questions asked while designing the driver is, "what has to be done to produce the product type that are increasing the total environmental impacts for the plant, and how is it increasing"?

**ENVIRONMENTAL ACTIVITY BASED COST USING DISCRETE EVENT SIMULATION** ABSTRACT Jon Andersson Anders Skoogh Bjorn Johansson Chalmers University of Technology Product and Production Development SE-41296 Gothenburg, SWEDEN Discrete event simulation (DES) provides engineers with a flexible modeling

capability for extensive analysis of a production flow and its dynamic behavior. Figure 1: LCA and DES are linked with ABC as a bridge

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### 1.3 Criteria for Approach Evaluation

The criterion for evaluation compares if there are any advantages of using ABC in DES for environmental impact analysis over a static LCA analysis. A static model lacks the capabilities to analyze a system's dynamic behaviors, e.g., economic and environmental impacts of machine operations, breakdowns, and variations in cycle times. Bringing all three areas together, an ABC environmental simulation could provide deeper understanding about environmental impacts in the manufacturing processes than a regular Life Cycle Assessment (LCA) analysis. The paper examines two approaches/methods; ABC calculations combined with DES and ABC calculations with environmental impact analysis. Very often, environmental impact analysis is based on static methods such as Life Cycle Assessment (LCA), which is a common and standardized method (ISO 140040 and ISO 14044) (European Commission 2010). However, it is extremely time consuming and costly to perform a detailed ABC calculation because there are simply too many products and activities combinations of manufacturing operations on the shop floor (Spedding and Sun 1999). When drivers (weight, volume, area) for costs are defined, it is possible to use DES model to allocate fixed overhead

893 Andersson, Skoogh, and Johansson costs down to individual batch or unit of product. Figure 4: Major parts of activity-based LCA design model by Emblemssvag and Bras (1999)

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### 3.1 Allocation of Environmental Impact Costs using ABC

To perform a robust environmental impact analysis, many different factors must be considered. Table 1: Allocation examples in a production environment

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### 4 DES ACTIVITY BASED ENVIRONMENTAL IMPACT ANALYSIS

The link between environmental impact calculations and DES with the help of ABC is shown to be self-evident. Many of the problems of environmental impact calculations are consistent throughout all environmental impact estimation methods, e.g. quality environmental impact data is hard to get and hard to verify. However, there is no evidence that problems are increased while using the methods combined as of now. For a company that both want to use DES as a tool and at the same time need environmental footprint analyses, the merged methods has the advantage of investigating environmental effects and concurrently analyze economical and production key performance indicators (KPI). Extensions and improvements of the usability in simulation models would greatly benefit DES as an analysis tool, and thus, making it more worthwhile to use. Several studies have shown that environmental labeling of a product provides a positive and competitive advantage for companies if the work is communicated to customers (Gallego-Alvarez et al. 2010; Russo and Fouts 1997).

### 1.2 Objective

The objective of this paper's research is to evaluate the feasibility of performing environmental impact analysis with DES models using the ABC framework.

### ACTIVITY BASED COST IN DISCRETE EVENT SIMULATION

ABC calculation is a well-known method for analyzing, allocating, and distributing costs for operations to products or services. The ABC calculation adds a deeper understanding to the original sources of cost and help engineers find low-profit products in a multi-product manufacturing environment. The International Reference Life Cycle Data System (ILCD) Handbook (European Commission 2010) provides best practices in LCA projects for companies.

| Costs | Machine | Energy costs | Auxiliary machine support | External transport | Internal transport | Machine Maintenance/ Set-up | Product Support-ing |
|-------|---------|--------------|---------------------------|--------------------|--------------------|-----------------------------|---------------------|
|       |         |              |                           |                    |                    |                             |                     |

Functions System Maintenance Facility Costs Cost level Unit Unit Unit/Batch Unit/Batch Batch Product

Product Facility Resource/cost driver Machine time an unit is manufactured. The inability to allocate overhead costs for multi-purpose processes is a major weakness and criticism on LCA (Reap et. al. 2008).

#### 4.1 Case Example A study on a manufacturing company was conducted to analyze implementation of ABC in DES with environmental footprint analysis.

For manual station, welding station, and paint shop, static environmental impact method was used to account for the use of shield gas, welding rod, and paint for each 898 Andersson, Skoogh, and Johansson unit. In any case, it is important to declare environmental impacts for all stages of product lifecycle, that is, raw material extraction/production, production, usage and maintenance, and recycle. Activity based costing (ABC) modeling can provide additional knowledge about the monetary costs related to the manufacturing processes in DES. This paper proposes to use ABC modeling in conjunction with DES to perform a more detailed economic and environmental impact cost analysis.

Products 978-1-4577-2109-0/11/\$26.00

(C)2011 IEEE 891 Andersson, Skoogh, Johansson and Leong that come with a declaration of environmental impact have a competitive advantage over those without even though the product without the declaration might be more environmental friendly. A recent study by MIT Sloan (Haanaes et al. 2011) has shown that more than 90 % of manufacturing companies in a wide range of industries believe that pursuing sustainability is necessary to be competitive. If the environmental impact analysis is performed, using a DES model, accuracy can be improved and less rework is required for future LCA analyses. Previous papers studied the possibilities of combining ABC calculations together with DES models (Beck and Nowak 2000). EcoProIT aims at develop a tool, which can be used by industry for evaluating and marking product environmental footprints throughout the product's lifecycle. Related problems to the separated approaches ABC in a DES environment and environmental impact analysis in ABC models should be reduced or be equally extensive. This paper examines and studies a few common impact categories such as carbon footprint, Global Warming Potential (GWP), and acidification. Hence, the coupling between DES to ABC is possible and furthermore the environmental impact calculation to ABC correlates with the foundation of the ABC method. Sensitivity analysis could provide analyst with information about possible strengths, weaknesses, and relative importance of factors in the calculation. The ability to track and trace the costs to environmental factors is an important feature for standard ABC calculations as well as for activity-based environmental impact analysis (Cohen, Venieris, and Kaimenaki 2005; Emblemssvag 2001). When activity-based environmental impact analysis is implemented into a DES model, the cost can be tracked down to individual units and to environmental impact sources. Indirect costs from supporting functions and facility are allocated to the product level by use of the dedicated storage area for the examined product and its components compared to dedicated storage area for all products. Thus, previous studies have separately brought ABC into DES and ABC into environmental impact analysis.

#### 1 INTRODUCTION

Discrete event simulation (DES) is a powerful tool for analyzing and evaluating production flows without affecting the production. It elaborates the benefits of the synergistic effect of the combined approach and the problems associated with the method. A DES model can be used as a sandbox system to run experiments to evaluate, not only the efficiency, but also the environmental impact and the real economic costs of production. The inputs are energy

and raw material while the outputs are the product, carbon dioxide emissions, toxic materials, and waste. These studies have investigated the advantages of performing environmental impact analyses using ABC calculations. It discusses a method to analyze the environmental impact of a product using ABC calculation in combination with DES models.

**Activity Based Cost Model Traditional Cost Model**

**Figure 2: A conceptual ABC model and a traditional cost model**

The multitude of problems encountered while designing an efficient ABC model makes good support software essential and necessary. Beck and Nowak (2000) investigated how to merge DES with ABC calculation. Moreover, in Spedding and Sun's (1999) investigation, it was concluded that DES could help solve some of the issues in allocating and distributing overhead cost to resources with ABC. For example, allocation of the heating cost for product produced at the production site could be computed by accumulating the amount of time a batch of product spent at the site and by the area for which a produced batch is occupying or stored. Indirect environmental impacts are those that originate from supporting resources such as facility, support organizations, and maintenance or repairs. It is a challenge when modeling an ABC calculation to distribute the indirect expenses such as administration, facility, and labor costs to the products. Many of the indirect costs are allocated preferable with time as an impact driver. Hence, a DES environment could support implementation of these recommendations from the handbook. Environmental impact costs are added as terms to an impact function:  $\text{Environmental impact costs} = \text{Raw material costs} + \text{Transport costs} + \text{assembled parts costs} + \text{assembly costs} + \text{packaging costs} + \text{overhead costs for time in factory} + \text{delivery costs}$ . The cost vector for the Assembly station could be a function as: As other cost vectors are added, the function is growing.

**4.1.1 Case Background** The manufacturer being studied is a supplier of machined parts to the Swedish industry with approximately 20 employees. As output, the case example is using Global Warming Potential (GWP), which includes several types of emissions and represents them as CO<sub>2</sub> equivalents. The individual cycle time of the batch/unit through the workstations is easily modeled and tracked in a DES. Depending on the type of product and processes, the ratio between environmental impacts of different life cycle phases can differ a lot. DES is mainly used for evaluating process improvements and justifying investment decisions. It deliberates on the opportunities of using the ABC approach in a DES environment to investigate the environmental and economic costs of a production system. A study made by Thiede, Herrmann and Kara (2011) analyzed the current state of art in using DES to study a multi-machine production system with environmental issues. The criteria are defined to achieve a fruitful and better use of both LCA and DES in combination rather than using the two methods on their own. Their studies shown that an ABC calculation fits properly and can be implemented with minimum effort into an existing DES model. The cost objects are represented in the DES models as products produced in the simulation. Moreover, Emblemssvag and Bras (1999) presented a schematic method for designing an activity-based LCA model. It is possible to connect direct environmental impacts to individual products while further definition and analysis are needed to account for indirect environmental impacts. The handbook describes, among other things, allocation policies for costs in a multifunctional environment and provides example on allocation problems for several common overhead costs. It is then possible to analyze the effects of individual products in a dynamic 897 Andersson, Skoogh, and Johansson model. Nevertheless, there is still no

formal standard method to account for and effectively allocate environmental impacts cost. There are many criticisms on the standard method LCA, which mainly originates from the subjective steps of the analysis. As new products and processes are introduced, dynamic effects that are hard to analyze using a static LCA tool can be performed with the proposed approach. However, from a marketing point of view, it is beneficial to declare environmental footprint incurred from production. "The merger of discrete event simulation with activity based costing for cost estimation in manufacturing environments." To enable pervasive and wider use of DES by companies on a daily basis, DES tools should be made more user friendly, more analytical and provide decision support. This paper reviews how ABC can be used to allocate environmental impact costs to batches or units of products. Despite of the benefits, the adoption rate of ABC among companies is as low as around 10–30 % depending on the size, location, and type of company (Cohen, Venieris, and Kaimenaki 2005). The model will track the total areas for all the batches at the site and distribute e.g. heating costs accordingly among the batches of products.

## 2.1 ABC Implemented using DES

There are multiple methods available for designing an ABC model. Figure 3: Five generic steps in ABC calculations

1. Identify the cost objects is an inventory on the products/services that carry costs in the organization. In an environmental footprint analysis, any undefined number of outputs can be evaluated. Studies have found that there are correlations on calculating environmental impacts and economics costs (Emblemsvag 2001). These categories can be mapped to environmental impact, i.e. direct environmental impact and indirect environmental impact. Allocation of overhead (indirect) costs to a batch or unit of product is an important function in ABC modeling. In a DES-ABC approach, the DES-tool can easily implement such a feature. When ABC models are used consistently in the organization, it is easy to add new cost objects to the existing ABC models (Emblemsvag and Bras 1999). Emblemsvag and Bras (1999) study had over 60 % correlation in cost drivers on the unit level between economical cost and energy consumption. The company has a job shop with Computer Numerical Control (CNC) machines, cutting machines, a welding station, a paint shop, and assembly stations. The company produces multiple custom made products using a functional layout. Hence, it is more vital in this case to improve product design and used components than to improve production processes. Auxiliary media usage for CNC machines was added to the unit level using machine time as allocation method. It is especially true in the inventory phase because many assumptions must be made to limit the scope of the system (Reap et al. 2008). The ABC approach for environmental impact analysis in a DES model is a feasible method. The approach is synergistic with calculating economical costs for products. The approach that has been presented helps evaluating environmental impact from the production phase, but it can theoretically be expanded to include the other phases. It is emphasized that the time to perform both analysis in one simulation is shorter or equal to perform them separately.
- 1.1 Background There is an increased need to analyze and present environmental impact of manufactured products. Dynamic models, on the other hand, provide deeper understanding of complex production systems and determine the sources of the environmental impact. This paper evaluates a combination of existing methods to use for the environmental calculations in the tool. It should be cheaper or less time consuming to use the proposed approach compared using both DES and LCA separately. Analyze the activities is an enumeration of the activities performed to the

cost objects. The scope and purpose of the analysis defines the needed input and output. Often times during the study, the analyst is compelled to make assumptions that may significantly influence the end result. As long as the products are continuously processed through the production line, environmental costs are captured and added to the product. An iterative approach is preferred when performing an environmental impact analysis. Thus, it is supportive and important to do a sensitivity analysis (Emblemsvag and Bras 1999; European Commission 2010). The study supports the conclusion that it is feasible to combine ABC with LCA. External outsourcing dependencies are added as static impacts to the product level. Moreover, it could also show how standardized working methods could minimize environmental impact. However, most of the drivers in the model would correlate to economic measurements. The case example indicated that DES is a viable tool for environmental analyses. The comparison result supports that the model was comparable to a LCA analysis in terms of LCA output results. However, the method does not improve the speed of implementation for an environmental impact analysis. Compared to a static LCA approach, it is possible to analyze dynamic effects in production and for new improvements of production.

"ABC: adopters, supporters, deniers and unawares."

"Integrating Economic and Environmental Performance Measurements Using Activity-Based LCA."

"Are social and environmental practices a marketing tool? Empirical evidence for the biggest European companies."

Lindskog, E., L. Lundh, J. Berglund, Y. T. Lee, B. Johansson, and A. Skoogh 2011. In addition, ABC modeling has been proposed as a tool for environmental impact analysis. It concludes with a discussion on the criteria used to evaluate the approach described. The researchers explored twelve approaches; the main is the material flow approach. Besides economical costs, environmental impacts can be analyzed as costs as well (Emblemsvag 2001). In the literature review and the case example, the criterion is used to evaluate if the solution is better than LCA or not. The environmental impact analysis should be less or as dependent on the analyst as using an LCA analysis by itself. The method is able to reveal the real production cost for the products, and traces costs more easily to their origins. ABC accounting is more adaptive and a better representation of the real costs in production and organization compared to traditional cost accounting. Nevertheless, there will always be decision problems in coping with allocation of overhead costs. The complexity of allocating overhead costs is discussed in Emblemsvag and Bras (1999). A product that carries a bigger portion of overhead costs will lead to a lower overhead costs for other products. Product A will have to carry more of the overhead costs from heating and administration. The original method included energy consumption and a waste index. An activity-based LCA design is presented in Figure 4 and it is in general terms similar to the ABC method. Because of continuous research, new environmental footprint measurements are considered. It correlates well also to economic ABC accounting. Time and area the batch occupies the facility. DES keeps track of machined batches. Static cost. DES tracks the time and area the batch occupies the facility. To avoid conflicting end results, sensitivity analysis is important to mitigate the risks. In a dynamic model, sensitivity analysis is done preferably using a computer. In Figure 5, the individual impact terms are functions that results in a vector of environmental costs. The model provides information about the origins of environmental impact costs for every product (Emblemsvag and Bras 1999). The allocation of overhead costs is an important problem, which can partly be solved using a DES

approach. To-date, the allocation task is still done on an ad-hoc manner and it is still dependent on the ability and skills of the analyst. The case example is partly based on a case description that is provided by Lindskog et. al. (2011). For activities in the CNC and cutting machines, the used electricity for the machines was measured in a data collection phase. The energy used while the machine was busy was directly allocated to the individual unit. Usage of Auxiliary media per machine time was approximated in a data collection phase by total usage divided by total machine time. The time for welding and painting is varying and affects the energy used in the stations. A detailed study on the working method in the manual stations would definitely result in a better cost model. For an economic analysis, it would require costs data such as labor costs, marketing costs, and administration costs. However, you will get a better understanding on the sources of impact and other benefits from regular DES analyses are available within the same model. In some cases, major differences exist in databases and in the variants of material used in the study, for example, steel. For electrical consumer product, the environmental impact from usage phase is usually higher than the production phase. For example, a design change that makes a product more efficient to produce could increase environmental impact during the usage stage or recycle stage. "Diffusion of Discrete Event Simulation in Swedish Industry." "A survey of unresolved problems in life cycle assessment." "State of Research and an innovative Approach for simulating Energy Flows of Manufacturing Systems." Moreover, the approach can resolve some LCA problems. It does most often take much time and effort to build a sound DES model that accurately mimics the behavior of a production system. It is difficult to estimate the impact of dynamic changes to a complex production environment using such a static model. It analyzed sustainability factors of the machines in the production system. It has been shown that ABC can be used in a DES environment to analyze costs. The following criteria are used:

1. The approach should be able to provide equal or more information compared to using DES and LCA separately. Important steps on how to perform the ABC design is described by Gunasekaran (1999). In a manufacturing environment, it is often a matter of end products and major premade parts. Then Product B and C will carry less overhead costs, which translates to a lower environmental impact. The document can serve as the framework for allocating overhead costs. The cost level was introduced in section 2.1 and represents the associated level for the overhead costs. From the cost level, cost can be allocated to all the individual units for summation of unit level impact costs. Equally allocated by time at the machine during a production period, e.g. one day Share of product value in turnover. From product, the cost is allocated equally to the number of products. The cost is allocated equally to the number of products. For three-dimensional storages, volume is used. Static cost Transport is simulated and time tracked. The problem could be solved by using a combination of ABC in DES and LCA. One product in the production flow was analyzed using DES software. The total impact was mainly dependent on raw material and purchased components.

#### 4.1.2 Case Result and Lessons Learned

To limit the scope of the case, only one product was examined even though it is a multi-product site. The allocation approach gave the best representation for the actual facility usage by the product. The energy used during idling was allocated to the batch level according to the time batch was using the machine. In a general case, the impact from wasted product would be put on the product level and allocated equally to the individual units. The case study was compared with a simplified LCA

analysis. The LCA method comparison was used to validate the concept. To make LCA analysis comparable, the same data must be used. Making assumptions may affect the calculations and its outcome as well as in decision-making based on the calculations. The analyst will still take the same amount of time and resources to collect data and perform environmental cost impact calculations. Hence, in comparison the impacts from production will only have a minor effect on the total environmental impact. This presents possibilities to analyze how a product change could impact different stages of the product lifecycle. DES is a tool for highly skilled specialists. It is difficult for an untrained person to make use of the tool. "Activity-Based Costing In Cellular Manufacturing Systems." "A framework for the design and audit of an activity based costing system." "Sustainability: The 'Embracers' Seize Advantage." "A Resource-Based Perspective on Corporate Environmental Performance and Profitability." However, only few companies use DES technology on a regular basis (Ericsson 2005). This need is driven by government regulations as well as by consumer's interests. Once such a model is developed, it is important to use it for as many beneficial purposes as possible. Figure 3 shows a schematic image of such an ABC design. The waste index is out of scope for this paper. Costs can be categorized as direct and indirect costs. An important step is to decide on the drivers for different products' costs. Table 1 shows common costs and how it is coupled to a DES environment as well as the cost level. Total cost for Auxiliary machine support is shared by all units of products. DES model tracks the system usage. Instead of summing the costs directly, it is possible to include additional terms to an impact function. Figure 5: An example of a simple production line to exemplify activities in production. It is then possible to perform sensitivity analysis on the entire function. That is to analyze the impact function and trace the costs to the individual activity and individual resources. The power of ABC lies in the level of details it provides. Likewise is the level of details also become its biggest criticism. The time in facility is used to allocate facility cost from product level to batch/unit level. This would give a more accurate model that would reveal problems with time variance. Wasted products are not taken into consideration in the case study. In the case, no economic costs were analyzed. The activity-based environmental cost approach fits in the DES environment. Experience from the case support the fact that the DES approach takes more time to implement. 5 DISCUSSION Environmental impact calculations are complicated. "Activity-Based Life-Cycle Costing." *Managerial Auditing Journal*, 14(3): 118–126. Haanaes, K., et al. 2011. MIT Sloan Management Review, 2011: Winter: 1–27. "Industrial and Management Systems Engineering." "Application of discrete event simulation to the activity based." This is the first paper for the project called EcoProIT (2011). For example, after a change in production flow, product A has to increase the time it spends in the storage. Time an unit of product is machined. Time or distance and mass or volume. Time and mass or volume. Depending on the amount of time the system is used to support the product type. Solved in Actual machine time is tracked in the model. Machine time is tracked in the model. It takes much resources and time to design and support an ABC system. However, according to Gunasekaran (1999) it is often well worth the time. Changes to improve the case are suggested and discussed. This example is focused on the internal processes. Three different machine states were used: idle, busy, and down. In the case example, the environmental impact for the production was low compared to the impact from the raw material. To effectively use the tool, training is



required. Gunasekaran, A. 1999. 2.3.4. Many of these problems are hard to avoid. *Management Decision*, 48(10): 1440–1455.