Sizing production for a boutique soda pop manufacturer

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ABSTRACT

Manufacturing companies come in all shapes and sizes, ranging in volume (output capability) and variety (flexibility) of products. Repetitive manufacturing is used in high-volume industries where products are mostly homogeneous, whereas job shops entail low-volume products made to a specific customer's unique specification. However, not all manufacturing systems are high-volume mass production facilities making a homogeneous product, nor are they low-volume facilities making a custom product. There is a hybrid process between repetitive manufacturing and job shops—referred to as batch manufacturing. Batch manufacturing produces a given item in increments—lots or batches of production—before transitioning to another typically highly related product with only minor differences. Economic production quantity (EPQ) is a commonly used method of sizing production quantity (lot or batch size) for batch manufacturing processes, where only one product—or a portfolio of extremely related products—is made for a specific number of days. This case study applies EPQ concepts to a nearly 100-year old boutique soda pop manufacturer to add clarity and context to this often misunderstood topic.

Keywords: batch, economic order quantity, job shop, repetitive, make-to-order

INTRODUCTION

Manufacturing companies come in all shapes and sizes, ranging in volume (output capability) and variety (flexibility) of products. Repetitive manufacturing is used in high-volume industries (e.g., automobile manufacturers) where products are mostly homogeneous (make-to-stock), whereas job shops entail low-volume products (e.g., custom cabinet manufacturer) made to a specific customer's unique specification (make-to-order).

One of the major inputs to manufacturing—the most important input of all—is customer demand; actual and/or anticipated. Supply chains exist only for the benefit of fulfilling customer demand, of which revenue and (hopefully) profits are eventually realized. Many people associate manufacturing with Henry Ford's initial repetitive assembly lines in which a customer could have any color of Model-T desired… so long as it was black! However, not all manufacturing systems are high-volume mass production facilities making a homogeneous product, nor are they low-volume facilities making a custom product. There is a "hybrid" process between repetitive manufacturing and job shops—referred to as batch manufacturing—which has higher flexibility than repetitive manufacturing and higher volume than job shops. Batch production can be thought of as producing a given item in increments—lots or batches of production—before transitioning to another typically highly-related product with only minor differences. The relationship between job shops, batch, and repetitive assembly in regard to both volume and variety (product uniformity) as indicated in Figure 1 (Appendix).

Batch products have an interesting dynamic in that they are generally consumed continuously but made intermittingly, such as will be illustrated in the forthcoming case study. Economic production quantity (EPQ) is a mathematical approach to deriving optimal production output (lot or batch size) given a host of underlying assumptions. Economic production quantity (EPQ) and economic order quantity (EOQ) belong to a family of optimal inventory quantity models. While EOQ focuses externally on the optimal order quantity to purchase from a supplier (e.g., a raw material input), EPQ focuses internally on the optimal number to produce. Per Stevenson (2018), the decision on how much to produce at any time reflects a trade-off between how much money is tied up in inventory itself versus the return that can be generated from using the money for other purposes, such as investing in additional research and development or acquiring new equipment. The core EPQ assumptions include:

a) Only one product is involved
b) Annual demand is known
c) The usage rate is consant
d) Usage (i.e., consumption) occurs continually, but production occurs periodically
e) The production rate is constant when production is occurring

The EPQ formula is listed in Figure 2 (Appendix) and is used for calculating the optimal production quantity (i.e., batch or lot size), where D = annual demand, S = setup cost, H = per unit holding (carrying) cost, p = production rate, and u = usage (consumption) rate. Setup cost (S) refers to a host of activities involved at the start of making a new batch of product, such as calibrating equipment, prepping raw materials, confirming quality specifications, performing safety checks, or cleaning and/or flushing of lines, to name a few.

Holding cost (H) refers to activities involved with holding inventory beyond the cost of the inventory itself, such as warehousing, security, property insurance (considering inventory is an asset), deterioration, theft, and obsolescence, amongst others. Holding cost (H) is generally expressed as a per-unit value. For example, if annual holding costs are $2,000,000 per year and 200,000 units are held on average at any particular time, the average annual holding cost is $10 per unit ($2,000,000 / 200,000 units). Production (p) refers to the rate at which a product can be made in a defined time period (e.g., output per day), whereas consumption (u) refers to the rate at which a product is used over a time period. A key highlight from the assumptions above is EPQ typically assumes the consumption rate to be continual (daily over the course of a year), whereas production may occur on a less regular basis. The upcoming case study highlights this key point.

CASE FOUNDATION: LITERATURE REVIEW

The EPQ model is a significant concept in supply chain management, particularly when looking at production inventory management, considering various factors to optimize production quantity and costs (Nakhaeinejad, 2023). By including elements like inspection policies for non-conforming items, energy-saving measures, and demand fluctuations, the EPQ model provides insights into improving operational efficiency and reducing overall costs while also considering sustainability concerns (Mallick et al., 2023).

Salameh et al. (2000) share that while the EPQ inventory model was introduced in the early 1900s, it is still widely used across many industries today, a testament to the longevity and simplicity of the model. Still, the EPQ model is not without its limitations, as while the assumptions may be simplistic, they are also overly naïve in terms of how businesses operate. For example, the model does not consider defect rates for items produced. The model also assumes a continuous non-interrupted supply of raw materials, which is ideal but hardly realistic. As such, many supply chain analysts use the basic EPQ formula for initial calculations, but then consider additional variables to derive a more realistic production quantity (e.g., output rounded to a full day's production).

Jaber et al. (2008) also highlighted the benefits of optimal order quantity models and the simple mathematical calculations, while also highlighting the naivety of assumptions that are somewhat unrealistic, and the need to augment the model with supplemental calculations as required. For example, one of the major assumptions of the EPQ model is that the production rate is constant with a smooth and continuous flow of output for a defined run duration. However, there are many factors that can impact how long it takes to manufacture a production batch, including raw material availability, machine uptime/downtime, safety issues, and quality concerns. Optimal production quantity model calculations are based on "best case" assumptions, whereas there are a host of variables that could cause a production run to take longer than expected under sub-optimal conditions.

Multiple studies have worked to extend the traditional EPQ model incorporating different factors for optimization. For example, Nakhaeinejad et al. (2023) proposed an EPQ model that looks at non-conforming items and inspection costs, highlighting cost trade-offs. Yee et al. (2023) developed sustainable EPQ models by integrating greenhouse gas and wastewater emission costs. Additionally, Nguyen et al. (2022) analyzed EPQ models considering the impact of energy consumption on optimal solutions and decision-making. Furthermore, Nobil et al. (2023) explored the inclusion of a warm-up phase in EPQ models to enhance productivity, reduce defects, and minimize maintenance costs. These recent studies show the versatility and adaptability of EPQ models in addressing production challenges in today's rapidly changing environment.

CASE STUDY: COMPANY PROFILE

Ale-8 One is a family-owned business that has produced carbonated beverages since the mid-1920s at their facilities in the central Kentucky bluegrass region. For nearly 100 years Ale-8 produced one signature flavor using a secret family recipe. In 2003 the company introduced Diet Ale-8 (now Ale-8 Zero Sugar), and during the last few years has begun making other flavors, including Cherry, Orange Cream, and most recently, Blackberry, which was introduced in 2022. Ale-8 has historically only been sold throughout Kentucky and neighboring states but signed a partnership agreement with Cracker Barrel Old Country Stores in 2016 to carry their beverages across forty-two states and 630 Cracker Barrel retail locations (The Lane Report, 2016).

> "Ale-8's crisp, clean taste is handcrafted batch by batch using a secret recipe passed down through four generations. Lightly carbonated and made with real ginger and citrus, experience a flavor that pops, especially when chilled. Since 1926, we have been committed to delivering the one-of-a-kind taste of the original Ale-8 and remained loyal, steady, and proudly unconventional." (Ale-8 corporate website)

Figure 3 (Appendix) is an illustrative example of Ale-8's annual demand by flavor. Ale-8 makes its flavored beverages on one manufacturing line employing a batch production process, making one flavor for a period of days before transitioning to a different flavor. Annual demand for Ale-8 flavors varies, such that the number of days each flavor is produced (lot or batch size) at any one time also varies. What makes a "flavor" unique is a combination of natural and artificial additives, special preservatives, unique ingredients, and food coloring. As new flavors are introduced, and as customer demand changes, production volume for each flavor changes accordingly. Figure 4 (Appendix) conceptually illustrates Ale-8's manufacturing plan in terms of the number of days each flavor is produced and theoretical production sequencing.

3-C'S CONCEPTUALIZED CRITICAL THINKING MODEL

Senior managers and executives must perform various calculations as part of quantitative decision-making. According to Easterling and Barthel (2023), performing a calculation(s) is simply the first step in the overall managerial process. The 3-Cs Conceptualized Critical Thinking Model can be used for not only production planning, but any quantitative measure or key performance indicator (see Figure 5; Appendix).

Calculate: Perform the Required Calculation(s)

This step involves applying mathematical computations to a set of raw data, pulling data from a report, and can even include gathering/quantifying qualitative data. Before performing calculations, steps should be taken to ensure data are accurate, dependable, and relative to the decision. Performing calculations with poor data (inputs) leads to unreliable results (output) that can subsequently lead to poor decision-making (Steps 2-3), which is often referred to as “garbage in…garbage out” (GIGO). Specific inputs to EPQ calculations for Ale-8 are listed above and include assumptions for annual demand by flavor, inventory holdings costs, daily consumption rates, and production output.

Clarify: Clarify the Results

This step includes interpreting the calculation results. In other words, answering what are the key takeaways and what are the key questions one must answer to make decisions. For example, clarifying could include comparing calculations to prior and current internal goals; benchmarking external competitors to gauge overall industry competitiveness; evaluating results compared to project timelines goals and plans; assessing risk; evaluating timing trade-offs; measuring the success of mitigation plans; and seeking input/feedback from other functional areas. Specific clarifying steps for Ale-8 might include analyzing how demand for each flavor changed from the previous time period (leading to corresponding changes in production plans), as well as understanding how and why holding costs changed due to higher (or lower) inventory accuracy and obsolescence (write-offs).

Communicate: Communicate an Action Plan

This step provides an opportunity to explain what follows logically from the prior work: improvement plans, initiatives, and decision recommendations, for example. This step is especially important as organizational leaders must continually implement improvement initiatives to drive higher levels of performance. Additionally, organizational leaders must ensure all employees understand their individual roles in contributing toward functional, strategic business unit, and corporate goals. It is essential to also communicate externally with downstream (toward end customers) and upstream (toward suppliers) in a collaborative manner so that plans can be synchronized across trading partners. Specific communication steps for Ale-8 might include posting the planned production schedule in advance so that preventive maintenance can be proactively completed and unique raw materials (e.g., flavoring, additives, food colors) can be secured and staged in advance.

APPLY THE CONCEPTS: ALE-8 ONE CASE STUDY

This case study can be used as a guided assignment to be completed as an overall class project, a team project, or an individual assessment. Additionally, the concept of the 3-Cs, as a template to guide student critical thinking, should be applied to assess comprehensive understanding and mastery of the material. The numbers and data expressed in this case study are purely illustrative and do not reflect Ale-8’s actual sales, manufacturing, capability, or performance.

Student Instructions

Using your expanded knowledge of economic production quantity (EPQ), complete the analysis below and answer the following questions. Assume the annual demand for all flavors is twenty million gallons. Before starting the assignment and attempting to answer the questions, take time to conceptually understand the data, which can be illustrated by two (2) key points:

Key Point #1: Annual demand for all flavors is twenty million gallons per year (given). Multiply the % of Annual Demand for each flavor x 20,000,000 gallons to get the respective Annual Demand by Flavor (Gallons). This is the starting point.

Key Point #2: Daily production rate is 60,000 gallons whereas the average daily consumption rate is significantly less for each flavor. Hence the logic and reasoning for calculating the optimal production quantity for each respective flavor.

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
		Annual Demand ***(D)*** in Gallons (all flavors)	Production Rate ***(p)*** per day	Consumption Rate ***(u)*** per day @ 365 days/yr.	Setup Cost ***(S)***	Holding Cost ***(H)***			
	GIVEN	(Multily Column 1 x Annual Demand (all flavors)	GIVEN	(Divide Column 2 / 365)	GIVEN	GIVEN	Perform EPQ mathematical equation	Divide Column 7 / Column 3	Divide Column 7 / Column 4
Flavor	**% of Annual Demand**	**Annual Demand by Flavor (Gallons)**	**Production Rate (Gallons per day)**	**Daily Consumption Rate (Gallons)**	**Setup Cost**	**Holding Cost (per unit)**	**Economic Production Quantity (EPQ)**	**Production Length (# of days)**	**Consumption Length (# of days)**
Original Ale-8	72%		60,000		$3,000	$0.55			
Ale-8 Zero Sugar	7%		60,000		$3,000	$0.55			
Caffeine Free Ale-8	6%		60,000		$3,000	$0.55			
Cherry	5%		60,000		$3,000	$0.55			
Cherry Zero Sugar	3%		60,000		$3,000	$0.55			
Orange Cream	5%		60,000		$3,000	$0.55			
Blackberry	2%		60,000		$3,000	$0.55			
	100%								

$$\textbf{EPQ} = Q_p = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}}$$

Question 1 (Calculate): Complete the table above for each Ale-8 flavor.

Question 2 (Clarify): What observation(s) can you make regarding the relationship between annual demand and EPQ quantity and the number of days of production required?

Question 3 (Clarify): Interpret the meaning of Column 8 & Column 9.

Question 4 (Clarify): What are some actual factors that could cause the number of days produced to vary with the theoretical EPQ calculation? What kinds of analysis would be helpful for understanding differences between EPQ calculation (e.g., # of production days planned) vs. actual number of production days required?

Question 5 (Communicate): What types of communication and coordination could/should be done with other internal departments as well as with external suppliers in terms of the planned production per flavor?

Question 6 (Communicate): Explain the relationship between EPQ quantity and Setup Cost. If Setup Cost goes up (or down), does EPQ quantity go up (or down)? Hint: answering this question using a simple Excel sheet is highly effective.

Case Study Example Responses

	Column 1	Column 2	Column 3	Column 4	Column 5	Column 6	Column 7	Column 8	Column 9
		Annual Demand ***(D)*** in Gallons (all flavors)	Production Rate ***(p)*** per day	Consumption Rate ***(u)*** per day @ 365 days/yr.	Setup Cost ***(S)***	Holding Cost ***(H)***			
	GIVEN	(Multily Column 1 x Annual Demand (all flavors)	GIVEN	(Divide Column 2 / 365)	GIVEN	GIVEN	Perform EPQ mathematical equation	Divide Column 7 / Column 3	Divide Column 7 / Column 4
Flavor	**% of Annual Demand**	**Annual Demand by Flavor (Gallons)**	**Production Rate (Gallons per day)**	**Daily Consumption Rate (Gallons)**	**Setup Cost**	**Holding Cost (per unit)**	**Economic Production Quantity (EPQ)**	**Production Length (# of days)**	**Consumption Length (# of days)**
Original Ale-8	72%	14,400,000	60,000	39,452	\$3,000	\$0.55	677,278	11.3	17.2
Ale-8 Zero Sugar	7%	1,400,000	60,000	3,836	\$3,000	\$0.55	127,733	2.1	33.3
Caffeine Free Ale-8	6%	1,200,000	60,000	3,288	\$3,000	\$0.55	117,685	2.0	35.8
Cherry	5%	1,000,000	60,000	2,740	\$3,000	\$0.55	106,916	1.8	39.0
Cherry Zero Sugar	3%	600,000	60,000	1,644	\$3,000	\$0.55	82,036	1.4	49.9
Orange Cream	5%	1,000,000	60,000	2,740	\$3,000	\$0.55	106,916	1.8	39.0
Blackberry	2%	400,000	60,000	1,096	\$3,000	\$0.55	66,669	1.1	60.8
	100%								

$$\textbf{EPQ} = \; Q_p = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}}$$

Question 1 (Calculate): Complete the table above for each Ale-8 flavor. See table above.

Question 2 (Clarify): What observation(s) can you make regarding the relationship between annual demand and EPQ quantity and the # of days of production required?

The table above highlights the calculated EPQ (Column 7) for each flavor. For example, the EPQ for "Original Ale-8" is 677,278 gallons, meaning that when "Original Ale-8" is produced, it should be produced in a batch (or lot size) of 677,278 gallons.

Question 3 (Clarify): Interpret the meaning of Column 8 & Column 9.

Column 8 shows how many days of production will be needed to complete the EPQ production size. This number is found by dividing the EPQ production size (for each flavor) by the daily production rate (Column 3)

Column 9 shows how long a batch of production (EPQ size) will last, based on the average daily consumption rate. This number is found by dividing the EPQ production size (for each flavor) by the daily consumption rate (Column 4)

Question 4 (Clarify): What are some actual factors that could cause the # of days produced to vary with the theoretical EPQ calculation? What kinds of analysis would be helpful for understanding differences between EPQ calculation (i.e., # of production days planned) vs. the actual # of production days required?

EPQ assumes constant and continuous production when production is occurring. Optimal production quantity model calculations are based on "best case" (or optimal) assumptions, whereas there are a host of variables that could cause a production run to take longer than expected under sub-optimal conditions, such as raw material availability, machine uptime/downtime, safety issues, or quality concerns.

A Pareto analysis highlighting the contributing factors would be very helpful, with departments and/or individuals assigned for driving resolution. Figure 6 (Appendix) is a hypothetical example illustration of the Pareto concept. Generally, the items that are contributing most to a particular problem are addressed first, which in this example would be reducing machine malfunctions (highest contributor), then addressing raw material shortages (second highest contributor), and so forth.

Question 5 (Communicate): What types of communication and coordination could/should be done with other internal departments as well as with external suppliers in terms of the planned production per flavor?

Supply Chain Management requires effective communication upstream (towards suppliers) as well as downstream (towards customers). Proactive collaboration is essential throughout all trading partners to have a smooth and continuous flow of raw materials, production, and delivery to customers.

Specific communications and coordination would include, for example, required artificial ingredients, various packaging types, and expected production start and end dates, for each respective flavor.

Question 6 (Communicate): Explain the relationship between EPQ quantity and Setup Cost. If Setup Cost goes up (or down), does EPQ quantity go up (or down)? Hint: answering this question using a simple Excel table is highly effective.

	Flavor	Column 1 % of Annual Demand	Column 2 Annual Demand by Flavor (Gallons)	Column 3 Production Rate (Gallons per day)	Column 4 Daily Consumption Rate (Gallons)	Column 5 Setup Cost	Column 6 Holding Cost (per unit)	Column 7 Economic Production Quantity (EPQ)	Column 8 Production Length (# of days)	Column 9 Consumption Length (# of days)
Base Case	Original Ale-8	72%	14,400,000	60,000	39,452	$3,000	$0.55	677,278	11.3	17.2
Worst Case Scenario	Original Ale-9	72%	14,400,000	60,000	39,452	$3,500	$0.55	731,544	12.2	18.5
Best Case Scenario	Original Ale-10	72%	14,400,000	60,000	39,452	$2,500	$0.55	618,267	10.3	15.7

Setup Cost refers to those activities, such as calibrating equipment, prepping raw materials, confirming quality specifications, performing safety checks, or flushing lines & systems. As Setup Cost increases, EPQ increases. As Setup Cost decreases, EPQ decreases. The table above highlights the Base Case (Setup Cost $3000), Worst Case Scenario (Setup Cost increases to $3500), and Best Case Scenario (Setup Cost decreases to $2500). You can also see the associated effect on Columns 8-9.

CONCLUSION

Economic production quantity (EPQ) is a commonly used method of sizing production quantity (lot or batch size) for batch manufacturing processes, where only one product—or a portfolio of extremely related products—is made for a specific number of days. While the EPQ formula for calculating theoretical optimal production quantity is straightforward and simple to calculate, the basic assumptions are naïve and are often supplemented with 'real-world' perspectives. As such, while the EPQ calculation is often used initially for understanding the "rough-cut" production quantity and associated timing, additional considerations such as supplier delivery performance, quality levels, machine uptime/downtime, availability of raw materials, worker productivity, safety concerns, and other factors must be considered.

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APPENDIX

Variety \ Volume	Lower	Moderate	Higher
Lower			Repetitive
Moderate		Batch	
Higher	Job Shop		

Figure 1: Comparison of Manufacturing Processes

$$\textbf{EPQ} = Q_p = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-u}}$$

Figure 2: Economic Production Quantity (EPQ) formula

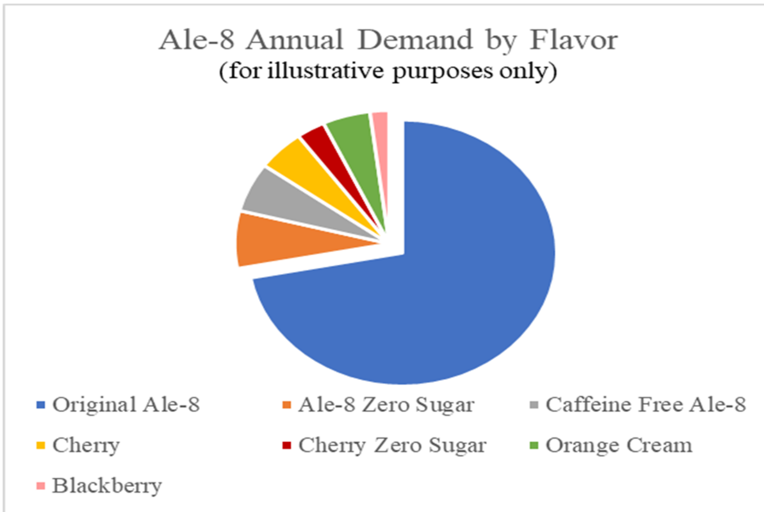

Figure 3: Ale-8 Annual Demand by Product (illustration only)

Ale-8 Production Plan

(for illustrative purposes only)

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1-Mar	2-Mar	3-Mar	4-Mar	5-Mar	6-Mar	7-Mar
8-Mar	9-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar
15-Mar	16-Mar	17-Mar	18-Mar	19-Mar	20-Mar	21-Mar
22-Mar	23-Mar	24-Mar	25-Mar	26-Mar	27-Mar	28-Mar
29-Mar	30-Mar	31-Mar				

Flavor Identifer

- Original Ale-8
- Ale-8 Zero Sugar
- Caffeine Free Ale-8
- Cherry
- Cherry Zero Sugar
- Orange Cream
- Blackberry

Figure 4: Ale-8 Production Plan by Flavor (illustration only)

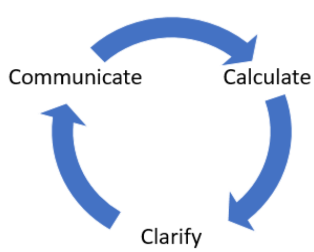

Figure 5: 3-Cs Conceptualized Critical Thinking Model

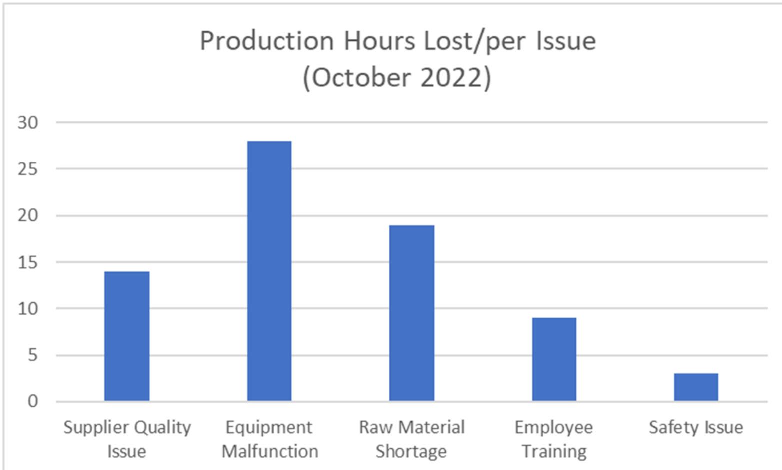

Figure 6: Example Illustration of the Pareto Concept