DYNAMIC ANALYSIS OF COST MODELING FOR PRODUCTION LINE

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***Abstract*: The proposed methodology is a dynamic activity-based costing method that relies on real-time production line data to track costs, specifically the costs of unused capacity and the added costs due to downtime events such as machine breakdowns. The methodology aims to trace these costs to responsible cost centers, activities, and stations on the production line to give a better representation of the total cost of production, specifically in regards to normal manufacturing costs, added downtime costs, and added costs from excess capacity. In addition to monetary costs, the methodology provides a framework for tracking environmental "costs", such as energy use and waste, in order to aid plant managers with determining the environmental impact of their operations. Methodology addresses a gap between activity-based costing and downtime costing by combining the two under a single methodology. It traces both monetary and environmental costs to cost centers on the manufacturing line to aid continuous improvement efforts and the allocation of resources. By using real-time data, the methodology alerts management to changing system performance in a shorter timeframe than static costing systems. The methodology quantifies system performance in monetary values, which elicit more emotion and attention than traditional non-financial production metrics. The methodology is shown in a case study of an automotive assembly plant. Specifically, the case study models the cost and resource use of an automotive paint shop and trace this resource use to specific areas of the paint shop to highlight possible areas for improvement. The case study provides results that show how the proposed methodology can allocate costs to normal production and the added costs of downtime and unused capacity. The case study splits these costs over the modeled case study stations and highlights possible areas of improvement. This work primarily focuses on the development of the methodology and a framework for implementation. This thesis does not address the logistics of implementing a costing system based on the proposed methodology using actual automated data from actual production line data acquisition systems. Additional work is needed to address this logistics and to further refine the method.**

***Keywords*: dynamic activity, real-time production line, automotive assembly plant**

Introduction

A **production line** is a set of sequential operations established in a factory where components are assembled to make a finished article or where materials are put through a refining process to produce an end-product that is suitable for onward consumption Typically, raw materials such as metal ores or agricultural products such as foodstuffs or textile source plants like cotton and flax require a sequence of treatments to render them useful. For metal, the processes include crushing, smelting and further refining. For plants, the useful material has to be separated from husks or contaminants and then treated for onward sale.

An **assembly line** is a manufacturing process (often called a *progressive assembly*) in which parts (usually interchangeable parts) are added as the semi-finished assembly moves from workstation to workstation where the parts are added in sequence until the final assembly is produced. By mechanically moving the parts to the assembly work and moving the semi-finished assembly from work station to work station, a finished product can be assembled faster and with less labor than by having workers carry parts to a stationary piece for assembly. Assembly lines are common methods of assembling complex items such as automobiles and other transportation equipment, household appliances and electronic goods.Workers in charge of the works of assembly line are called **Assembler**.

Developing new products is an essential part in many firms to maintain profitability. To get a realistic assessment whether these new products meets the profitability expectations the firms need to make early estimates of the costs associated with the product. An early cost estimation of the product serves as an important tool in assessing profitability and supports decision making in the future development of the product. Product costing centers around calculations of cost and/or revenues derived from a specific object, such as a product or service. Product costing can be used prospectively to estimate potential future costs and revenues associated with a product. These cost estimates can be used to support various decisions regarding a product. For new products a cost estimate can be used to support decisions regarding the following: which products to pursue, at which production volume, and through which production processes. However, the cost estimate needs to reach an adequate level of precision to base decision upon it.

The process of product design is driven toward achieving design specifications while meeting cost targets. Designers typically have models and tools to aid in functional and performance analysis of the design but few tools and little quantitative information to aid in cost analysis. Estimates of the cost of manufacture often are made through a cost multiplier based on material cost. Manufacturing supplies guidelines to aid in design, but these guidelines often lack the detail needed to make sound design decisions.

A need was identified for a quantitative way for modeling manufacturing costs at Motorola. After benchmarking cost modeling efforts around the company, an activity-based costing method was developed to model manufacturing cycle time and cost. Models for 12 key manufacturing steps were developed. The factory operating costs are broken down by time, and cost is allocated to each product according to the processing it requires.

Although the majority of a product's cost, typically about 80%, is determined early in the design stage, many decisions about the design are made during this stage with little knowledge of the effect on downstream cost centers. Manufacturing costs, in particular, are difficult to estimate and depend on many factors. Design decisions that affect the cost to manufacture the final product often are based on rules of thumb or the urging of experienced manufacturing engineers. Several models attempt to quantify the "manufacturability" of a design. The popular Boothroyd-Dewhurst index, for example, builds an estimate of design manufacturability relative to factors such as assembly complexity and number of parts. Other models attempt to quantify design for X metrics to guide design decision making or model trade-offs between design goals. These methods provide an assessment of the worth of the overall design but, in their effort to remain generally applicable, do not necessarily capture the economic aspects of the design with the rigor needed for design decision making. More often, these methods ask designers not only to be experts in the technical aspects of design but to understand how the design may affect other aspects in the product's life cycle. Sullivan (1991) noted that a paradigm shift is occurring in engineering economy as a result of the "engineer's role in strategic and design-related decision processes." Indeed, new approaches to addressing economic concerns in the design process are needed.

1.1 Four types of production

There are 4 different types of productions which are most commonly used. Which type of production should be used by the company depends on the type of product being manufactured, the demand of the product as well as the supply of raw materials. Taking these factors into consideration, below are the 4 types of Production.

1) Unit or Job type of production

This type of production is most commonly observed when you produce one single unit of a product. A typical example of the same will be tailored outfits which are made just for it or a cake which is made just like want it.

2) Batch type of Production

It is one of the types of production most commonly used in consumer durables, FMCG or other such industries where there are large variety of products with variable demands. Batch production takes place in batches. The manufacturer already knows the number of units he needs to a manufacturer and they are manufactured in one batch.

So, if a manufacturer has the shortage of Product X and 100 units of this product is consumed in one month, then the manufacturer can give orders for batch production of 100 units of Product X.

3) Mass Production or Flow production

One of the best examples of mass production is the manufacturing process adopted by Ford. Mass production is also known as flow production or assembly line production. It is one of the most common types of products used in the automobile industry and is also used in industries where continuous production is required.

An Assembly line or mass production plant typically focuses on specialization. There are multiple workstations installed and the assembly line goes through all the workstations turn by turn. The work is done in a specialized manner and each workstation is responsible for one single type of work. As a result, these workstations are very efficient and production due to which the whole assembly line becomes productive and efficient.

4) Continuous production or Process production

There is a lot of confusion between mass production and continuous production. It can be differentiated by a single element. The amount of mechanical work involved. In Mass production, both machines and humans work in tandem. However, in continuous production, most of the work is done by machines rather than humans. In continuous production, the production is continuous,24×7 hours, all days in a year.

Dynamic ABC Method

System Definition and Scope

The system of interest for this methodology is a manufacturing line. Specifically, the production line of interest for this methodology is assumed tohave automated data acquisition systems that already provide plant management with information about line behavior. The methodology aims to use this previously captured information in a different way in order to more accurately assess costs, particularly the added costs of downtime and excess capacity in the short term. By presenting this previously captured information in monetary units, the proposed methodology presents system behavior in a way that is more in line with the financial goals of the organization than nonfinancial performance metrics as suggested by Karlsson and discussed. This example examines a fictitious internal combustion engine assembly line. This engine assembly line is presumed to be highly automated and, therefore, has a sophisticated data acquisition and information technology systems. The example will be discussed in more detail in Section 3.4 after discussing the general methodology in more detail.

The case study presented in Chapter 4is applied to an automated paint shop at an automotive assembly plant. This paint shop is heavily automated with robots and conveyor systems doing the bulk of the work. The example production line of this case study will be discussed in more detail with the presentation of the case study.

Methodology Development and Overview

The methodology draws mainly from traditional activity-based costing as proposed by Cooper and Kaplan(Cooper and Kaplan 1988).Activity-based costing follows the idea that cost objects consume activities which, in turn, consume resources. Activity-based costing is logical in its approach because when a cost object such as a good or service is created, there are a combination of performed activities to deliver the end result. For instance, these activities could be machining activities or shipping operations. Every activity requires at least one resource and could require several resources. Example resources include electricity, water, labor, raw materials, and supplied components. Figure 3-1 shows the flow of consumption from resources to activities to cost objects.

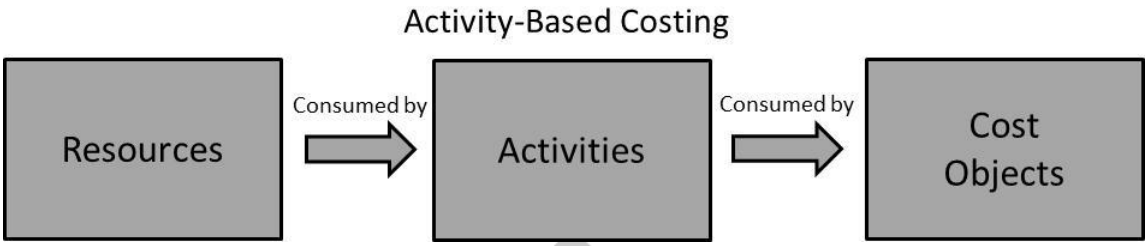


Figure Error! No text of specified style in document.**.1: ABC Consumption Flow**

The concept of ABC is easily understood in a manufacturing environment. For example, one can look at the production of a wooden baseball bat. In this example, the lone cost object may be the wooden baseball bat. There are many activities that are performed to produce this cost object. An activity is any process or task that is performed within the system being studied, in this case a baseball bat production line.Some activities directly alter the bat from a split of wood into a finished product such as shaping or staining the bat. In addition to these direct activities, there are several indirect activities, such as material handling, maintaining production equipment, or even lighting the production floor. All of these activities, both direct and indirect, help to create the cost object, in this case, a wooden baseball bat.Just as a cost object cannot be created without activities, activities cannot be performed without resources. The concept of resources is fairly intuitive.A resource can be anything that is used during the completion of an activity. In the baseball bat production example, resources could include the wood used to make the bat, the machines used to shape the bat, and workers that operate the machines.Resources and activities are consumed in specific amounts. The rates of consumption are characterized by resource drivers and activity drivers. Resource drivers describe the rate of consumption of each resource when an activity is performed. Activity drivers describe the rate of consumption of each activity as cost objects are created. These consumption drivers can be defined in many ways. For example, an activity driver can be defined on a "per job" basis. In this case, for every cost object produced, there would be a specific unit of the activity consumed. Likewise, consumption drivers can be defined on a per unit time basis such as an hourly labor rate.Development of an activity-based costing system is largely up to the designer. An ABC system can be defined on any reasonable scale, from the facility or company level to the most basic activity level. The scope of the ABC system should be defined at the level for which the system will most directly impact. ABC systems developed for creating external reports, for instance, will be quite different than ABC systems developed to aid management on a specific production line.

Returning to the previous baseball bat example, one has a wide array of choices for the level of detail with the choice of activities alone. When defining the direct activities in this example (and disregarding indirect activities such as maintenance and material handling), one could simply define two activities, creating the bat and testing the bat. Alternatively, one could break these two activities down into sub-activities. The creation activity contains many sub-activities: selecting appropriate wooden splits, lathing the wooden splits into billets, seasoning the billets to remove sap and gum, lathing and sanding the billets into bat shape, and varnishing or painting the bat. One could continue to break these sub-activities down further and further.With the development of any system, it is important to properly define the scope and level of detail that will produce the wanted results, ideally in the simplest way. Information comes at a price. As the level of detail increases, the costs of achieving that level of detail increase. It is similarly true that when the scope of the system increases, the costs of the system increase. It is important to strike the right balance between costs and benefits. An ABC system is useless if it does not capture enough information to increase the user's knowledge of the system of interest and help the user make better decisions. Conversely, an ABC system that captures too much information may be too costly or too unwieldy to implement or, more importantly, maintain.Static activity-based costing systems may rely on intermittent updates to keep the information contained within up-to-date. If the system is large or the data is not automated, maintenance of this system quickly becomes unwieldy, and the benefits of the system could quickly be outweighed by the negatives of maintaining such a system. If the system is smaller in scale and/or uses automated data, maintenance is significantly easier, and the benefits of the system become readily apparent.

Much data is already captured by modern manufacturing lines. This data corresponds to statistics such as production counts, throughput, cycle time, or availability. In order to ease the level of effort required to develop a dynamic ABC system, it is important to structure the system around the data types that are already captured by line equipment as much as possible. By structuring the dynamic costing system around the data that is presently available, one minimizes the amount of additional data that needs to be captured manually.For instance, a dynamic ABC system may use automated production count data to determine the consumption of direct resources. This real-time production count data allows managers to see the amount of direct resources used until that point in time. Information about the current state of a station or line could be used to determine utility resource use. These data typesare already captured by many data acquisition systems. The proposed methodology merely usesthis data and relevant cost information

to present system information in a different way.The proposed methodology differs from "traditional activity-based costing" significantly. Whereas ABC systems are often used to determine the costs generated by different product lines, the proposed methodology looks to determine the costs caused by different areas of the production line. "Traditional" ABC systems will look at what resources are used and what activities use these resources. Then, the system will determine what activities each product uses in order to determine the costs caused by each product.The proposed methodology is slightly different in terms of its structure, scope, and overall goal. While a traditional ABC system is interested in the costs allocated to different product lines, the proposed methodology is more interested in the costs allocated to different areas of the production line in order to improve operational control and identify areas for improvement during the manufacturing phase. Because of this connection between physical locations of a production line and resource and activity usage in this proposed ABC methodology, there is a need to address the interface between the physical line and the setup of the ABC system.

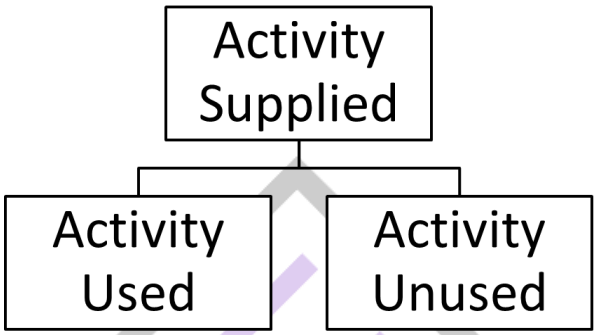


Figure Error! No text of specified style in document.**.2: Usage of Supplied Activity**

In addition to this split between used and unused activity, one can split the cost of activity used into the cost of normal activity usage and the cost of abnormal activity usage. Normal activity usage in a manufacturing system would correspond to normal production. This pertains to times when the manufacturing line is producing product without incident. For instance if a line segment is rated to produce 40 jobs per hour (JPH), the line segment will produce 40 jobs during an hour of normal production.Conversely, abnormal activity usage corresponds to times when the manufacturing system (or a subsection of it) is not producing normally. This could correspond to times when a section of the line is broken down or if a section of the line is idling while waiting to return to production.

The abnormal activity usage corresponding to times when a section of the manufacturing system fails adds costs in the form of downtime costs. This provides the basis of the downtime costing portion of the proposed methodology. The calculation of these added downtime costs is more fully discussed in Section 3.3.2.

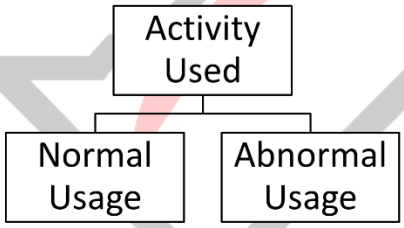


Figure Error! No text of specified style in document.**.3: Ways Activity Can Be Used**

The cost of activity unused is described in this thesis as the added costs of unused capacity. These costs are come from providing excess capacity compared to what is needed. This unused capacity may be in labor, machinery, etc. The calculation of these added unused capacity costs is further discussed in Section 3.3.3.Because the proposed methodology looks to separate costs into normal production costs, added downtime costs, and added unused capacity costs, its structure is slightly different from the "traditional" structure of ABC. The activities of the proposed methodology closely match with individual workstations on the production line. For each station, there are three types of costs associated with it: normal production costs, added downtime costs, and added unused capacity costs. Effectively, each of these separate cost types for each station is a cost object. Each station may have sub activities associated with it, but these are merely used to determine resource drivers for the main activity (the activity associated with the station). For instance, a workstation may exist to paint the exterior of a vehicle. This main activity (painting the vehicle exterior) may have many sub activities such as mixing the paint or evacuating airborne paint particles. These sub activities merely give more information about the resources being used by the station.

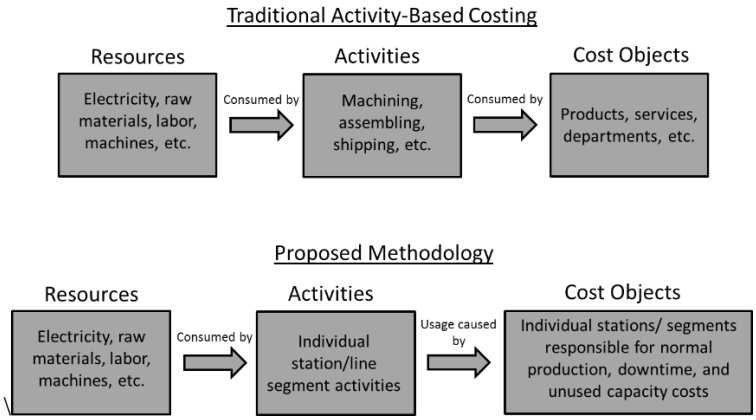


Figure **Error! No text of specified style in document.**.4: Comparison of Traditional ABC and Proposed Methodology Structures

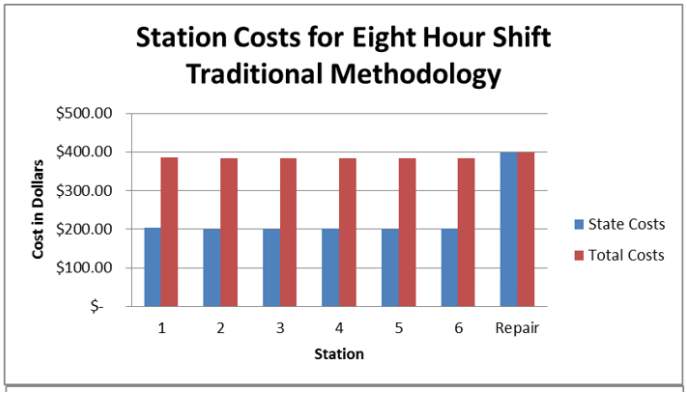
Implementation

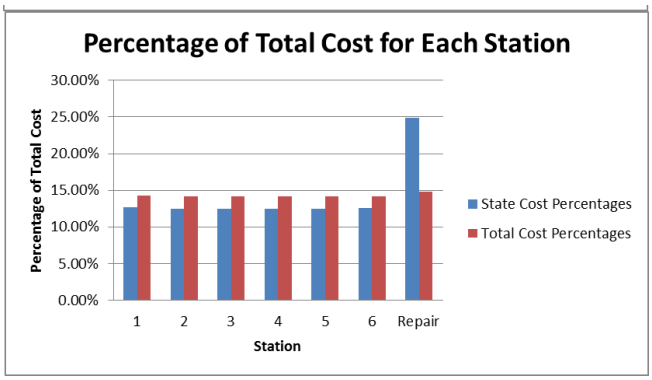
Implementation Overview

The first stage of implementation of the proposed costing methodology is to determine the important areas of the production line to be monitored. These areas will be studied for possible areas of improvement and will be considered the cost objects of this costing system. After the production line areas have been selected, relevant production and support activities need to be selected to reflect all of the pertinent activity consumption of the various production areas. These activities are selected to closely match physical workstations on the production line. This is done to match areas for improvement to specific stations and to better use information captured by automated data acquisition systems on the production line. The resources that are used by the different activities then need to be listed. These resources could be labor, machinery, facility space, utilities, raw materials, and many other things. These resources will also correspond to any resources used by subactivities that are used by the station.After listing and separating the different cost objects, activities, and resources, it is important to determine the activity drivers and resource drivers which will need to be calculated and tracked. One can look at the available production line data to determine how consumption drivers can be derived and defined. It is important to define consumption drivers based on previously and/or easily available automated data. By doing this, costing system maintenance is much easier, and the costing system is much more accurate.Chapter 4shows one method of implementation for this presented methodology through the use of spreadsheet software, namely Microsoft Excel. The methodology could be implemented into an actual costing system in this way or using dedicated software. Microsoft Excel was chosen due to its ease of use and simple interface, allowing work to focus on the implementation of the methodology and not on learning new software.

Implementation Example

In order to illustrate a possible implementation of the proposed methodology, an example implementation is presented in this section. This small example is meant to briefly show how the methodology could be implemented for a simple system and to compare results of the proposed methodology to results from a more traditional allocation methodology. The case study presented in Chapter 4 covers a much larger and more complex system.The system of interest for this example is a heavily automated internal combustion engine assembly line. This assembly line produces small four-cylinder engines from supplied engine components. The assembly line performs some light machining of the engine block before assembling the full engine assembly. This assembly line is modeled as a supplier that produces a set contracted amount every day for a customer. It is assumed that the assembly line can only produce for one eight-hour shift a day; therefore, overtime is not possible to replenish a permanent loss of production during a shift.





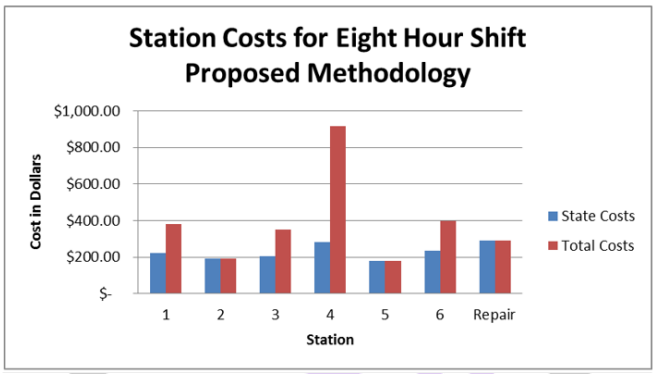


Figure Error! No text of specified style in document.**.5: Engine Assembly Station Costs Using Traditional Methodology**

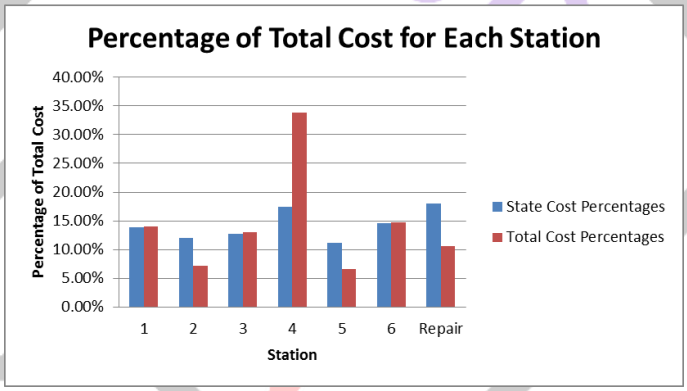


Figure Error! No text of specified style in document.**.6: Engine Assembly Station Costs Using Proposed Methodology**

One can see that there is a large difference between the allocated station costs between the two methodologies. The traditional methodology portrayed costs very evenly across all stations for both system state related costs and total costs. The proposed methodology, on the other hand, allocated additional costs to "trouble" stations that suffered from a lot of downtime. In the traditional methodology, the standby maintenance activity was the largest source of costs; however, station four was the largest source of costs under the proposed methodology. The example shows the usefulness of the proposed methodology. Under the traditional methodology, the management of this assembly line would have little direction for determining areas for improvement and little idea of the cost benefits of improving different areas. By using the proposed methodology, the management of this assembly line knows that it can focus improvement efforts towards station four in order to make the largest impact on total cost. Management could use this proposed methodology over a long timeline to get a better idea of system behavioral trends and possible areas for process or capital improvement. Upcoming provides another example implementation of the proposed methodology.

Final Summary and Conclusions

This Section provides a final summary of this thesis and conclusions pertaining to this thesis. This chapter revisits the research questions originally presented in Section 1.5 and discusses how well this thesis answered these research questions. While discussing these research questions, this chapter also provides a quick discussion of the validity of the methodology. Lastly, a discussion of possible future work is presented, followed by some closing remarks.

Research Questions

In Chapter 1, Section 1.5, several research questions were posed that helped to guide this work. These research questions are presented again below.

1. Can an activity-based costing methodology be developed to accurately capture the effects of dynamic events that occur during manufacturing?

2. Can the proposed methodology separate manufacturing costs into normal production costs and added costs due to downtime events and unused capacity?
3. Can this methodology be implemented within a realistic case study of an industrial facility to model an actual activity-based costing model using spreadsheet software?
4. Does this model produce results and insights that can be used to aid short-term and long-term decision-making to ultimately help the company's bottom line?

First Research Question

The first research question asked, "Can an activity-based costing methodology be developed to accurately capture the effects of dynamic events that occur during manufacturing?". This question is difficult to answer quantitatively; however, qualitatively, the answer is yes. The proposed methodology relies on regularly updated, automated production line data. Assuming that this production line data is correct, the proposed methodology can capture cost effects of changing system behavior. In the case of utility usage, the methodology provides a reasonable approximation of utility usage. The proposed methodology uses static resource drivers that correspond to each system state (as discussed in Section 3.3.1) and will not be perfectly accurate because it will not capture erratic behavior like power spikes. However, the methodology will be able to reasonably approximate this resource use and still show cost trends due to system behavior. This allows the methodology to be used without additional expensive utility meters at the station level. Ultimately, a costing model based on the methodology presented in this thesis is only as accurate as its input information. If the costing model is given faulty data, it has no hope of being accurate.

Second Research Question

The second research question asked, "Can the proposed methodology separate manufacturing costs into normal production costs and added costs due to downtime events and unused capacity?"

The answer to this question is yes. The methodology separates manufacturing costs into normal production costs and added downtime and unused capacity costs. The methodology does this by relying on automated production line data regarding station state and production line buffer levels to capture system dynamics.

The methodology uses this information to allocate station activity costs for the previous update interval to the responsible cost center. Normal production costs are allocated to the station where the costs were generated. Downtime costs are allocated to the malfunctioning station that is responsible for those costs. Downtime costs may be due to stations entering a setback state during the downtime event (e.g. idling costs), or they may be connected with a permanent loss of production during a downtime event (e.g. costs of lost sales). Unused capacity costs in this methodology are connected to idling costs from stations that enter a setback state due to blockage or starvation caused by a slower station. These unused capacity costs can either be allocated to the idling, faster station or to the slower station, depending on user preference and project goals.

Third Research Question

The third research question asked, "Can this methodology be implemented within a realistic case study of an industrial facility to model an actual activity-based costing model using spreadsheet software?"The work presented in Chapter 4 answers this question affirmatively. The proposed methodology was implemented within a case study of a paint shop within an automotive assembly plant. The methodology was used to capture resource use corresponding to five resources: electricity, natural gas, compressed air, hot water, and chilled water. The methodology was implemented in conjunction with simulation code that mimicked paint line system behavior. The case study proved that the proposed methodology can be useful for separating the costs connected to use of the five examined resources into normal production costs, downtime costs, and unused capacity costs and allocating these costs to the responsible stations in the paint line system.

Fourth Research Question

The fourth research question asked, "Does this model produce results and insights that can be used to aid short-term and long-term decision-making to ultimately help the company's bottom line?"

The proposed methodology could be used in various ways to aid decision makers with short-term and long-term decisions. Scenario 3 in Section 4.7.3 illustrated one possible use of the methodology in conjunction with simulation code to prioritize station preventative maintenance. If the proposed methodology is used on a production line using automated data acquisition, it can alert plant management of changing manufacturing system behavior in a short time frame. Depending on the flexibility of the system, this updated view of station behavior could aid plant management with the distribution of plant resources, such as labor force or buffer space, in the short term.The proposed methodology can be useful for aiding long-term decisions by providing a more accurate view of costs and by highlighting specific stations and areas for possible improvement projects. This is done by splitting station costs into normal production costs and added costs due to downtime and unused capacity and allocating these costs to responsible cost centers. By using historical downtime cost data captured by a costing system based on the proposed methodology, plant management can better prioritize and justify line improvement projects such as installing new machinery, altering preventative maintenance policies, or hiring additional maintenance workers. By using historical unused capacity cost data captured by the costing system, plant management can also identify possible improvement projects to diminish this unused capacity, such as altering production schedules or adding buffer space. All possible improvements, specifically short-term improvements, are dependent on some flexibility in the manufacturing system in order to most easily and effectively minimize cost.

Future Work

Additional work is needed to fully develop and improve the dynamic activity-based costing methodology presented in this work. Specifically, work should be performed regarding

1) The inclusion of more resource types within the implementation of this costing method,
2) Additional work to further refine the method of calculating downtime costs from permanent production loss,
3) The logistics of implementing this methodology using actual production line data acquisition systems, and
4) Additional work to ease implementation of this methodology with commercial discrete event simulation software.

The inclusion of more resource types within the costing model would give users a better understanding of the true costs of unused capacity and downtime. The costing model implementation for the case study did not include several resource types that would have better highlighted the added costs of downtime and unused capacity. In the case study costing model, only utility resources were included. These resources are still used when a station enters a setback state due to downtime or unused capacity; however, they are often used at a much lower rate during this setback state. The reduction in resource drivers due to this setback state causes the representation of downtime and unused capacity costs to be lower than if other resources that have consistent resource drivers, such as labor or amortization costs of machinery, were included. For example, labor resource drivers remain constant during a downtime event. As such, the cost of labor per unit time remains relatively high, leading to higher costs of downtime.

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