Dynamic Lot Sizing Model for Perishable Products in Animal Pharmaceutical Industry with Quality Deterioration

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Abstract

Optimizing supply chain operations by reducing costs, increasing responsiveness, and remaining competitive in a dynamic environment are important things for pharmaceutical companies. Perishable products in pharmaceutical companies make production planning problems more complex. The quality of perishable products is one of the characteristics that need to be considered because perishable products are not static parameters but are very dynamic variables. Determining the quantity of products that must be produced in order to reach consumers before the product shelf life runs out is one of the challenges in industries with perishable products. Demand fluctuates between periods during the planning horizon requires the model used to be dynamic model in order to represent the reality. Dynamic lot sizing will be used in this study which developed by taking quality deterioration into account. The decrease in the quality of perishable products in the study was affected by time, temperature, and humidity. Perishable products and backorders can be considered as complementary phenomena because when an item is highly perishable, demand may need to be accommodated to contain costs due to damage, so that losses can be avoided. This study aims to identify production, inventory, and backorder decisions during the planning horizon that will affect the cost of goods manufactured. The cost of goods manufactured is a measure of a company's competitiveness, therefore it is one of the focuses of this research. The cost of goods manufactured for the optimal quantity of production will be compared with the cost of goods manufactured under the existing conditions of the company.

Keywords

Dynamic Lot Sizing (DLS), Perishable Product, Quality Deterioration, Production Planning, Cost of Goods Manufactured (COGM).

Introduction

Pharmacy is one of the industries related to human and animal life. The business entity that is authorized by the government in the production of medicines and medical devices is the pharmaceutical industry. Pharmaceutical companies recognize the importance of optimizing their supply chain operations to reduce costs, increase responsiveness and stay competitive in a dynamic environment. Production planning problems faced by pharmaceutical companies are becoming more complex with perishable products. Perishable products include pharmaceutical products, where the durability of the final product is a dominating factor in production planning and control (Acevedo-Ojeda & Chen 2020). Perishability relates to products that cannot be stored without damage or devaluation (Billaut 2011).

The quality of perishable products is one of the characteristics that needs to be considered because perishable products will decrease over time due to a limited lifetime, not only due to physical product changes, loss of functionality and volume (or quantity), but also obsolescence (Hertog et al. 2014 & Acevedo-Ojeda et al. 2019). Shelf life is partly determined by microbial activity and the impact of this activity is strongly influenced by storage temperature, in fact, freshness is almost exclusively a function of time and temperature (Aung & Chang 2014). Temperatures that are too high increase the rate of respiration and growth of microorganisms, which can spoil some food products within hours or days (Hertog et al. 2014). Perishable products such as vaccines and antibiotics, exposure to temperatures outside the range can cause a significant reduction in drug efficacy and also increases the possibility of spoilage (Bishara, 2006). Inappropriate storage conditions can result in drug ineffectiveness and can even cause damage that will harm the company and patients who will consume the drug (Karlida & Musfiroh 2017). Appropriate storage at the specified temperature will prevent or minimize quality degradation which will affect drug safety (GMP 2018). Kouki (2010) also said that improving the quality and safety of perishable products requires controlled temperature and humidity levels because the shelf life of perishable products is sensitive to storage conditions.

Ghosh, et al. (2011) in the case of perishable products, companies may need to do backorders to avoid costs due to damage. Abad's research (2000) states that perishable and backorder goods can be considered as complementary phenomena because when an item is highly perishable, demand may need to be accommodated to contain costs due to damage, so that losses can be avoided. Dynamic lot sizing is a planning model used for changing requests over the production planning period. Cumulative demand throughout the planning horizon is calculated to determine the optimal lot size and production time (Dumont 2020).

Production planning is one of the most important aspects in a manufacturing company because companies must be able to minimize costs in carrying out production activities before products are sold to consumers. The cost of production is a determinant of the selling price which will affect the survival of a company (Pastarina, 2015). Therefore, with an efficient cost of production, the company will have a competitive advantage through a cost leadership strategy. The perishable products described above include veterinary drug products. This veterinary pharmaceutical product will be the object of this research.

Santhi and Karthikeyan (2018) explains the drug supply model using economic order quantity which depends on quality degradation over time. Atamturk and Kucukyavuz (2007) presented dynamic programming for lot sizes with limited inventory and fixed costs for biopharmaceutical products. In the research by Sahling and Hahn (2019) considering lot sizes for the manufacturing process of biopharmaceutical products so that inventory costs and obsolescence due to decreased quality can be more economical by using a multi-level capacitated lot sizing model. Research by Yamada, et al. (2021) selects the optimal lot size in the manufacture of injectable drugs using an economic lot sizing model that includes risk, product defect rates, quality control, and replacement operations that have been developed.

Objectives

The purpose of this study is to create a calculation model related to determining the amount of production with dynamic lot sizing based on the objective function in the form of minimizing total costs and reducing quality constraints also determining the minimum total costs and optimal production quantities.

2.Literature Review

2.1 Perishable Pharmaceutical Inventory

Problems related to managing perishable inventories arise in various sectors including pharmaceutical products (Nahmias, 1982). The analysis of this problem raises complexity, one of which is because of the dimensions of the inventory age vector. Described by Gebicki, et al. (2013), some pharmaceutical products are perishable products meaning they have a certain period of time when they must be used. If the product exceeds the expiry date, then it is a waste that has a negative impact on finances.

In Vila-Parrish, et al. (2008) study modeled inventory and ordering policies for perishable products in a hospital inpatient pharmacy setting. The research considers two stages of inventory: raw materials and finished goods. The pharmaceutical ingredients manager in the study was challenged with developing a supply policy given changing demand, limited suppliers, and regulations affecting supply. Perlman and Levner (2014) examined pharmaceutical products in a perishable system, represents a multi-echelon, multi-supplier inventory system and brings together perishable and outsourcing aspects under a deterministic demand for perishable products.

2.2 Dynamic Lot Sizing for Perishable Product

The dynamic lot sizing model is a model that can be used for changing demands over the planning horizon. According to Jing & Chao (2021) dynamic lot sizing for perishable products is more complex than the problem of dynamic lot sizing for durable products. Hsu (2000) studied the quality of the inventory deteriorated with the level of damage in each period and the cost of holding the unit depended on the age. Sargut and Isik (2017) consider the same problem as Hsu (2000) by extending the problem and adding production capacity constraints. The problems in this study are presented with heuristics based on dynamic programming. Onal et al. (2015) also studied that the product has a deterministic degree of damage. Onal (2016) considers lot sizes with perishable products in a two-level supply chain.

2.3 Quality Deterioration

Goods that decline in quality refer to goods that have lost utility or marginal value. Goods that decline in quality are not bound by shelf life alone. The impact of quality reduction on inventory management is usually modeled as a proportional decrease in terms of utility or physical quantity (Kouki 2010). Acevedo-Ojeda, et al. (2019) present the lot size problem aggregating perishable raw materials and analyze how these considerations impose special constraints on a set of fundamental decisions. Wang and Li (2012) explains the quality of perishable products can be considered as a dynamic state that decreases continuously to the point where it is not suitable for sale or consumption.

Perishable products may experience non-uniform deterioration over time due to the significant effect of temperature on the quality of perishable products. Ketzenberg et al. (2015) discusses the use and value of time and temperature information to manage perishable goods in the context of retailers selling products with a random shelf life that depends on stochastic demand and lost sales. Product lifetime is largely determined by temperature history (along with other environmental factors such as humidity, handling, and lighting) and time it flows through the supply chain.

Jing and Chao (2021) says that most perishable products require strict storage conditions, such as the appropriate temperature and humidity. Kouki (2010) said that improving the quality and safety of perishable products requires controlled temperature and humidity levels. Kim et al. (2015) said humidity higher than the optimum value encourages the growth of microorganisms and results in excessive food spoilage. The smaller the gap between actual environmental conditions and product requirements, the better quality can be maintained.

Backorder

Peng, et al. (2008) said that sometimes it is better to replenish stock with emergency orders because producers must guarantee the quality of their products, so the production costs for perishable products must be higher if they are produced first. Perishability and backorder are complementary conditions because when a product is highly perishable, demand may need to be accommodated to contain damage costs. Ghosh, et al. (2011) production planning decisions are very important and when a product is perishable, requests need to be postponed to avoid costs due to damage.

1. Model Development

The model that is used as a reference is the model developed by Sargut and Isik (2017). The use of this model is based on research that refers to the theory developed by Hsu (2003). This research considers the conditions in the field so that it can be represented in the model, so modifications and development of the model are carried out to suit the objectives of the research.

Production cost is the cost required to convert raw materials into finished products. Production cost in this model is the cost of producing x units in period t which will be multiplied by the volume of production in period t.

- Production cost:

$$\sum_{t=1}^{n} c_t(x_t)$$

Product holding cost is the cost required as long as the product is in storage. Holding cost is obtained by multiplying the remaining y units during period t (produced in period i and remaining at the beginning of period t) with a predetermined cost.

- Holding cost:

$$\sum_{i=1}^{t} H_{it}(y_{it})$$

Backorder cost is the cost of not being able to fulfill an order immediately and promising the customer that the order will be completed with an upcoming delivery. This cost is calculated from the number of z units of demand for period t and from production in period i multiplied by the specified cost.

- Backorder cost:

$$\sum_{i=t+1}^{n} B_{it}(z_{it})$$

After obtaining the cost components starting from production costs, holding costs, and backorder costs, the objective function in minimizing these costs can be obtained. The following is the objective function of the costs described above:

- Objective function:

$$Min \sum_{t=1}^{n}[c_t(x_t) + \sum_{i=1}^{t} H_{it}(y_{it}) + \sum_{i=t+1}^{n} B_{it}(z_{it})] \quad [1]$$

Mathematical equation (4.1) displays the cost minimization objective function. The total costs required during the planning period are production costs, holding costs, and backorder costs. Production cost is the cost required to produce perishable products from raw materials, work in process, to finished goods. Then, the next cost component is the holding cost which is obtained by multiplying the inventory quantity during the perishable product period stored with a predetermined cost. Backorder occurs if product inventory cannot meet demand in that period and will be fulfilled in the next period. The backorder cost is obtained by multiplying the predetermined cost by the total quantity of products that make backorders. Holding costs and backorder costs are costs that are inversely proportional, so the model will choose to store more inventory or do more backorders.

In addition to calculating the objective function, constraints on the model are needed in order to obtain optimal results. There is a limitation that the model can represent real conditions. The following are the constraints that have been made, namely inventory level limits, inventory levels after degradation, percentage decline in quality, quality ratio, actual quality time ratio, input temperature and humidity, demand fulfilment, production capacity, and non-negativity.

- First constraint: inventory level each period

$$x_t - \sum_{i=1}^{t} z_{ti} = y_{it} \text{ untuk } (1 \leq t \leq n) \quad [2]$$

Equation (4.2) is the limit of product inventory stored in each period. The remaining product from production volume (x_t) at the beginning of period t minus the demand that has been fulfilled in period t is a way of calculating the number of products stored at the end of period t.

- Second constraint: inventory level after downgrade

$$(1 - \alpha_{i,t-1})y_{i,t-1} - z_{it} = y_{it} \text{ untuk } (1 \leq i \leq t \leq n) \quad [3]$$

Equation (4.3) is the limit of product inventory in period t when inventory in period t-1 experiences a decrease in quality. This determination is made by calculating the remaining amount at the beginning of period t-1 from the production of period i ($y_{i,t-1}$) after the decline in quality and demand has been fulfilled in period t.

- Third limitation: request fulfilment

$$\sum_{i=1}^{n} z_{it} = d_t \text{ untuk } (1 \leq t \leq n) \quad [4]$$

Equation (4.11) ensures that the demand for each period is met at the end of the planning horizon. The amount of production in period i to meet the demand for period t is denoted as z_{it}, the sum of all periods must equal the demand in one planning horizon.

- Fourth limitation: production capacity

$$0 \leq x_t \leq C \text{ untuk } (1 \leq t \leq n) \quad [5]$$

Equation (4.5) limits production rates based on capacity and ensures nonnegativity. Production volume (x_t) in each period must be produced less than or equal to the predetermined production capacity (C).

- Fifth limitation: nonnegativity

$$y_{it} \geq 0 \quad \text{untuk } (1 \leq i \leq t \leq n) \qquad [6]$$

$$z_{it} \geq 0 \quad \text{untuk } (1 \leq i, t \leq n) \qquad [7]$$

Equations (2.6) and (2.7) are nonnegativity constraints. This constraint ensures that the resulting values are not negative.

The linear model was developed based on research by Osvald and Stirn (2008). In this study, the quality reduction model is not influenced by time input but is influenced by temperature and humidity. The assumption used in the development of this quality reduction model is that the shelf life and planning horizon have the same span of time. This causes a significant reduction in quality as long as it is within the shelf life of the product.

- Sixth limitation: time of degradation as temperature and humidity increase

In equation (4.8) the shelf life (SL) for a predetermined product is divided by the difference between the maximum temperature (T_{max}) and the optimal temperature (T_0) according to the product. Thus, the shelf life is divided for every 1OC which is the basis for a decrease in quality if there is an increase in temperature. Likewise for equation (4.9) which is related to product humidity. The units for the two equations are days/^{O}C temperature and days/% humidity.

$$Wk_t = \frac{SL}{(T_{max} - T_0)} \qquad [8]$$

$$Wk_h = \frac{SL}{(h_{max} - h_0)} \qquad [9]$$

- Seventh limitation: actual quality time ratio

Equations (4.10) and (4.11) calculate the actual quality time ratio based on the input temperature and humidity according to the actual situation. The difference between the maximum temperature and humidity values (T_{max} and h_{max}) and the input values (T and h) is multiplied by the storage time when the temperature increases 1^{O}C and 1% humidity. Both equations use units of days.

$$Wa_t = Wk_t(T_{max} - T) \qquad [10]$$

$$Wa_h = Wk_h(h_{max} - h) \qquad [11]$$

- Eighth limitation: quality ratio

Equations (4.12) and (4.13) calculate the quality ratio of temperature and humidity according to the specified quality percentage weights (P_S and P_L). Maximum temperature and humidity (T_{max} and h_{max}) divided by the desired input temperature and humidity (T and h). Then, the product shelf life (SL) that has been determined according to its shelf life is reduced by the actual time ratio (W_{at} and W_{ah}) and divided by the shelf life. After that, the results of the temperature and humidity are multiplied by the calculation of the shelf life. The results of these calculations will be a multiplier of the quality percentage weight that has been determined previously to determine the quality of temperature and humidity (S and L). Percentages are used for the units of the two equations.

$$S = P_s\left(\frac{T_{max}}{T} * \frac{(SL - Wa_t)}{SL}\right) \qquad [12]$$

$$L = P_L\left(\frac{h_{max}}{h} * \frac{(SL - Wa_h)}{SL}\right) \qquad [13]$$

- Ninth limitation: percentage level of quality loss

Equation (4.4) is the percentage level of quality degradation based on temperature and humidity whose value is less than or equal to 1 (one). This limitation is the development of quality degradation in equation (4.3). The degradation considered within these limits is the temperature and humidity in which the product is stored.

$$\alpha = S + L \; untuk \; \alpha \leq 1 \qquad [14]$$

- Tenth limitation: temperature and humidity input

Equations (4.9) and (4.10) are the temperature and humidity input limits between the optimal temperature and the specified maximum temperature. This limit ensures that the input will not be less than the optimal temperature and will not be more than the maximum temperature that has been determined.

$$T_0 \leq T < T_{max} \qquad [15]$$

$$h_0 \leq h < h_{max} \qquad [16]$$

3.Data Collection

Data on production costs for klorin gard products for each period experienced fluctuating changes. This is influenced by direct material costs, direct labor costs, and overhead costs in production. The following is production cost data during the 2021 planning horizon for klorin gard products:

Table 1. Production Cost

Period	Production Cost 1	Production Cost 2	Production Cost 3
January	Rp 76,308	Rp 74,165	Rp 74,165
February	Rp 67,937	Rp 65,794	Rp 65,794
March	Rp 67,937	Rp 65,794	Rp 65,794
April	Rp 67,937	Rp 65,794	Rp 65,794
May	Rp 81,151	Rp 79,008	Rp 79,008
June	Rp 67,937	Rp 65,794	Rp 65,794
July	Rp 76,308	Rp 74,165	Rp 74,165
August	Rp 67,937	Rp 65,794	Rp 65,794
September	Rp 67,937	Rp 65,794	Rp 65,794
October	Rp 75,079	Rp 72,937	Rp 72,937
November	Rp 67,937	Rp 65,794	Rp 65,794
December	Rp 67,937	Rp 65,794	Rp 65,794
Total	**Rp 852,338**	**Rp 826,624**	**Rp 826,624**

Storage costs are obtained by calculating warehouse storage costs, service fees, and risk costs in storing goods. The basis for storage costs for each storage period is considered the same. Storage costs during period t are calculated starting from the goods produced in period i and remaining at the beginning of period t. The following is the storage cost data obtained (in thousands of rupiahs):

Backorder costs include costs incurred when unable to fulfill an order promptly and promising the customer that it will be completed by a later delivery date. Backorder costs can be estimated directly, indirectly, or ambiguously. Backorder costs are charged when demand for period t is met from production in period i. The company determines the backorder cost of 10% of production costs per period. Therefore, the basis for determining backorder costs is different for each period. For each item that is backordered for more than one period, the backorder fee at the beginning of that period is multiplied.

Table 2. Holding Cost

Period (i/t)	1	2	3	4	5	6	7	8	9	10	11	12
1	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5	13.75	15
2	0	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5	13.75
3	0	0	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25	12.5
4	0	0	0	1.25	2.5	3.75	5	6.25	7.5	8.75	10	11.25
5	0	0	0	0	1.25	2.5	3.75	5	6.25	7.5	8.75	10
6	0	0	0	0	0	1.25	2.5	3.75	5	6.25	7.5	8.75
7	0	0	0	0	0	0	1.25	2.5	3.75	5	6.25	7.5
8	0	0	0	0	0	0	0	1.25	2.5	3.75	5	6.25
9	0	0	0	0	0	0	0	0	1.25	2.5	3.75	5
10	0	0	0	0	0	0	0	0	0	1.25	2.5	3.75
11	0	0	0	0	0	0	0	0	0	0	1.25	2.5
12	0	0	0	0	0	0	0	0	0	0	0	1.25

Results and Discussion

Numerical Calculations

Numerical calculations are carried out in order to find out whether the model can provide a cost minimization solution when quality reduction takes into account temperature and humidity affecting the amount of production and product storage carried out. The following are the storage conditions that have been created, with two variations of temperature and humidity levels in different product storage:

Table 3. Temperature and Humidity

Conditions	Temperature	Humidity
Condition 1	25^{O}C	40%
Condition 2	26^{O}C	45%
Condition 3	29^{O}C	67%

Numerical calculations are performed in order to find out whether the model can provide a minimal cost solution for various levels of temperature and humidity control in product storage. The product shelf life is determined for 365 days. The results of numerical calculations will be analyzed starting from the amount of total production volume, total inventory, total backorder, and the amount of total cost obtained. The storage conditions that have been created in relation to the different storage temperatures and humidity are as follows:

Table 4. Production Quantity

Period (t)	Production 1	Production 2	Production 3
1	584	470	470
2	840	840	840
3	840	688	600
4	840	840	840
5	0	0	71
6	840	823	840
7	344	80	80
8	840	840	840
9	840	714	714
10	39	712	712
11	840	840	840
12	467	467	467
Total	**7314**	**7314**	**7314**

Table 4 presents the results of total production for all Condition during the planning horizon. There are seven periods with the amount of production in accordance with the maximum capacity, which is 840 units in Condition 1. During the planning horizon, only period 5 does not carry out the production process. Period 5 Condition 2, the production process is not running so no units are produced. There were four periods where production units were 840 units, following the maximum capacity in chlorine production. In Condition 3, all periods carry out the production process so that there is no period with zero production. This is because the high quality loss causes no product storage to occur and the product is better to backorder. So, inventory in Condition 3 is zero units (Table 5).

Table 5. Inventory Quantity

Period (i,t)	Inventory 1	Inventory 2	Inventory 3
2,2	114	-	-
3,3	354	88	-
4,4	119	-	-
6,6	283	-	-
8,8	547	-	-
9,9	673	-	-
Total	**2090**	**88**	**0**

Table 5 shows the amount of inventory stored in Condition 1. Production at the beginning of period i is stored until the end of period t as shown in Table 4.16 above. There are six different periods that carry out inventory storage with a duration of one period. In Condition 1, the total inventory stored during the planning horizon is 2,090 units. For Condition 2, production at the beginning of period 3 was stored as inventory until the end of the period of 88 units. Inventory storage in Condition 2 only occurs in one period due to a decrease in quality which affects the condition of the product if it is stored for too long.

Table 6. Backorder Quantity

Period (i,t)	Backorder 1	Backorder 2	Backorder 3
2,1	251	365	365
5,4	-	-	71
6,4	-	147	164
6,5	-	119	119
8,7	-	547	547
12,11	110	110	110
Total	**361**	**1288**	**1376**

The number of backorders that occur can be seen in Table 6. The backorder that occurred for Condition 1 in period 1 was filled with production in period 2 of 251 units. Then, production in period 12 was able to fulfill the backorder of 110 units that occurred in period 11. The total backorder during the planning horizon in Condition 1 was 361 units. More backorders in Condition 2 are carried out compared to Condition 1 because it considers a decrease in quality which is affected by temperature and humidity. There were five periods where demand was met through backorders and the fulfillment was carried out from four different production periods. There are five periods where demand is met through backorders in Condition 3 and these fulfillments are made from five different production periods.

Figure 1 shows the total cost of producing klorin gard in three conditions after numerical calculations have been carried out. The total cost is obtained from production costs, storage costs, and backorder costs. In Condition 1, the largest total cost is IDR 509,922,527. The cost of setting air, namely thermohydro, causes the total cost in Condition 1 to be the highest compared to the other two conditions. This is done so that the supplies are in storage conditions with optimum temperature and humidity. The total cost for Condition 2 is IDR 500,844,651 with a low decrease in quality, namely 0.1950855. Condition 3 with the highest quality reduction causes the total cost to be the highest, which is IDR 502,502,448 over the planning horizon.

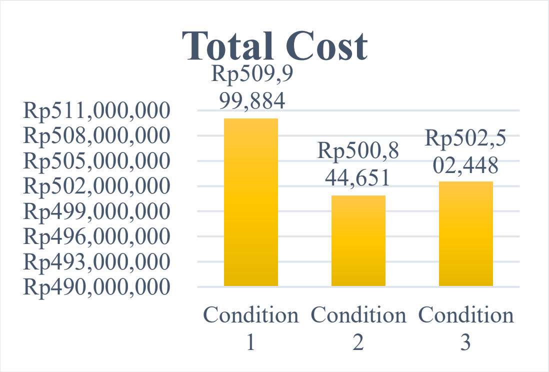

Figure 1. Total Cost

2. Conclusion

The resulting model is the development of a dynamic lot sizing model with reduced quality for perishable products. Deterioration in models is affected by temperature and humidity. This decrease in quality will affect the amount of production of perishable products. In the dynamic lot sizing model, the objective function is to minimize the total costs incurred within the planning horizon. The decision variables obtained are how much production and backorders are made and the inventory stored in order to produce a minimum total cost.

In numerical calculations, there are three conditions that are carried out based on inventory storage which affect temperature and humidity inputs and will have an impact on quality degradation. Storage in a room with an air control device in Condition 1 can regulate temperature and humidity in optimal conditions, namely 25^{O}C for temperature and 40% for humidity. The decrease in quality in Condition 1 was not significant. In Condition 1, the resulting total cost of IDR 509,999,900 is the highest total cost with a production volume of 7,314 units, inventory stored during the planning horizon of 2,090 units, and backorders made to meet demand of 361 units. Supplies in Condition 2 are stored in a room without air conditioning, the room temperature is 26^{O}C with 45% humidity. The total cost resulting from Condition 2 is IDR 500,844,600 with a decrease in quality of 0.1950855. There were 7,314 units of production, 88 units of stored inventory from this production, and 1,288 units of demand fulfillment by means of backorders. Then, in Condition 3 the supplies are stored outdoors without being exposed to direct sunlight, the temperature is 29^{O}C with humidity of 67% outdoors. Condition 3 produces a total cost of IDR 502,502,400 with a decrease in quality of 0.7068451. Production that occurred in Condition 3 was 7,314 units with a backorder of 1,376 units which functioned to meet demand because there was no inventory stored during the planning horizon.

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