COST ENGINEERING AND PRICING IN AUTONOMOUS MANUFACTURING SYSTEMS

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Preface

Automation will substantially disrupt markets throughout the economy in the coming decade, ranging from construction to financial services. By understanding how technological changes will impact these markets, businesses can take advantage of the situation. Most importantly, buyers should be aware that those falling wages costs will help slow price growth in these markets, potentially providing the flexibility to delay purchasing decisions. Due to high tendency in employing high-tech machines and devices in industry and with respect to extensive consideration in automation, it is significant to investigate specific problems and challenges related to autonomous systems. However, such expensive systems require large amount of economic investment. Thus, identifying cost factors, analyzing them, and developing engineering paradigms for control and optimization need to be studied. Engineering design impacts whole-life cost of products produced. Understanding true cost of a product and the cost drivers during the design stage could guide the design process to obtain more competitive solutions. Cost engineering is concerned with cost estimation, cost control, business planning and management, profitability analysis, cost risk analysis and project management, planning, and scheduling. There are many different approaches and methods for estimating or assessing costs, all of which have advantages and disadvantages under particular circumstances. Cost estimating helps companies with decision making, cost management, and budgeting with respect to product development. It is the start of the cost management process. Cost estimates during the early stages of product development are crucial.

Also, to have more productive system and to obtain profit, appropriate pricing models should be developed to handle the operational costs in autonomous manufacturing systems. Price is one of the most flexible elements of the marketing mix, which interferes directly and in a short term over the profitability and cost effectiveness of a company. In fact, businesses can combat the destructive pricing environments that result from increased competition and globalization by implementing a more strategic pricing approach. This method provides businesses with the ability to maximize profit by providing visibility to pricing sensitivity – allowing you to maximize price in every transaction.

Therefore, both academicians and practitioners can find the book helpful. Graduate students can use the book as a course textbook or as further reading source. Industrial practitioners can learn significant concepts and applied models to be employed in real cases investigations and implementations.

Therefore, this book encompasses variety of topics in cost analysis for autonomous systems and pricing models. Different topics such as scheduling costing, agent-based costing, cost parameters of an advanced manufacturing system and operations planning with respect to cost management and cost minimization are considered in the book. Also, due to high competitive market and profit aspects, pricing concepts and models for autonomous manufacturing systems are developed. The models are novel and adapted based on autonomous manufacturing systems. Some of the distinct properties of the book are listed as follows:

- A pioneer book in cost engineering for autonomous systems.
- Introducing cost parameters, elements, and optimization models.
- Pricing models adapted for autonomous manufacturing.

This book covers several general and technical concepts involved in optimal decision making for manufacturing systems and also the use of autonomous systems as industrial automation for both researchers and executive managers. The book can be employed as a course book in graduate studies of industrial and systems engineering, operations management, logistics, etc.

Structure of the book and the materials in each chapter are further explained here.

In Chapter 1, an overview of the book and significance of the concepts considered in the book are given. In Chapter 2, the basics of costing and different cost models are explained within a scheduling problem in advanced manufacturing system. In Chapter 3, pricing models are discussed in detail and a case is investigated. Analytical studies on the performance of the pricing models in different conditions are also included. In Chapter 4, various cost parameters in manufacturing systems and costing models are reported and detailed in a case problem where specific data are extracted and a costing model is implemented. The impact of each cost parameter is also analyzed. In Chapter 5, cost minimization is discussed with respect to engineering paradigm in product design and manufacturing planning. In Chapter 6, cost/price interaction for profit modeling is handled. Profit maximization is a common goal of manufacturing needing to consider both cost and price at the same time. In Chapter 7, pricing model for advanced systems is detailed and implemented for a specific system. In Chapter 8, price optimization with respect to costs is modeled for an advanced manufacturing system. The model considers a comprehensive set of parameters and provides a generic framework for other systems.

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Hamed Fazlollahtabar
Mohammad Saidi-Mehrabad

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Chapter 1

Introduction

1.1. Autonomous Manufacturing System

Intelligent machining systems facilities adaption to the changes in manufacturing environment, such as orders and changes happening in the system. In machining system, machine tools play an important role in manufacturing products with high quality, low cost, and high productivity. This chapter presents a new concept of intelligent machining system, namely Autonomous Manufacturing System (AMS).

In traditional manufacturing systems, the workers play an important role, with their knowledge and experience. They adapt flexibly to changes in the manufacturing environment. With every new problem, their knowledge is updated through learning. Abilities in processing information and cognitive abilities enable workers to play an important role in monitoring, control, and production planning. Those workers with the ability to solve problems and high cognitive capacity enable adaption with changing manufacturing environment. However, the system manipulated by workers with a high price is only suitable for small production. In the era of computer-integrated manufacturing, workers are replaced by automatic control systems and robots, hence the cognitive abilities of workers in solving problems such as perception, learning, and reasoning to make a decision also are removed.

The limitations of the automatic control system fail to adapt to the changes due to the system operating under preset programs. Hence, the system needs to reset and restart when an error occurs. To overcome these shortcomings, a combination of both advanced automatic control system and the cognitive abilities of human, cognitive sciences and artificial intelligence as well as the biology-inspired technologies have been applied to the manufacturing systems, which make the production system to become more intelligent and more flexible.

Industries today seek the reduction and elimination of waste through continuous improvement projects that enable increased productivity within the production process, while preserving quality and serving the customer within each other (Gracanin, Buchmeister, & Lalic, 2014). These operational improvements proposed to maximize efficiency and effectiveness throughout the production system, reducing the non-value-added activities, costs, and eventually increase net income (Ruiz-de-Arbulo-Lopez, Fortuny-Santos, & Cuatrecasas-Arbós, 2013).

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These perspectives makes evident that the increasing global competition among companies have adopted new production approaches such as Lean Manufacturing in order to make them more competitive (Ruiz-de-Arbulo-Lopez et al., 2013). Some industries have been through physical and cultural transformation processes by adopting the Lean concept (Abuthakeer, Mohanram, & Kumar, 2010). Briefly, Lean Manufacturing is a model that seeks to increase productivity by reducing or eliminating waste through activities that do not add value in the production processes (Ohno, 1997; Shingo & Dillon, 1988; Womack, Jones, & Roos, 1991).

The adoption of Lean by companies implies the need for improvement in the accounting system. The lean organizations see the traditional accounting systems as unfavorable for eliminating waste. After all, the traditional costing system is not conceptually prepared to operate efficiently in the lean production model (Malta & Cunha, 2011; Pike, Tayles, & Mansor, 2011). In fact, even in normal companies that has a wide range of products the traditional approach to cost when applied has a distortion in the cost information (Gunasekaran & Sarhadi, 1998; Kaplan & Copper, 1998). Given this paradigm, Lean Accounting emerges as a way to adapt or change the traditional costing methods in order to support businesses and lean industrial processes (Gracanin et al., 2014; Wang & Yuan, 2009).

Producing quality and reliable products at a realistic cost has always been a fundamental objective for manufacturers. In recent years, customer expectations for quality at low cost have only intensified. As manufacturers strive to achieve these goals, they eventually reach a point where tradeoffs must be made between increasing quality and lowering costs.

For a specific product type, the product size and the resulting weight also affect the incremental manufacturing cost of cordless products. The weight is dependent on both the size and the type of material used for the window covering. For example, faux wood blinds have higher weight than identically sized vinyl blinds. Increasing the size and the weight may result in design modifications. In some cases, these modifications may be as simple as adding additional cordless modules to the product or changing the sizes of components, whereas in other cases, the required design changes may make the design concept unusable. For example, the use of constant force springs with friction is appropriate for products where the change in weight over the travel of the bottom rail is small. However, in large faux wood blinds where the change in weight is high, the design may not be feasible.

Additionally, any customization of the product (e.g., changes in width and length, choice of fabric, etc.) requires that the cordless technology be designed to work for the entire range of customization, thereby increasing the cost.

Reducing the energy consumption of machine tools can significantly improve the environmental performance of manufacturing systems. To achieve this, monitoring of energy consumption patterns in the systems is required. It is vital in these studies to correlate energy usage with the operations being performed in the manufacturing system. However, this can be challenging due to complexity of manufacturing systems and the vast number of data sources.

Manufacturing and the processes involved consume substantial amounts of energy and other resources and, as a result, have a measurable impact on the environment. Reducing the energy consumption of machine tools can significantly improve the environmental performance of manufacturing processes and systems. Furthermore, given that machining processes are used in manufacturing the tooling for many consumer products, improving the energy efficiency of machining-based manufacturing systems could yield significant reduction in the environmental impact of consumer products.

The problem of optimal manufacturing systems design was explored by many researchers during the last ten years. It is rather frequent to find in literature the description of methodology of design of rigid transfer lines or traditional manufacturing shop-floors.

1.2. Costing and Pricing

There is a cost associated with higher quality products. For cordless technologies, the same concept can be manufactured at different qualities by using different materials (e.g., steel gears instead of plastic gears), different tolerances and surface finish, and using sophisticated transmission systems for smoother operation. Higher quality increases the life and reliability of the product, thereby reducing warranty costs for the manufacturers.

The cost is dependent on whether the parts are directly manufactured by the same firm or purchased from suppliers. Similarly, the cost is also dependent on whether the parts are manufactured within the United States or overseas.

The Manufacturing Cost Levelization Model is an analytical method for estimating all of the manufacturing costs necessary to produce a given product and compute a levelized cost per-unit of that manufactured product. Levelized cost is the minimum per-unit price ($/unit of product) necessary to recover all of the costs associated with manufacturing the product over an assumed financial cycle and manufacturing facility lifetime. Manufacturing costs typically includes: a) manufacturing facility capital investments; b) raw material and energy purchases; c) fixed and variable operations and maintenance costs including labor; d) financing costs, and e) taxes. Engineering economic methods are used to project each of these costs into cash flows over the life-time of the manufacturing facility. Because taxes are a function of product sales revenue, the levelized cost is the per-unit sales prices where the net present value (NPV) of all costs (including taxes) equals the NPV of all sales revenues. Thus, the levelized cost is the NPV of all of the cost cash flows divided by the NPV of the product units produced. It can be thought of as the minimum per-unit product sales price that pays all expenses including raw materials, labor wages, debt service for both loans (debt) and owner's investments (equity), and taxes – but no profit above just these cash flow expense items.

The model is designed to reflect a notional manufacturing facility specific to the production of a technology or product. Although the model can be utilized to estimate the production cost of any manufactured product, it is specifically designed to help guide technology R&D research. Estimating the production cost implications of research at an early stage can help researchers develop processes and designs that minimize the eventual manufacturing costs and increase the likelihood of successful technology deployment. Utilizing the model does require the development of the core components of any specific manufacturing processes: the manufacturing equipment, raw materials cost, labor costs, etc. Several methods are embedded in the model to help a technology researcher produce ballpark estimates quickly. However, the accuracy of these core components determines the accuracy of the levelized cost estimate and therefore the model should be utilized over the course of R&D allowing it to evolve alongside the R&D process and guide research focus toward the most significant cost drivers.

Managers are most experienced with cost presented as monetary expenses in an income statement. Politicians and policy analysts are more familiar with costs as an expense item in a budget statement. Consumers think of costs as their monthly bills and other expenses.

But economists use a broader concept of cost. To an economist, cost is the value of sacrificed opportunities. What is the cost to you of devoting 20 hours every week to studying microeconomics? It is the value of whatever you would have done instead with those 20 hours (leisure activities, perhaps). What is the cost to an airline of using one of its planes in scheduled passenger service? In addition to the money the airline spends on items such as fuel, flight-crew salaries, maintenance, airport fees, and food and drinks for passengers, the cost of flying the plane also includes the income the airline sacrifices by not renting out its jet to other parties (e.g., another airline) that would be willing to lease it. What is the cost to repair an expressway in Chicago?

Besides the money paid to hire construction workers, purchase materials, and rent equipment, it would also include the value of the time that drivers sacrifice as they sit immobilized in traffic jams. Viewed this way, costs are not necessarily synonymous with monetary outlays.

When the airline flies the planes that it owns, it does pay for the fuel, flight-crew salaries, maintenance, and so forth. However, it does not spend money for the use of the airplane itself (i.e., it does not need to lease it from someone else). Still, in most cases, the airline incurs a cost when it uses the plane because it sacrifices the opportunity to lease that airplane to others who could use it.

Because not all costs involve direct monetary outlays, economists distinguish between explicit costs and implicit costs. Explicit costs involve a direct monetary outlay, whereas implicit costs do not. For example, an airline's expenditures on fuel and salaries are explicit costs, whereas the income it forgoes by not leasing its jets is an implicit cost. The sum total of the explicit costs and the implicit costs represents what the airline sacrifices when it makes the decision to fly one of its planes on a particular route.

1.2.1. Opportunity Cost

The economist's notion that cost is the value of sacrificed opportunities is based on the concept of opportunity cost. To understand opportunity cost, consider a decision-maker, such as a business firm, that must choose among a set of mutually exclusive alternatives, each of which entails a particular monetary payoff. The opportunity cost of a particular alternative is the payoff associated with the best of the alternatives that are not chosen.

The opportunity cost of an alternative includes all of the explicit and implicit costs associated with that alternative. To illustrate, suppose that you own and manage your own business and that you are contemplating whether you should continue to operate over the next year or go out of business. If you remain in business, you will need to spend $100,000 to hire the services of workers and $80,000 to purchase supplies; if you go out of business, you will not need to incur these expenses. In addition, the business will require 80 hours of your time every week. Your best alternative to managing your own business is to work the same number of hours in a corporation for an income of $75,000 per year. In this example, the opportunity cost of continuing in business over the next year is $255,000. This amount includes an explicit cost of $180,000 – the required cash outlays for labor and materials; it also includes an implicit cost of $75,000 – the income that you forgo by continuing to manage your own firm as opposed to choosing your best available alternative.

The concept of opportunity cost is forward looking, in that it measures the value that the decision-maker sacrifices at the time the decision is made and beyond. To illustrate this point, consider an automobile firm that has an inventory of sheet steel that it purchased for $1,000,000. It is planning to use the sheet steel to manufacture automobiles. As an alternative, it can resell the steel to other firms. Suppose that the price of sheet steel has gone up since the firm made its purchase, so if it resells its steel the firm would get $1,200,000. The opportunity cost of using the steel to produce automobiles is thus $1,200,000. In this illustration, opportunity cost differs from the original expense incurred by the firm.

After reading this last example, students sometimes ask, "Why isn't the opportunity cost of the steel $200,000: the difference between the market value of the steel ($1,200,000) and its original cost ($1,000,000)?" After all, the firm has already spent $1,000,000 to buy the steel. Why the opportunity doesn't cost the amount above and beyond that original cost ($200,000 in this example)? The way to answer this question is to remember that the notion of opportunity cost is forward looking, not backward looking. To assess opportunity cost we ask: "What does the decision-maker give up at the time the decision is being made?" In this case, when the automobile company uses the steel to produce cars, it gives up more than just $200,000. It forecloses the opportunity to receive a payment of $1,200,000 from reselling the steel. The opportunity cost of $1,200,000 measures the full amount the firm sacrifices at the moment it makes the decision to use the steel to produce cars rather than to resell it in the open market.

Opportunity costs depend on the decision being made. The forward-looking nature of opportunity costs implies that opportunity costs can change as time passes and circumstances change. To illustrate this point, let us return to our example of the automobile firm that purchased $1,000,000 worth of sheet steel.

When the firm first confronted the decision to "buy the steel" or "don't buy the steel," the relevant opportunity cost was the purchase price of $1,000,000. This is because the firm would save $1,000,000 if it did not buy the steel.

But – moving ahead in time – once the firm purchases the steel and the market price of steel changes, the firm faces a different decision: "use the steel to produce cars" or "resell it in the open market." The opportunity cost of using the steel is the $1,200,000 payment that the firm sacrifices by not selling the steel in the open market.

Same steel, same firm, but different opportunity cost! The opportunity costs differ because there are different opportunity costs for different decisions under different circumstances.

1.2.2. Opportunity Costs and Market Prices

Note that the unifying feature of this example is that the relevant opportunity cost was, in both cases, the current market price of the sheet steel. This is no coincidence.

From the firm's perspective, the opportunity cost of using the productive services of an input is the current market price of the input. The opportunity cost of using the services of an input is what the firm's owners would save or gain by not using those services. A firm can "not use" the services of an input in two ways. It can refrain from buying those services in the first place, in which case the firm saves an amount equal to the market price of the input. Or it can resell unused services of the input in the open market, in which case it gains an amount equal to the market price of the input. In both cases, the opportunity cost of the input services is the current market price of those services.

1.2.3. Price

Price is one of the most flexible elements of the marketing mix, which interferes directly and in a short term over the profitability and cost effectiveness of a company (Simon, Bilstein, & Luby, 2008). Despite the importance a price has on the performance of businesses, it seems that this element has not received proper attention from many academics and marketing professionals (Avlonitis & Indounas, 2006). Typically, in marketing, the main focus is placed on the development of new products, distribution channels, and communication strategies, and according to Lancioni (2005) this could lead to precipitated pricing decisions without properly evaluating market and cost factors.

Thus, pricing is treated as the simplest strategy within marketing, perhaps because many companies determine their prices based on intuition and the manager's market experience (Simon, 1992). In addition, only few managers strategically think about pricing while proactively administrating their prices in order to create favorable conditions that lead to profits (Nagle & Holden, 2003). Considering this, Liozu and Hinterhuber (2012) highlight the need for more research regarding the pricing preferences and practices because, according to the authors, less than 2% of all published articles in marketing journals are focused on pricing.

Strategic pricing requires a stronger relationship between marketing and the other sectors of a company. In order to enhance companies' economic and financial performance, the pricing policies should be defined by their internal capacities and on the basic systematical understanding of needs and wishes of their customers, in addition to market conditions such as economic conditions and degree of competition (Besanko, Dranove, Shanley, & Schaefer, 2012; De Toni

& Mazzon, 2013b). In this context, this study's objective is to propose and test a theoretical model that indicates the impacts of pricing policies on company's profit. In this regard, the theoretical assumptions consider as pricing policies the definitions that comprise the pricing strategies and the price levels used by companies in their respective markets.

Pricing strategies are based on Nagle and Holden (2003) studies, namely value-based, competition-based, and cost-based pricing strategies; whereas the pricing levels are classified as high and low prices (Urdan & Osaku, 2005). Besides identifying the direct effects of these elements over profitability, this research also analyzed the impacts of moderating effects considering some independent variables on the business profitability (dependent variable).

According to Monroe (2003), price decisions are one of the most important decisions of management because it affects profitability and the companies' return along with their market competitiveness. Thus, the task of developing and defining prices is complex and challenging because the managers involved in this process must understand how their customers perceive the prices, how to develop the perceived value, what are the intrinsic and relevant costs to comply with this necessity, as well as consider the pricing objectives of the company and their competitive position in the market (De Toni & Mazzon, 2013a, 2013b; Hinterhuber & Liozu, 2014; Monroe, 2003).