

Value-chain factors influencing production volume and gross margin: evidence from a Thai dairy processing firm

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Abstract

The dairy industry is vital for food security and economic stability, particularly in developing markets such as Thailand. Understanding factors related to production volume and gross margin in dairy processing firms can help inform performance and profitability considerations. Based on Porter's value chain framework and a perception-based survey approach, this study used document reviews, in-depth interviews with 14 key informants, and an employee perception survey ($n = 21$) covering 74 relevant factors. Results indicated significant differences across ten activity categories for both production volume ($X^2 = 53.59$, $df = 9$, $P < 0.001$) and gross margin ($X^2 = 26.89$, $df = 9$, $P < 0.001$). For production volume, research and development (3.96 ± 0.66), human resources management (3.93 ± 0.63), and external factors (3.82 ± 0.82) had the highest mean perceived importance scores. For gross margin, external factors recorded the highest mean score (3.96 ± 0.81). At the factor level, the Thai government-regulated raw milk price was classified as the most important factor associated with production volume, while fuel prices were the most important factor related to gross margin. Both factors had the highest proportion of "High" and "Very High" responses (90.5%). These findings highlight the importance of aligning internal activities with external conditions within an institutional and policy context. This study provides insights into how institutional and policy constraints shape the way firm-level activities and external conditions are perceived and prioritized, and how these perceptions relate to performance in dairy processing firms in Thailand.

Keywords: agribusiness, employee perception, external factors, operational activities, Thailand

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Introduction

The dairy processing sector in Thailand faces a range of challenges arising from both internal operational conditions and external institutional and market forces (Vajirabhoga, 2020; Vajirabhoga *et al.*, 2021), which influence production volumes and financial performance (Thongplew *et al.*, 2016). A key structural challenge lies in the fragmented raw milk supply chain. The chain consists of numerous smallholder farms with limited herd sizes that are dispersed across rural areas. This constrains logistical efficiency and coordination (Garcia *et al.*, 2005; Mor *et al.*, 2017). At the processing level, the sector comprises a mix of domestic and multinational firms operating across diverse product segments (Gerosa and Skoet, 2012; Embassy of Brazil in Bangkok, 2021; Perapalanunt *et al.*, 2022). Under these conditions, effective infrastructure, quality assurance systems, and operational efficiency are important for firm-level competitiveness and profitability (Mor *et al.*, 2017).

In addition to market-related pressures, dairy processors in Thailand operate under significant institutional constraints, particularly government policies designed to stabilize the market by regulating raw milk procurement and supporting small-scale dairy farmers. These policies, formalized through Memoranda of Understanding (MoU), require dairy cooperatives, private enterprises, and government-operated facilities to maintain procurement arrangements with local farmers at predetermined prices (Ongkunaruk, 2015; Singhara Na Ayutthaya, 2020). While such arrangements contribute to income stability for farmers and ensure raw milk availability, they reduce processors' flexibility to adjust production volumes and product portfolios in response to fluctuations in demand or cost conditions (Mor *et al.*, 2017). Consequently, operational imbalances frequently emerge.

Rapidly evolving consumer preferences further intensify these challenges. These shifts require continuous innovation and periodic restructuring of production and marketing activities (Gerosa and Skoet, 2012), as dairy processors adjust their operations and value-creation activities to remain competitive in changing markets (FrieslandCampina, 2022; Marketeer, 2022). Accordingly, identifying key operational components and understanding how they interact with broader market and institutional dynamics has become essential for sustaining long-term competitiveness in the Thai dairy processing sector (Mor *et al.*, 2017).

Against this backdrop, this study adopts Porter's Value Chain Analysis (VCA), which organizes firm activities into primary and support activities, as the primary analytical framework to examine internal operational activities and their roles in value creation within Thailand's dairy processing industry (Porter, 1985). Although the framework has been widely applied in manufacturing industries to improve operational performance (McPhee and Wheeler, 2006; Li *et al.*, 2008; Aguko, 2014; Flanagan *et al.*, 2018; Garay-Rondero *et al.*, 2020), empirical applications in the dairy industry remain limited, particularly in developing countries characterized by decentralized supply

systems and strong policy interventions. This study therefore emphasizes a context-specific application of VCA by demonstrating how the framework can be used to organize and interpret operational activities and constraints within a regulated, multi-stakeholder dairy processing environment, rather than proposing a new or modified value chain model.

The objective of this exploratory study is to apply Porter's value-chain framework to examine employee perceptions of internal operational activities and external contextual factors related to production volume and gross margin in the Thai dairy processing sector. Using the Muak Lek Dairy Plant (MLDP) as a case study, the analysis explores how value-chain activities and external conditions are perceived within a specific organizational and institutional setting.

This study contributes to the literature by highlighting how institutional and policy constraints help shape how operational factors are perceived and prioritized within a regulated dairy processing context.

Materials and Methods

Dairy processing firm selection: This study utilized the Muak Lek Dairy Plant (MLDP) as a case to examine the value chain of a dairy processing firm. The MLDP is one of five dairy processing factories owned by the Dairy Farming Promotion Organization of Thailand (DPO), a state enterprise under the Ministry of Agriculture and Cooperatives. It is the DPO's first and primary factory, located in the Muak Lek district of Saraburi Province, Thailand. The MLDP receives between 300 and 500 tons of raw milk daily from contracted and non-contracted suppliers in Saraburi, Lopburi, and Nakhon Ratchasima provinces. This supply scale is supported by a regional dairy cow population of 230,140 heads in 2021 (Boonthongneum, 2021). The MLDP produces various UHT and pasteurized products, including ready-to-drink milk, yogurt, and ice cream, none of which contain skim milk powder. Its primary customers include agencies, retailers, and schools.

Participant selection: A desk review was conducted using organizational information from the DPO website (<https://www.dpo.go.th/>) to identify relevant MLDP actors, their activities associated with products, and to inform the design of the data collection approach.

In-depth interviews (IDIs): From the identified list of MLDP actors, roles and associated activities were examined to determine an appropriate initial informant. The MLDP director was selected for an in-depth interview (IDI) to validate the actor list, confirm role responsibilities, and clarify activity details. Following the director's IDI, additional informants were identified through consultation to address information gaps across specific activities. Finally, purposive sampling was applied to ensure representation across all actor groups (Knott *et al.*, 2022).

Employee perception surveys: Beyond the key actors identified through the IDIs, employee-level

perceptions were collected through a survey administered to experienced milk processing staff with at least five years of experience. A snowball sampling method was used (Knott *et al.*, 2022), beginning with a recommended MLDP employee who referred other knowledgeable professionals within the MLDP or other dairy processing plants. Potential participants were contacted by telephone, informed about the study, and asked to provide informed consent prior to completing the questionnaire.

A total of 14 informants participated in the IDIs, including the MLDP director, five senior staff members, four production personnel, two outbound logistics personnel, one marketing and sales personnel, and one after-sales services personnel. In addition, 21 respondents completed the survey.

Data collection: Following participant selection, broader primary and secondary data were gathered to support the analysis. Formal collaboration with the MLDP was requested via an official letter to the DPO director; once authorized, the team accessed organizational documents and internal operational records. Secondary data on organizational structure and processes were obtained from the DPO website, while MLDP internal records provided quantitative information on milk supply quantities, costs, and product prices.

To supplement and contextualize these sources and internal records, IDIs were conducted with key actors between September and December 2020. Interviews were held individually or in small groups, depending on availability, and were used to fill gaps in available data and to elicit contextual detail on the MLDP's organization, product flow, production processes, and activities associated with different product lines. Interview prompts were organized around Porter's value chain framework to ensure comprehensive coverage of operational activities relevant to production volume and gross margin. All participants were informed about the study and provided consent prior to participation.

To measure perceptions of the factors of production volume and gross margin, we developed a structured questionnaire with closed-ended questions. The questionnaire comprised two sections: (1) respondents' work experience and (2) items organized across ten activity categories aligned with Porter's value chain framework: inbound logistics (IL), production (PD), outbound logistics (OL), marketing and sales (MS), after-sales services (AS), infrastructure (IF), human resources management (HR), research and development (RD), and procurement (PC), with a tenth category for external factors (EF) relevant to Thailand (e.g., disease outbreaks, fuel prices, and electricity tariffs). Employee surveys were administered between September and December 2022. Fig. 1 illustrates examples of factors related to production volume and gross margin.

The 74 factors listed in Table 1 were initially developed by the research team by integrating quantitative data from MLDP internal records, insights from IDIs, and the structure of Porter's value chain activities, rather than being adopted from prior studies. To ensure face validity and content relevance,

the preliminary list of factors was reviewed by four professionals: a senior MLDP staff member, a private dairy processing firm's owner, and two lecturers from the Faculty of Veterinary Science at Chulalongkorn University in Bangkok, Thailand. The experts were asked to assess the relevance, clarity, and practical plausibility of each factor, and to suggest the removal, revision, or consolidation of items where appropriate. This iterative review process continued until consensus was reached among all experts regarding the suitability of the final set of factors for use in an exploratory survey instrument.

Instrument reliability was examined at the activity level using Cronbach's alpha to provide a descriptive indication of internal coherence among factor groupings within the value-chain framework. Because the factors were not designed as unidimensional psychometric scales, Cronbach's alpha was interpreted cautiously and was not used as a criterion for item modification or exclusion. Following conventions in exploratory research, alpha values in the moderate range were regarded as appropriate for descriptive interpretation, rather than as strict thresholds for scale evaluation (Gignac, 2025).

The finalized questionnaire then employed a five-point scale (1 = very low impact, 2 = low impact, 3 = moderate impact, 4 = high impact, and 5 = very high impact) to capture respondents' perceptions of the importance of each factor in relation to production volume and gross margin. Respondents evaluated items based on their knowledge and experience. Quantitative records, interview-derived insights, and survey responses were subsequently analyzed as described in Data analysis.

Data analysis: This study primarily adopts a quantitative analytical approach based on survey data, with the survey instrument developed using insights from document review and IDIs with key informants. Quantitative information was obtained from internal operational records spanning October 2017 to March 2020, which included product type, milk supply volumes, production volumes, processing costs, storage quantities, sales quantities, and selling prices. The dataset was examined for inconsistencies and missing values. Cases with minimal missing information (fewer than 5% of observations) were completed using supplementary records and expert judgment to preserve data completeness. Dairy products were grouped into ten product families based on processing methods for subsequent analyses.

Descriptive statistics were calculated using Microsoft Excel 2023 (Student and Home edition) (Microsoft Corporation, 2023). Costs and selling prices in Thai Baht (THB) were converted to US dollars (USD) using an average exchange rate of 1 THB = 0.032 USD (Exchange Rates UK, 2020). Mean values and standard deviations (SD) were computed for production volume (metric tons per quarter and as a percentage of total output) and financial variables across product families. These values were reviewed with informants and experts to ensure consistency with operational practices, and the validated production and financial data were used to construct production flow diagrams and financial structures.

Information from IDIs was used to clarify operational procedures, support the alignment of activity categories, and ensure consistency between the data and the operational practices of the firm.

To evaluate perceived differences across value-chain activities in relation to production volume and gross margin, activity-level scores were calculated at the respondent level by averaging all factors within each activity category (Bhandari and Nikolopoulou, 2020), ignoring incomplete responses (NA values) on a person-by-person basis. These respondent-level activity scores were used for statistical comparison across ten activity categories. Descriptive statistics (mean and SD) were calculated from these respondent-level scores. Given the ordinal origin of the survey responses, the relatively small sample size, the presence of missing values, and the repeated-measures structure of the data, a non-parametric approach was employed. The Skillings-Mack test, an extension of the Friedman test suitable for unbalanced block designs

(Skillings and Mack, 1981), was used to assess overall differences across activity categories at $\alpha = 0.05$. When significant differences were detected, pairwise comparisons were conducted using the Wilcoxon signed-rank test with Holm adjustment for multiple comparisons. All analyses were performed in RStudio (version 2023.06.1-254) (R Core Team, 2023).

To assess the perceived influence of specific factors, factor-level summaries treated responses as ordinal data. For each factor, response frequencies were converted into percentages (Boone Jr and Boone, 2012), and the combined proportion of ratings "High" (4) and "Very High" (5) represented the overall perceived influence. Following established criteria, factors were classified as Strong ($\geq 80\%$), Moderate ($\geq 70\%$ and $<80\%$), or Low ($<70\%$) (Reijnierse *et al.*, 2023), and results were visualized using stacked bar charts and descriptive summaries to illustrate relative importance across activity categories and factor groups.

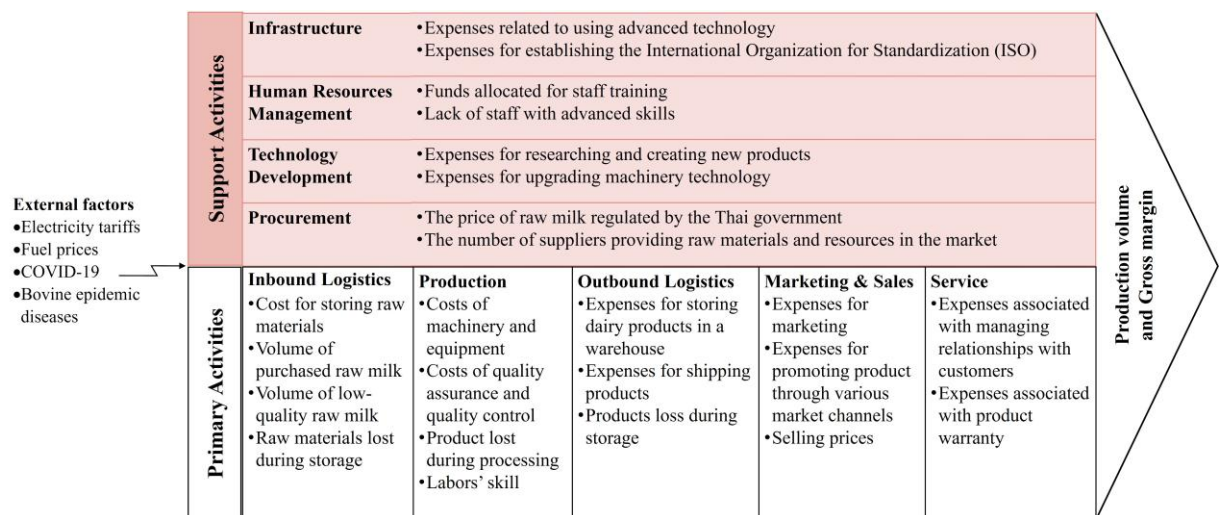


Figure 1 The figure shows internal and external factors related to production volume and gross margin in dairy processing firms (authors, 2026).

Table 1 Activities and factors listed in the questionnaire.

Activity	Factor	Code
IL	Volume of unqualified raw milk	IL01
	Volume of purchased raw milk	IL02
	Volume of low-quality raw milk (high bacterial loaded) but still be qualified	IL03
	Cost of storing raw milk in cooling tanks ($\leq 4^{\circ}\text{C}$) before use	IL04
	Amount of raw milk lost during storage before used	IL05
	Price of other raw materials	IL06
	Cost of storing additional raw materials	IL07
	Amount of other raw materials lost or exceeding requirements due to storage issues	IL08
	Price of packaging	IL09
	Cost of storing packaging materials	IL10
	The number of packaging materials lost or in surplus due to storage issues	IL11
PD	Cost of machinery	PD01
	Machinery Capacity	PD02
	Machinery maintenance cost	PD03
	Cost of raw materials and packaging	PD04
	Salary and wages for staff working on production lines	PD05
	Expertise and abilities of employees operating on manufacturing lines	PD06
	The quantity and adequacy of personnel operating on manufacturing lines	PD07
	Costs associated with ensuring product quality	PD08
	Expenses for quality control	PD09
	Costs associated with testing packaging materials, such as milk cartons, during the production process	PD10
	Amount of pasteurized milk discarded due to not meeting quality standards	PD11
	Amount of ultra-high temperature sterilized milk discarded due to failing quality standards	PD12

Activity	Factor	Code
OL	Amount of milk wasted because of altered taste or color changes resulting from the use of shared production lines	PD13
	Number of dairy products wasted because of faulty packaging	PD14
	Number of dairy products manufactured for other firms, e.g., school milk products	PD15
	Expenses for storing dairy products in a warehouse	OL01
	Warehouse maintenance cost	OL02
	Expenses for renting storage space from external warehouse providers	OL03
	Losses incurred from dairy products in stock	OL04
	Number of days from receiving an order to complete delivering	OL05
	Expenses incurred by MPF for delivering products	OL06
	Expenses for shipping products using external logistics companies	OL07
MS	Losses of products during transportation	OL08
	Expenses for brand development and fostering customer loyalty	MS01
	Expenses incurred in marketing strategies aimed at attracting new customers	MS02
	Expenses for marketing activities targeting global customers	MS03
	Expenses for promoting products through television	MS04
	Expenses for promoting products on social media platforms	MS05
	Expenses for promoting products through radio	MS06
	Number of products sold to modern trades such as supermarkets	MS07
	Number of products sold through traditional retail channels	MS08
	Number of products sold through online marketplaces	MS09
AS	Price of products sold to customers within the country	MS10
	Price of products sold to customers in foreign markets	MS11
	Expenses associated with maintaining and managing relationships with customers	AS01
	Expenses incurred in handling customer complaints and resolving related issues	AS02
	Expenses associated with providing warranties for products	AS03
	Return and refund processing cost	AS04
	Expenses incurred for processing returned products in exchange for other items	AS05
IF	Expenses related to using information technology to enhance the efficiency of production processes	IF01
	Expenses for establishing and upkeeping ISO standards	IF02
HR	Expenses incurred in forming partnerships with other businesses to strengthen bargaining capabilities	IF03
	Funds allocated for employee training and growth	HR01
	Lack of employees with advanced skills or expertise	HR02
RD	Expenses for technology that can replace human labor	HR03
	Expenses for developing and upgrading machinery technology	RD01
	Expenses for developing information technology systems to manage the business	RD02
PC	Expenses for researching and creating new products	RD03
	Price of raw milk regulated by the Thai government	PC01
	The number of suppliers providing materials or resources in the market	PC02
	The quantities and frequency of orders placed with suppliers	PC03
	The process of choosing providers for goods or services	PC04
	Categories of orders placed for goods or services	PC05
	The scale of the business, its ability to procure resources, and its power to negotiate terms	PC06
	Using sales information to predict and plan for future resource needs	PC07
EF	Rates charged for electricity usage	EF01
	Fuel prices	EF02
	International confrontations	EF03
	Free trade agreement for dairy products in 2025	EF04
	The COVID-19 pandemic	EF05
	Bovine epidemic diseases (e.g., foot-and-mouth disease)	EF06
	The baht depreciation	EF07
	Government funding for a program providing milk to schools	EF08

Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

Results

The passage of products through various stages: Raw milk was delivered from milk collection centers to the Muak Lek Dairy Plant (MLDP), quality-evaluated at reception, and stored in tanks at 4 °C prior to processing. Storage capacity was 350 tons/day, while production capacity was 500-580 tons/day. During periods of low product demand, surplus raw milk was transferred to other facilities within the network. In production, raw milk was pasteurized, separated into skim and cream, standardized, and processed into two product types: UHT (U1-U3) and pasteurized (P1-P5) product families; separated cream was processed into two cream families (C1-C2). Finished products were

warehoused and distributed via third-party logistics or customer pickup (Fig. 2).

Product volumes: On a quarterly basis, the MLDP procured $32,661.22 \pm 3,390.49$ tons of raw milk; contracted suppliers accounted for $97.50\% \pm 2.00\%$ and non-contracted suppliers for $2.50\% \pm 2.00\%$ (Fig. 3). The plant utilized $90.24\% \pm 10.65\%$ of supplied raw milk to produce UHT, pasteurized, and cream products. UHT products accounted for $94.26\% \pm 1.17\%$ of utilized raw milk. By volume, U1 ranked first, followed by U2 and P2; within pasteurized products, P2 ranked first. Agencies were the primary purchasers across most families; schools predominantly acquired U1 and P2. Defective, quality-control, and promotional quantities

are computed as the residual between production and total purchases (Fig. 3).

Manufacturing cost of products, selling price, and gross margin: The plant procured raw milk at approximately 0.63×10^3 USD/ton from both contracted and non-contracted suppliers (Fig. 4). Unit costs varied across product families; among UHT

products, U2 exhibited higher unit costs ($1.18 \pm 0.89 \times 10^3$ USD/ton). Pasteurized products showed pronounced cost dispersion, with P1 at $2.56 \pm 0.79 \times 10^3$ USD/ton (highest) and P2 lowest within the pasteurized group. Yogurt (P5: $2.28 \pm 0.25 \times 10^3$ USD/ton) and cream (C1: $1.61 \pm 0.00 \times 10^3$ USD/ton) also showed higher costs.

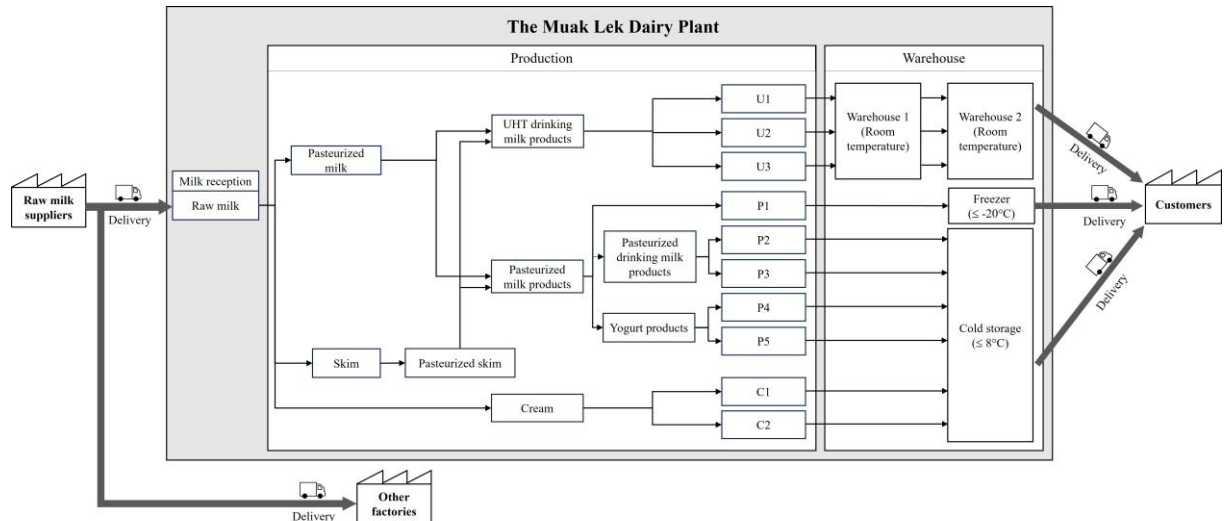


Figure 2 The figure shows the flow of dairy products across the Muak Lek Dairy Plant (MLDP), from milk suppliers to end customers.

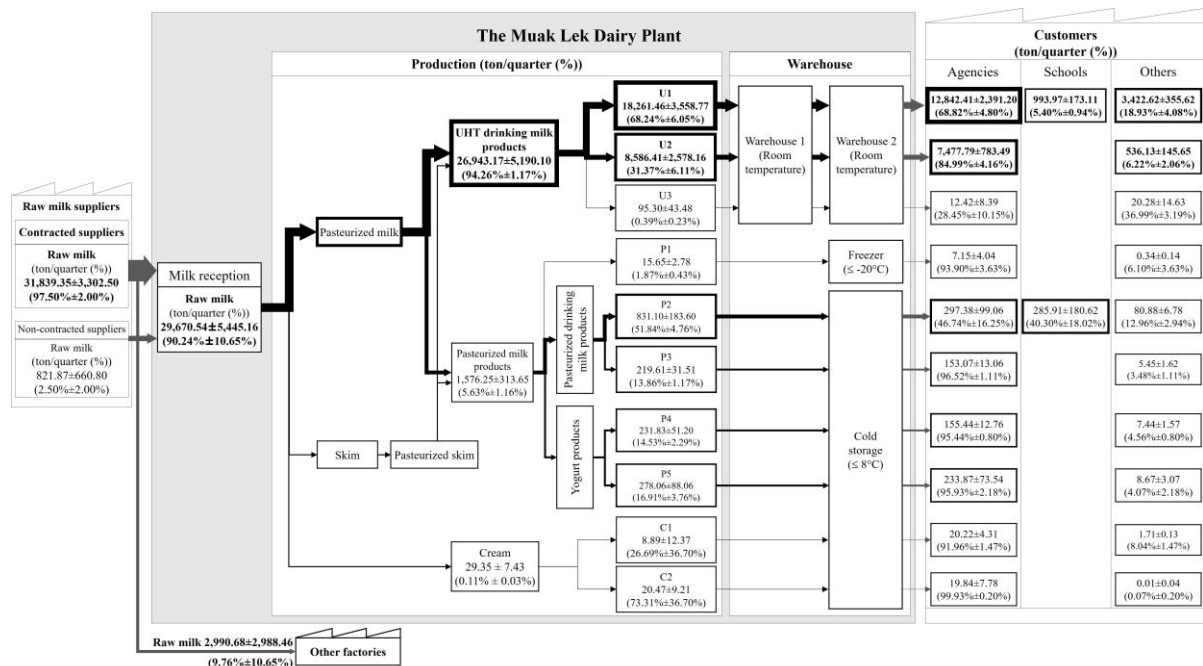


Figure 3 The figure depicts the flow of dairy products through the Muak Lek Dairy Plant's (MLDP) value chain, showing average quarterly volume in tons and distribution percentages, expressed as Mean ± SD.

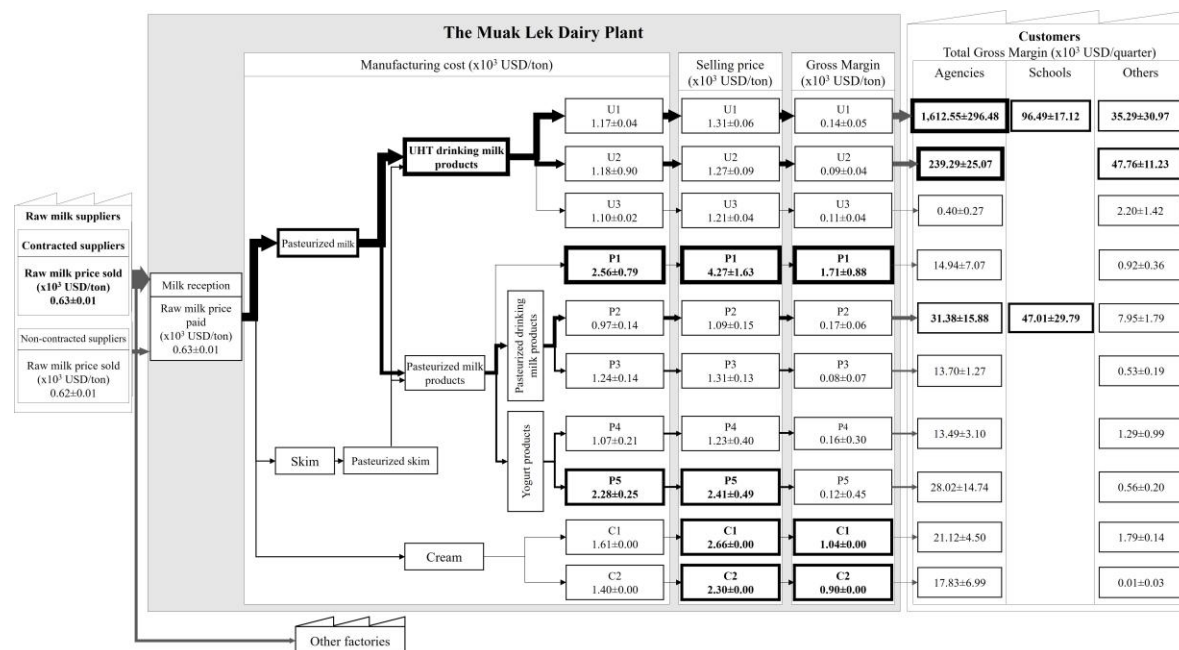


Figure 4 The figure illustrates the flow of dairy products, including raw milk prices, average product manufacturing costs, average selling prices, and average gross margins (x103 USD/ton) of ten product families and their quarterly total gross margins (x103 USD/quarter), based on the volume purchased by three customer groups. Values are presented as the Mean ± SD.

Selling prices corresponded to the observed unit costs: P1 ($4.27 \pm 1.63 \times 10^3$ USD/ton) and P5 ($2.41 \pm 0.49 \times 10^3$ USD/ton) were higher among pasteurized products, and C1 was also priced higher within its category (Fig. 4). Gross margins varied across families; P1 recorded the largest gross margin, followed by C1 and C2. Agencies were the largest customer segment and contributed the majority of quarterly gross margins, particularly through U1. U1, U2, and P2 generated substantial quarterly gross margins among the ten families.

Dairy processing firm's value chain: Based on document review and information from interviews, the firm's internal activities and organizational units were mapped onto Porter's value chain framework; relevant external factors were documented alongside internal activities.

Primary activities: Inbound Logistics (IL). IL included milk delivery, reception, and quality evaluation; acquisition and grading of manufacturing inputs (e.g., flavorings, packing); and raw-milk storage and allocation. The Quality Control Division (QC) oversaw raw-milk quality assessment, receiving, and grading. The Supply and Service Division managed non-milk production inputs. The Division of Production Planning (DPP) managed raw-milk storage, supply scheduling, and distribution of production inputs.

Production (PD). PD was executed by the DPP, the Division of UHT Product Production (DUHT), and the Division of Pasteurized Dairy Products (DPAS). DPAS produced pasteurized milk and cream, and DUHT produced UHT products. Production departments operated under the International Organization for Standardization (ISO), Good Manufacturing Practices (GMP), Hazard Analysis Critical Control Point (HACCP), and halal standards. The Division of Plant Engineering managed plant engineering functions to

ensure safe and efficient production, and the QC performed product-quality control.

Outbound logistics (OL). OL comprised quality checks, warehousing, order processing, and dispatch. The UHT Product Warehouse Division managed UHT products, and the Pasteurized Product Warehouse Division managed pasteurized and cream products. Customer orders were processed and shipped within approximately one week. The QC conducted quality checks during storage and prior to dispatch.

Marketing and Sales (MS). MS activities were performed by the Marketing and Sales Division and included coordination with production on product planning, price setting, and customer relationship management (e.g., client visits and feedback collection).

After-Sales Services (AS). AS was administrated by the Marketing and Sales Division and included the handling of consumer complaints, product exchanges, and refunds.

Support activities: Infrastructure (IF). IF activities were conducted by the General Administration, Accounting and Finance, Supply and Service, and Quality Systems and Standards Divisions. The General Administration Division covered operations, personnel, and budgeting. The Accounting and Finance Division managed cost tracking and financial planning. The Supply and Service Division coordinated materials and services. The Quality Systems and Standard Division maintained ISO, GMP, and HACCP compliance.

Human Resources Management (HR). HR activities comprised workforce planning, staff recruitment, performance appraisal, and employee development. The General Administration Division oversaw these activities. Performance appraisals were conducted by the director and division heads as appraisers.

Research and Development (RD). At the MLDP, the Research and Development Division conducted market research, product testing, and technology assessment related to product development and process improvement. Activities included exploring new dairy product opportunities and refining existing product lines.

Procurement (PC). The Supply and Service Division managed procurement activities, including supplier sourcing and contracting; purchasing, receiving, and inspecting inputs; inventory and asset management for raw materials, packaging, equipment, and machinery; and procurement documentation and reporting.

External factors (EF): External factors (EF) documented in relation to internal VC activities and costs included rates charged for electricity usage (EF01), fuel prices (EF02), international confrontations (EF03), the 2025 free trade agreement for dairy products (EF04), the COVID-19 pandemic (EF05), bovine epidemic diseases (EF06), the baht depreciation (EF07) and government-supported milk programs (EF08). These factors were mapped alongside activities as part of the value-chain analysis (Fig. 5).

EF01 was relevant to energy-intensive processing operations (e.g., UHT and pasteurization) and cold storage, and with facility-wide utilities captured in production and warehousing costs, while EF02 was linked to inbound milk collection, outbound distribution, and freight charges for procured inputs managed by suppliers or third-party logistics providers. EF03 was related to input price and availability, transport and freight conditions, and market access for import-export of materials and finished products. EF04 was associated with tariff and market-access conditions relevant to PD, MS, RD, and PC activities. EF05 was linked to variations in customer demand, workforce constraints and protocols, and logistics scheduling, as reflected in production and distribution. EF06 was associated with raw-milk supply volume and quality at the IL and subsequent PD activities, while EF07 affected the costs of import inputs, export and foreign-market pricing, and financial valuation and reporting. EF08 was associated with order volumes and timing for specific product lines and distribution scheduling to agencies and schools.

Figure 5 summarizes the activity categories, participating organizational units, and associated external factors in the MLDP value chain.

The perceived importance of activity categories and individual factors are reported in Employee perception.

Employee perception: The following results are based on the employee survey ($n = 21$), with instrument development, reliability assessment, and analytical procedures described in Data collection and Data analysis within Materials and Methods.

Cronbach's alpha values varied across activity categories (Table 2). Most activities showed moderate to high internal coherence for perceived importance to both production volume and gross margin, with alpha values generally exceeding 0.70. IF exhibited lower

internal coherence, reflecting greater heterogeneity of factors within this activity category.

Respondents' work experience: Twenty-one respondents participated, distributed across milk reception (5; 23.81%), manufacturing (3; 14.29%), final-product warehousing (4; 19.05%), and management and policy planning (8; 38.10%); one respondent (4.75%) did not specify a role.

Activity-level differences: The Skillings-Mack test indicated statistically significant differences across activity categories for both production volume (chi-squared = 53.59, degrees of freedom = 9, $P < 0.001$) and gross margin (chi-squared = 26.89, degrees of freedom = 9, $P = 0.001$).

For production volume, activity scores fell within the Moderate to High range (Table 3). Mean $\pm$ SD values were relatively higher for RD, HR, and EF compared to other activity categories. However, pairwise comparisons revealed more detailed differences (Fig. 6). RD was assigned to the highest statistical group; however, its scores overlapped with those of HR and EF, indicating no clear statistical separation among these higher-scoring activities. In contrast, AS formed the lowest statistical group and differed significantly from several higher-scoring activities. Most remaining activity categories showed overlapping statistical groupings, indicating that their perceived importance was not clearly distinguishable at the statistical level.

For gross margin, activity scores were also within the Moderate to High range, with EF recording the highest mean score (Table 3). The Skillings-Mack test confirmed significant overall differences across activity categories; however, pairwise comparisons indicated limited separation among most activities (Fig. 6). EF was assigned to a higher statistical group; however, significant differences were observed only with some lower-scoring activities (AS and IF), while most activities showed overlapping groupings. These results show that, although EF is perceived as relatively more important for gross margin, differences among most activity categories remain modest and not clearly differentiated.

Perceived importance of individual factors: Figures 7-8 display the perceived importance of individual factors using a five-point color scale: very low (dark blue), low (light blue), moderate (pink), high (light red), and very high (dark red); while grey dots indicate "no opinion". Factor importance is summarized as the combined proportion of "High" and "Very High" responses and categorized as Strong ($\geq 80\%$), Moderate (70- $<80\%$), or Low ($<70\%$), as indicated by the reference lines in the figures.

For production volume, three factors were classified as Strong: IL02 (raw-milk purchase volume), PC01 (Thai government-regulated raw-milk price), and EF06 (bovine epidemic diseases). Among these, PC01 had the highest proportion of "High/Very High" responses (90.5%). Four additional factors were classified as Moderate, while the remaining 67 were classified as Low (Fig. 7).

For gross margin, five factors were classified as Strong: PD05 (salary and wages for production-line staff), OL03 (costs of renting external storage), EF01 (electricity rates), EF02 (fuel prices), and EF05 (COVID-19). EF02 recorded the highest “High/Very High” proportion (90.5%). Nine factors were Moderate, and 60 were Low (Fig. 8).

Based on employee perceptions, factors perceived as most important for production volume were

concentrated in raw milk pricing, supply shocks, and purchased volumes. In contrast, employees perceived the most important factors for gross margin to be concentrated among external costs and cost-bearing internal activities, including utilities, transport fuels, pandemic effects, labor costs, and external warehousing.

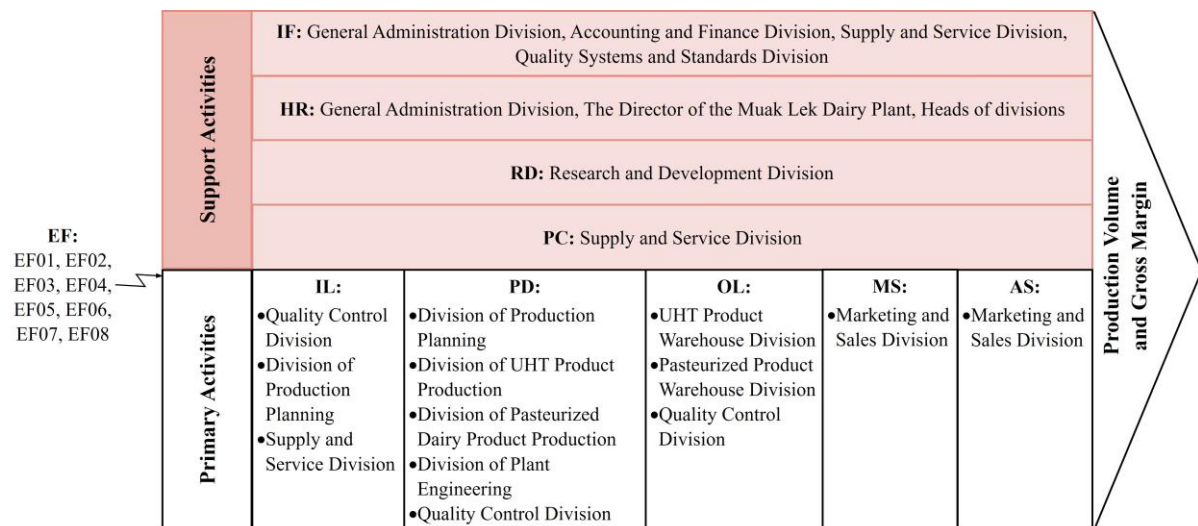


Figure 5 The figure shows the activity categories, participating actors, and external factors of the Muak Lek Dairy Plant (MLDP) value chain. Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; EF: External Factors; EF01: Rates charged for electricity usage; EF02: Fuel prices; EF03: International confrontations; EF04: Free trade agreement for dairy products in 2025; EF05: The COVID-19 pandemic; EF06: Bovine epidemic diseases (e.g., foot-and-mouth disease); EF07: The baht depreciation; EF08: Government funding for a program providing milk to schools.

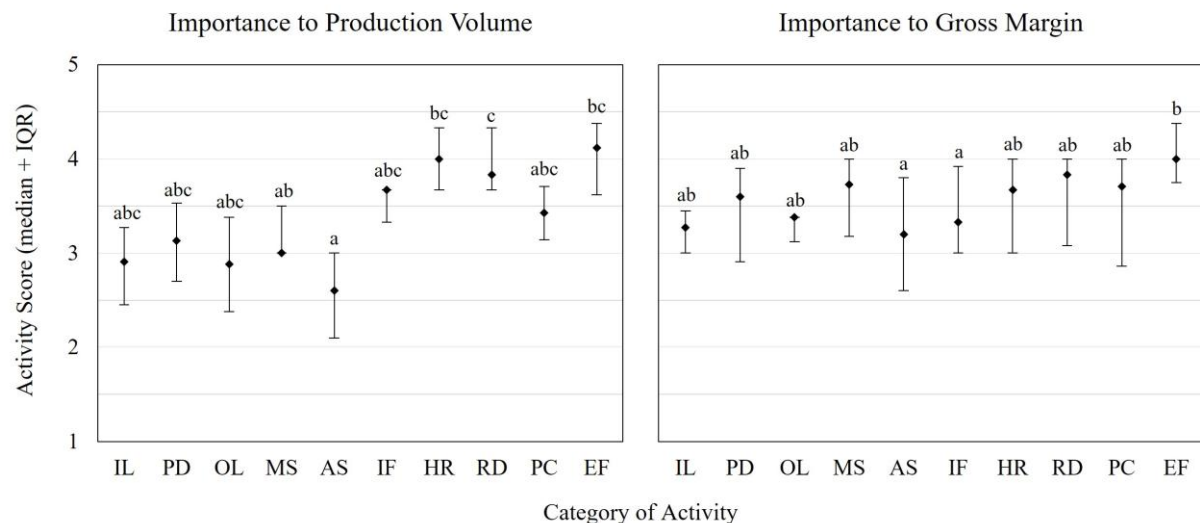


Figure 6 Activity scores (median ± IQR), across value-chain activity categories for production volume and gross margin. Significant differences across categories were identified at $\alpha = 0.05$ using nonparametric tests. Categories that do not share a common letter are significantly different. Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

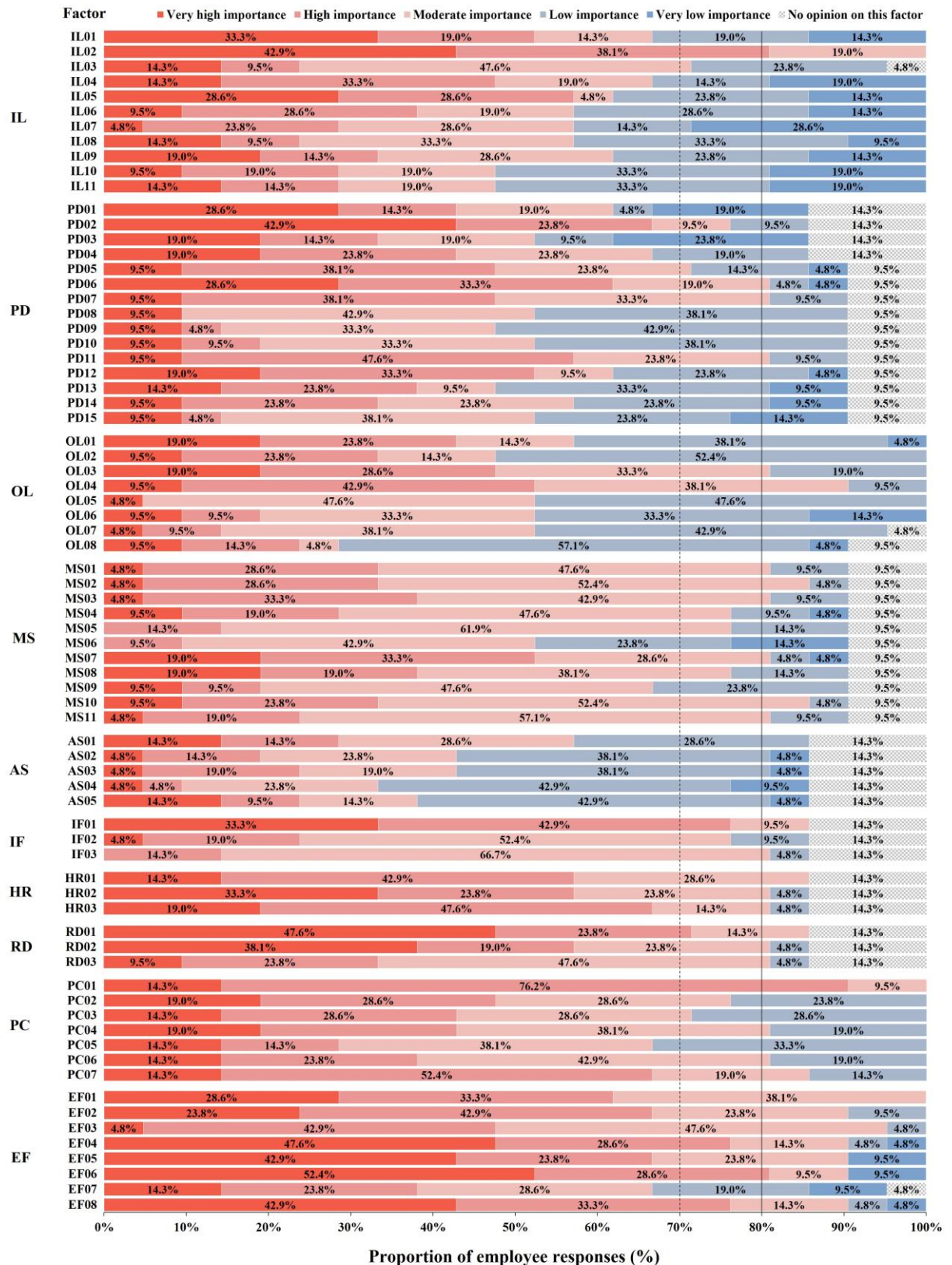


Figure 7 The figure shows the proportion of employee responses regarding the perceived importance of factors related to production volume. Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

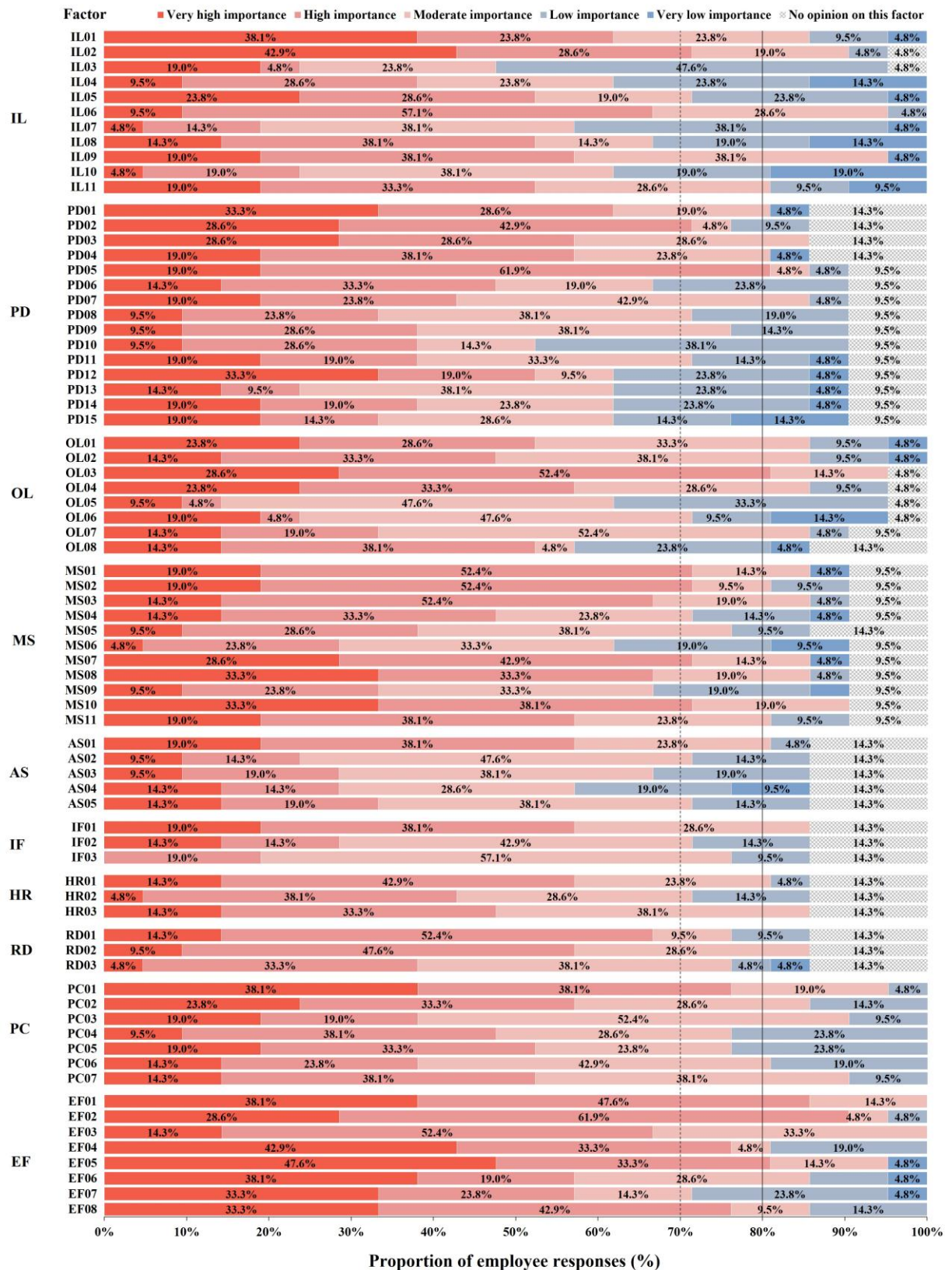


Figure 8 The figure shows the proportion of employee responses regarding the perceived importance of factors related to gross margin. Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

Table 2 Cronbach's alpha values for factor groupings within each category of activity.

Category of Activity	Number of Factors	Cronbach's alpha	
		Importance to Production Volume	Importance to Gross Margin
IL	11	0.81	0.79
PD	15	0.89	0.92
OL	8	0.87	0.86
MS	11	0.80	0.92
AS	5	0.94	0.91
IF	3	-0.02	0.32
HR	3	0.63	0.72
RD	3	0.64	0.75
PC	7	0.89	0.91
EF	8	0.93	0.92

Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

Table 3 Mean standard deviation (SD) of perceived importance across activity categories for production volume and gross margin.

Activity	Production Volume (Mean $\pm$ SD)	Gross Margin (Mean $\pm$ SD)
IL	3.08 $\pm$ 0.75	3.34 $\pm$ 0.63
PD	3.25 $\pm$ 0.73	3.52 $\pm$ 0.74
OL	2.97 $\pm$ 0.73	3.44 $\pm$ 0.71
MS	3.23 $\pm$ 0.49	3.69 $\pm$ 0.7
AS	2.79 $\pm$ 0.94	3.28 $\pm$ 0.89
IF	3.54 $\pm$ 0.36	3.44 $\pm$ 0.51
HR	3.93 $\pm$ 0.63	3.63 $\pm$ 0.65
RD	3.96 $\pm$ 0.66	3.65 $\pm$ 0.66
PC	3.47 $\pm$ 0.75	3.56 $\pm$ 0.78
EF	3.82 $\pm$ 0.87	3.96 $\pm$ 0.81

Here: IL: Inbound Logistics; PD: Production; OL: Outbound Logistics; MS: Marketing and Sales; AS: After Sales and Service; IF: Infrastructure; HR: Human Resources Management; RD: Research and Development; PC: Procurement; and EF: External Factors.

Discussion

This study applied Porter's value chain framework, mapping activities across the firm, and an employee perception survey to explore the perceived importance of internal activities and external conditions in relation to production volume and gross margins in a Thai dairy processing context. To our knowledge, few empirical studies have combined activity-level and factor-level evidence in a regulated dairy environment, offering insights for managerial practice and the role of institutional and policy constraints in relation to firm-level outcomes.

To interpret these findings, it is useful to clarify the analytical positioning of the value chain framework used in this study. Porter's value chain focuses on internal organizational activities and the contribution to firm-level performance (Porter, 1985), making it appropriate for examining a single dairy processing firm. In contrast, industry-level and global value chain

approaches typically emphasize inter-firm relationships, governance structures, and coordination across broader supply chains (Kaplinsky and Morris, 2000; Gereffi *et al.*, 2005; Gereffi and Fernandez-Stark, 2016). While these approaches offer valuable perspectives, they are less suited to examining activity-level dynamics within a single organization.

In this study, the firm-level framework is extended by incorporating selected external and institutional factors relevant to the dairy processing context. This allows the analysis to capture how internal activities and external factors jointly shape production volume and gross margin. However, the analysis does not examine governance structure or relationships across the wider supply chain. Therefore, the findings should be interpreted within the scope of the focal organization and based on employees' perceptions.

Visualization of volumes and margins highlights the role of customer demand in shaping product mix and earnings at the MLDP. Consistent with work on

demand-driven strategies, high-demand agency products (e.g., U1-U2) were associated with higher overall throughput and total margin despite variation in unit profitability, whereas limited demand for a higher-margin pasteurized family (P1) contributed less to total margin (Santa *et al.*, 2022). These patterns suggest the importance of monitoring real demand and adjusting production plans accordingly, especially when products differ substantially in their per-unit margins.

The consistency of responses within each activity category provides important context for interpreting the activity-level perception results. Lower Cronbach's alpha values for infrastructure (IF) reflect the heterogeneous nature of the underlying factors included in this category. IF involves different operational aspects, such as information technology-related costs, quality system expenses (e.g., ISO compliance), and costs associated with business partnerships, which employees may view differently. As a result, lower internal coherence was expected and should not be interpreted as a weakness of the measurement, but as a reflection of the varied operational roles captured by this activity category.

At the activity-category level, the results suggest that both internal firm activities, including RD and HR, and external conditions, represented by EF, are perceived as relevant to production volume. This configuration aligns with the literature: process and product innovation enhance operational efficiency and adaptability (Won and Park, 2020), while capable workforces underpin stable operations and reliable execution of production activities (Karwasra *et al.*, 2024). For gross margin, the results highlight the perceived role of EF in profitability. This pattern is consistent with the characteristics of energy- and logistics-dependent processing systems, where external cost conditions are recognized as important determinants of unit costs and margins (Dillon and Barrett, 2016).

At the factor level, the strongest perceived drivers of production volume clustered around procurement constraints and supply conditions: the government-regulated raw-milk price, purchased raw-milk volumes shaped by prevailing procurement arrangements, and bovine disease outbreaks. A regulated price limits short-run flexibility in sourcing decisions (Bureau of Animal Nutrition Development, 2016), while disease outbreaks can reduce available raw-milk supply, limiting the plant's ability to operate at its intended production level (Das *et al.*, 2021; Chanchaidechachai *et al.*, 2022). By contrast, the strongest perceived factors of gross margin were concentrated in external costs: fuel and electricity, and in cost-intensive internal activities: production-line labor and external warehousing, with pandemic-related disruptions compounding these pressures (Urgaonkar *et al.*, 2011; Kozai, 2013; Dillon and Barrett, 2016; Preechanjarn *et al.*, 2020; TNA, 2020; Acosta *et al.*, 2021). Together, these patterns are consistent with a processing system in which profitability appears sensitive to energy and transport costs, labor intensity on production lines, and storage strategies during supply-demand imbalances.

Beyond identifying the relative importance of cost-related factors, the findings suggest a central role of institutional and policy constraints in shaping how these factors relate to firm-level performance. In the Thai dairy processing context, regulated raw milk procurement arrangements under government-supported frameworks introduce institutional rigidity that may limit processors' flexibility in sourcing and input cost management. At the same time, although the processors in this context retain some ability to adjust product prices, such adjustments are constrained, in practice, by market competition and demand conditions. These may limit the extent to which rising costs can be passed on to consumers.

As a result, the processors appear to operate within a dual-constraint environment, where both input-side and output-side adjustments may be restricted. External cost pressures, including fuel and electricity prices, appear to be embedded within a pricing system influenced by both market mechanisms and government interventions, including regulatory controls, taxation, and stabilization policies (EPPO, 2023). These arrangements may constrain the processors' ability to fully adjust operating expenses, particularly in the short term, thereby potentially increasing the practical challenges associated with such cost fluctuations.

Given this configuration, three managerial priorities can be identified. First, strengthen market-intelligence-focused RD (i.e., using demand and market data to guide product decisions) to calibrate product-family planning and launch or discontinue products in response to demand signals; where margins vary widely across families, timely demand insights may help mitigate the risk of over-allocating production capacity to slower-moving, high-margin items. Second, target HR development toward capabilities that support operational efficiency and responsiveness, rather than broad, diffuse training agendas (Won and Park, 2020; Fatima *et al.*, 2022; Gangoda *et al.*, 2023; Dinlersoz and Wolf, 2024). Third, address cost exposure where the plant retains some control: electricity management and shift-timing (e.g., scheduling energy-intensive steps during lower-tariff periods); logistics planning that limits reliance on external storage; and carefully managed labor deployment across production activities. These actions do not eliminate exogenous cost shocks, but they may help reduce exposure to per-unit cost fluctuations and stabilize margins.

Because several factors perceived as highly important lie outside the control of the plant (e.g., electricity tariffs, fuel prices, the National School Milk Program, disease control), public-sector measures may help improve the economic viability of dairy processing operations in this context. Clarity and predictability in regulated electricity charges for energy-intensive food processing, transparency in fuel-tax and stabilization mechanisms, effective implementation of the National School Milk Program, and sustained investment in animal-health surveillance and response could collectively help reduce cost volatility and supply disruptions borne by processors in this context (Yothasamut *et al.*, 2018; EPPO, 2023).

Limitations and future research: This study is based on one dairy processing plant with responses from 21 employees. The analysis relies on perception-based ratings of operational and external factors. The use of snowball sampling within one organization and the limited number of respondents constrain representativeness and statistical power. Accordingly, the findings should be interpreted as context-specific and exploratory, rather than as causal or broadly applicable.

Future research may extend this exploratory work by examining institutional and policy-related factors in greater detail. For example, studies using operational and cost data collected more frequently over time could explore how policy arrangements, such as regulated raw-milk pricing and structured procurement arrangement, interact with internal value-chain activities under changing demand and cost conditions. This could allow a clearer examination of how external cost pressures, including energy and fuel costs, may be reflected in production volume and gross margin.

In addition, studies involving multiple processing plants or different ownership types could help assess whether similar institutional and policy-related factors are observed in other contexts. Future work may also develop and test activity-specific measurement scales using larger samples and confirmatory approaches.

In conclusion, this study contributes by highlighting how institutional and policy constraints help shape how operational factors are perceived and prioritized within a regulated dairy processing context. The findings indicate that cost pressures, including energy, fuel, and labor expenses, become more challenging under prevailing institutional and policy arrangements that may limit flexibility in sourcing inputs and adjusting outputs. Under these conditions, internal capabilities, particularly in research and development and human resources, emerge as important areas that may support adaptation.

These findings suggest a dynamic, volatility-prone operating environment in which external price movements and episodic shocks (e.g., epidemics) are reflected in unit costs and output, reinforcing the importance of demand-responsive planning and cost discipline at the plant level. For managers, near-term levers are improved demand monitoring, targeted capability building, and disciplined control of energy, logistics, and labor costs. For policymakers, stable and transparent frameworks for energy, fuel, public procurement, and animal health may help improve processing conditions and reduce the transmission of cost shocks to margins. Alignment between firm-level actions and system-level supports may provide the greatest gains in both production efficiency and margin stability.

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Visualization, Project administration. Aqeel Raza: Methodology, Writing-original draft preparation, Writing-review and editing. Kittisak Ajariyakhajorn: Methodology, Writing-original draft preparation, Writing-review and editing, Supervision. Davids Makararpong: Methodology, Investigation, Writing-original draft preparation, Supervision. Henk Hogeveen: Methodology, Supervision. Chainarong Paojin: Validation, Resources, Supervision. Nampueng Mesprasat: Validation, Resources. Chaidate Inchaisri: Conceptualization, Methodology, Validation, Investigation, Writing-original draft preparation, Writing-review and editing, Supervision, Project administration, Funding acquisition. All authors have read and approved the final version of the manuscript.

Declaration of artificial intelligence use: The authors declare that QuillBot (<https://quillbot.com/>) and Copilot Chat (Basic) by Microsoft Copilot (<https://m365.cloud.microsoft/chat>) were used only for language editing to improve grammar and readability. No artificial intelligence tools were used for data analysis, interpretation of results, generation of scientific conclusions, preparation of scientific figures or development of the scientific content of this manuscript. All authors have reviewed and approved the final manuscript and take full responsibility for the content of the manuscript.

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