



Dynamic Pricing in Manufacturing SMEs: a Literature Review

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Abstract: This literature review explores the implementation of dynamic pricing (DP) in Small and Medium-sized Manufacturing Enterprises (SMEs) navigating a competitive market and facing a VUCA (Volatility, Uncertainty, Complexity, and Ambiguity) environment. We assess how this strategy could affect their profitability and competitiveness, particularly for those differentiating through customized product offerings. Our methodology involves a detailed analysis of 28 models suited to the manufacturing context, revealing a predominant focus on capacity management rather than integration and minimization of overall production costs. Our findings suggest an underutilized potential of DP, combined with production management, as leverage for agility in these enterprises. The study highlights the need for models more aligned with SME operational realities and opens avenues for future research, especially through practical cases and implementation cost evaluations.

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Keywords: Dynamic Pricing, SMEs, Profitability, Competitiveness, VUCA, Cost Management, Production Optimization.

1. INTRODUCTION

In a constantly changing market, Small and Medium-sized Manufacturing Enterprises (SMEs) are often in reactive mode, adjusting their production to fluctuations. However, while flexibility is a crucial asset, it can also lead to increased production costs jeopardizing the profit margin (Brunoe and Nielsen, 2016). Yet, as flexibility becomes increasingly important, why do so many of firms stick to fixed pricing? Imagine the competitive advantage if they dared to adopt pricing as dynamic as their environment. It is from this perspective that we explore the possibility for manufacturing SMEs to implement Dynamic Pricing (DP), an innovative approach that could redefine industry standards.

SMEs, defined by the Canadian government as having between 1 and 99 employees for small businesses, and between 100 and 499 for medium-sized businesses, are distinguished from large companies by their organizational flexibility and responsiveness to market changes (Innovation, Science and Economic Development Canada, 2021). These characteristics confer a competitive advantage in the face of the rigid structures and lengthy decision-making processes typical of large companies (Man and al., 2002). However, SMEs face disadvantages, particularly in terms of economies of scale and difficulties in accessing technology and skilled labor, exacerbated by limited capital (Stancu and al., 2020, Charoenrat and al., 2013). Additionally, they play a crucial role in the economy, employing a significant portion of the workforce in Canada, Asia, and the European Union (Innovation, Science and Economic Development Canada, 2021, Charoenrat and al., 2013, Stancu and al., 2020).

Particular attention needs to be given to these SMEs, faced with resource constraints and a competitive market intensified by globalization and mass customization (MC). They must leverage their distinctive attributes to innovate and enhance their competitiveness. Unlike large companies that benefit from economies of scale, international outsourcing and mass-produce standardized products (Stancu and al., 2020, Caskey,

2015), manufacturing SMEs are noted for their flexibility and responsiveness, often focusing on complex, low-volume production. Thus, SMEs could quickly adjust to the fluctuating demand and maintain close relationships with their customers, giving them a significant competitive advantage (Brunoe and Nielsen, 2016).

However, adapting offer to demand presents several challenges. Product diversity often leads to increased complexity in production management, and consequently higher costs (Brunoe and Nielsen, 2016). Brunoe and Nielsen (2016) mention that this situation can make the manufacturing of certain parts unprofitable, especially when new varieties are added without formally evaluating their impact. To quantify this phenomenon, (Gamache and al., 2017) carried out a study of 148 SMEs in Quebec, Canada focused on meeting customer requirements to demonstrate their overall performance. The results of this analysis revealed an average Overall Equipment Effectiveness (OEE) of 21.14%. The authors advance that SMEs do indeed have gaps in operational capacity, since production equipment are inefficient. This may be due to frequent shutdowns, production speeds lower than machine capacities, or a high rate of production of defective parts, leaving money on the table. In a less competitive market, high production costs, or inefficiency, are less concerning as customers, lacking alternatives, are willing to pay more for tailored products. However, today's global and technologically evolving market provides consumers with more options and pressure manufacturers to reduce prices (Stojanova and al., 2012).

MC allows companies to provide personalized, affordable products through flexible processes, effectively meeting individual customer expectations without compromising cost, time, or quality (Suzic and Forza, 2023). This strategy not only streamlines production and reduces management costs (Brunoe and Nielsen, 2016) but also cuts inventory and overheads, minimizing waste (Stojanova and al., 2012). Consequently, MC significantly lowers production costs while still offering products for specific consumer needs, which is a

key attribute for SMEs. However, they remain reactive to changing external fluctuations. Flexibility, reconfiguration, and adaptability were once key for competitive success but are now deemed insufficient (Wecken and al., 2023). SMEs must now manage both internal and external fluctuations to maintain competitiveness. The literature identifies the VUCA environment's four components to understand such instability: Volatility indicates unpredictable changes; Uncertainty reflects a lack of knowledge about potential outcomes; Complexity involves the interconnection of numerous elements; and Ambiguity signifies a limited understanding of situations, where cause and effect are unclear (Lam and Khare, 2015). Addressing these elements often requires experimental strategies, particularly in complex or foreign contexts (Bennett and Lemoine, 2014). SMEs, with limited resources and inadequate information systems, find themselves having to operate in a complex environment that makes them particularly vulnerable (Troise and al., 2022). Given that internal efficiency strategies like MC are insufficient in a VUCA environment (Suzic and Forza, 2023), it becomes essential to also reassess other areas such as pricing to better handle external fluctuations.

Li (2023) argues that pricing strategies based solely on production costs are insufficient as they neglect key factors like customer willingness to pay and cost variability. Conversely, market-based pricing fails to account for internal cost fluctuations. Consequently, fixed pricing strategies in a VUCA environment, which involve variations such as market shifts, competition, customer demand, and production costs, are jeopardizing profit margins (Li, 2023). Hinterhuber (2008) notes that 17% of companies use value-based pricing, 37% use cost-based pricing, and 44% follow market pricing, suggesting that about 80% may price sub-optimally in a VUCA context, either ignoring customer willingness-to-buy or disconnecting from their production costs.

DP is a strategy that sets prices for different customer segments based on factors such as market demand, production capacity, and product perishability (Li, 2023). It effectively addresses internal and external variations that influence both prices and costs. DP is widely discussed in industries with perishable goods like airlines and tourism, and is also extending into e-commerce and inventory management (Seele and al., 2021). Both authors' research indicates that DP can improve cost efficiency and revenue by better matching prices with market demand. However, the systematic review of 315 articles conducted by Seele and al. does not address dynamic pricing within the context of manufacturing SMEs. (Elmaghraby and Keskinocak, 2003) also demonstrated that DP significantly reduces sales variability compared to static pricing, especially in systems closely linked to inventory management.

Therefore, if DP is effective in an uncertain market for the tourism industry and e-commerce, it is relevant to explore the applicability of this approach in manufacturing SMEs facing limited production capacity, subject to fluctuations, and constrained by complexity. This approach would enable consideration of the dynamic states of both the production system and market conditions, which are subject to continual

change and influenced by fluctuations characteristic of the VUCA environment. Based on the previous literature reviews, there seems to be an interest in DP in the manufacturing environment, which leads to the questions of this research:

Q1: Do DP models considering a SME production system exist?

Q2: Can DP increase the profitability of a manufacturing SME?

Q3: Have these models been implemented in SMEs, and if so, what are the results?

To answer the research questions, a literature review focusing on DP models in the manufacturing sector has been carried out. *The objective of this article is therefore to examine whether the adoption of DP by manufacturing SMEs, offering customized products in a complex and changing context, is feasible and profitable.*

Given this objective, this article highlights a significant gap in the development and implementation of dynamic pricing within SMEs, as well as in manufacturing enterprises in general, despite the success of this approach in the tourism and e-commerce sectors. This paper is divided into five sections: introduction, methodology, literature review, discussion, and conclusion.

2. METHODOLOGY

To answer the first research question, we sought to determine if dynamic pricing had already been implemented in SMEs. To do this, we used the keywords “dynamic pricing” and “SME” in SCOPUS with the string “(“dynamic pricing” OR “dynamic price”) AND (“SME” OR “SMEs”). The search led to 7 articles, of which one article was relevant. The others were rejected as they addressed energy, supply chain and e-commerce. To answer Q2 and Q3, a second and third searches were realized. The aim was to identify all DP models applied to the manufacturing sector in general. The first search uses the string “(“dynamic pricing” OR “dynamic price”) AND “manufacturing”)” and results in 85 articles. The keyword “manufacturing” is added to target models focused on the production of goods rather than services, such as a hotel company, for example. For the second search, the string “(“dynamic price” OR “dynamic pricing”) AND “capacity” AND (“enterprise” OR “firm”)” is used, giving 69 results. The keywords “capacity,” “enterprise,” and “firm” are used to find models related to any production system. The keywords used were “dynamic pricing,” “dynamic price,” “manufacturing,” “capacity,” “enterprise,” and “firm”. A total of 147 articles were obtained by the two searches. 73 articles were retained after reading the titles and removing duplicates. The article is retained if it proposes a model of dynamic pricing in manufacturing. Otherwise, the article is rejected if it is applied to the sale of service, tourism, energy distribution, or e-commerce. Subsequently, reading the abstracts led to the elimination of 47 articles based on the absence of a mathematical model and the same criteria used in the title review. Following a second search with the same keywords, 2 models were added. As a result, 28 DP models were selected for in-depth analysis. The models were analyzed and ranked in

a matrix according to 6 comparison criteria. Initially, we examine the type of production system to determine if dynamic pricing is more advantageous in specific contexts. The objective function and model orientation are evaluated to understand how models aim to achieve their goals. We also consider how models account for production costs, as these variable costs are an additional factor compared to service sales, such as purchasing an airline ticket. Additionally, results are reviewed to assess under which conditions DP is profitable. Finally, the validation method is noted to determine whether dynamic pricing has been implemented in manufacturing context or remains a theoretical concept.

Table 1. Comparison Matrix of TD Models

Reference	Objective Function	Type of Production System	Validation Method	Result	Model Orientation	Product Cost Evaluation
Sun et al., 2024	Maximize profit	Make-to-stock	Numerical example	Increases profit (considering capacity)	Capacity optimization	Fixed
Liang et al., 2024	Maximize profit	Make-to-stock	Numerical example	Increases profit (considering stock management)	Stock management	Fixed
Ata and Barjesteh, 2023	Maximize profit	Make-to-stock	Simulation	Increases profit (if fluctuating uncertain demand)	Capacity optimization	Fixed
Karabag and Gokguz, 2023	Maximize profit	Make-to-stock	Numerical example	Increases profit	Cost balancing	Fixed
Öner-Közen and Manner, 2018	Maximize profit	Make-to-order	Numerical example	Increases profit	Capacity optimization	None
Renna, 2016	Maximize profit	Make-to-order	Simulation	Increases profit (if fluctuating uncertain demand)	Capacity optimization	None
Chen and al., 2015	Maximize profit	Make-to-order	Numerical example	Increases profit (considering order sequencing)	Cost balancing	Fixed
Gao and al., 2015	Maximize profit	Make-to-stock	Numerical example	Increases profit (considering stock management)	Stock management	None
Mardaneh and Caccetta, 2015	Maximize profit	Make-to-stock	Numerical example	Increases profit (if fluctuating uncertain demand)	Cost balancing	Fixed
Kogan, 2012	Maximize profit	Make-to-stock	Numerical example	Increases profit	Stock management	None
Adida and Perakis, 2010	Maximize profit	Make-to-stock	Numerical example	Increases profit	Capacity optimization	Dynamic
Adida and Perakis, 2010	Maximize profit	Make-to-stock	Numerical example	Better than static	Stock management	Fixed
Adida and Perakis, 2007	Maximize profit	Make-to-stock	Numerical example	Increases profit (if fluctuating uncertain demand)	Stock management	Fixed
Chen and Gallego, 2022	Maximize profit	Make-to-stock	Theoretical	Increases profit	Stock management	None
Lei and Jassin, 2020	Maximize profit	N/A	Theoretical	Better than static	Capacity optimization	None
Ceryan, 2019	Maximize profit	Make-to-stock	Numerical example	Increases profit (if fluctuating uncertain demand)	Stock management	Fixed
Chen and Gallego, 2019	Maximize welfare	Make-to-stock	Numerical example	Increases profit (if fluctuating uncertain demand)	Stock management	None
Wen and al., 2016	Maximize profit	One-of-a-kind	Numerical example	Better than static	Stock management	None
Feng and al., 2015	Maximize profit	Make-to-stock	Numerical example	Better than static	Stock management	None
Besbes and Sauré, 2014	Maximize profit	Make-to-stock	Numerical example	Increases profit (if fluctuating uncertain demand)	Stock management	None
Mei and Tu, 2014	Maximize profit	One-of-a-kind	Theoretical	Better than static	Capacity optimization	None
Ceryan and al., 2013	Maximize profit	FMS	Numerical example, simulation	Increases profit (considering capacity)	Cost balancing	Fixed
Ata and Olsen, 2013	Maximize profit	Make-to-order	Numerical example, simulation	Increases profit (considering capacity)	Capacity optimization	None
Zhang, 2012	Maximize profit	One-of-a-kind	Case study, simulation	Increases profit (considering capacity)	Capacity optimization	None
Chaharsooghi and al., 2011	Maximize profit	Make-to-order	Numerical example	Increases profit (considering capacity)	Cost balancing	Fixed
Hall and al., 2009	Maximize profit	Make-to-order	Numerical example, simulation	Increases profit (considering capacity)	Capacity optimization	None
Transchel and Manner, 2009	Maximize profit	Warehouse	Numerical example	Increases profit	Stock management	None
Maglaras and Messner, 2006	Maximize profit	Make-to-order	Numerical example	Better than static	Capacity optimization	None

3. LITERATURE REVIEW

A review of the literature shows, as in Table 2, that 96.4% of the models have the objective of maximizing the company's profits, regardless of which aspects of production management are involved. Only one model aims to maximize customer welfare.

Table 2. Overview of Objective Functions in TD Models

Objective function	Occurrence	Percentage
Maximize profit	26	96.4%
Maximize welfare	1	3.6%

In fact, models are generally based on 10 distinct elements to evaluate a price: supply, system capacity, order sequencing, order types, inventory management, production rates,

competition, demand, advertising, and customer welfare. Only one model establishes welfare maximization as an objective function. Furthermore, the authors did not specify a firm size or sector for the manufacturing models. Only one article in the selection proposes a DP model focused on SMEs. To better compare the application of DP in manufacturing, the 28 models were segmented in Table 3 into three approaches: stock management, capacity optimization, and cost minimization.

Table 3. Approach of TD Models

Orientation	Occurrence	Percentage
Capacity optimization	11	39.3%
Cost balancing	5	17.8%
Stock management	12	42.9%

The "stock management" category is concerned with increasing revenues by managing storage costs, in response to customer needs with uncertain demand (Ceryan, 2019, Adida and Perakis, 2010, Kogan, 2012, Besbes and Sauré, 2014) or seasonal products (Liang et al., 2024). This approach applies to both perishable (Chen and Gallego, 2022, Chen and Gallego, 2019) and non-perishable (Transchel and Minner, 2009, Adida and Perakis, 2007) products and enables more informed sourcing decisions to be made that will boost profits (Stasinski, 2020, Wen and al., 2016, Gao and al., 2015). Production costs are generally not considered for this category since the models consider the product as finished and thus not its manufacturing.

Next, the "capacity optimization" approach is the most used in the literature. To maximize profits, the algorithms aim to allocate the limited capacity of a production system to several products according to the remuneration rate for orders, with the aim of increasing revenues rather than reducing manufacturing costs (Adida and Perakis, 2010, Chaharsooghi and al., 2011, Hall and al., 2009). The remuneration obtained for orders can be assessed based on several parameters, such as the costs associated with capacity and resource utilization (Ata and Barjesteh, 2023, Renna, 2016), meeting customer delivery deadlines (Öner-Közen and Minner, 2018, Ata and Olsen, 2013) production rate (Li and Zhang, 2012), and customer satisfaction or welfare (Selove, 2019). Models in this category do not extensively integrate the various costs inherent to a manufacturing system. Only 27% of the models consider production costs, but they do so to guide pricing and production decisions based on constraints. Adida and Perakis (2010) Consider production costs as quadratic relative to the production rate, implying that costs increase disproportionately as capacity saturation approaches, due to the inefficiencies associated with operating at maximum capacity, such as inefficient use of machines and overtime. Others view manufacturing costs as fixed and specific to each product (Sun et al., 2024, Ata and Barjesteh, 2023). The authors use these costs to make decisions on whether to manufacture in-house or outsource production. Despite the consideration of a manufacturing system in DP, only two models account for the interaction between demand and production costs as input parameters in their models for the "capacity optimization" orientation.

Finally, the "Cost balancing" category refers to the mathematical model that seeks to maximize a firm's profit by reducing costs (Mardaneh and Caccetta, 2013). These models use multiple parameters focused on production management, such as production costs, stockout costs, delay costs, storage costs, and raw material costs, to understand their evolution based on manufacturing decisions. Of the five models in this group, Karabağ and Gökgür (2023) establish basic unit production costs for each product, and consider storage and delay costs to find an optimal solution. Chaharsooghi and al. (2011) integrate the unit cost of production with a larger framework that considers several factors related to order management, such as storage costs, late delivery penalties and out-of-stock penalties. The other three models suggest production costs dependent on the state of the system such as purchase price of raw materials, the time required to process the product, and the cost associated with stock-outs, type of resource used and sequencing of orders (Karabağ and Gökgür, 2023, Ceryan and al., 2013). To fully consider production costs, Chen and al. (2015) use order sequencing to evaluate production costs. In their research, the optimal solution guides not only production decisions (how much to produce and when) but also pricing strategies to maximize profit while minimizing costs, which allows for the evaluation of both internal and external variations.

Table 4 illustrates how production costs are considered in different approaches. 73% of the models within the "Capacity Optimization" orientation do not explicitly consider production costs to maximize profits. Models from the "Cost Balancing" approach, representing only 17.9% of the models reviewed in the literature, all consider these costs as fixed, regardless of the system's state. Overall, 57.1% of the models ignore production costs, focusing instead on revenue, demand satisfaction, capacity management, and/or inventory management.

Table 2. Evaluation of Production Costs by Model Orientation

Orientation	Production Costs Evaluation		
	Dynamic	Fixed	None
Stock management	0	3	8
Capacity optimization	1	2	8
Cost balancing	0	5	0
Percentage:	3.6%	39.3%	57.1%

Regarding model validation and applicability, the review reveals that 78.6% of articles present a DP model and verify it using numerical examples. Of this proportion, five authors added stochastic elements using simulation to obtain results more plausible to reality. It's also important to underline the fact that only Zhang and al. (2012) published a case study on DP demonstrating its implementation. This is done in an SME with a one-of-a-kind production system to control variations in the supply chain for two classes of customer. Despite the implementation of DP, the author gives no specific details on its implementation and the associated costs. This is also true of all the other authors in the literature review. Even Karabağ and Gökgür (2023), Feng and al. (2015) and Koenig and

Meissner (2010) state in their limitations or future developments the importance of highlighting its costs to ensure that the operation of the DP strategy is profitable. Finally, it appears that 100% of reviewed articles conclude that DP would help increase the profits of manufacturing companies. Indeed, six of them specifically state that DP is more profitable than a static pricing strategy in an uncertain environment. Among the articles favoring DP, several authors mention key parameters for improving its performance in their results. A significant proportion emphasizes the need for *variable or uncertain customer demand*. Some articles point to the importance of *flexible production* and *known capacity*. Others highlight the effectiveness of DP with *segmented customers*, often into two groups sensitive to price or lead times. One article discusses the impact of *order sequencing* on profitability.

4. DISCUSSION

A review of DP models in the manufacturing context provides a clear answer to the first two research questions. Although suitable models are available and increase firm profitability, it is notable that the dominant tendency is to favor capacity management as a reaction to the uncertain market, rather than using it as a lever directly linked to the production process and its cost structure (Elmaghraby and Keskinocak, 2003, Stasinski, 2020). This approach may prove limiting, especially for SMEs which, due to their specialization in customized products, are more sensitive to the costs of production complexity. This finding suggests a mismatch between DP objectives and the operational realities of SME companies offering customized products. Indeed, we note that the "stock management" and "capacity optimization" categories of DP models focus primarily on the cost-effective allocation of orders. However, they omit to significantly integrate production costs, as well as the complexity costs associated with product diversity, into their calculations. Only one model dynamically incorporates production costs based on the system state. Unlike the tourism sector, *the capacity of a production system can be exploited to minimize production costs*, for example, by prioritizing the most economical products to produce, depending on the dynamic state of the system, which is defined by residual machine capacities, current or planned production cycles, and the availability of raw materials. Following the lead of Chen and al. (2015), a production optimization algorithm could be combined with a DP model adapted to the manufacturing environment, to maximize production efficiency by proposing the sale of products that fit adequately into the existing production schedule, thus minimizing costs, residual capacity, and disruptions.

This literature review confirms the existence of DP models adapted to the manufacturing sector under three distinct approaches. However, the lack of current models that adequately consider dynamic production costs limit manufacturing SMEs' potential for revenue maximization through cost reduction, thereby hindering their capacity to generate profits. For the third research question, a tiny fraction, 3.8% of the work, conducts a concrete case study on the application of DP in a manufacturing environment. Moreover,

the only case study was based on a firm specializing in the manufacture of one-off products, where DP focuses on supply chain management, which does not entirely correspond to the needs of manufacturing SMEs offering customized products. This observation demonstrates a significant gap in the research field, marked by insufficient analysis of the adoption of DP strategies within these companies. The prevalence of numerical examples to validate models limits the evaluation of implementation and operating costs in the context of such a manufacturing strategy. In short, the contribution of this review resides in clarifying the potential of DP for manufacturing SMEs, revealing gaps between theory and practice, underlining the consensus among authors that DP is profitable, and emphasizing the importance of developing more adapted models and testing them in real-world scenarios.

5. CONCLUSION

Although strategies such as MC exist to mitigate internal variations, manufacturing SMEs find it challenging to remain competitive in the current complex and changing environment. Hence, a literature review of DP in the manufacturing sector is proposed to assess its potential to enhance the profitability of these enterprises. The findings reveal that, although profitable and adapted DP models exist for the manufacturing sector, the majority focus on capacity optimization rather than balancing production costs, thus limiting their effectiveness for SMEs specializing in customized products. DP, combined with production optimization, could serve as an agility tool to fully manage the fluctuations faced by these SMEs. This underexplored approach opens the door to future research. It would be interesting to better integrate production management and planning with DP, evaluate its performance through case studies in the manufacturing environment, and examine implementation challenges, particularly in terms of costs such as technological investment, staff training, and strategy deployment.

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